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Technical Support Document: Development of the Advanced Energy Design Guide for Medium Box Retail—50% Energy Savings

E.T. Hale, D.L. Macumber, N.L. Long, B.T. Griffith, K.S. Benne, S.D. Pless, and P.A. Torcellini

Technical Report
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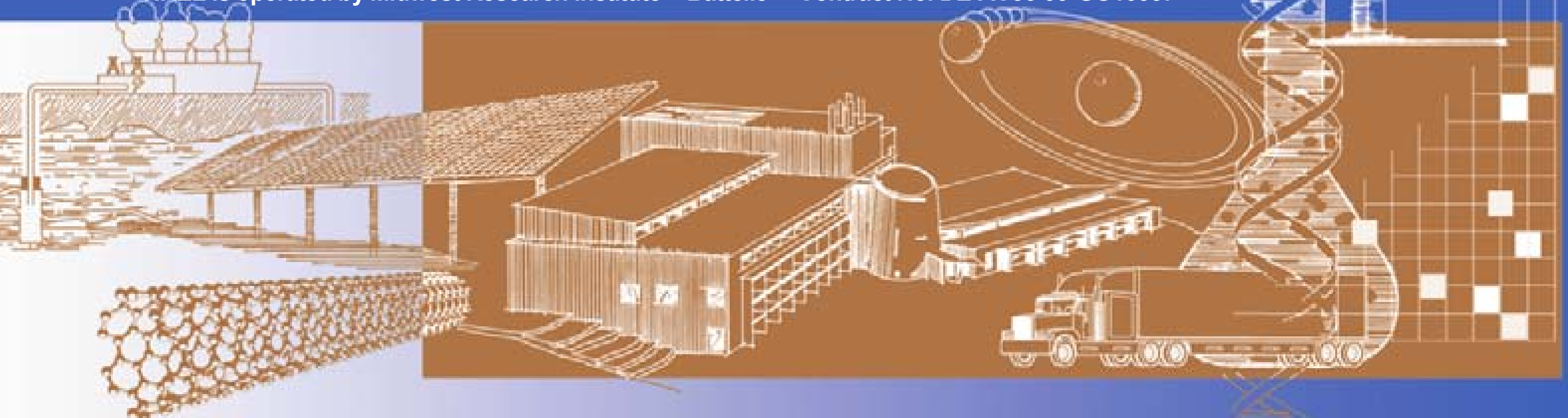

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National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
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Executive Summary

This report documents technical analysis aimed at providing design guidance that achieves whole-building energy savings of at least 50% over ASHRAE Standard 90.1-2004 in medium-sized retail buildings. It represents an initial step towards determining how to provide design guidance for energy savings targets larger than 30%, and was developed by the Commercial Buildings Section at the National Renewable Energy Laboratory (NREL), under the direction of the DOE Building Technologies Program.

This report:

- Documents the modeling and integrated analysis methods used to identify cost-effective sets of recommendations for different locations and business activities.
- Demonstrates sets of recommendations that meet, or exceed, the 50% goal. There are forty eight sets of recommendations, one for each combination of sixteen climate zones and three levels of unregulated plug loads.

This technical support document *(TSD)*, along with a sister document for grocery stores (Hale et al. 2008), also evaluates the possibility of compiling a 50% *Advanced Energy Design Guide (AEDG)* in the tradition of the 30% *AEDG*s available through the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and developed by an inter-organizational committee structure. In particular, we comment on how design guidance should be developed and presented in the next round of 50% *TSD*s for deployment as *AEDG*s.

Methodology

Because it is important to account for energy interactions between building subsystems, NREL used EnergyPlus to model the predicted energy performance of baseline buildings and low-energy buildings to verify that the goal of 50% energy savings can be met. EnergyPlus was selected because it computes building energy use based on the interaction of the 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 both 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:

- Define architectural-program characteristics (design aspects not addressed by ASHRAE 90.1-2004) for typical retail stores, thereby defining prototype models.
- Create baseline energy models for each climate zone that are elaborations of the prototype models and are minimally compliant with ASHRAE 90.1-2004.
- Create a list of perturbations called energy design measures (EDMs) that can be applied to the baseline models to create candidate low-energy models.
- Select low-energy models for each climate zone that achieve 50% energy savings. 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 combinations of energy design measures 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 1) its ability to transform high-level building parameters (building area, internal gains per zone, HVAC system configuration, etc.) into a fully parameterized input file for EnergyPlus, 2) its ability to conduct automated searches to optimize multiple criteria, and 3) its ability to manage distributed EnergyPlus simulations on the local CPU and a Linux cluster. In all, 214,878 EnergyPlus models were run. The economic criterion used to filter the recommendations is five-year total life-cycle cost (using a 2.3% discount rate). The five-year analysis period was established in the statement of work for this project and is considered acceptable to a majority of developers and owners.

The bulk of this report (Chapter 3) documents the prototype building characteristics, the baseline building model inputs, and the modeling inputs for each EDM. Three different levels of (unregulated) plug loads, 0.23 W/ft^2 (2.48 W/m^2), 1.08 W/ft^2 (11.6 W/m^2), and 1.76 W/ft^2 (18.9 W/m^2), are used to create three prototype stores. The prototype buildings are 50,000 ft^2, one-story rectangular buildings with a 1.25 aspect ratio. We assume 1,000 ft^2 of glazing on the façade, which gives a 20% window-to-wall ratio for that wall, and a 5.6% window-to-wall ratio for the whole building. The prototype building has 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. The EDMs considered in this work fall into the following categories:

- **Lighting technologies**. Reduced lighting power density (LPD), occupancy controls, and dayligthing controls.
- **Plug loads**. Reduced density and 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), energy recovery ventilators (ERVs), and indirect evaporative cooling.
- **Generation**. Photovoltaic (PV) electricity generation.

Findings

The results show that 50% net site energy savings is achievable in this subsector with varying cost premiums. Buildings in cold climates or with low unregulated plug loads can meet the goal without photovoltaic (PV) electricity generation, which was the only on-site generation technology considered in this work. Specific recommendations for achieving 50% are tabulated for all climate zones and for the three plug load levels. The following energy design measures are recommended in all cases:

- Place daylighting sensors and controls in all zones with side- or top-lighting, and use a 400 lux control set point.
- Reduce lighting power density by 40%, and use occupancy sensors in the active storage, office, lounge, restroom, and electrical/mechanical spaces.
- Shade all windows on the façade (assumed south-facing).
- Reduce the façade glazing by 20%.
- Install efficient fans in all rooftop HVAC units.

Although this *TSD* is fairly comprehensive and finds the 50% energy savings goal achievable, additional technical analyses may assist future efforts, and a better product could be generated by adopting some of the recommendations outlined in the last subsection of this report. Some EDMs are not included in this study for lack of modeling capability and reliable input data. Measures we feel are deserving of increased attention, but omitted due to 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; and state- or utility-specific rebate programs for PV.

Conclusions

This report finds that achieving 50% energy savings is possible for medium-sized retail buildings in each climate zone in the United States with plug load levels no greater than 1.76 W/ft^2 (18.9 W/m^2). Reaching 50% is largely cost-effective for stores with low plug load levels, but costs as much as 17% more than baseline for medium plug load stores, and as much as 22% more for high plug load stores, based on a five-year total life cycle cost. Several efficiency measures are recommended for all stores (all climates and all plug load levels), but customized paths are required to finish the work of achieving 50% energy savings.

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 energy design measures. 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.

Future work carried out in collaboration with industry experts could improve our recommendations by refining the inputs of this *TSD* and adopting some of the suggestions in the last subsection of this document. We also suggest that some of the EDMs be generalized, for instance, to broad statements like "daylight 100% of the floor area," while recognizing that some work will be required to verify the validity of such statements.

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Figures, Tables, and Equations

Figures

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Nomenclature

5-TLCC	five-year total life cycle cost
ACH	air changes per hour
AEDG	Advanced Energy Design Guide
AIA	American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CEUS	California Commercial End-Use Survey
CBECS	Commercial Buildings Energy Consumption Survey
CDD	cooling degree day
c.i.	continuous insulation
CO_2	carbon dioxide
COP	coefficient of performance
DOE	U.S. Department of Energy
DX	direct expansion
EER	energy efficiency ratio
EIA	Energy Information Administration
EMCS	energy management control system
ERV	energy recovery ventilator
EUI	energy use intensity
HDD	heating degree day
HVAC	heating, ventilation, and air conditioning
IECC	International Energy Conservation Code
IES	Illuminating Engineering Society
LPD	lighting power density
NREL	National Renewable Energy Laboratory
OA	outside air
O&M	operations and maintenance
PNNL	Pacific Northwest National Laboratory
OMB	Office of Management and Budget
PSZ	a package single zone DX rooftop unit
PV	photovoltaics
SHGC	solar heat gain coefficient
SSPC	Standing Standard Project Committee
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

1 Introduction

This report (often referred to as the *Technical Support Document*, or *TSD*) provides design guidance that architects, designers, contractors, developers, owners and lessees of medium box retail buildings can use to achieve whole-building net site energy savings of at least 50% compared to the minimum requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004 (ASHRAE 2004). The recommendations are given by climate zone, and address building envelope, fenestration, lighting systems (including electrical lights and daylighting), HVAC systems, building automation and controls, outside air (OA) treatment, service water heating, plug loads, 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* is one of the first studies aimed at the 50% milestone on the path toward Zero Energy Buildings (ZEBs). 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 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.

As a proof-of-concept work for the interorganizational *Advanced Energy Design Guide* (*AEDG*) effort, this *TSD* falls within the timeframes outlined by the ASHRAE Vision 2020 Committee and the *AEDG* Scoping Committee for enabling interested parties to achieve 50% energy savings by 2010 (Mitchell et al. 2006; Jarnagin et al. 2007).

Prior to this *TSD*, the methodology for developing 30% *AEDG*s was established by committees working on the 30% *TSD*s and *AEDG*s for small office buildings, small retail buildings, K-12 schools, and warehouses (ASHRAE et al. 2004; ASHRAE et al. 2006; Jarnagin et al. 2006; Liu et al. 2006; Liu et al. 2007; Pless et al. 2007; ASHRAE et al. 2008; ASHRAE et al. 2008). These guides suggest that 30% energy savings is achievable and cost effective in many commercial building sectors. The initiation of this *TSD* was also informed by other research projects and facts on the ground:

- Numerous buildings, including some listed in the High Performance Buildings Database (DOE and NREL 2004), already use significantly less energy than standard construction.
- A sector-wide analysis concluded that, on average, retail buildings can become net producers of energy (Griffith et al. 2007).
- The K-12 *AEDG TSD* describes a middle school design that achieves 50% savings (Pless et al. 2007).

By specifying a target goal and identifying paths for each climate zone to achieve the goal, this *TSD* provides some ways, but not the only ways, to build energy-efficient medium box retail buildings that use 50% less energy than those built to minimum energy code requirements. The recommendations are not exhaustive, but do emphasize the benefits of integrated building design. We hope that the example buildings inspire further analysis and innovation, including the evaluation of additional energy design measures (EDMs) and project-specific economics.

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 (Hale et al. 2008). This work should reach its intended audience of architects, designers, contractors, developers, owners, and lessees of medium box retail buildings, either through the production of an ASHRAE 50% *Advanced Energy Design Guide* (AEDG), or the Retailer Energy Alliance (DOE 2008). The completion of a *TSD* before the formation of an *AEDG* committee represents a departure from previous practice that decouples the research and methodology questions raised by higher energy savings targets from the process of receiving detailed modeling assistance from industry representatives.

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**. Separate recommendation sets are provided for three levels of plug (appliance) loads. Sensitivity analyses are provided to facilitate adaptation to programmatic or architectural constraints.
- **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.
- **Verify energy savings**. The achievement of the energy savings goal is verified using EnergyPlus and the modeling assumptions described in Sections 2 and 3.

The specific objectives for this *TSD* include:

1. Document the methodology used to find cost-effective designs that achieve 50% energy savings.
2. Develop prototypical medium box retail characteristics.
3. Develop baseline EnergyPlus medium box retail models, one set for each climate zone location.
4. Develop a list of EDMs that can be applied to the baseline models.
5. Present EnergyPlus medium box retail models that achieve 50% savings over ASHRAE 90.1-2004.
6. Propose a formulation and analysis procedure for 50% *AEDG*s.
7. Discuss EDMs recommended for future studies.

1.2 Scope

This document provides recommendations and design assistance to designers, developers, and owners of medium box retail buildings that will encourage steady progress toward net ZEBs. To ease the burden of the design and construction of energy-efficient retail stores, this document describes a set of designs that reach the 50% energy savings target for each climate zone. The recommendations and discussion apply to retail stores between 20,000 and 100,000 ft^2 with plug loads and accent lighting loads up to 1.76 W/ft^2 (18.9 W/m^2).

The *TSD* is not intended to substitute for rating systems or other references that address the full range of sustainable issues in retail stores, 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 assume good design skills and expertise in retail store design.

1.3 Report Organization

This report is presented in four sections. Section 1 presents introductory information including project background, scope, and goals. Section 2 describes the analysis methodology. Section 3 describes the development of prototype models, baseline models, and a list of energy design measures; and documents all modeling assumptions. Section 4 documents the final recommendations, discusses baseline and low-energy model performance, describes the sensitivity analyses presented in Appendix B, and lists recommendations for future work.

Appendix A contains the baseline model schedules. Appendix B presents, by climate zone, detailed descriptions of each low-energy model, and the results of a sensitivity study. Appendix C provides end use EUIs for all of the low-energy models, in both absolute and percentage units.

2 Methodology

This chapter describes the methodology and assumptions used to develop the recommended low-energy models and verify that they result in 50% energy savings. Section 2.1 presents a general overview of our methodology. Section 2.2 introduces the analysis tools used to conduct the study. Section 2.3 presents the 50% energy savings definition used in this work. Building model development is described in Section 3.

2.1 Guiding Principles

The objective of this study is to find retail store designs that achieve 50% energy savings over ASHRAE 90.1-2004. Secondarily, we seek designs that are cost effective over a 5-year analysis period. These objectives lead us to simultaneously 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, that is, 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 building subsystems is a paramount concern. As an example, a reduction in installed lighting power density can often be accompanied by a smaller HVAC system, but only will be if an integrated design process allows for it. (In one instance we found that the capacity of the HVAC system could be reduced by 0.3014 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 the building's energy use. The list of prospective EDMs is developed using the following guiding principles:

- An *AEDG* Scoping Committee report and the Small Retail *AEDG TSD* are starting points for determining candidate EDMs (Mitchell et al. 2006; Liu et al. 2007).
- We recommend off-the-shelf technologies that are available from multiple sources, as opposed to technologies or techniques that are one of a kind or available from only one manufacturer.
- The EDMs are limited to technologies that can be modeled using EnergyPlus and the NREL Opt-E-Plus platform.

The methodology for developing candidate integrated designs is discussed in Section 2.2. 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 (see Sections 3.1.7, 3.2, and 3.3).

2.2 Analysis Approach

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 5-TLCC. After the user specifies these objective 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 (IDFs). The output of the optimization is a 5-TLCC versus Percent Energy Savings graph, see Figure 2-1, that includes one point for each building, and a curve that connects the minimum cost buildings starting at 0% savings and proceeding to the building with maximum percent savings.

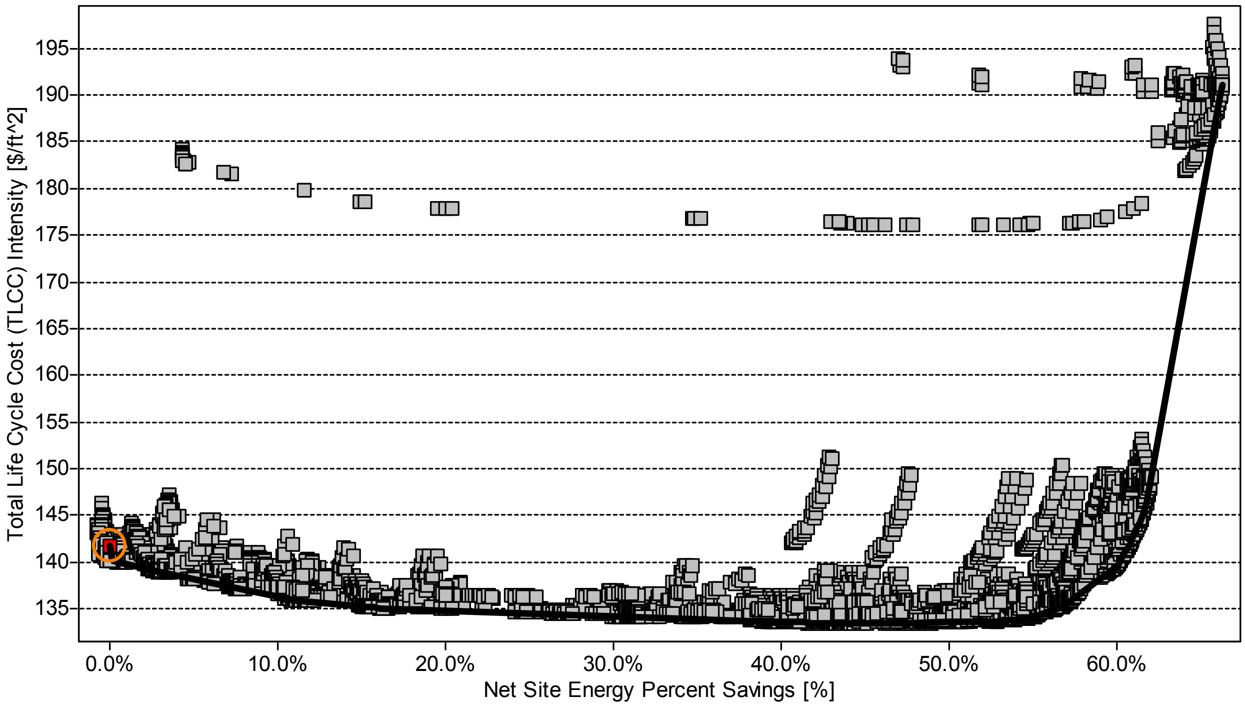

Figure 2-1 Example Opt-E-Plus Output

An interesting part of the minimum cost curve starts at the minimum cost building and continues in the direction of higher percent energy savings. The buildings lying along this segment are called *Pareto points* and are optimal for a given Opt-E-Plus run and its fixed set of EDMs in the sense that only by adding more EDMs can one make a building model that is both more energy efficient and less expensive than any Pareto point. The set of Pareto points determines a *Pareto Front*, which is a curve that represents a cost-effective pathway for achieving low-energy buildings. In Figure 2-1, the Pareto front is the portion of the black curve from about 45% savings to 65% savings.

2.2.1 Initialization

To set up the analysis, methods are applied 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, utility rates, economic multipliers, and other values specified by ASHRAE 90.1-2004 and ASHRAE 62.1-2004. Economizers are manually added to the baseline buildings in climate zones 3B, 3C, 4B, 4C, 5B, and 6B (see Section 2.3.4.2 for the climate zone definitions). All of the EDMs described in Section 3.2.6 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.

2.2.2 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 3.1.7.6, and is calculated using the economic data in Sections 3.1.7, 3.2, and 3.3.

Even with the sequential search algorithm, execution of an Opt-E-Plus search often requires a large number of simulations. For this study, each optimization required 3,000 to 6,500 simulations, and each simulation took 4 to 11 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 60 simulations simultaneously. When the simulations are complete, the database run manager within Opt-E-Plus specifies the next batch of simulations and distributes them based on the available resources.

2.2.3 Post-processing

The recommended low-energy design measures are derived from one of two buildings:

- The first Opt-E-Plus Pareto point that achieves 50% energy savings and does not include PV electricity generation, for example, the green point in Figure 2-2.
- The first Opt-E-Plus Pareto point that includes PV electricity generation, with the area devoted to PV panels perturbed so the resulting building just achieves 50% energy savings. For example, see the green point at 50% energy savings in Figure 2-3.

A sensitivity analysis in which sets of EDMs are reverted to the baseline level is then used to assess the relative importance of the EDMs included in the low-energy designs. In our example figures, Figure 2-2 and Figure 2-3, the sensitivity analysis buildings are highlighted in yellow (disregarding the yellow point at 55% savings in Figure 2-3), and include, for example, one building that is identical to the corresponding (green) low-energy model except that the lighting power density is set to the baseline level, rather than to the EDM level, which is 40% less than baseline. The analysis is meant to convey the relative importance of strategies such as daylighting, increased envelope insulation, and advanced outdoor air strategies to readers of this document who may face particular programmatic, architectural, or cultural barriers to implementing some of the recommendations.

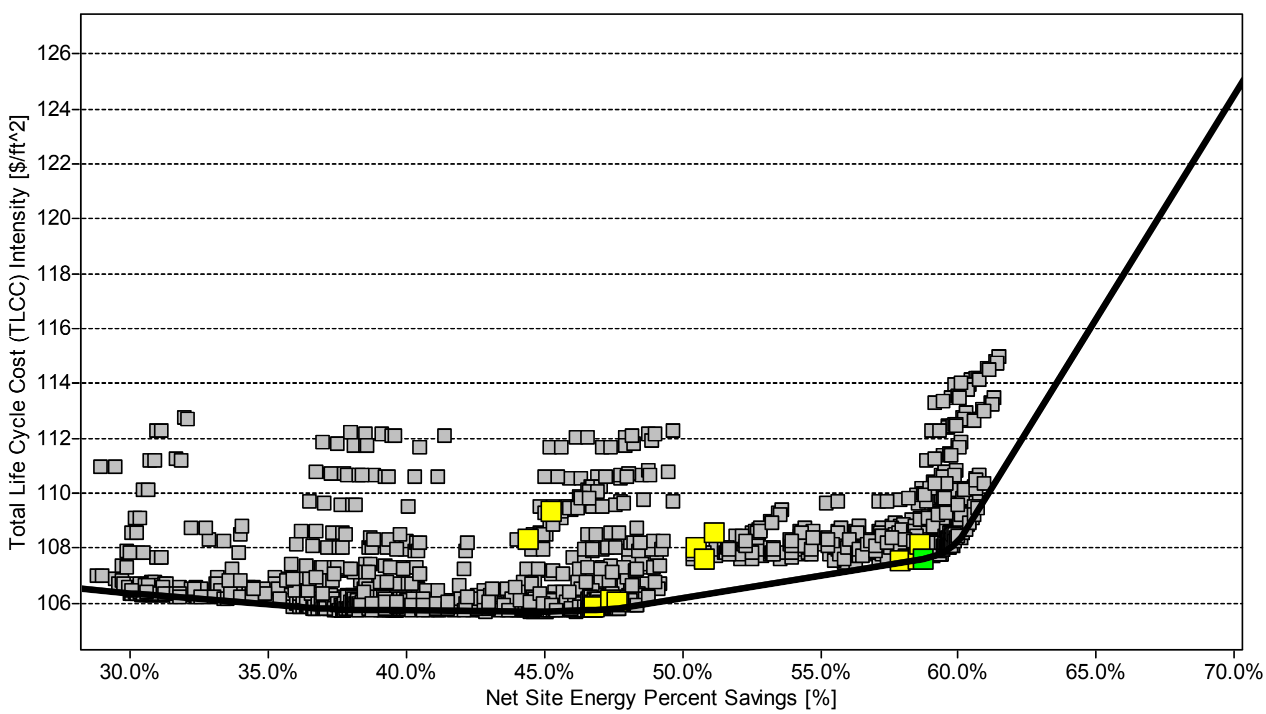

Figure 2-2 A Pareto Point that Achieves 50% Savings without PV

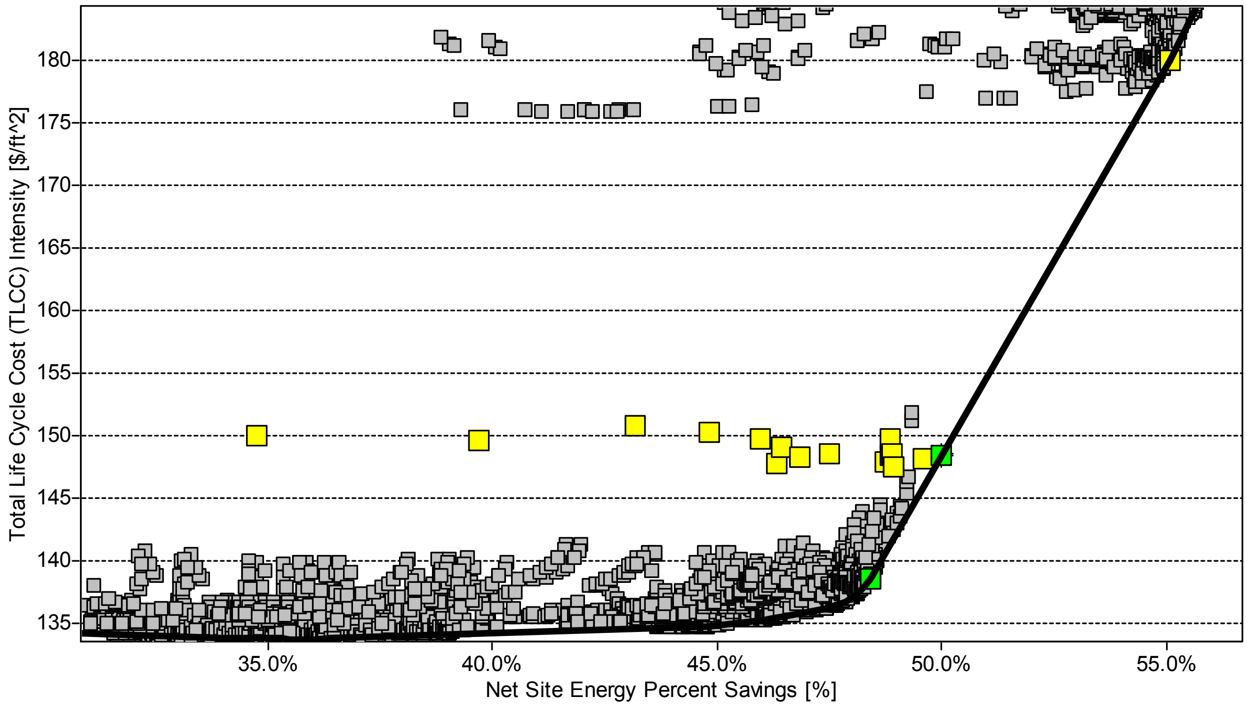

Figure 2-3 A Pareto Point with the Amount of PV Perturbed to Just Reach 50% Energy Savings

2.3 Energy Savings Definition

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 2004). 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 retail 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 perturbations called energy design measures (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. Give preference to those models that have low five-year total life cycle cost.

2.3.1 Net Site Energy Use

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

2.3.2 Whole-Building Energy Savings

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, on the other hand, include all loads (regulated and unregulated) in the calculations. In general, whole-building savings are more challenging than regulated loads savings given the same numerical target, but more accurately represent the impact of the building 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 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% *AEDG*s, and we study multiple plug load levels to reflect the variation present in the medium box retail subsector.

2.3.3 ASHRAE Baseline

This report is intended to help owners and designers of medium box retail stores achieve energy savings of at least 50% compared to the minimum requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004 (ASHRAE 2004). 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 Standard 90.1-2004. The baseline models are constructed in a manner similar to what was used in the previous *TSD*s (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 to represent a more realistic split of EER between the supply fan and the compressor/condenser system.
- 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.

2.3.4 Modeling Methods

2.3.4.1 EnergyPlus

EnergyPlus version 2.2 (DOE 2008), 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 were 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 the DOE simulation tool that computes building energy use based on the interaction of the climate, building form and fabric, internal gains, HVAC systems, and renewable energy systems. The simulations were run with EnergyPlus Version 2.2 compiled on local 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).

2.3.4.2 Climate Zones

The *AEDG*s contain a unique set of energy efficiency recommendations for each International Energy Conservation Code (IECC)/ASHRAE climate zone. The eight zones and 15 sub-zones in the United States are depicted in Figure 2-4. 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. Sub-zones indicate varying moisture conditions. Humid sub-zones are designated by the letter A, dry sub-zones by B, and marine sub-zones 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).

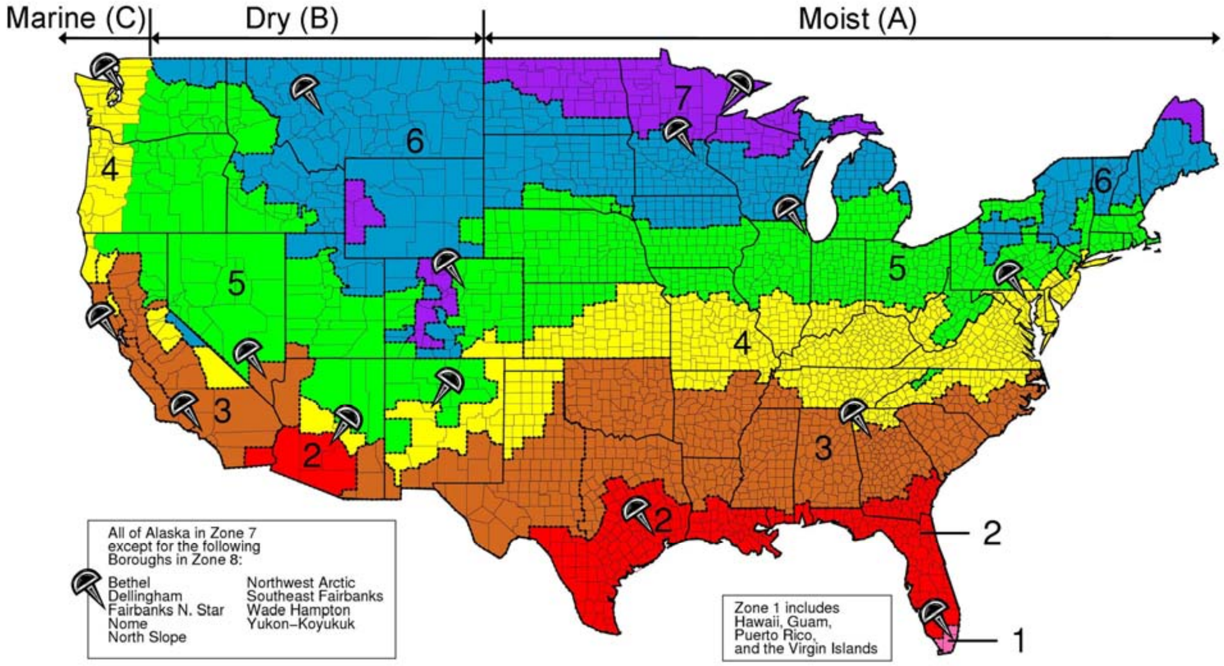

Figure 2-4 DOE Climate Zones and Representative Cities

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 2-4 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 partially 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)

3 Model Development and Assumptions

This section documents the development of model inputs. Section 3.1 describes the programmatic characteristics of a typical medium box retail store and uses them to develop high-level, prototype models. Section 3.2 elaborates on Section 3.1 to define the EnergyPlus baseline models that provide a reference for determining percent savings and are minimally compliant with Standard 90.1-2004. Section 3.3 describes the list of energy design measures (EDMs) used to create low-energy models.

3.1 Prototype Model

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

- *2003 Commercial Buildings Energy Consumption Survey* (*CBECS*) (EIA 2005)
- *Technical Support Document: The Development of the Advanced Energy Design Guide for Small Retail Buildings* (Liu et al. 2006)
- *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)

After a brief description of each data source, the reasoning behind the prototype model assumptions is described in several functional groupings. Three prototype models are developed, one for each of three plug load levels. They are summarized in Section 3.1.8.

3.1.1 The Data Sources

This section gives a brief overview of the data sources used to generate the medium box retail prototype model.

3.1.1.1 2003 Commercial Buildings Energy Consumption Survey

The *Commercial Buildings Energy Consumption Survey* (*CBECS*) is a survey of U.S. commercial buildings conducted by the Energy Information Administration (EIA) every four years. The *2003 CBECS* describes 5,215 buildings and provides weighting factors to indicate how many buildings in the current U.S. stock each represents (for a total of 4.86 million buildings). The building descriptions consist of numerous standardized data, including floor area, number of floors, census division, basic climatic information, principal building activity, number of employees, energy use by type, and energy expenditures. Because building energy use typically scales with floor area rather than with number of buildings, the *CBECS* statistics in this *TSD* are weighted by the aforementioned weighting factors multiplied by floor area.

The *2003 CBECS* includes 355 non-mall retail buildings, which represent 121,000 buildings and 4.32 billion ft^2 (401 million m^2) of floor area nationwide (6% of the total area represented by *CBECS*). This *TSD* focuses on new construction, so only survey buildings that were built since 1970 and renovated since 1980 are used to develop prototype assumptions. To minimize redundancy, we refer to these buildings simply as the retail buildings built since 1970, with the understanding that the buildings built between 1970 and 1980 are also screened for renovations. The area-weighted distribution of the *CBECS* retail buildings by year of construction is shown in Figure 3-1. The portion built since 1970 consists of 158 survey buildings representing 2.05 billion ft^2 (190 million m^2) of floor area. These buildings are distributed among three more specific building activities: vehicle dealerships and showrooms, retail stores, and other retail. Most of the post-1970 retail floor area of interest is in proper retail stores—just 12% is in vehicle dealerships and showrooms, and 2.9% is other retail.

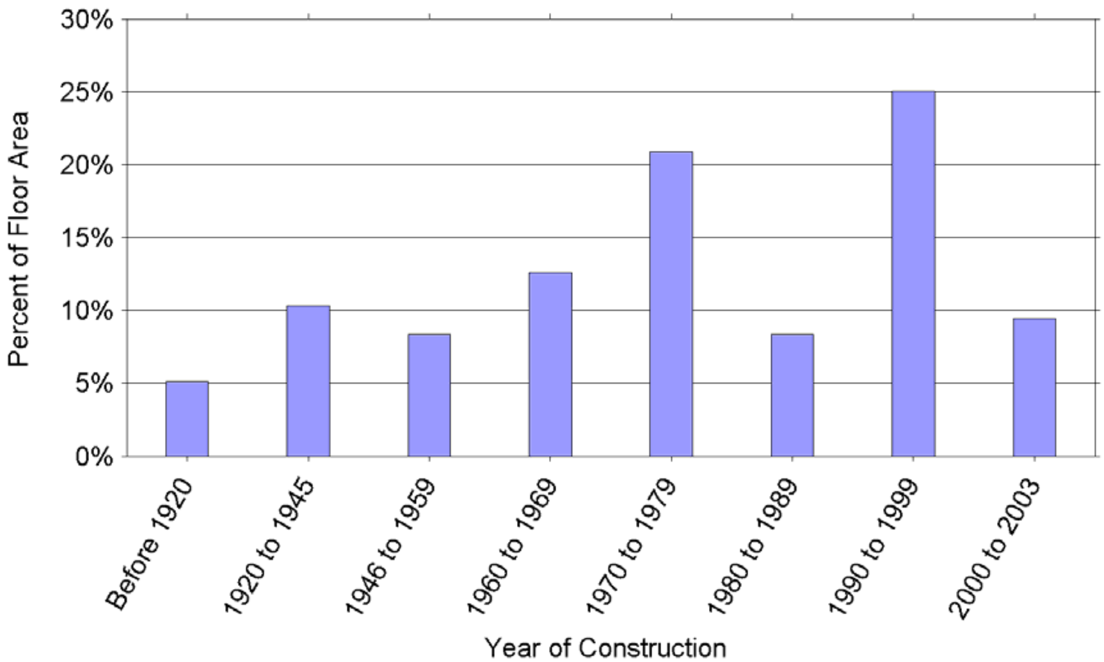

Figure 3-1 Area Weighted Histogram of Retail Store Vintage

3.1.1.2 Technical Support Document: The Development of the Advanced Energy Design Guide for Small Retail Buildings

The *Small Retail AEDG TSD* relied largely on its AEDG committee, phone interviews with representative store managers, and ASHRAE building standards for the development of its prototype and baseline model assumptions. Some decisions were made or verified using the *2003 CBECS* dataset (Liu et al. 2006). The *AEDG* assumptions for small retail were used where appropriate; however, no AEDG committee is associated with this *TSD*, so we cannot always follow our predecessors' example in developing model assumptions.

3.1.1.3 DOE Commercial Building Research Benchmarks for Commercial Buildings

Concurrently with this *TSD*, DOE developed a new generation of subsector-specific benchmark building models (Deru et al. 2008). As the retail building model developed for that project is 41,786 ft^2 (3,882 m^2), and therefore falls within the scope of this work, we collaborated with the benchmark project team. However, the retail benchmark model was not used directly in this study so we could use a floor plan that is conducive to daylighting.

3.1.1.4 Methodology for Modeling Building Energy Performance across the Commercial Sector

NREL recently developed methods for modeling the entire commercial building sector (Griffith et al. 2008). The resulting sector-wide model is based on the *2003 CBECS* and a few other data sources, notably CEUS, the California Commercial End-Use Survey (CEC and Itron Inc. 2006). In some respects, this synthesizing work is probably more reliable than the individual data sources taken on their own.

3.1.1.5 Other Literature

A document from the Maryland Planning Department (Perry and Noonan 2001) informs the definition of medium box (as opposed to small or large box) retail.

3.1.2 Program

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

3.1.2.1 Building Size

This *TSD* assumes that medium box retail stores have 20,000 to 100,000 ft^2 (1,850 to 9,300 m^2) of floor area. The lower bound originates from the inclusion of stores up to 20,000 ft^2 in the *Advanced Energy Design Guide for Small Retail Buildings* (ASHRAE et al. 2006). The upper bound represents a reasonable boundary between so-called medium box and big-box stores. Perry and Noonan (2001) list four types of stores:

- Discount department stores – 80,000 ft^2 to 130,000 ft^2 (7,400 m^2 to 12,000 m^2) buildings that house retailers such as Kmart, Target, and Walmart.
- Category killers – 20,000 ft^2 to 120,000 ft^2 (1,850 m^2 to 11,150 m^2) buildings with retailers such as Circuit City, Office Depot, Sports Authority, Lowe's, Home Depot, and Toys "R" Us, which focus on one type of merchandise.
- Outlet stores – 20,000 ft^2 to 80,000 ft^2 (1,850 m^2 to 7,400 m^2) buildings that house outlet stores for major department stores and brand name goods.
- Warehouse clubs – 104,000 ft^2 to 170,000 ft^2 (9,650 m^2 to 15,800 m^2) buildings that house retailers, such as Costco Wholesale, Pace, Sam's Club, and BJ's Wholesale Club, which offer goods in bulk.

These descriptions generally support a 100,000 ft^2 (9,300 m^2) cut-off, since the resulting medium box and big-box classifications are fairly clear. Most category killer, and all outlet stores, are medium box; discount department stores, warehouse clubs, and the largest category killers are big-box.

The size distribution of retail stores built since 1970, according to the *2003 CBECS*, is shown in Figure 3-2. The labels correspond to bin maxima. Thus, medium box retail comprises 29% of the total floor area under consideration. About 12% of that (71.4 million ft^2 of 600 million ft^2) is ascribed to vehicle dealerships between 25,000 ft^2 and 55,000 ft^2. The remaining 88% is in retail stores, because all the other retail buildings are smaller than 10,000 ft^2.

Only 33 *2003 CBECS* non-mall retail buildings built since 1970 have floor areas between 20,000 ft^2 and 100,000 ft^2. Nonetheless, those buildings are most representative of the new construction we are trying to influence, and so are the sole basis of the *2003 CBECS* statistics presented in the remainder of this report.

Our prototype store is 50,000 ft^2 (4,645 m^2), as this size lies well between 20,000 ft^2 and 100,000 ft^2 and is near the area-weighted mean off the 33 medium-sized CBECS retail stores (see Figure 3-3).

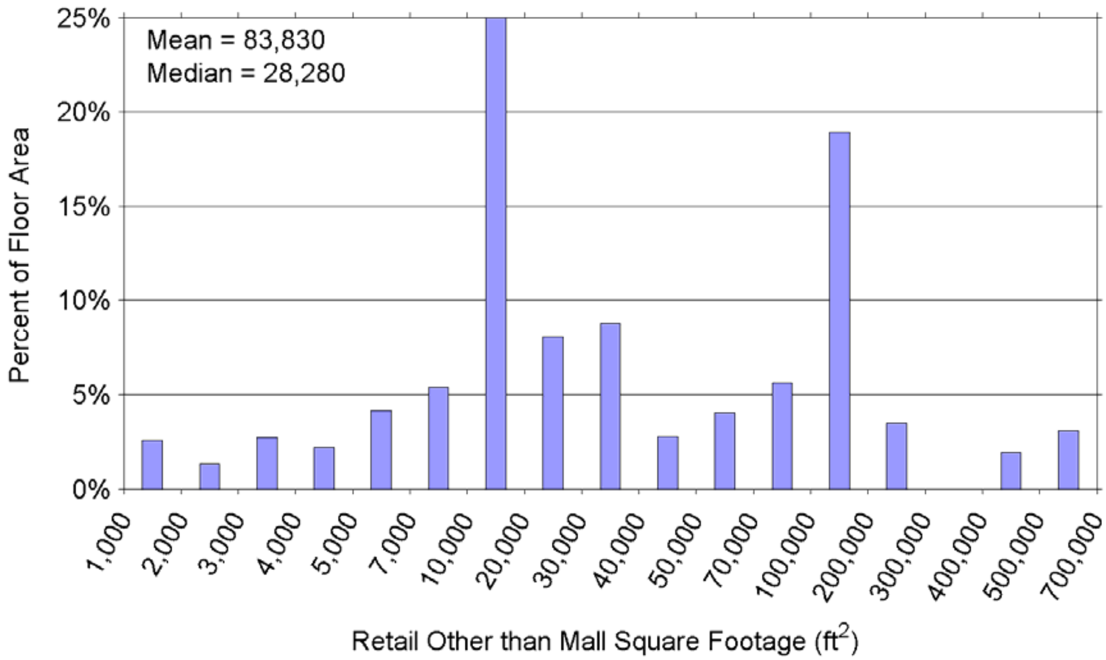

Figure 3-2 Area Weighted Histogram of Post-1970 Retail Store Size

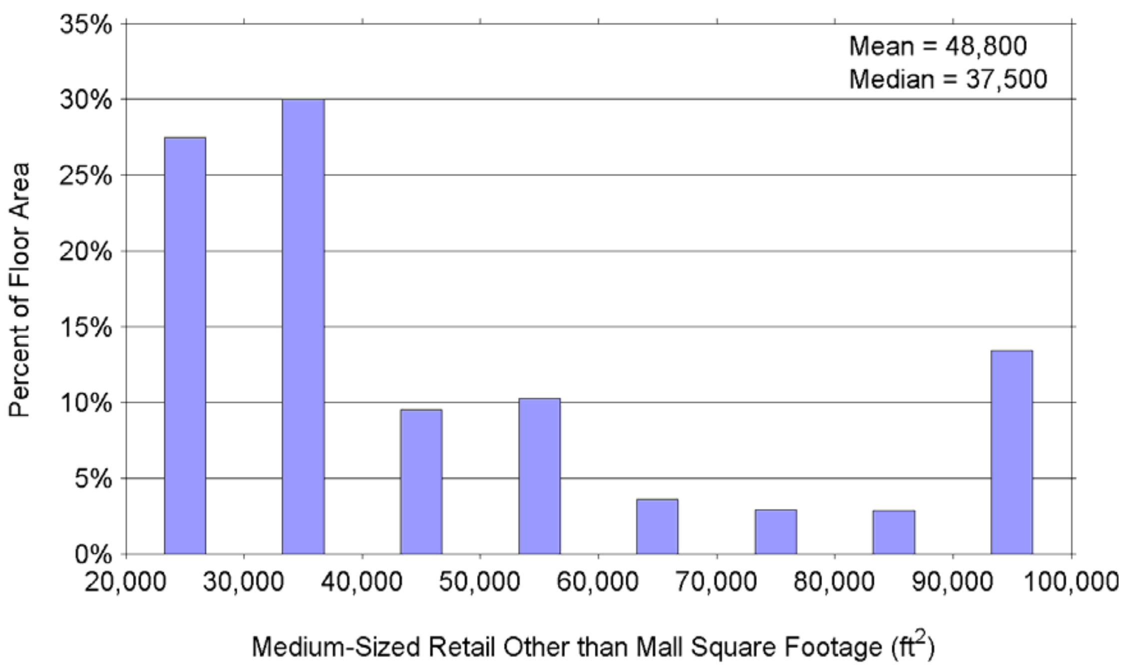

Figure 3-3 Area Weighted Histogram of Post-1970 Medium Retail Building Size

3.1.2.2 Zones and Space Types

Liu et al. (2006) assumed that merchandising accounted for 70% of the floor area in their prototype stores. The rest is allocated to active storage (20%), office (5%) and other use (5%) spaces. In contrast, the benchmark retail building, which is significantly larger than the small retail prototypes in Liu et al., has approximately 90% of its area devoted to merchandising (Deru et al. 2008).

Based on these guidelines, and the common-sense notion that larger buildings likely require a smaller proportion of non-merchandising space, our final layout has 10% to 15% of the floor area set aside for storage, office, and other uses. The thermal zones should also be set up for perimeter daylighting, which limits the perimeter zones to maximum depths of 15 ft.

3.1.2.3 Internal Load Densities and Schedules

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

3.1.2.3.1 Operating Hours

None of the *2003 CBECS* medium-size, post-1970 retail buildings was vacant for any significant duration during the 12 survey months. Only 3.5% of the represented floor area is not typically open every weekday, and just 2.4% is in stores that are open 24 hours per day. All the stores are open sometime during the weekend. The distribution of operating hours per week depicted in Figure 3-4 supports schedules with 70 to 90 open hours per week.

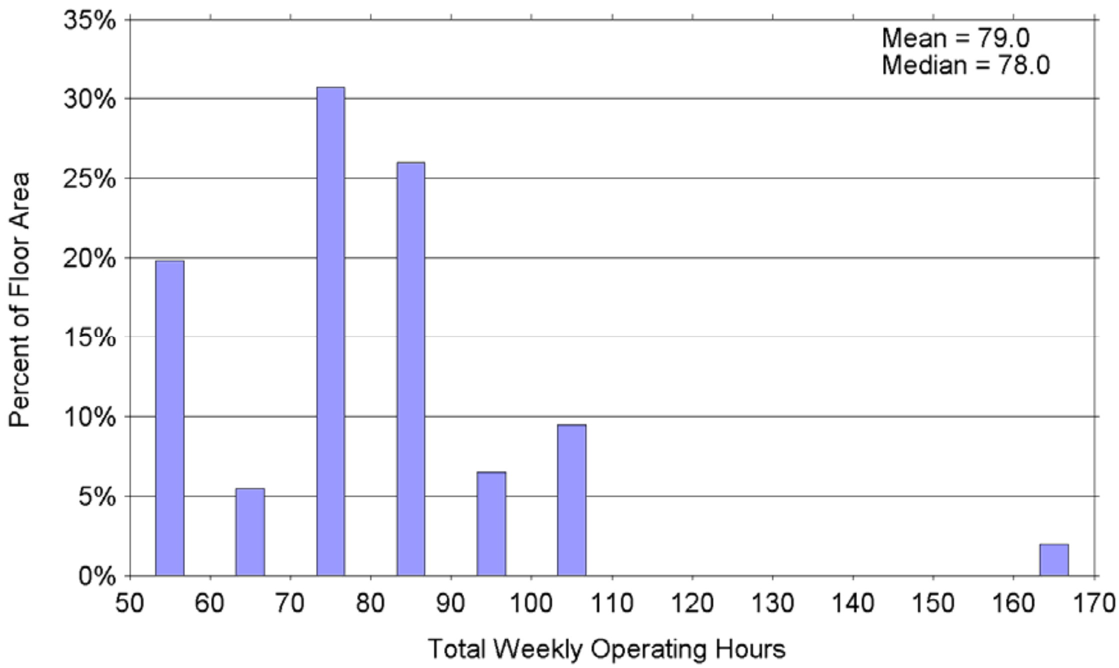

Figure 3-4 Area Weighted Histogram of Post-1970 Medium Retail Weekly Operating Hours

Liu et al. (2006) modeled operating hours based on phone conversations with three store managers. The open hours for those stores were 64, 71, and 93 per week; staff was present for an additional two to three hours per day. The benchmark project retail store follows the occupancy schedules provided by ASHRAE Standard 90.1-1989, which do not explicitly state when the store is assumed to be open, just occupied by staff, or otherwise in use (Deru et al. 2008). However, assuming that 10% occupied indicates the presence of staff only, and that all other nonzero occupancy values correspond to open hours, one can infer a weekly schedule of Monday through Saturday 8:00 a.m. to 9:00 p.m., and Sunday 10:00 a.m. to 6:00 p.m., which totals 86 hours per week.

Based on these findings and a few store schedules (posted online), we assume that the prototype store is open Monday through Saturday 9:00 a.m. to 9:00 p.m., and Sunday 10:00 a.m. to 6:00 p.m. (80 hours per week), and that staff occupies the store for two additional hours per day, one hour before opening and one hour after closing.

3.1.2.3.2 Occupancy

The *2003 CBECS* survey provides little information about occupancy levels in retail stores. It does report the number of employees during the main shift, however. Figure 3-5 shows those statistics normalized by building floor area.

Figure 3-5 Area Weighted Histogram of Post-1970 Medium Retail Employee Density

Peak occupancy values for the *Small Retail AEDG TSD* were taken from ASHRAE Standard 62, which lists 15 people per 1,000 ft^2. This value seems reasonable, as it ensures that the store HVAC system is designed to provide the outside air required on the busiest days. An alternative occupant density and schedule is listed in the Standard 90.1-2004 User's Manual. That density, at 3.33 people/1000 ft^2, seems much too low for a busy shopping day, but some aspects of the schedule seem more realistic than the *Small Retail AEDG TSD* occupancy schedule (such as the lack of a lunch-hour spike during the weekend). Thus the peak occupant density for this *TSD* is 15 people/1000 ft^2 (16.14 people/100 m^2), and the occupancy schedule, which is a blend of the *Small Retail AEDG TSD* and the Standard 90.1 User's Guide schedules, is listed in Table 3-1. The occupancy level before opening and after closing, 0.05, corresponds to 0.75 people/1000 ft^2 (0.81 people/100 m^2), which is similar to the employee density reported by the *2003 CBECS*.

Table 3-1 Prototype Store Occupancy Schedule, in Fraction of Peak Occupancy

Hour	Weekdays	Saturdays	Sundays, Holidays
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	0	0
9	0.05	0.05	0
10	0.10	0.10	0.05
11	0.20	0.30	0.10
12	0.40	0.40	0.20
13	0.40	0.60	0.50
14	0.25	0.70	0.50
15	0.25	0.70	0.50
16	0.50	0.70	0.50
17	0.50	0.70	0.50
18	0.50	0.70	0.20
19	0.30	0.60	0.05
20	0.30	0.40	0
21	0.20	0.40	0
22	0.05	0.05	0
23	0	0	0
24	0	0	0

3.1.2.3.3 Lighting

The *2003 CBECS* data indicate that almost no medium-size, post-1970 retail buildings have independent lighting controls or sensors. However, 71% of floor area is subject to an energy management control system (EMCS) that controls lighting, and 80% of floor area is lighted with electronic ballast fixtures. Figure 3-6 and Figure 3-7 show the distribution of lighting percentage when the store is open and closed, respectively. These figures and the abundance of EMCS systems support a lighting schedule with significant reductions during unoccupied hours—this *TSD* follows the Small Retail *AEDG TSD* by setting lighting levels to 10% during unoccupied hours, 50% when only staff is present, and 95% during open hours. The increase in off-hours lighting over the *2003 CBECS* median is based on engineering experience with egress lighting.

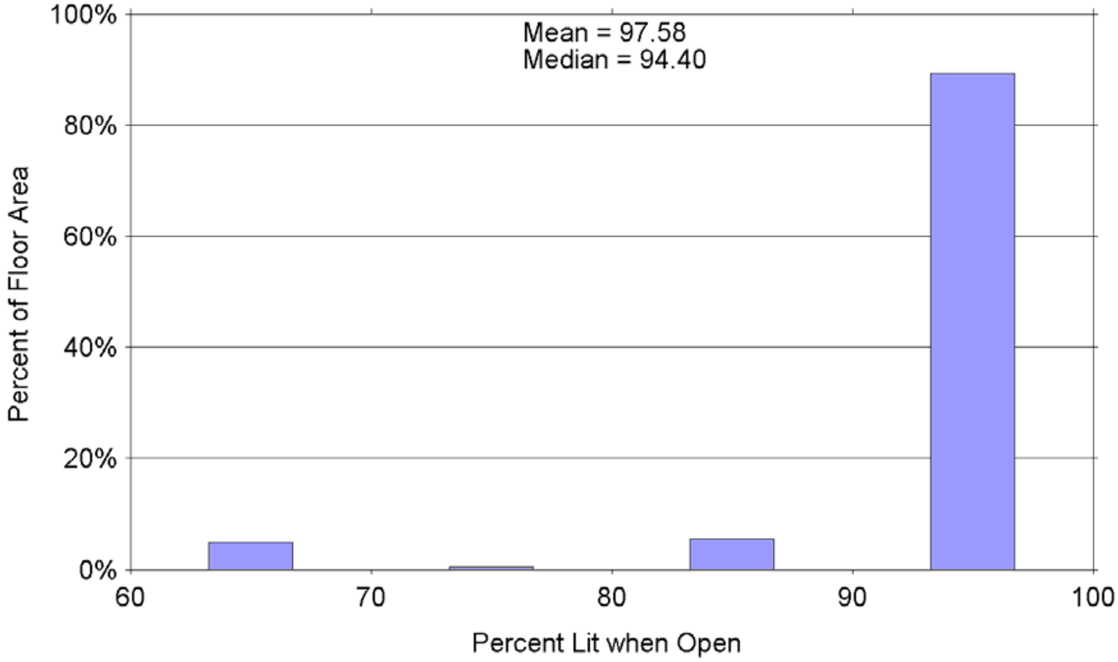

Figure 3-6 Area Weighted Histogram of Post-1970 Medium Retail Open Hours Lighting Percentage

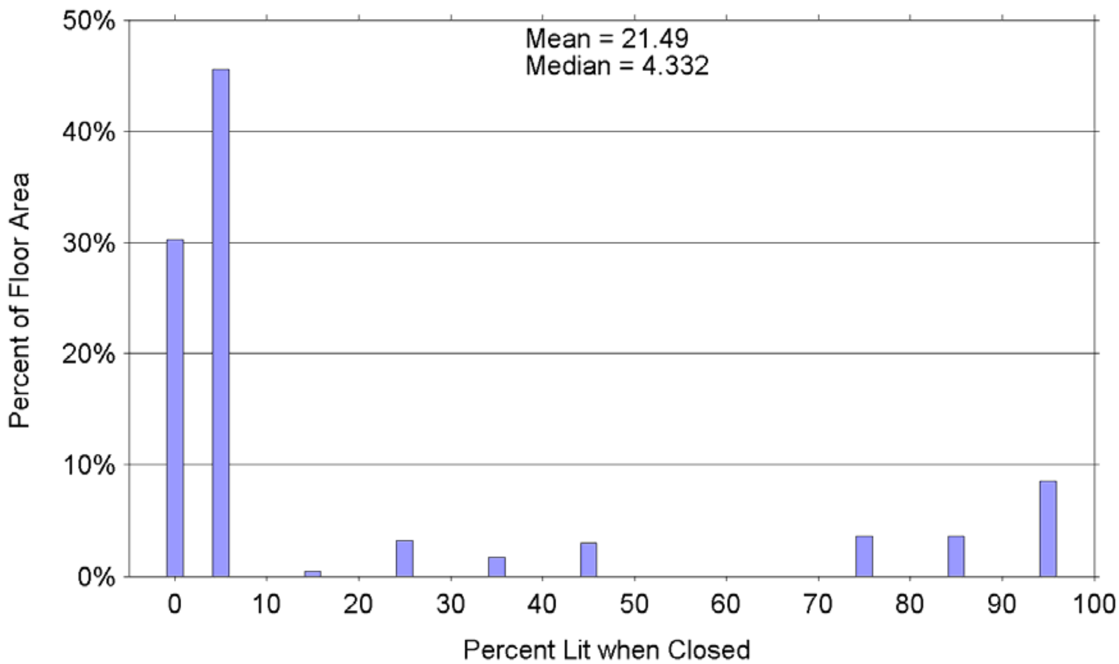

Figure 3-7 Area Weighted Histogram of Post-1970 Medium Retail Closed Hours Lighting Percentage

3.1.2.3.4 Plug and Process Loads, Accent Lighting

Plug and process loads are notoriously difficult to estimate. Griffith et al. (2008) tried to reconcile the *2003 CBECS* and *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 retail 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 0 to 3.9 W/ft^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; high-value items such as jewelry, china, silver, and art are allowed 3.9 W/ft^2.

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 closed hours percentage was derived directly from the *2003 CBECS* variable specifying whether or not equipment is turned off during off hours, RDOFEQ8. The *Small Retail TSD* plug load schedule was simply 0.4 W/ft^2 (4.3 W/m^2) peak density, 5% of this during off hours, 90% of this during operating hours, and an hour-long transition at 50%. 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.

For the current study, we specify plug load and accent lighting levels on a space-by-space basis, and then compute zone-level plug load averages that include both contributions. There are three prototype models based on whole-building plug load densities of approximately 0.25, 1.00, and 1.75 W/ft^2. Proper plug loads are set to 0.2 to 0.6 W/ft^2; the remaining density comes from accent lighting. (See Subsection 3.1.8 for details about the final distribution of plug and accent lighting loads across space types.) The low plug load level is meant to model stores such as bookstores, which have little to no accent lighting or plug-in merchandise. Example medium and high plug load stores are office supply stores and electronics stores, respectively, which have increasing amounts of plug-in merchandise and accent lighting.

The plug load schedule is 15% on during off hours, 50% on during transition hours, and 90% on during operating hours for the low and medium plug load models. The high plug load models only reduce loads to 40% during off hours and 65% during transition hours, in an attempt to model electronics stores in which it is impractical to shut off many of the products that are on display.

The sector-wide methodology study determined that retail 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. 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 retail store has no gas process loads.

3.1.3 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.

3.1.3.1 Building Shape

Based on *2003 CBECS* statistics (see Figure 3-8), the 50,000 ft^2 prototype stores are one-story rectangular buildings with a 1.25 aspect ratio. More specifically, the footprint will be 250 ft × 200 ft (76.2 m × 61.0 m).

The *Small Retail TSD* assumed an 11-ft ceiling and a 14-ft floor-to-floor height for the strip mall prototype, and a 12-ft ceiling and a 16-ft floor-to-floor height for the standalone prototype. Since larger stores tend to have a more open feel, we assume a ceiling and floor-to-floor height of 20 ft (no drop ceiling).

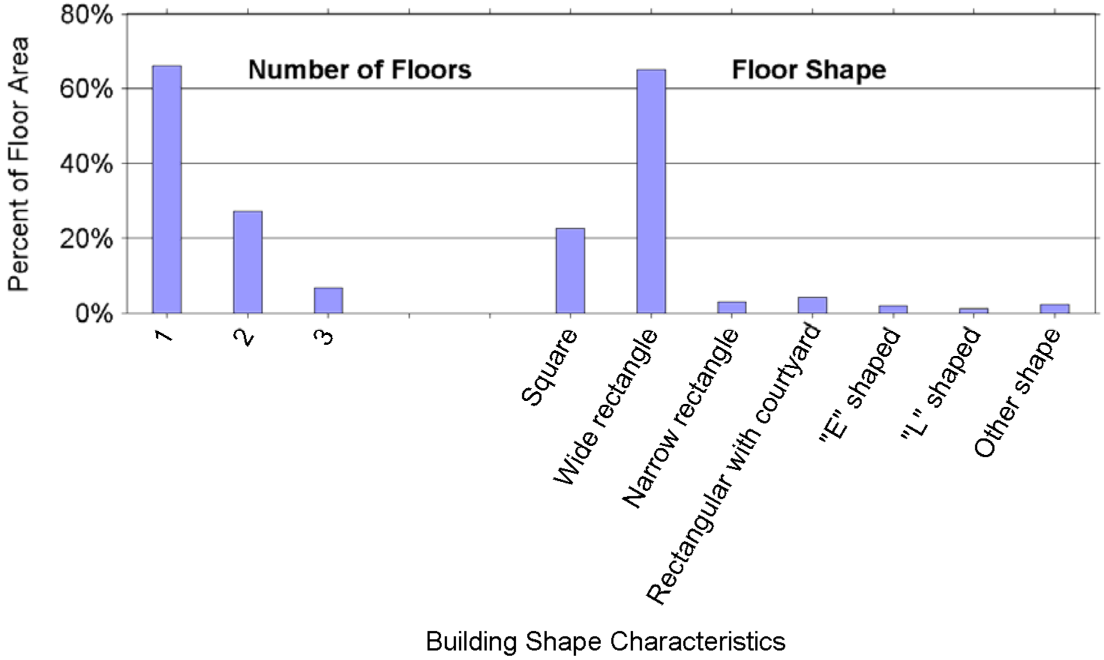

Figure 3-8 Area Weighted Histograms of Post-1970 Medium Retail Store Shape Characteristics

3.1.3.2 Fenestration

The *2003 CBECS* reports on several aspects of fenestration form. Statistics on the amount and distribution of windows in medium box retail stores are shown in Figure 3-9; Figure 3-10 gives statistics on window shading (with awnings or overhangs), skylights, and what percentage of individual stores' floor area is daylit.

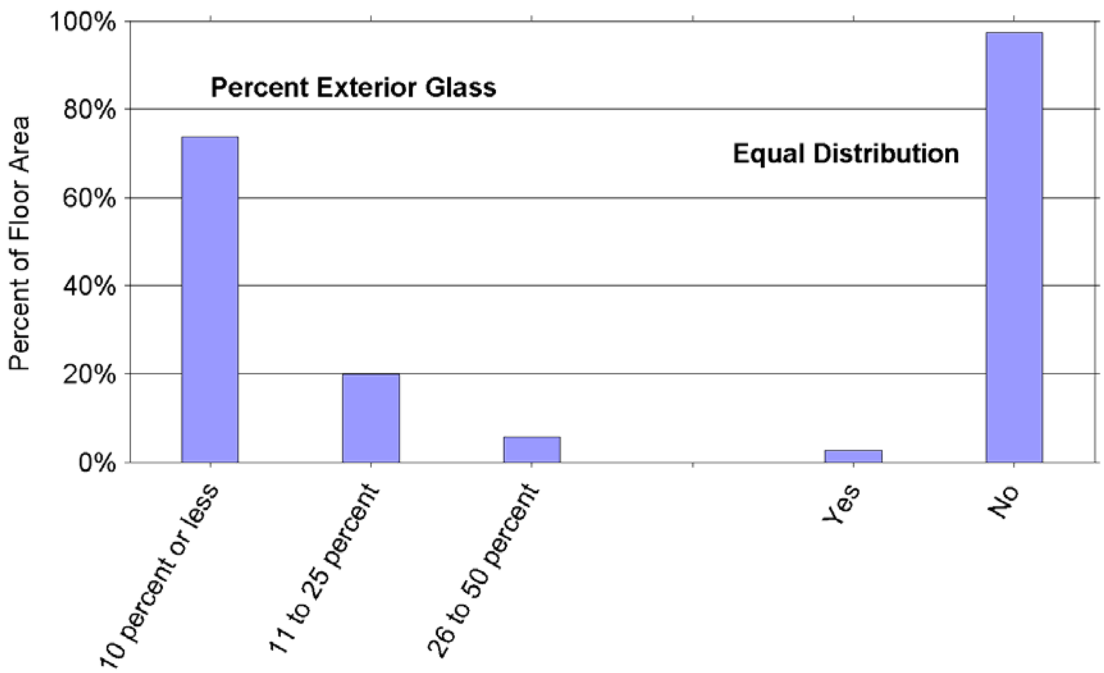

Figure 3-9 Area Weighted Histograms of Post-1970 Medium Retail Fenestration Amounts

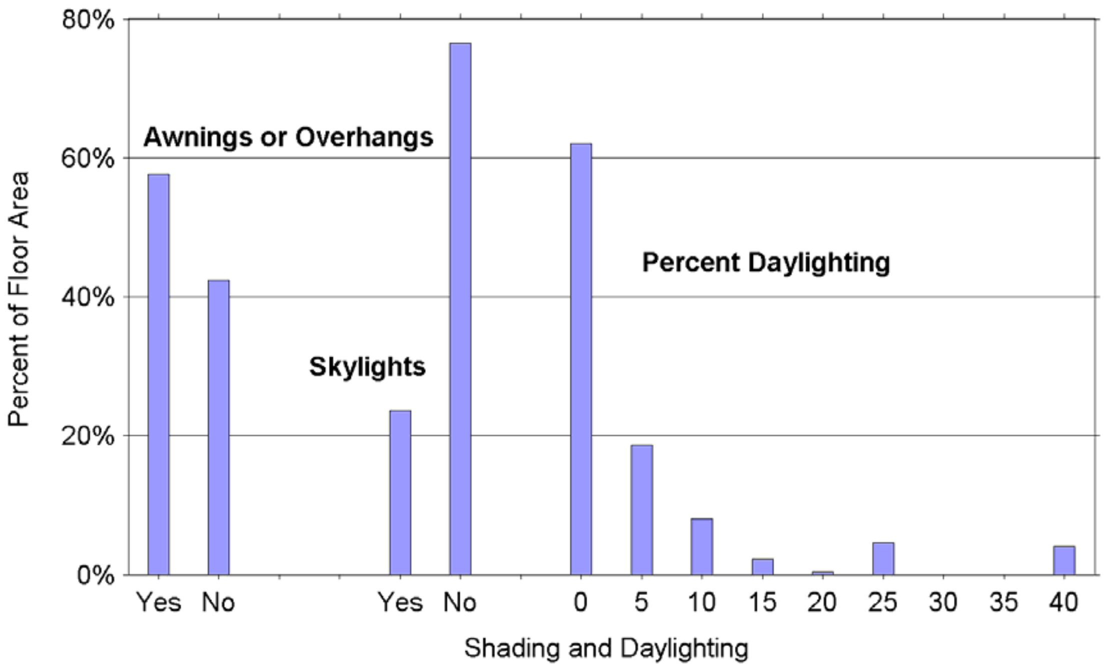

Figure 3-10 Area Weighed Histogram of Post-1970 Medium Retail Sunlight Management

Based on the *2003 CBECS* data, our prototype stores' wall area is less than 10% glazed, and the glazing is unevenly distributed across the exterior walls. There will be no skylights or daylight controls. Although the *2003 CBECS* supports the inclusion of overhangs, they are not included in the prototype stores based on the Appendix G procedures in Standard 90.1-2004.

The *Small Retail TSD* had all fenestration on the façade—in particular, 70% of the front wall was glazed in both prototypes. This results in 20% and 17% overall window-to-wall ratios (WWRs) for the strip mall and the standalone store, respectively. Based on the building dimensions, the amount of glazing was 980 ft^2 for the strip mall and 1,344 ft^2 for the standalone building. We assume that the amount of glazing on a retail store is fairly independent of store size. Glazing areas between 200 ft^2 and 1,400 ft^2 seem reasonable—the prototype stores have 1,000 ft^2 of glazing on the façade, which yields a 20% WWR for that wall, and a 5.6% overall WWR.

3.1.4 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 3.2.2, since Standard 90.1-2004 specifies the minimum performance of these components.

3.1.4.1 Construction Types

The *2003 CBECS* data for wall and roof construction types are shown in Figure 3-11. The prototype building has masonry wall construction (which includes brick, stucco, and the varieties of concrete) and a roof with all insulation above deck (which encompasses all the categories below except slate or tile shingles). The masonry wall assumption ignores the 34% of medium-sized retail buildings that have metal walls.

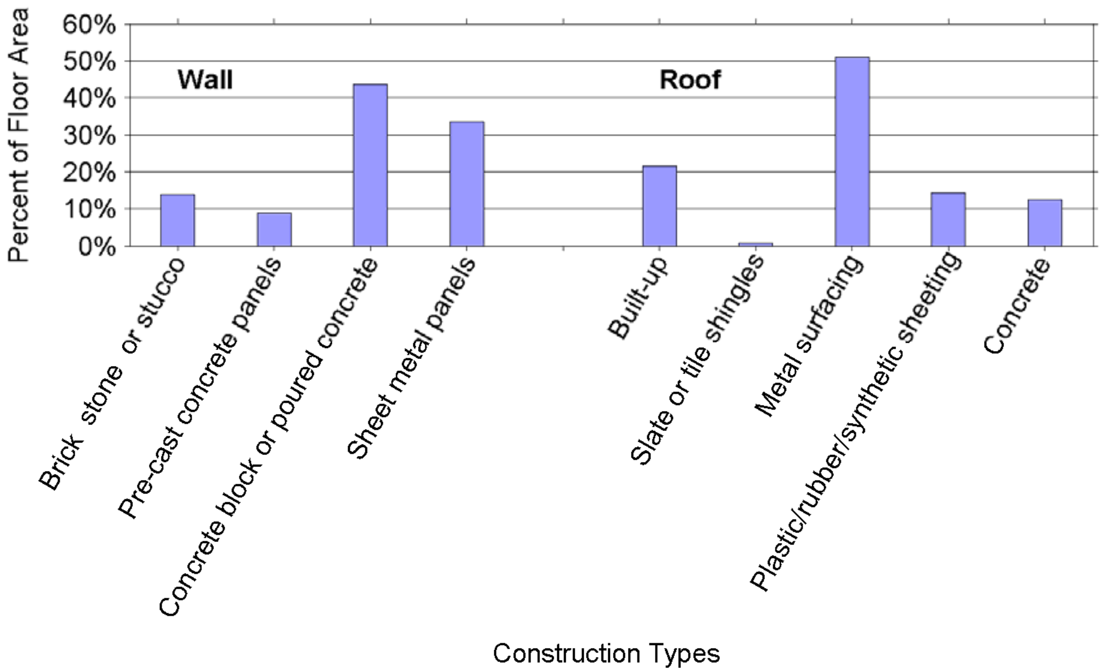

Figure 3-11 Area Weighted Histograms of Post-1970 Medium Retail Store Construction Types

3.1.4.2 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 100,000 ft^2 (9,290 m^2) of 6-in. (0.15-m) thick wood.

3.1.5 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 3.2.5 and 3.2.6.

3.1.5.1 Heating, Ventilating, and Air-Conditioning

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

Figure 3-12 summarizes the CBECS statistics on what types of heating and cooling equipment are used in medium box retail stores. All cooling is electric; the types of fuel used for heating are shown in Figure 3-13. 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 with natural gas furnaces for heating, and electric direct-expansion coils with air-cooled condensers for cooling. The units do not have VAV systems since the *2003 CBECS* reports that just 27% of 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 (EMCS), and the rest rely on manual reset. Our prototype store captures such behavior with a thermostat schedule (see Section A.5).

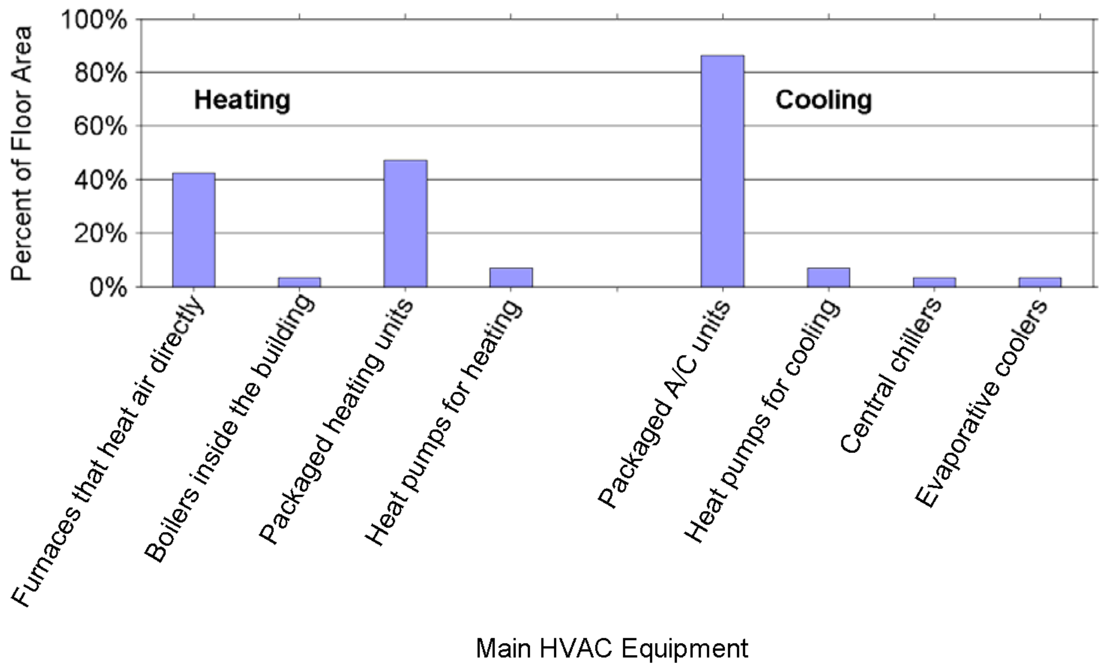

Figure 3-12 Area Weighted Histogram of Post-1970 Medium Retail Heating and Cooling Equipment

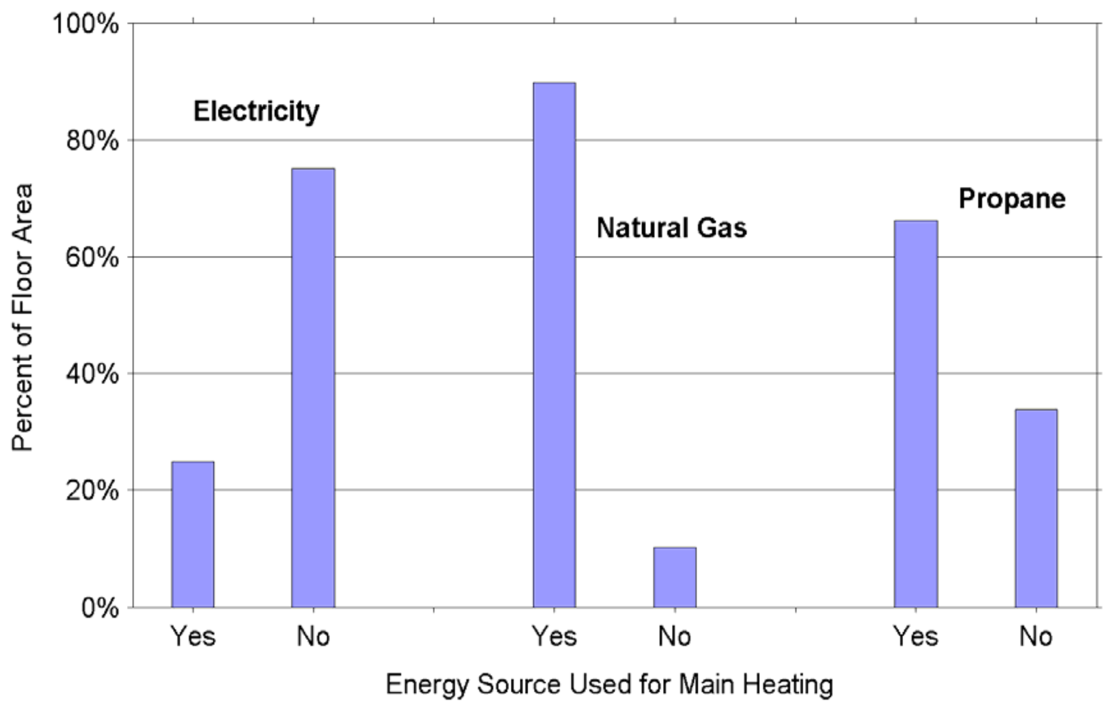

Figure 3-13 Area Weighted Histogram of Post-1970 Medium Retail Main Heating Source

3.1.5.2 Service Water Heating

The *2003 CBECS* data shown in Figure 3-14 indicate that most medium-sized retail 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 sized according to the ASHRAE *HVAC Applications Handbook*, Chapter 49 (ASHRAE 2003), see Section 3.2.6.

3.1.6 Energy Use Trends

To analyze the energy use of retail stores in the *2003 CBECS* by ASHRAE climate zone, we used the data generated by the sector-wide model of Griffith et al. (2008). Building location determines several important simulation parameters for this model, including weather file, utility tariffs, emissions factors, site-to-source conversion factors, latitude, longitude, and elevation; however, the *2003 CBECS* masks the locations of buildings for anonymity. The *CBECS* does provide the census division and values for HDDs and CDDs, which Griffith et al. (2008) used to find the closest TMY2 weather data location (and thus, the climate zone) for each *2003 CBECS* building. The interested reader is referred to Griffith et al. (2008) for further details on the location selection algorithm and simulation assumptions.

The resulting area-weighted average site EUIs for the 33 *2003 CBECS* post-1970 medium-sized retail stores are shown by ASHRAE climate zone in Table 3-2. Table 3-2 also shows how many of those *2003 CBECS* buildings are in each climate zone: there are none in climate zones 1 or 8, and only one in zone 7.

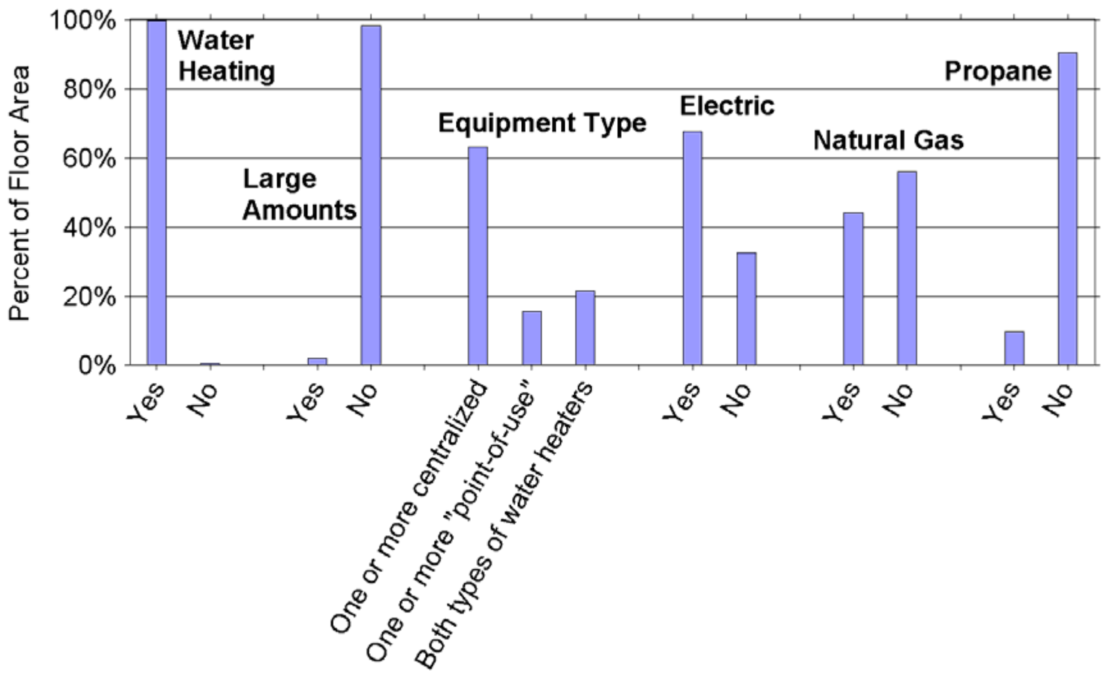

Figure 3-14 Area Weighted Histograms of Post-1970 Medium Retail Service Hot Water Characteristics

Table 3-2 Area Weighted Average Site EUI by ASHRAE Climate Zone, Post-1970 Medium Retail

ASHRAE Climate Zone	Number of Retail Stores in CBECS	Area Weighted Average Site EUI (kBtu/ft^2)	Area Weighted Average Site EUI (MJ/m^2)
1	0	N/A	N/A
2	3	81.17	922.1
3	9	71.12	807.9
4	6	60.52	687.5
5	10	68.47	777.8
6	4	87.98	999.4
7	1	129.8	1474
8	0	N/A	N/A
All	33	71.31	810.1

The national area-weighted average site EUI is 71.31 kBtu/ft^2 (810.1 MJ/m^2). The by climate zone data are depicted graphically in Figure 3-15. Note that the highest EUI is in cold climate zone 7 (there are no data for zone 8), and the lowest is in zone 4, which is quite temperate.

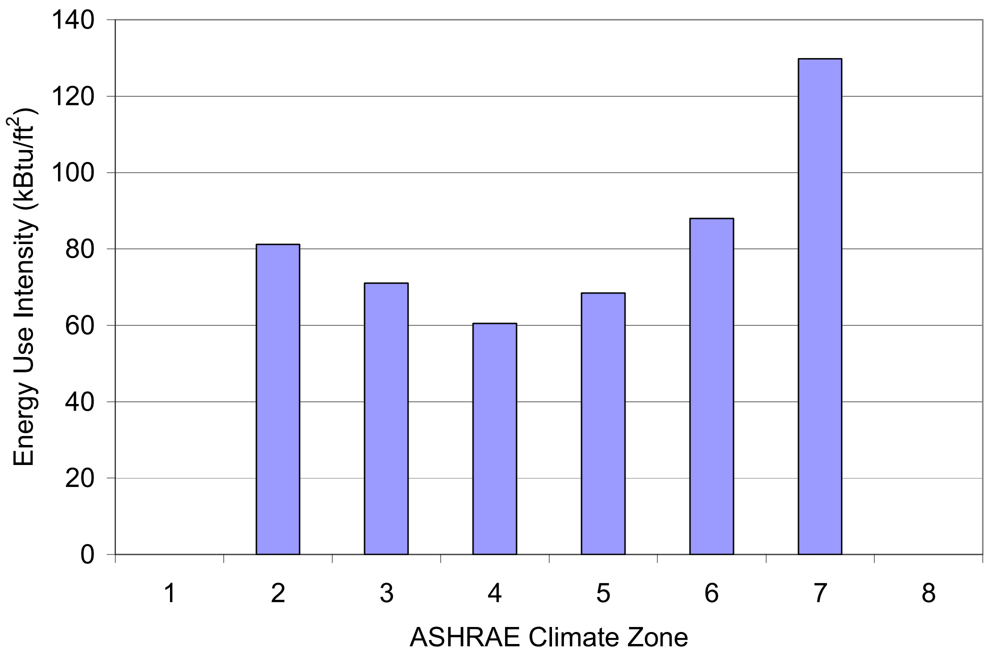

Figure 3-15 *2003 CBECS* Site EUI by Climate Zone, Post-1970 Medium Retail

3.1.7 Economics

One of the outcomes of this project is a list of cost-effective design recommendations. The objective function of interest is Five-Year Total Life Cycle Cost (5-TLCC), which is further described below.

3.1.7.1 Building Economic Parameters

The statement of work for this project mandates that the design recommendations are to be analyzed for cost effectiveness based on a five-year analysis period, a time frame that is considered acceptable to a majority of developers and owners. The other basic economic parameters required for the 5-TLCC calculation are taken from RSMeans and the Office of Management and Budget (OMB) (Balboni 2005; 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. The modifiers are available from the RSMeans data sets and are applied before any of the additional fees listed in Table 3-3, three of which are also provided by RSMeans. All costs are in 2005 dollars as most of the cost data are from 2005; time did not allow a complete update to 2008.

Table 3-3 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

3.1.7.2 Energy Design Measure Cost Parameters

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

- **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 the time period has expired, the EDM is replaced, that is, the full materials and installation costs are added to that year's cash flows.
- **Materials Cost** is the cost of all materials required for the EDM, given on a per unit basis.
- **Installation Cost** is the cost of installing the EDM, given on a per unit basis.
- **Fixed Operation & Maintenance** is a per unit, per year cost.
- **Variable Operation & Maintenance** is a per unit, per year cost.
- **Salvage Cost** is the price an EDM can be sold for after it has exceeded its useful life. This per unit cost is subtracted from the cash flows the year the EDM is replaced.

Note that the five-year analysis period used in this report precludes reaping any benefit from salvage cost. It is therefore not discussed in the remainder of this document. We also report fixed and variable operation and maintenance costs together as a single maintenance cost.

3.1.7.3 Baseline and Energy Design Measure Cost Data Sources

The cost data used for the EDMs and the baseline walls, roofs, windows, lighting systems, and HVAC equipment are adapted from multiple sources and are adjusted to 2005 dollars. The envelope costs were acquired from personal communications with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007). The ABO Group developed a cost database for energy efficient overhang designs (Priebe 2006). The HVAC cost data were generated by the RMH Group (a mechanical design contractor) who received price quotes on a range of HVAC system types and sizes (RMH Group 2006). All other cost data, including maintenance costs, come from the RSMeans data set (Keenan and Georges 2002; Mossman and Plotner 2003; Balboni 2005; Mossman 2005; Waier 2005), the PNNL *AEDG TSD*s (Liu et al. 2006; Liu et al. 2007), and other sources (Emmerich et al. 2005). The cost data sources and values are listed explicitly throughout Section 3.2.

3.1.7.4 Baseline Capital Costs

It is widely accepted that cost estimates at early planning stages are not very accurate. This report also 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, and so we adjusted our baseline cost per unit area to match that found in the 2005 RSMeans *Square Foot Costs* book for one story department stores (Balboni 2005). The adjustment is made before regional adjustments, contractor fees, and architecture fees are applied, and results in an approximate baseline cost of $70.00/ft^2 in 2005 dollars. This cost assumes exterior walls made of decorative concrete block with a reinforced concrete frame, a 50,000 ft^2 floor area, a perimeter of 900 ft, and a height of 20 ft. 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.

3.1.7.5 Utility Tariffs

The utility data are determined by location. The EIA compilation of state-by-state monthly prices for November 2003 through October 2004 provides the natural gas costs (EIA 2004). Electricity costs are based on tariff data for the companies listed in Table 3-4. As the gas data are linked to the electric utilities' primary locations, the states used to determine gas prices sometimes vary from the state the climate zone location is in, and thus are also listed in the table.

Table 3-4 Utility Data Sources for Each Climate Zone Location

ASHRAE Climate Zone	Location*	Electric Utility Company	State Used for EIA Gas Prices
1	Miami, FL	Florida Power & Light	Florida
2A	Houston, TX	Reliant Energy	Texas
2B	Phoenix, AZ	Arizona Public Service	Arizona
3A	Atlanta, GA	Georgia Power	Georgia
3B	Las Vegas, NV	Nevada Power	Nevada
3B	Los Angeles, CA	Southern California Edison	California
3C	San Francisco, CA	Pacific Gas and Electric	California
4A	Baltimore, MD	Virginia Electric and Power Company (Dominion)	Virginia
4B	Albuquerque, NM	Public Service Colorado	Colorado
4C	Seattle, WA	Puget Sound Energy	Washington
5A	Chicago, IL	Cinergy/PSI	Indiana
5B	Denver, CO	Public Service Company of Colorado	Colorado
6A	Minneapolis, MN	Northern States Power	Minnesota
6B	Helena, MT	NorthWestern Energy	Montana
7	Duluth, MN	Northern States Power	Minnesota
8	Fairbanks, AK	Chugach Electric	Alaska

* AK=Alaska, AZ=Arizona, CA=California, CO=Colorado, FL=Florida, GA=Georgia, IL=Illinois, MD=Maryland, MN=Minnesota, MT=Montana, NM=New Mexico, NV=Nevada, WA=Washington

3.1.7.6 Total Life Cycle Cost

As mentioned in Section 2.1, the objective for this project 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 accounts for inflation of energy and O&M costs using the real discount rate as opposed to using the nominal discount rate paired with explicit estimates of energy and O&M inflation.

To calculate the 5-TLCC, the annual cash flow is summed over the five-year analysis period. The annual energy use is assumed to be constant over the analysis period. The equation to calculate the annual cash flows is shown in Equation 3-1. Energy and O&M inflation rates are excluded based on the use of the real discount rate.

$$C_n = \left(\sum_{j=0}^{J} MC_n + IC_n - SC_n + FOM_n + VOM_n \right) + C_g + C_e$$

Equation 3-1 Calculation of Annual Cash Flows

Where:
C_n = cost in year n
J = total number of unique energy efficiency measures
MC_n = material cost
IC_n = installation cost
SC_n = salvage 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.

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

Equation 3-2 Calculation of 5-TLCC

Where:
5-TLCC = present value of the five-year 5-TLCC
C_n = cost in year n
d = annual discount rate

3.1.8 Prototype Model Summary

This section summarizes the building characteristics that define the medium box retail prototype models. In particular, the prototype model must specify characteristics that are not found in ASHRAE 90.1-2004 or ASHRAE 62.1-2004, but are needed to develop baseline and low-energy models. Many characteristics are summarized in Table 3-5, the space type sizes are in Table 3-6, the floor plan is shown in Figure 3-16, and the plug loads and accent lighting levels are listed in Table 3-7. The three levels of plug loads developed in Section 3.1.2.3.4 and shown in Table 3-7 define three distinct prototype models that will be carried forward through the remainder of this work. They will be referred to as the low, medium, and high plug load models or scenarios.

Table 3-5 Medium Box Retail *TSD* Prototype Characteristics and Data Sources

Retail Store Characteristic	Medium Box Retail TSD Prototype	Source
Program		
Size	50,000 ft^2 (4,645 m^2)	*2003 CBECS*
Space types	See Table 3-6	Assumption
Operating Hours	Monday through Saturday 9:00 a.m. to 9:00 p.m., Sunday 10:00 a.m. to 6:00 p.m.	*2003 CBECS*; Assumption
Occupancy	Peak density of 15 people/1000 ft^2, see Table 3-1 for schedule	ASHRAE 62.1-2004; Assumption
Lighting	10%/50%/95% on during unoccupied/staff-only/operating hours	*2003 CBECS*; Assumption
Plug and Process	See Table 3-7	Small Retail *TSD*; ACSHRAE 90.1-2004; Assumption
Form		
Number of floors	1	*2003 CBECS*
Aspect ratio	1.25	*2003 CBECS*; Assumption
Floor-to-floor height	20 ft	Assumption
Window area	1,000 ft^2 (0.056 window-to-wall ratio)	*2003 CBECS*; Assumption
Floor plan	See Figure 3-16	
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	90,000 ft^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 cooling	Assumption
HVAC controls	Setback during unoccupied hours	*2003 CBECS*
Service hot water	Electric resistance heating with storage tank	*2003 CBECS*

Table 3-6 Space Types and Sizes in the Medium Box Retail Prototype Models

Space Type	Total Size (ft^2)	Total Size (m^2)	% of total
Retail-Sales Area	43,965	4,084	87.9
Corridor/Transition*	447	41.5	0.9
Restrooms*	580	53.9	1.2
Office-Enclosed*	580	53.9	1.2
Lounge/Recreation*	484	44.9	1.0
Active Storage	3,750	348.4	7.5
Electrical/Mechanical*	194	18.0	0.4
Total	50,000	4,645	100

*All or part of this space is in the Auxiliary Spaces Zone depicted in Figure 3-16.

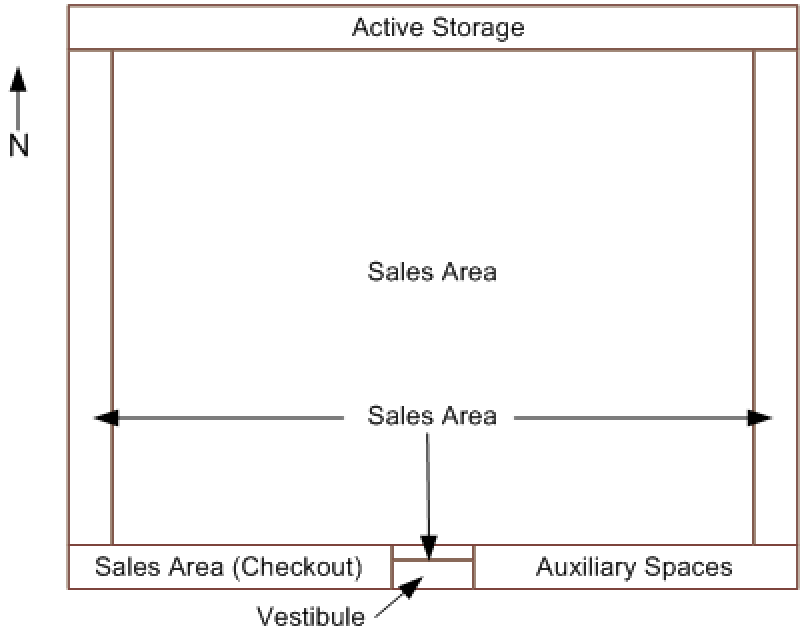

Figure 3-16 Medium Box Retail Store Prototype Model Floor Plan

Table 3-7 Medium Box Retail Store Prototype Peak Plug Loads

Space Type	Plug Scenario 1			Plug Scenario 2			Plug Scenario 3		
	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)	Electric (W/ft^2)	Accent Lighting (W/ft^2)	Total (W/ft^2)
Retail-Sales Area: Checkout	0.4	0	0.4	0.4	0	0.4	0.4	0	0.4
Retail-Sales Area: Main	0.2	0	0.2	0.4	0.8	1.2	0.6	1.4	2.0
Corridor/Transition	0	0	0	0	0	0	0	0	0
Restrooms	0.1	0	0.1	0.1	0	0.1	0.1	0	0.1
Office-Enclosed	0.75	0	0.75	0.75	0	0.75	0.75	0	0.75
Lounge/Recreation	2.6	0	2.6	2.6	0	2.6	2.6	0	2.6
Active Storage	0.2	0	0.2	0.2	0	0.2	0.2	0	0.2
Electrical/Mechanical	0	0	0	0	0	0	0	0	0
Average			0.23			1.08			1.76

3.2 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 retail stores were developed by applying the criteria in ASHRAE Standard 90.1-2004 and ASHRAE Standard 62.1-2004 to the prototype characteristics.

3.2.1 Form and Floor Plate

The prototype characteristics documented in the previous section together with a few modeling assumptions are used to generate the baseline models' form and floor plate. Per ASHRAE 90.1, Appendix G no overhangs are included. The baseline models also do not include plenums.

Form and floor plate parameters are listed in Table 3-8. A rendering of the medium box retail store baseline model is shown in Figure 3-17, which shows an isometric view from the southwest.

Table 3-8 Selected Baseline Modeling Assumptions

Model Parameters	Value
Floor area	50,000 ft^2 (4,645 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)

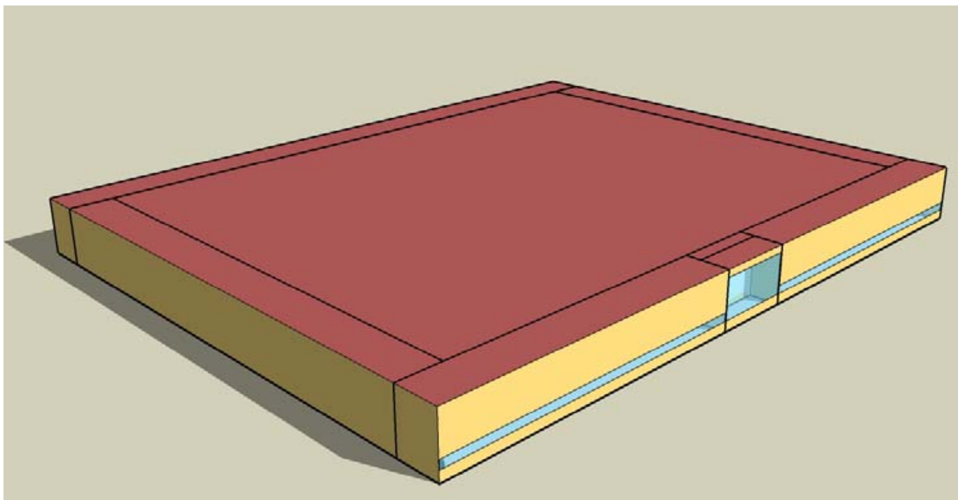

Figure 3-17 Retail Store Baseline Model Rendering: View from Southwest

3.2.2 Envelope

Based on the *2003 CBECS* and engineering experience, we assume that medium box retail 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.

3.2.2.1 Exterior Walls

The baseline medium box retail stores are modeled with mass wall constructions. The layers consist of stucco, concrete block, rigid 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 R-values are selected to meet the minimum R-values required in Section 5 (Building Envelope Requirements) of ASHRAE 90.1-2004. The baseline exterior walls' performance metrics, including costs, are listed in Table 3-9. The mass wall includes the following layers:

- Exterior air film (calculated by EnergyPlus)
- 1-in. exterior stucco
- 8-in. medium weight concrete block with solid grouted cores, 140 lb/ft^3
- 1-in. metal clips with rigid insulation (R-value varies by climate)
- 0.5-in. thick gypsum board
- Interior air film (calculated by EnergyPlus)

The materials and installation costs are based on personal communication with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007). 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 3-9 Baseline Exterior Wall Constructions

EDM Instance	Climate Zone					
	1 and 2	3 and 4	5	6	7	8
EDM 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
Materials Cost ($/ft^2)	$2.69	$3.82	$3.99	$4.13	$4.27	$4.41
Installation Cost ($/ft^2)	$1.16	$1.65	$1.72	$1.78	$1.84	$1.90

3.2.2.2 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 Section 5 (Building Envelope Requirements) of ASHRAE 90.1-2004, which vary by climate zone. The thermal performance metrics and construction costs are listed by climate zone in Table 3-10. The costs are based on personal communication with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007).

Table 3-10 Baseline Roof Constructions

EDM Instance	Climate Zone	
	1 through 7	8
EDM 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
Materials Cost ($/ft^2)	$3.19	$3.43
Installation Cost ($/ft^2)	$1.38	$1.48

The prescriptive portion of Standard 90.1-2004 does not specify performance characteristics like roof reflectance or absorption. Appendix G states that the reflectivity of reference buildings should be 0.3. We assume that the baseline roof exterior finish is a single-ply gray ethylene propylene diene terpolymer membrane (EPDM) with solar reflectance 0.3, thermal absorption 0.9, and visible absorption 0.7.

3.2.2.3 Slab-on-Grade Floors

The baseline buildings are modeled with slab-on-grade floors. The layers consist 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 2008). It determines the temperature of the ground under the slab based on the area of the slab, the location of the building, and 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.

3.2.2.4 Fenestration

The baseline retail 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 2004), 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 match the required assembly performance level. The baseline window constructions and costs are summarized in Table 3-11. The costs are based on personal communication with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007).

Table 3-11 Baseline Window Constructions

EDM Instance	Climate Zone				
	1 and 2	3	4 through 6	7	8
EDM Key	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction
SHGC	0.250	0.250	0.390	0.490	0.490
VLT	0.250	0.318	0.495	0.490	0.490
U-Factor (Btu/h·ft^2·°F)	1.21	0.570	0.570	0.570	0.460
Materials Cost ($/$ft^2$)	$16.83	$22.63	$20.06	$20.06	$22.80
Installation Cost ($/$ft^2$)	$27.17	$27.17	$27.17	$27.17	$27.17
Fixed O&M Cost ($/$ft^2$)	$0.22	$0.22	$0.22	$0.22	$0.22

Some of the recommended designs for 50% energy savings include daylighting with skylights. One skylight construction choice is set to match the fenestration performance criteria outlined in Appendix B of ASHRAE 90.1-2004. These baseline skylight constructions are summarized in Table 3-12. Costs based on personal communication with the ASHRAE 90.1 Envelope Subcommittee are also listed (ASHRAE 2007).

3.2.2.5 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 0.322 air changes per hour (ACH), and that the infiltration rate is cut by half when the HVAC system is on. Thus, there are only 0.161 ACH during operating hours, when the HVAC system is enabled and pressurizes the building. The peak value consists of 0.24 ACH through the building envelope, and 0.082 ACH through 192 ft^2 (12.3 m^2) of automatic sliding doors. The envelope infiltration rate is derived from the section on retail buildings in Emmerich et al. (2005). The infiltration through the sliding doors is modeled using the door opening event modeling of Yuill et al. (2000) and the infiltration per area and event data of Vatistas et al. (2007).

Table 3-12 Baseline Skylight Constructions

EDM Instance	Climate Zone			
	1 through 3	4 through 6	7	8
EDM Key	Baseline Skylight Construction	Baseline Skylight Construction	Baseline Skylight Construction	Baseline Skylight Construction
SHGC	0.360	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
Materials Cost ($/ft^2)	$19.11	$20.06	$20.05	$23.87
Installation Cost ($/ft^2)	$27.17	$27.17	$27.17	$27.17
Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22	$0.22

3.2.3 Internal Loads

Internal loads include heat generated from occupants, lights, and appliances (plug loads such as computers, printers, and small beverage machines; and process loads such as cooking). For the occupancy load, the peak intensity is the highest occupancy observed at one time during the year, normalized by floor area. In-store lighting and plug loads are represented by peak power density in watts per square foot. Peak exterior façade lighting density is given in watts per linear foot of façade length. The equipment load intensities are described in Section 3.1.2.3 and Section 3.1.8. The peak plug loads are listed in Table 3-7. Plug load schedules, occupancy schedules, and lighting schedules are documented in Section 3.3.6.

3.2.3.1 Occupancy and Lighting

The occupancy loads are based on the default occupant density in ASHRAE 62.1-2004 (ASHRAE 2004). The baseline interior lighting power density (LPD) for each specific area is derived using the space-by-space method described in Standard 90.1-2004. The baseline LPDs and peak occupancy are shown in Table 3-13. For the location of each space type, see Figure 3-16.

Table 3-13 Baseline Lighting and Occupancy Loads by Space Type

Space Type	LPD (W/ft^2)	LPD (W/m^2)	Maximum Occupants (#/1000 ft^2)	Maximum Occupants (#/100 m^2)
Retail-Sales Area	1.7	18.3	15	16.1
Corridor/Transition	0.5	5.4	15	16.1
Restrooms	0.9	9.7	15	16.1
Office-Enclosed	1.1	11.8	15	16.1
Lounge/Recreation	1.2	12.9	15	16.1
Active Storage	0.8	8.6	15	16.1
Electrical/Mechanical	1.5	16.1	15	16.1
Weighted Average	1.6	17.2	15	16.1

The baseline cost of the lighting system is modeled as $2,268/kW for materials, $1,932/kW for installation, and $190/kW·yr for maintenance, where kW refers to the total peak load. The material and installation costs are estimated based on RSMeans *Square Foot Costs* (Balboni 2005); the maintenance costs are estimated using the 2003 RSMeans *Facilities Maintenance and Repair Cost Data* (Mossman and Plotner 2003). Thus the baseline capital costs are approximately $335,550, and the baseline maintenance costs are about $15,180/year.

The internal load derived from the occupants is calculated assuming 132 W (450 Btu/h) of heat per person, which is the value listed for "standing, light work; walking" in Table 1 of Chapter 30 of the *ASHRAE 2005 Fundamentals Handbook*. 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).

3.2.4 Exterior Loads

The baseline retail have 1 W/ft (3.28 W/m) of exterior façade lighting, per ASHRAE 90.1-2004, Table 9.4.5 (ASHRAE 2004).

3.2.5 HVAC Systems and Components

3.2.5.1 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, direct expansion (DX) cooling, and gas-fired furnace in each thermal zone. To apply ASHRAE 90.1-2004, we develop performance data consistent with 10-ton, 4,000 cfm (1.88 m^3/s) rooftop units, 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 rooftop units. The design-day data for all 16 climate locations are developed from the "Weather Data" contained in the *ASHRAE Handbook: Fundamentals* (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.

3.2.5.2 Outside Air

Ventilation rates by space type are determined based on ASHRAE 62.1-2004 (ASHRAE 2004), as shown in Table 3-14. The office values are used for the entire auxiliary zone since they are close to the values one obtains by calculating an area weighted average across all of the space types in that zone.

For the buildings with motorized dampers, OA is scheduled based on the HVAC system availability schedule. Buildings without motorized dampers used gravity dampers, which open whenever the fans operate. The motorized dampers are closed during unoccupied hours, resulting in no OA when the system night cycles.

Table 3-14 Baseline Minimum Ventilation Rates

Space Type	Ventilation per Person		Ventilation per Area	
	cfm/person	L/s·person	cfm/ft^2	L/ s·m^2
Retail Sales	7.5	3.8	0.12	0.6
Office	5.0	2.5	0.06	0.3
Storage	–	–	0.12	0.6
Corridor	–	–	0.06	0.3

3.2.5.3 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 rooftop units include economizers in these climate zones only.

3.2.5.4 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 rooftop units 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 energy efficiency ratio (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. In this report we assume EER and compressor/condenser 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.

3.2.5.5 Fan Power Assumptions

We assume that the package rooftop system 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, while recognizing 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 3-15 summarizes the breakdown of the fan total static pressure for the baseline rooftop system. The 10-ton unit without an economizer has a total fan static pressure of 1.53 in. water column (w.c.) (381 Pa); the units with economizers have a total static pressure of 1.62 in. w.c. (404 Pa).

As outlined above, we back out the baseline total fan efficiency from the 10.1 EER requirement, the static pressures just listed, 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 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, the fan power per volumetric unit of air is 0.788 hp/1000 cfm (1245 W/(m^3/s)). This is well within the Standard 90.1-2004 requirement that units with less than 20,000 cfm have fans with nameplate motor power less than 1.2 hp/1000 cfm.

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

3. Calculate fan efficiency:

   The fan efficiency is equal to the total static pressure divided by the nameplate motor power per supply air volume, in compatible units. Thus the rooftop units without economizers have a fan efficiency of 30.6%, and the units with economizers have an efficiency of 32.4%.

Table 3-15 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.)
2-in. plated filters	0.18	0.18
Heating coil/section	0.14	0.14
DX cooling coil	0.28	0.28
Acoustical curb	0.07	0.07
Economizer	0.00	0.09
Total internal static pressure	0.67	0.76
Diffuser	0.10	0.10
Supply ductwork[1]	0.36	0.36
Return ductwork	0.09	0.09
Grille	0.03	0.03
Fan outlet transition	0.20	0.20
10% safety factor	0.08	0.08
Total external static pressure	0.86	0.86
Total static pressure drop	1.53	1.62

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

3.2.5.6 Summary and Costs

This report uses HVAC system cost data prepared for NREL by the RMH Group (2006). The 10-ton rooftop units 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 $6,400 plus $1.78/cfm for duct work materials and installation. Assuming 400 cfm per ton of cooling, the cost of ductwork for a 10 ton unit is $7,120, and the total system cost is $1,352/ton of cooling ($384.53/kW). The cost of an economizer, including controls and an additional relief hood, is given as $943 for a 10-ton unit, that is, an extra $94.30/ton of cooling ($26.82/kW). Maintenance costs for the 10-ton unit are $150/year for fixed O&M plus $1,170/year for repair and replacement costs: $132/ton·yr ($37.54/kW·yr) total. Table 3-16 summarizes the primary HVAC performance characteristics and cost data for the baseline retail stores.

Table 3-16 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
Materials cost ($/ton cooling)	1,352	1,446
Installation cost ($/ton cooling)	158	158
O&M cost ($/ton cooling·yr)	132	132

3.2.6 Service Water Heating

As discussed in Section 3.1.5.2, the baseline service water heating system for the retail stores 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.

The consumption rates of hot water are determined using the *ASHRAE Handbook: HVAC Applications* (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 retail buildings is similar to that in office buildings. The baseline retail stores' peak hot water consumption rate is modeled as 18 gph (1.89E-5 m^3/s), based on 40 gph (4.21E-5 m^3/s) for sinks and 20 gph (2.10E-5 m^3/s) for public lavatories, multiplied by a demand factor of 0.3. The storage tank has a volume of 50 gallons (0.1893 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 Appendix A.6. The hot water outlet temperature is assumed to be 104ºF (40ºC). The water heater set point is 140ºF (60ºC).

3.3 Energy Design Measures

The optimization algorithm described in Section 2.2 determines which energy design measures (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 lighting power density (LPD) and occupancy controls
- Reduced plug load densities
- Reduced nighttime plug loads
- Photovoltaic (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 the installation of an air barrier and/or vestibule
- Higher efficiency HVAC equipment
- Higher efficiency fans
- Demand controlled ventilation (DCV)
- Energy recovery ventilators (ERVs)
- Economizers
- Indirect evaporative cooling

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 4.5.3.

3.3.1 Program

3.3.1.1 Lighting Power Density

Two whole-building LPD reductions are considered: 20% and 40%. For the sales areas, this corresponds to LPDs of 1.36 W/ft^2 (14.64 W/m^2) and 1.02 W/ft^2 (10.98 W/m^2), respectively, which are well within what is possible with high-efficiency lamps and ballasts. These measures are costed based on the marginal costs of Liu et al. (2007), who found that for a 50,000 ft^2 (4,645 m^2) warehouse better bulbs and ballasts reduce installed lighting power by 26 kW and cost an additional $1,982.50. Thus we assume an extra cost of $76 for every kilowatt of lighting power reduction.

All of the LPD EDMs include 1% LPD reductions based on the inclusion of occupancy sensors in the active storage, office, lounge, restroom, and electrical/mechanical spaces. The whole-building LPD reduction of 1% is calculated by assuming that the sensors achieve 10% savings in the areas in which they are installed. Because those areas comprise just 11.3% of the building and have lower LPDs than the sales floor, one arrives at a whole-building LPD reduction of 1%.

The cost of one occupancy sensor is $135.68 ($90.10 for materials and $45.58 for labor) in 2005 dollars (Keenan and Georges 2002). Assuming that 10 sensors would cover the affected areas, the approximate cost of this EDM is $1,085.44 ($720.80 for materials and $364.64 for labor) for the entire store.

In Opt-E-Plus, the lighting costs are expressed in dollars per installed kilowatt. Since each EDM results in fewer installed kilowatts, the baseline cost and the 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 EDMs are shown in Table 3-17.

Table 3-17 Lighting Power EDMs

EDM Key	Power Density (W/ft^2)	Materials Cost ($/kW)	Installation Cost ($/kW)	Fixed O&M Cost ($/kW·yr)
Baseline	1.60	$2,268.00	$1,932.00	$190.00
Occupancy Sensors	1.59	$2,302.00	$1,957.00	$191.90
20% LPD Reduction and Occupancy Sensors	1.27	$2,904.00	$2,452.00	$240.50
40% LPD Reduction and Occupancy Sensors	0.947	$3,916.00	$3,284.00	$322.00

3.3.1.2 Plug Loads

The only measure affecting peak plug load densities, which here include both electrical equipment and accent lighting, reduces them by 10%. Such a reduction should be achievable in most situations, but perhaps through different means. For instance, one store might install energy-efficient equipment that exceeds ENERGY STAR® requirements, another might switch to LED display lighting, and still another might determine that it can display a different mix of electronic products.

Thus, an accurate cost for this design measure cannot be captured in the broad context of this work. We therefore choose fairly high costs for this EDM: $3,600 for materials and $900 for installation per kilowatt of peak plug load reduction. For comparison, Table 3-18 lists estimated capital and maintenance costs per kilowatt of peak plug load reduction for selected ENERGY STAR product types. The cost and energy use numbers are taken from the ENERGY STAR savings calculators (EPA and DOE 2008); the peak kilowatts saved are estimated assuming that the equipment is always on.

Table 3-18 Cost per kW of Peak Load Saved with Selected ENERGY STAR Equipment

Product Type	Quantity	ENERGY STAR – Conventional Product Cost	Conventional – ENERGY STAR Annual kWh	Estimated $/kW Saved
Computers	1	$0	457	0
Monitors	100	$15,000	42,598	3,000
Laser Printers	20	$0	101,923	0
Freezers	100	$3,300	8,034	3,600
Refrigerators	100	$3,000	7,211	3,650
Vending Machines	1	$0	1,659	0
DVD Players	1	$4	10	3,400
Compact Fluorescent Lamps	100	–$2,584	4,956	–4,500
Lighting Fixtures	2	$25	222	1000
Ceiling Fans	1	$2	155	100
Water Coolers	100	$0	36,289	0

3.3.1.3 Schedules

The schedules used in the low-energy models are the same as those of the baseline models, except when a modification is used to model a specific EDM. The only EDM that is modeled using schedules is for the high plug load scenarios only; it reduces the plug load percent on from 40% to 15% at night (and from 65% to 50% on during transition hours). This is equivalent to, and implemented as, switching from the high plug load-specific equipment schedule to the low and medium plug load equipment schedule, both of which are shown in Section A.3.

The cost of this EDM is difficult to estimate. Conceptually, one might implement an integrated hardware and software solution that automatically powers down and reboots equipment at the proper time. For simple equipment, such as accent lighting, radios, and the like, such systems are already available and are fairly simple to use. However, computers and high-tech TVs are often not turned off at night because they are difficult to shut down and restart properly using manual methods. Systems that handle this smoothly are fairly expensive, and likely require some human oversight.

For this reason, we conservatively estimate the cost of this EDM as $87,500 ($70,000 for materials and $17,500 for installation) plus $3,500 per year for annual maintenance. The maintenance costs model one person managing the nighttime plug load reduction systems for 20 to 30 stores. The material and installation costs are intentionally higher than those estimated for the plug load density reductions, which, for the high plug load stores, come to $35,200 for materials and $8,800 for installation.

3.3.1.4 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.

In all cases, the panels are assumed to be 10% efficient, the DC to AC inverters are assumed to be 90% efficient, and the panels are modeled as lying flat on the roof. For simplicity, we assume that the PV efficiency does not degrade with increasing temperature, and that the panels do not shade the roof. The cost is $9.54 for materials and $1.06 for installation per installed Watt based on the price of a 10-kW, grid-connected system in 2005 dollars (Keenan and Georges 2002). The EDM used by Opt-E-Plus covers 30% of the net roof area (total area minus skylight area) with PV panels and is sized assuming 1000 W/m^2 incident solar radiation.

3.3.2 Form

3.3.2.1 Fenestration

Two EDMs change the amount of façade fenestration. One reduces the amount by 20%, and one increases it by 20%. The resulting window-to-wall ratios (WWRs) are shown in Table 3-19. The sill height remains constant for each EDM, except when it must be lowered to fit a particular window into the provided surface area. This happens in the vestibule zone with the increased glazing EDM, whose sill height becomes 3.18 ft (0.97 m).

Table 3-19 South Window Fraction EDMs

EDM Key	South WWR (%)
80% of baseline glazing	16.0
120% of baseline glazing	24.0

Another set of EDMs adds skylights to the baseline building. Skylights are added only to the zones that are not adjacent to the façade, see Figure 3-18. The skylight EDMs result in 3%, 4%, or 5% coverage of the roof area in those zones.

None of these EDMs have an inherent cost—instead they determine the amount of glazing. Window and skylight costs are calculated by multiplying the glazing areas (as determined by these EDMs and the baseline glazing amount) by the cost per unit area of the selected glazing types (see Section 3.3.3.3).

3.3.2.2 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 ranging from 0.1 to 1.5, in steps of 0.2. This yields 8 EDMs, which were all priced at \$9.50/ft^2 (\$102.26/m^2) of overhang (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 yields a 2.475-ft (0.75-m) deep by 3-ft (0.91-m) wide overhang.

3.3.2.3 Daylighting

The daylighting EDM adds light sensors and dimming controls to those zones with access to daylight, that is, with windows or skylights. Each zone has access to at most one daylighting source, see Figure 3-18. Skylights are not added by this EDM, rather, the EDM impact and cost is dependent on how many, if any, skylights are installed.

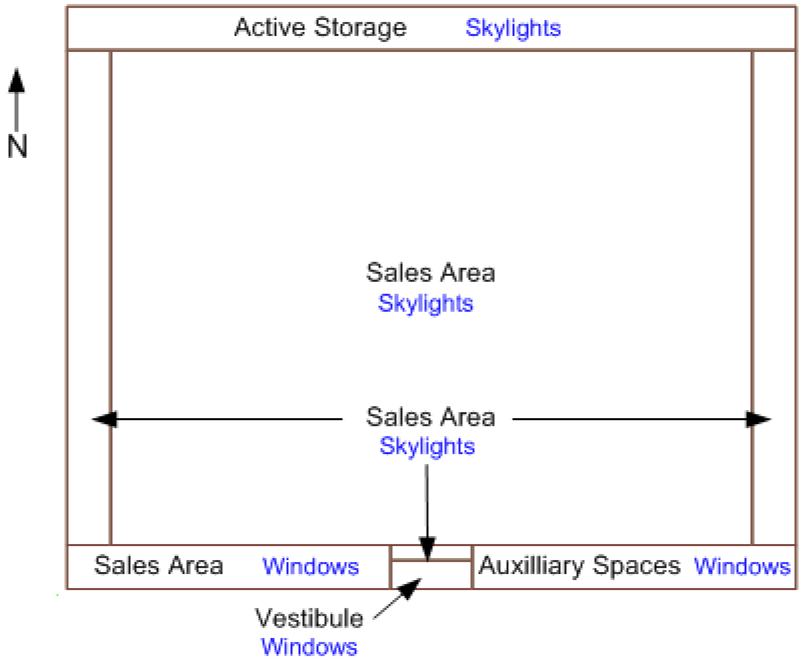

Figure 3-18 Potential Daylight Sources for Each Zone

There is one light sensor per zone, placed in the center at a height of 2.95 ft (0.90 m). The sensor is placed between two skylights if there is a skylight blocking its normal location. 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 input power is 30% of maximum (the light output is 20% of maximum), whichever comes first.

We used two set point options: 400 lux and 600 lux. The cost of the 600 lux set point system is $0.38/ft^2 ($4.10/m^2) of daylit area, split evenly between materials and installation (Liu et al. 2007). To reflect the increased difficulty of tuning a daylighting system to achieve a 400 lux set point while maintaining visual comfort, the installation cost of that EDM is 15% higher than the 600 lux installation cost. These EDMs are summarized in Table 3-20.

Table 3-20 Daylighting Set Point EDMs

EDM Key	Materials Cost ($/ft^2)	Installation Cost ($/ft^2)
600 lux set point	$0.19	$0.19
400 lux set point	$0.19	$0.22

3.3.3 Fabric

3.3.3.1 Exterior Walls

The mass walls EDMs are shown in Table 3-21, along with materials and installation costs that are based on personal communication with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007). The construction of the EDM walls in the EnergyPlus models is identical to that of the baseline walls, except for the amount of continuous insulation (c.i.). Thus, the walls are identified by the R-value of that insulation. In practice, the highest R-values will not be achieved with the exact constructions modeled, but with something like a double wall. These alternative constructions are reflected in the cost data, which vary discontinuously with R-value.

Table 3-21 Exterior Wall EDMs

EDM Key	U-Factor (Btu/h·ft²·°F)	Materials Cost ($/ft²)	Installation Cost ($/ft²)
R-5.7 c.i.	0.173	$3.82	$1.65
R-9.5 c.i.	0.137	$3.99	$1.72
R-13.3 c.i.	0.0859	$4.41	$1.90
R-20 c.i.	0.0633	$4.89	$2.11
R-31.3 c.i.	0.0399	$5.77	$2.49
R-43.8 c.i.	0.0304	$6.65	$2.86
R-56.3 c.i.	0.0253	$7.54	$3.25
R-62.5 c.i.	0.0228	$7.98	$3.44

3.3.3.2 Roofs

The insulation above deck roof EDMs are shown in Table 3-22, along with materials and installation costs that are based on personal communication with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007). 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 presence of high albedo (cool) roofs. Thus, the roofs are simply described by the R-value of the c.i. and the presence or absence of a cool roof.

Table 3-22 Roof EDMs

EDM Key	U-Factor (Btu/h·ft²·°F)	Materials Cost ($/ft²)	Installation Cost ($/ft²)
R-20 c.i.	0.0507	$3.43	$1.48
R-20 c.i. with cool roof	0.0507	$3.43	$1.48
R-25 c.i.	0.0405	$3.68	$1.58
R-25 c.i. with cool roof	0.0405	$3.68	$1.58
R-30 c.i.	0.0332	$3.95	$1.70
R-30 c.i. with cool roof	0.0332	$3.95	$1.70
R-35 c.i.	0.0289	$4.19	$1.81
R-35 c.i. with cool roof	0.0289	$4.19	$1.81
R-40 c.i.	0.0229	$4.54	$1.95
R-50 c.i.	0.0201	$4.80	$2.07
R-60 c.i.	0.0161	$5.33	$2.29
R-75 c.i.	0.0134	$5.86	$2.53
R-95 c.i.	0.0109	$6.39	$2.76

The high albedo/cool roofs have a Solar Reflective Index (SRI) 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.

3.3.3.3 Fenestration

Table 3-23 lists the 19 window EDMs, including a short description, performance data, and cost data. The set is selected from a list of glazing systems compiled by the ASHRAE 90.1 Envelope Subcommittee to provide a good mix of available performances. The performance data for each window construction are generated by the EnergyPlus layer-by-layer model. EnergyPlus layer-by-layer descriptions of each glazing system are developed by matching glazing systems that are available in the data sets released with EnergyPlus to those in 90.1 envelope committee's set. The costs are part of the ASHRAE 90.1 Envelope Subcommittee data and are adjusted for inflation from 1999 to 2005 dollars using a 17% escalation rate (ASHRAE 2007).

Table 3-23 South Fenestration Construction EDMs

EDM Key	SHGC	VLT	U-Factor (Btu/h·ft^2·°F)	Materials Cost (\$/ft^2)	Installation Cost (\$/ft^2)	Fixed O&M Cost (\$/ft^2·yr)
Single pane low-iron glass	0.897	0.910	1.09	$17.29	$27.17	$0.19
Single pane with clear glass	0.810	0.881	1.08	$12.61	$27.17	$0.19
Single pane with pyrolytic low-e	0.710	0.811	0.745	$16.12	$27.17	$0.19
Single pane with tinted glass	0.567	0.431	1.08	$13.78	$27.17	$0.19
Double pane low-iron glass	0.816	0.834	0.481	$28.99	$27.17	$0.19
Double pane with low-e and argon	0.564	0.745	0.264	$19.63	$27.17	$0.19
Double pane with tinted glass	0.490	0.664	0.549	$18.16	$27.17	$0.19
Double pane with low-e2 and argon	0.416	0.750	0.235	$26.65	$27.17	$0.19
Double pane with low-e and tinted glass	0.382	0.444	0.423	$24.02	$27.17	$0.19
Double pane with low-e2 and tinted glass	0.282	0.550	0.288	$26.65	$27.17	$0.19
Double pane with reflective coating and tinted glass	0.240	0.440	0.518	$21.38	$27.17	$0.19
Double pane with highly reflective coating and tinted glass	0.142	0.046	0.487	$21.38	$27.17	$0.19
Triple pane with argon	0.679	0.738	0.288	$28.02	$27.17	$0.19
Triple layer with low-e polyester film	0.570	0.711	0.232	$32.58	$27.17	$0.19
Triple layer with low-e polyester film	0.355	0.535	0.215	$32.58	$27.17	$0.19
Triple layer with low-e polyester film	0.303	0.455	0.213	$32.58	$27.17	$0.19
Triple layer with low-e polyester film and tinted glass	0.210	0.274	0.213	$36.09	$27.17	$0.19
Triple layer with low-e2 polyester film and tinted glass	0.142	0.169	0.211	$36.09	$27.17	$0.19
Quadruple layer with low-e polyester films and krypton	0.461	0.624	0.136	$35.42	$27.17	$0.19

A smaller number of skylight EDMs are similarly chosen in an attempt to select high/low U-Factors and high/low SHGCs, see Table 3-24.

Table 3-24 Skylight Fenestration Construction EDMs

EDM Key	SHGC	VLT	U-Factor (Btu/h·ft²·°F)	Materials Cost ($/ft²)	Installation Cost ($/ft²)	Fixed O&M Cost ($/ft²·yr)
Single pane with high solar gain	0.610	0.672	1.22	$15.49	$27.17	$0.22
Single pane with medium solar gain	0.250	0.245	1.22	$19.11	$27.17	$0.22
Single pane with low solar gain	0.190	0.174	1.22	$19.11	$27.17	$0.22
Double pane with high solar gain	0.490	0.622	0.580	$14.10	$27.17	$0.22
Double pane with low-e and high solar gain	0.460	0.584	0.451	$14.19	$27.17	$0.22
Double pane with medium solar gain	0.390	0.495	0.580	$24.96	$27.17	$0.22
Double pane with low-e and medium solar gain	0.320	0.406	0.451	$29.90	$27.17	$0.22
Double pane with low solar gain	0.190	0.241	0.580	$25.98	$27.17	$0.22
Double pane with low-e and low solar gain	0.190	0.240	0.451	$30.24	$27.17	$0.22

3.3.3.4 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 0.24 to 0.05 ACH, and to cost $1.29/ft² ($13.92/m²) of exterior wall area (Emmerich et al. 2005). A vestibule is assumed to reduce the front door infiltration from 0.082 to 0.054 ACH, based on the door opening event modeling of Yuill et al. (2000) and the infiltration per area and event data of Vatistas et al. (2007). The cost of this EDM is assumed to be the cost of installing three additional sliding doors having a total surface area of 192 ft² (18 m²), that is, $5,184 for materials and $1,514 for installation (Waier 2005).

3.3.4 Equipment

3.3.4.1 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 manufacturer data suggest that the COP of the 10-ton rooftop units, which includes compressor and condenser, but not supply fan, power, can be improved as much as 20% over the baseline COP of 3.69. Thus, we have two EDMs that improve DX coil efficiency: a 10% increase in COP that costs an additional $51.79/ton cooling ($182.09/kW) in materials and $6.01/ton cooling ($21.13/kW) for installation, and a 20% increase in COP that costs an additional $103.66/ton cooling ($364.47/kW) in materials and $13.01/ton cooling ($45.74/kW) for installation. 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 3.2.5.6, that is, from 9.0 to 10.4 EER and from 9.0 to 11.0 EER, respectively (RMH Group 2006).

3.3.4.2 Higher Efficiency Fans

The spec sheets mentioned in Section 3.3.4.1 are also used to calculate the supply fan power for several 10-ton units. Because each unit has the same volumetric flow rate (400 cfm/ton cooling) at the ARI rating conditions, and is assumed to have similar internal static pressure drops, the fan power is inversely proportional to the fan efficiency. We thus calculate supply fan efficiencies of 30% to 50%. Given our baseline efficiencies of 30.6% and 32.4%, we assume that fan efficiency can be increased to about 50% with more efficient supply fan motors and blades. The cost for this EDM is assumed to be 10% of the baseline HVAC system materials cost, that is, an additional $135.20/ton cooling ($38.45/kW). This cost premium is roughly based on the incremental cost of upgrading from a constant volume supply fan to a variable air volume supply fan (Mossman 2005).

3.3.4.3 Economizers

In this analysis, economizers can be combined with any of the available HVAC systems. When included, economizers 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]). As in Section 3.2.5.3, the presence of an economizer increases system cost by $94/ton cooling ($26.81/kW), adds 0.09 in. w.c. (22.4 Pa) of static pressure, and replaces gravity dampers with motorized dampers.

As the DX coil efficiency, high-efficiency fan, and economizer EDMs are implemented together as HVAC system EDMs, a summary of the available systems is presented in Table 3-25.

3.3.4.4 Outside Air

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

Table 3-25 HVAC System EDMs

EDM Key	Cooling COP (Ratio)	Heating Efficiency (%)	Economizer	Motorized Damper	Fan Efficiency (%)	Fan Static Pressure (in. w.c.)	Materials Cost ($/ton)	Installation Cost ($/ton)	Fixed O&M Cost ($/ton·yr)
Baseline without economizer	3.69	80.0	No	No	30.6	1.53	$1,352.08	$157.98	$131.99
10% increased COP	4.06	80.0	No	No	30.6	1.53	$1,403.88	$164.00	$131.99
Baseline with economizer	3.69	80.0	Yes	Yes	32.4	1.62	$1,446.37	$157.98	$131.99
20% increased COP	4.43	80.0	No	No	30.6	1.53	$1,455.76	$171.00	$131.99
Baseline COP with efficient fan	3.69	80.0	No	No	50.8	1.53	$1,487.27	$157.98	$131.99
10% increased COP with economizer	4.06	80.0	Yes	Yes	32.4	1.62	$1,498.17	$164.00	$131.99
10% increased COP with efficient fan	4.06	80.0	No	No	50.8	1.53	$1,539.07	$164.00	$131.99
20% increased COP with economizer	4.43	80.0	Yes	Yes	32.4	1.62	$1,550.05	$171.00	$131.99
Baseline COP with economizer and efficient fan	3.69	80.0	Yes	Yes	52.6	1.62	$1,581.56	$157.98	$131.99
20% increased COP with efficient fan	4.43	80.0	No	No	50.8	1.53	$1,590.95	$171.00	$131.99
10% increased COP with economizer and efficient fan	4.06	80.0	Yes	Yes	52.6	1.62	$1,633.37	$164.00	$131.99
20% increased COP with economizer and efficient fan	4.43	80.0	Yes	Yes	52.6	1.62	$1,687.18	$171.00	$131.99

3.3.4.4.1 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 the cost of installing one CO_2 sensor per rooftop unit, since the rooftop units should be able to implement DCV without major modification. The cost of one sensor is $177.50 ($140 for materials and $37.50 for installation), such that DCV costs $14/ton cooling ($4.22/kW) for materials and $3.75/ton cooling ($1.13/kW) for installation, in 2005 dollars (Keenan and Georges 2002).

3.3.4.4.2 Energy Recovery Ventilators

ERVs with sensible effectiveness of 60%, 70%, or 80%, and latent effectiveness 10 percentage points lower are available as EDMs. The pressure drop through the ERVs and their costs vary with effectiveness (see Table 3-26). In general, more effective ERVs have higher pressure drops. The pressure drops listed in Table 3-26 are based on internal data. The additional cost of more effective units is roughly modeled based on effectiveness versus number of transfer units (NTU) curves for counterflow heat exchangers. We assume that a portion of the cost is fixed and the rest varies linearly with NTU, a proxy for amount of material required. The cost of the least effective unit is adapted from the cost of 2000 cfm ERVs given in Keenan and Georges (2002).

Table 3-26 Energy Recovery EDMs

EDM Key	Sensible Effectiveness (%)	Latent Effectiveness (%)	Pressure Drop (in. w.c.)	Materials Cost ($/ton)	Installation Cost ($/ton)
Low effectiveness	60.0	50.0	0.703	$68.97	$8.19
Medium effectiveness	70.0	60.0	0.863	$82.76	$8.19
High effectiveness	80.0	70.0	1.00	$103.43	$8.19

3.3.4.5 Indirect Evaporative Cooling

The initial set of simulations conducted for this report included an indirect evaporative cooling EDM. However, it was not chosen in any climate zone, likely because of the difficulties we had modeling it properly. We were not able to directly model a bypass of this unit when it was not needed, so the EDM added a significant amount of fan power. Although we tried to roughly model the effects of bypass by reducing the added pressure drop by one half, this was not enough to make the EDM attractive as modeled, and we do not feel comfortable lowering the pressure drop further without reliable, climate-specific data. As a result, this EDM was not included in the final set of simulations. Evaporative cooling should receive further attention and model development, however, and so is listed as a suggestion for future work in Section 4.5.3.

For reference, our model assumed 75% wet bulb effectiveness, a supply fan added pressure drop of 0.8 in. w.c. (200 Pa, reduced from 400 Pa to model bypass), a secondary fan efficiency of 40%, and a secondary fan pressure drop of 1.6 in. w.c. (400 Pa). The cost was $356.05/ton cooling ($101.26/kW) in materials, $118.67/ton cooling ($33.75/kW) for installation, and $37.76/ton cooling·yr ($10.74/kW·yr) for maintenance.

4 Evaluation Results

This section summarizes the performance of the baseline and selected low-energy models. We also present a sensitivity analysis for each low-energy model to show the relative impact of the EDMs.

4.1 Baseline Models: Performance

The energy and cost intensities of the baseline models are shown in Table 4-1, Table 4-2, and Table 4.3. To compare the EUIs of our baseline models to the *2003 CBECS* sector model data in Section 3.1.6, we use the climate zone weighting factors from Deru et al. (2008) to calculate average baseline EUIs for each numerical climate zone and the nation as a whole. The weightings are shown in Table 4-4; the resulting EUIs are depicted graphically in Figure 4-1. The dotted lines, which are colored to match the legend, show the national averages for each category. The baselines seem to show reasonable agreement with the *CBECS* data, considering the small number of medium-sized retail buildings in the *2003 CBECS*. Also note that the EUIs vary quite substantially over all the climate zones, such that achieving 50% energy savings is more difficult in some locations, and saves more energy in others. Costs vary in response to regional cost modifiers as well as climate-specific insulation levels, window types and thermal loads.

Moving from low to higher plug load levels also affects different locations differently. As one would expect based on the usefulness of plug load heat in cold climates and its exacerbation of the cooling problem in warm climates, the EUIs in climate zone 8 (Fairbanks, Alaska) increase much less, on an absolute and on a percentage basis, in moving from low to medium or high plug levels, than do the EUIs in climate zone 1A (Miami, Florida). The absolute and percent differences in EUI that result from moving from low to medium and from low to high plug load levels are shown in Table 4-5, in which the climate zones are sorted from biggest to smallest effect.

Table 4-1 Baseline Model Performance Summary: Humid Climates

Building Type	Units	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug Retail	SI	EUI ($MJ/m^2 \cdot yr$)	684	651	590	634	683	780
		5-TLCC Intensity ($\$/m^2$)	1,180	1,200	1,180	1,160	1,170	1,150
	IP	EUI ($kBtu/ft^2 \cdot yr$)	60.2	57.3	51.9	55.8	60.2	68.6
		5-TLCC Intensity ($\$/ft^2$)	110	112	109	108	109	107
Medium Plug Retail	SI	EUI ($MJ/m^2 \cdot yr$)	910	864	785	799	825	904
		5-TLCC Intensity ($\$/m^2$)	1,220	1,240	1,210	1,190	1,210	1,170
	IP	EUI ($kBtu/ft^2 \cdot yr$)	80.1	76.1	69.1	70.4	72.6	79.6
		5-TLCC Intensity ($\$/ft^2$)	113	115	113	110	112	109
High Plug Retail	SI	EUI ($MJ/m^2 \cdot yr$)	1,170	1,120	1,020	1,020	1,020	1,080
		5-TLCC Intensity ($\$/m^2$)	1,250	1,280	1,260	1,220	1,250	1,200
	IP	EUI ($kBtu/ft^2 \cdot yr$)	103	98.2	90.2	89.7	90.2	94.7
		5-TLCC Intensity ($\$/ft^2$)	116	119	117	113	116	111

Table 4-2 Baseline Model Performance Summary: Arid Climates

Building Type	Units	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug Retail	SI	EUI ($MJ/m^2\cdot yr$)	664	499	584	585	614	682
Low Plug Retail	SI	5-TLCC Intensity ($\$/m^2$)	1,190	1,170	1,180	1,130	1,130	1,150
Low Plug Retail	IP	EUI ($kBtu/ft^2\cdot yr$)	58.4	43.9	51.5	51.5	54.1	60.0
Low Plug Retail	IP	5-TLCC Intensity ($\$/ft^2$)	110	109	109	105	105	107
Medium Plug Retail	SI	EUI ($MJ/m^2\cdot yr$)	878	709	781	766	775	812
Medium Plug Retail	SI	5-TLCC Intensity ($\$/m^2$)	1,220	1,220	1,210	1,150	1,150	1,180
Medium Plug Retail	IP	EUI ($kBtu/ft^2\cdot yr$)	77.3	62.5	68.8	67.5	68.3	71.5
Medium Plug Retail	IP	5-TLCC Intensity ($\$/ft^2$)	113	113	113	107	107	110
High Plug Retail	SI	EUI ($MJ/m^2\cdot yr$)	1,130	957	1,010	987	980	989
High Plug Retail	SI	5-TLCC Intensity ($\$/m^2$)	1,250	1,260	1,250	1,180	1,180	1,210
High Plug Retail	IP	EUI ($kBtu/ft^2\cdot yr$)	99.6	84.2	89.1	86.9	86.3	87.1
High Plug Retail	IP	5-TLCC Intensity ($\$/ft^2$)	116	117	117	109	109	113

Table 4-3 Baseline Model Performance Summary: Marine and Cold Climates

Building Type	Units	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug Retail	SI	EUI ($MJ/m^2 \cdot yr$)	495	555	827	1,120
		5-TLCC Intensity ($\$/m^2$)	1,170	1,140	1,150	1,160
	IP	EUI ($kBtu/ft^2 \cdot yr$)	43.6	48.9	72.8	98.9
		5-TLCC Intensity ($\$/ft^2$)	109	106	106	108
Medium Plug Retail	SI	EUI ($MJ/m^2 \cdot yr$)	682	711	931	1,190
		5-TLCC Intensity ($\$/m^2$)	1,220	1,170	1,170	1,190
	IP	EUI ($kBtu/ft^2 \cdot yr$)	60.0	62.6	82.0	105
		5-TLCC Intensity ($\$/ft^2$)	114	108	108	111
High Plug Retail	SI	EUI ($MJ/m^2 \cdot yr$)	903	915	1,080	1,290
		5-TLCC Intensity ($\$/m^2$)	1,280	1,200	1,190	1,230
	IP	EUI ($kBtu/ft^2 \cdot yr$)	79.5	80.6	95.3	114
		5-TLCC Intensity ($\$/ft^2$)	119	111	110	114

Table 4-4 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

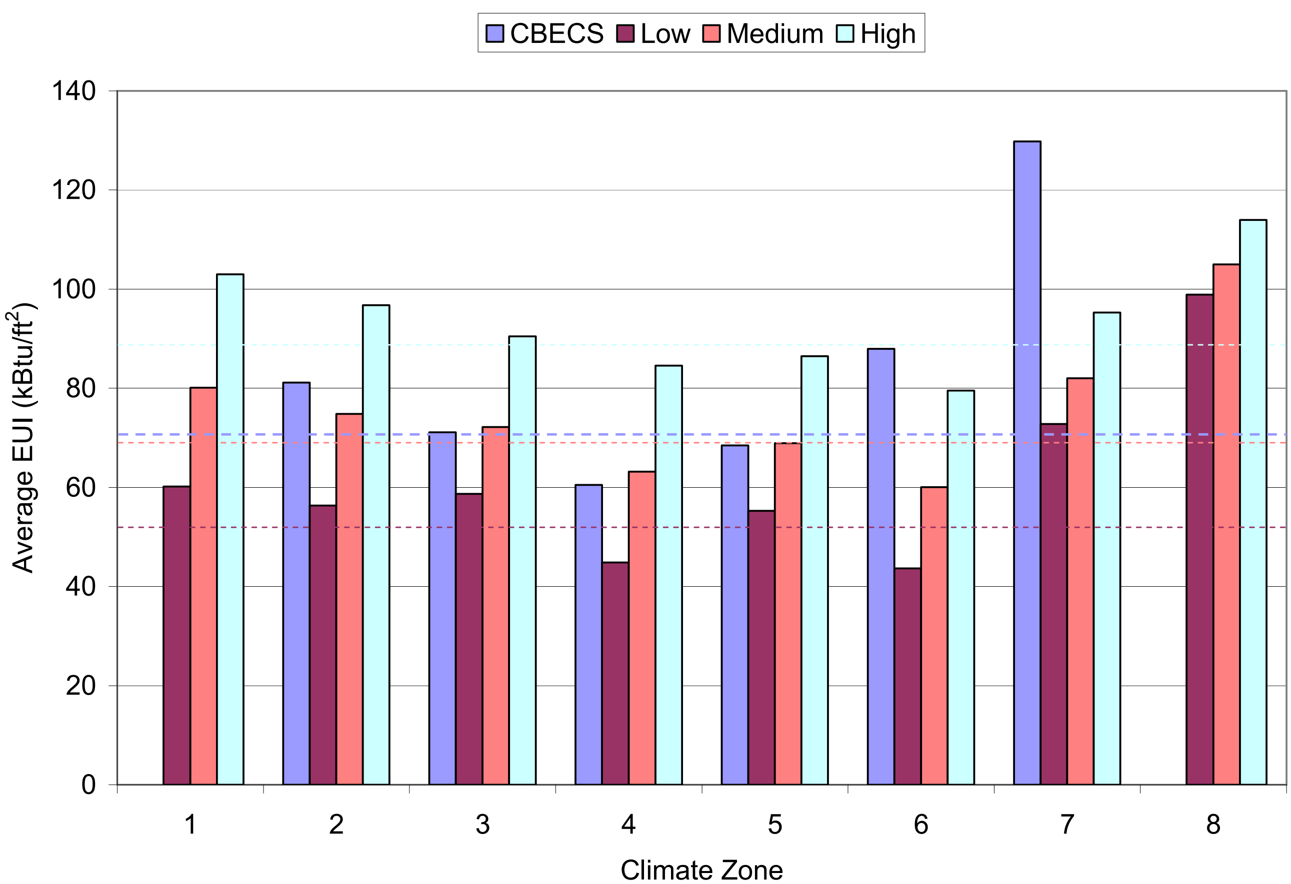

Figure 4-1 Low, Medium, and High Plug Load Baseline EUIs Compared to CBECS Data

Table 4-5 Effect of Increased Plug Loads by Climate Zone

	Absolute Increase (kBtu/ft²·yr)			Percent Increase	
Climate Zone	Low to Medium	Low to High	Climate Zone	Low to Medium	Low to High
1A	19.9	42.8	4A	42%	92%
3C	18.9	41.2	6A	38%	82%
2A	18.8	40.9	2B	33%	74%
4A	18.6	40.3	4B	34%	73%
2B	17.2	38.3	2A	33%	71%
4B	17.3	37.6	1A	33%	71%
6A	16.4	35.9	3C	32%	71%
4C	16.0	35.4	4C	31%	69%
3A	14.6	33.9	6B	28%	65%
5A	14.2	32.2	3A	26%	61%
6B	13.7	31.7	5A	26%	60%
3B-CA	12.4	30.0	3B-CA	21%	50%
5B	11.5	27.1	5B	19%	45%
3B-NV	11.0	26.1	3B-NV	16%	38%
7	9.2	22.5	7	13%	31%
8	6.1	15.1	8	6%	15%

4.2 Selected Low-Energy Models: Description

The low-energy models developed using the analysis methods described in Section 2.2 and the EDMs described in Section 3.3, are summarized in Table 4-6 through Table 4-14. Examining all of the data listed there reveals that several measures are chosen in all climate zones and for all plug load levels, namely:

- Daylighting sensors and controls are placed in all zones with side-lighting or top-lighting, and the control set point is 400 lux.
- LPD is reduced by 40%, and occupancy sensors are placed in the appropriate space types.
- All windows on the (south) façade are shaded with overhangs.
- The (south) façade glazing is reduced by 20%.
- The rooftop HVAC units are equipped with efficient fans.

Skylights are also quite common, but are not chosen in the coldest climates. In several respects, the medium and high plug load models can be contrasted with the low plug load models. For instance, the low plug load models never used PV electricity generation or economizers, but these measures were applied quite often in the medium and high plug load buildings. Some other general trends are:

- DCV is applied more often in humid environments.
- ERVs are used less when there are higher plug loads, likely because they are more effective in heating climates, and high plug loads effectively switch the dominant conditioning mode from heating to cooling in some climate zones.
- The wall and fenestration constructions chosen for 3B-CA (Los Angeles, California) are less stringent than those for 3B-NV (Las Vegas, Nevada), lending credence to our decision to model climate zone 3B with multiple cities.
- Double pane, low-emissivity, argon-filled windows are sufficient in most of the temperate and cold climates. However, at the highest plug loads, some of the colder climates' low-energy models include quadruple layer windows.
- Infiltration-reduction measures become more common as the plug loads increase. They are also applied more in colder climates, and the air barrier measure is always applied before the vestibule measure.
- Although the low-energy models would meet ASHRAE 90.1-2004 using the Energy Cost Budget method, individual components do not necessarily meet the prescriptive requirements.

The methodology for this study implies that our recommendations depend heavily on the choice of a five-year analysis period, and the energy performance and cost data for each EDM. In general, we have a high level of confidence in our energy performance data and modeling; however, our cost data are more suspect. Thus, these low-energy designs should be treated as starting points for more detailed, building-specific analyses that account for project-specific costs, rebates, and EDM options. In addition, if these designs are to become prescriptive recommendations in the tradition of the other *AEDG*s, it would be preferable to have smooth changes in insulation levels across the climate zones, and a greater reliance on the climate zone categories when recommending other EDMs. For instance, since Los Angeles and Las Vegas are in the same climate zone, it would be preferable for them to have the same level of wall insulation. Similarly, should Atlanta (climate zone 3A) really be the only humid, medium plug level store without DCV? More significantly, we are unsure if the methodology used in this report is sufficient or appropriate for determining general, prescriptive guidelines. We are confident, however, that the methodology allows us to systematically find designs that achieve 50% or greater energy savings for specific projects, and that this represents a useful step forward. We leave the question of how to develop *AEDG* recommendations based on the methodology and results of this *TSD* for a future project committee, with the caveat that all 50% *AEDG*s should encourage project specific analyses.

Table 4-6 Low Plug Low-Energy Model Descriptions: Humid Climates

Category	Subcategory	EDM Type	Humid					
			1A	2A	3A	4A	5A	6A
Program	Daylighting	Daylighting Controls	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point
	Generation	PV	None	None	None	None	None	None
	Lighting Power	LPD	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
	Plug Loads	Plug Loads	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Baseline
Form	Shading	Shading Depth	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.7	Projection factor of 0.5	Projection factor of 0.5
	Skylights	Skylight Fraction	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
Fabric	Fenestration	Skylights	Baseline Skylight Construction	Baseline Skylight Construction	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
		Windows	Baseline Window Construction	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	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
	Opaque Constructions	Walls	R-9.5 c.i.	R-13.3 c.i.	R-13.3 c.i.	R-13.3 c.i.	R-20 c.i.	R-20 c.i.
		Roof	R-20 c.i. with cool roof	R-20 c.i. with cool roof	R-20 c.i. with cool roof	R-25 c.i. with cool roof	R-30 c.i.	R-30 c.i.
Equipment	HVAC System	System	20% increased COP with efficient fan	20% increased COP with efficient fan	10% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan	10% increased COP with efficient fan
	Outdoor Air	DCV	Installed	Installed	Installed	Installed	Installed	None
		ERV	None	Low effectiveness	High effectiveness	High effectiveness	High effectiveness	High effectiveness

Table 4-7 Low Plug Low-Energy Model Descriptions: Arid Climates

Category	Subcategory	EDM Type	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Program	Daylighting	Daylighting Controls	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point
	Generation	PV	None	None	None	None	None	None
	Lighting Power	LPD	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
	Plug Loads	Plug Loads	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Baseline
Form	Shading	Shading Depth	Projection factor of 1.5	Projection factor of 1.5	Projection factor of 1.5	Projection factor of 0.9	Projection factor of 0.7	Projection factor of 0.7
	Skylights	Skylight Fraction	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
Fabric	Fenestration	Skylights	Baseline Skylight Construction	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
		Windows	Double pane with low-e and argon	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
	Infiltration	Infiltration	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
	Opaque Constructions	Walls	R-13.3 c.i.	R-9.5 c.i.	R-13.3 c.i.	R-13.3 c.i.	R-20 c.i.	R-31.3 c.i.
		Roof	R-20 c.i. with cool roof	R-20 c.i. with cool roof	R-20 c.i. with cool roof	R-25 c.i. with cool roof	R-25 c.i. with cool roof	R-30 c.i.
Equipment	HVAC System	System	20% increased COP with efficient fan	Baseline COP with efficient fan	20% increased COP with efficient fan	10% increased COP with efficient fan	Baseline COP with efficient fan	Baseline COP with efficient fan
	Outdoor Air	DCV	None	None	None	None	None	None
		ERV	None	None	Low effectiveness	High effectiveness	High effectiveness	High effectiveness

Table 4-8 Low Plug Low-Energy Model Descriptions: Marine and Cold Climates

Category	Subcategory	EDM Type	Marine		Cold	
			3C	4C	7	8
Program	Daylighting	Daylighting Controls	400 lux set point	400 lux set point	400 lux set point	400 lux set point
	Generation	PV	None	None	None	None
	Lighting Power	LPD	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
	Plug Loads	Plug Loads	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Baseline
Form	Shading	Shading Depth	Projection factor of 1.5	Projection factor of 0.9	Projection factor of 0.5	Projection factor of 1.1
	Skylights	Skylight Fraction	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	None	None
	Vertical Glazing	South Window Fraction	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
Fabric	Fenestration	Skylights	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	N/A	N/A
		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
	Infiltration	Infiltration	Baseline	Baseline	Tighter envelope	Tighter envelope
	Opaque Constructions	Walls	R-9.5 c.i.	R-13.3 c.i.	R-31.3 c.i.	R-31.3 c.i.
		Roof	R-20 c.i. with cool roof	R-25 c.i. with cool roof	R-30 c.i.	R-25 c.i. with cool roof
Equipment	HVAC System	System	Baseline COP with efficient fan	Baseline COP with efficient fan	Baseline COP with efficient fan	Baseline COP with efficient fan
	Outdoor Air	DCV	None	None	None	None
		ERV	Low effectiveness	High effectiveness	High effectiveness	High effectiveness

Table 4-9 Medium Plug Low-Energy Model Descriptions: Humid Climates

Category	Subcategory	EDM Type	Humid					
			1A	2A	3A	4A	5A	6A
Program	Daylighting	Daylighting Controls	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point
	Generation	PV	1.1% of net roof area	0.70% of net roof area	2.2% of net roof area	2.5% of net roof area	0.72% of net roof area	None
	Lighting Power	LPD	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
	Plug Loads	Plug Loads	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
Form	Shading	Shading Depth	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.7	Projection factor of 0.5	Projection factor of 0.7
	Skylights	Skylight Fraction	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
Fabric	Fenestration	Skylights	Baseline Skylight Construction	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
		Windows	Baseline Window Construction	Double pane with low-e2 and argon	Double pane with low-e2 and argon	Double pane with low-e2 and argon	Double pane with low-e2 and argon	Double pane with low-e and argon
	Infiltration	Infiltration	Baseline	Baseline	Tighter envelope	Tighter envelope	Tighter envelope	Tighter envelope
	Opaque Constructions	Walls	R-20 c.i.	R-31.3 c.i.	R-31.3 c.i.	R-31.3 c.i.	R-43.8 c.i.	R-31.3 c.i.
		Roof	R-25 c.i. with cool roof	Baseline Roof Construction , R-30 c.i. with cool roof	Baseline Roof Construction , R-30 c.i. with cool roof	R-35 c.i. with cool roof	R-35 c.i. with cool roof	Baseline Roof Construction , R-30 c.i. with cool roof

Category	Subcategory	EDM Type	Humid					
			1A	2A	3A	4A	5A	6A
Equipment	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
	Outdoor Air	DCV	Installed	Installed	None	Installed	Installed	Installed
		ERV	None	None	None	Low effectiveness	Medium effectiveness	High effectiveness

Table 4-10 Medium Plug Low-Energy Model Descriptions: Arid Climates

Category	Subcategory	EDM Type	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Program	Daylighting	Daylighting Controls	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point
	Generation	PV	2.1% of net roof area	2.0% of net roof area	5.1% of net roof area	2.5% of net roof area	4.0% of net roof area	None
	Lighting Power	LPD	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
	Plug Loads	Plug Loads	Baseline	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
Form	Shading	Shading Depth	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.5	Projection factor of 0.5	Projection factor of 0.5
	Skylights	Skylight Fraction	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing

Category	Subcategory	EDM Type	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Fabric	Fenestration	Skylights	Double pane with low-e and 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	Double pane with low-e and high solar gain
		Windows	Double pane with low-e2 and tinted glass	Baseline Window Construction	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e2 and argon	Double pane with low-e and argon
	Infiltration	Infiltration	Baseline	Baseline	Baseline	Tighter envelope	Tighter envelope	Tighter envelope and front door vestibule
	Opaque Constructions	Walls	R-31.3 c.i.	R-20 c.i.	R-31.3 c.i.	R-31.3 c.i.	R-31.3 c.i.	R-43.8 c.i.
		Roof	R-25 c.i. with cool roof	R-25 c.i. with cool roof	Baseline Roof Construction, R-30 c.i. with cool roof	Baseline Roof Construction, R-30 c.i. with cool roof	R-35 c.i. with cool roof	R-40 c.i.
Equipment	HVAC System	System	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan
	Outdoor Air	DCV	None	Installed	None	None	None	None
		ERV	None	None	None	None	Low effectiveness	Low effectiveness

Table 4-11 Medium Plug Low-Energy Model Descriptions: Marine and Cold Climates

Category	Subcategory	EDM Type	Marine		Cold	
			3C	4C	7	8
Program	Daylighting	Daylighting Controls	400 lux set point	400 lux set point	400 lux set point	400 lux set point
	Generation	PV	5.5% of net roof area	7.3% of net roof area	None	None
	Lighting Power	LPD	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
	Plug Loads	Plug Loads	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
Form	Shading	Shading Depth	Projection factor of 0.9	Projection factor of 0.7	Projection factor of 0.5	Projection factor of 1.1
	Skylights	Skylight Fraction	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	None
	Vertical Glazing	South Window Fraction	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
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	N/A
		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	Baseline	Tighter envelope	Tighter envelope	Tighter envelope
	Opaque Constructions	Walls	R-20 c.i.	R-43.8 c.i.	R-31.3 c.i.	R-31.3 c.i.
		Roof	Baseline Roof Construction, R-30 c.i. with cool roof	R-35 c.i. with cool roof	R-25 c.i. with cool roof	R-25 c.i. with cool roof
Equipment	HVAC System	System	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with efficient fan	Baseline COP with efficient fan
	Outdoor Air	DCV	None	None	None	None
		ERV	None	None	High effectiveness	High effectiveness

Table 4-12 High Plug Low-Energy Model Descriptions: Humid Climates

Category	Subcategory	EDM Type	Humid					
			1A	2A	3A	4A	5A	6A
Program	Daylighting	Daylighting Controls	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point
	Generation	PV	4.1% of net roof area	17% of net roof area	3.8% of net roof area	6.0% of net roof area	7.8% of net roof area	2.8% of net roof area
	Lighting Power	LPD	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
	Plug Loads	Plug Loads	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
		Schedule	Plug loads 15% at night	Baseline	Plug loads 15% at night	Plug loads 15% at night	Plug loads 15% at night	Plug loads 15% at night
Form	Shading	Shading Depth	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.7	Projection factor of 0.5	Projection factor of 0.5	Projection factor of 0.5
	Skylights	Skylight Fraction	4% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
Fabric	Fenestration	Skylights	Baseline Skylight Construction	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	Double pane with low-e and high solar gain
		Windows	Baseline Window Construction	Double pane with low-e2 and argon	Double pane with low-e and argon	Double pane with low-e and argon	Quadruple layer with low-e polyester films and krypton	Quadruple layer with low-e polyester films and krypton
	Infiltration	Infiltration	Baseline	Baseline	Tighter envelope	Tighter envelope	Tighter envelope	Tighter envelope and front door vestibule

Category	Subcategory	EDM Type	Humid					
			1A	2A	3A	4A	5A	6A
	Opaque Constructions	Walls	R-20 c.i.	R-31.3 c.i.	R-31.3 c.i.	R-43.8 c.i.	R-43.8 c.i.	R-43.8 c.i.
		Roof	R-25 c.i. with cool roof	R-25 c.i. with cool roof	R-30 c.i. with cool roof	R-30 c.i. with cool roof	R-30 c.i. with cool roof	R-30 c.i. with cool roof
Equipment	HVAC System	System	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan
	Outdoor Air	DCV	Installed	Installed	Installed	None	Installed	Installed
		ERV	None	None	None	None	Low effectiveness	Low effectiveness

Table 4-13 High Plug Low-Energy Model Descriptions: Arid Climates

Category	Subcategory	EDM Type	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Program	Daylighting	Daylighting Controls	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point	400 lux set point
	Generation	PV	0.28% of net roof area	5.1% of net roof area	8.0% of net roof area	8.1% of net roof area	7.7% of net roof area	9.4% of net roof area
	Lighting Power	LPD	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
	Plug Loads	Plug Loads	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
		Schedule	Plug loads 15% at night	Plug loads 15% at night	Plug loads 15% at night	Plug loads 15% at night	Plug loads 15% at night	Plug loads 15% at night
Form	Shading	Shading Depth	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.5	Projection factor of 0.5	Projection factor of 0.5
	Skylights	Skylight	3% of roof	3% of roof	4% of roof	4% of roof	4% of roof	4% of roof

Category	Subcategory	EDM Type	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
		Fraction	area in non-sidelit zones	area in non-sidelit zones	area in non-sidelit zones	area in non-sidelit zones	area in non-sidelit zones	area in non-sidelit zones
	Vertical Glazing	South Window Fraction	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
Fabric	Fenestration	Skylights	Double pane with low-e and 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	Double pane with low-e and high solar gain
		Windows	Double pane with low-e2 and argon	Baseline Window Construction	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon	Quadruple layer with low-e polyester films and krypton
	Infiltration	Infiltration	Baseline	Baseline	Baseline	Baseline	Tighter envelope	Tighter envelope
	Opaque Constructions	Walls	R-31.3 c.i.	R-13.3 c.i.	R-31.3 c.i.	R-31.3 c.i.	R-31.3 c.i.	R-43.8 c.i.
		Roof	R-25 c.i. with cool roof	R-25 c.i. with cool roof	R-25 c.i. with cool roof	R-30 c.i. with cool roof	R-30 c.i. with cool roof	R-30 c.i. with cool roof
Equipment	HVAC System	System	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan
	Outdoor Air	DCV	None	Installed	None	None	None	None
		ERV	None	None	None	None	None	Low effectiveness

Table 4-14 High Plug Low-Energy Model Descriptions: Marine and Cold Climates

Category	Subcategory	EDM Type	Marine		Cold	
			3C	4C	7	8
Program	Daylighting	Daylighting Controls	400 lux set point	400 lux set point	400 lux set point	400 lux set point
	Generation	PV	8.2% of net roof area	12% of net roof area	None	None
	Lighting Power	LPD	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
	Plug Loads	Plug Loads	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
		Schedule	Plug loads 15% at night	Plug loads 15% at night	Plug loads 15% at night	Plug loads 15% at night
Form	Shading	Shading Depth	Projection factor of 0.9	Projection factor of 0.7	Projection factor of 0.5	Projection factor of 0.9
	Skylights	Skylight Fraction	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	None
	Vertical Glazing	South Window Fraction	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
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	N/A
		Windows	Double pane with low-e and argon	Double pane with low-e and argon	Quadruple layer with low-e polyester films and krypton	Double pane with low-e and argon
	Infiltration	Infiltration	Baseline	Tighter envelope	Tighter envelope and front door vestibule	Tighter envelope
	Opaque Constructions	Walls	R-20 c.i.	R-43.8 c.i.	R-62.5 c.i.	R-31.3 c.i.
		Roof	R-25 c.i. with cool roof	R-30 c.i. with cool roof	R-30 c.i. with cool roof	R-30 c.i. with cool roof

Category	Subcategory	EDM Type	Marine		Cold	
			3C	4C	7	8
Equipment	HVAC System	System	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan
	Outdoor Air	DCV	Installed	None	None	None
		ERV	None	None	Low effectiveness	High effectiveness

4.3 Selected Low-Energy Models: Performance

The energy performance of the low-energy models is shown in Table 4-15, Table 4-16, and Table 4-17. The energy performance levels are largely dictated by the baseline EUIs, except that our selection methodology for the low-energy models without PV, in which we choose the Pareto point closest to, but exceeding, 50% energy savings, resulted in some models that have energy savings as high as 58%. This happened more often with the low plug load models, in which the Pareto Front curves were deeper and always reached 50% before adding PV.

Table 4-15 Low-Energy Performance Summary: Humid Climates

Building Type	Building Name	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug Retail	Baseline (SI units)	EUI (MJ/m²·yr)	684	651	590	634	683	780
	Low-Energy (SI units)	EUI (MJ/m²·yr)	282	283	285	312	334	389
	Baseline (IP units)	EUI (kBtu/ft²·yr)	60.2	57.3	51.9	55.8	60.2	68.6
	Low-Energy (IP units)	EUI (kBtu/ft²·yr)	24.8	24.9	25.1	27.5	29.4	34.3
	Low-Energy	Percent Energy Savings	58.7%	56.5%	51.7%	50.7%	51.1%	50.0%
Medium Plug Retail	Baseline (SI units)	EUI (MJ/m²·yr)	910	864	785	799	825	904
	Low-Energy (SI units)	EUI (MJ/m²·yr)	455	432	393	400	412	435
	Baseline (IP units)	EUI (kBtu/ft²·yr)	80.1	76.1	69.1	70.4	72.6	79.6
	Low-Energy (IP units)	EUI (kBtu/ft²·yr)	40.1	38.0	34.6	35.2	36.3	38.3
	Low-Energy	Percent Energy Savings	50.0%	50.0%	50.0%	50.0%	50.0%	51.9%
High Plug Retail	Baseline (SI units)	EUI (MJ/m²·yr)	1,170	1,120	1,020	1,020	1,020	1,080
	Low-Energy (SI units)	EUI (MJ/m²·yr)	587	558	512	509	512	538
	Baseline (IP units)	EUI (kBtu/ft²·yr)	103	98.2	90.2	89.7	90.2	94.7
	Low-Energy (IP units)	EUI (kBtu/ft²·yr)	51.7	49.1	45.1	44.9	45.1	47.4
	Low-Energy	Percent Energy Savings	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%

Table 4-16 Low-Energy Performance Summary: Arid Climates

Building Type	Building Name	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug Retail	Baseline (SI units)	EUI ($MJ/m^2 \cdot yr$)	664	499	584	585	614	682
	Low-Energy (SI units)	EUI ($MJ/m^2 \cdot yr$)	285	218	284	283	306	335
	Baseline (IP units)	EUI ($kBtu/ft^2 \cdot yr$)	58.4	43.9	51.5	51.5	54.1	60.0
	Low-Energy (IP units)	EUI ($kBtu/ft^2 \cdot yr$)	25.1	19.2	25.0	24.9	27.0	29.5
	Low-Energy	Percent Energy Savings	57.1%	56.3%	51.3%	51.7%	50.2%	50.8%
Medium Plug Retail	Baseline (SI units)	EUI ($MJ/m^2 \cdot yr$)	878	709	781	766	775	812
	Low-Energy (SI units)	EUI ($MJ/m^2 \cdot yr$)	439	355	390	383	388	404
	Baseline (IP units)	EUI ($kBtu/ft^2 \cdot yr$)	77.3	62.5	68.8	67.5	68.3	71.5
	Low-Energy (IP units)	EUI ($kBtu/ft^2 \cdot yr$)	38.7	31.2	34.4	33.7	34.1	35.6
	Low-Energy	Percent Energy Savings	50.0%	50.0%	50.0%	50.0%	50.0%	50.2%
High Plug Retail	Baseline (SI units)	EUI ($MJ/m^2 \cdot yr$)	1,130	957	1,010	987	980	989
	Low-Energy (SI units)	EUI ($MJ/m^2 \cdot yr$)	565	478	506	493	490	495
	Baseline (IP units)	EUI ($kBtu/ft^2 \cdot yr$)	99.6	84.2	89.1	86.9	86.3	87.1
	Low-Energy (IP units)	EUI ($kBtu/ft^2 \cdot yr$)	49.8	42.1	44.5	43.4	43.2	43.5
	Low-Energy	Percent Energy Savings	50.0%	50.0%	50.0%	50.0%	50.0%	50.0%

Table 4-17 Low-Energy Performance Summary: Marine and Cold Climates

Building Type	Building Name	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug Retail	Baseline (SI units)	EUI (MJ/m^2·yr)	495	555	827	1,120
	Low-Energy (SI units)	EUI (MJ/m^2·yr)	245	277	343	465
	Baseline (IP units)	EUI (kBtu/ft^2·yr)	43.6	48.9	72.8	98.9
	Low-Energy (IP units)	EUI (kBtu/ft^2·yr)	21.5	24.4	30.2	41.0
	Low-Energy	Percent Energy Savings	50.5%	50.1%	58.6%	58.6%
Medium Plug Retail	Baseline (SI units)	EUI (MJ/m^2·yr)	682	711	931	1,190
	Low-Energy (SI units)	EUI (MJ/m^2·yr)	341	356	444	564
	Baseline (IP units)	EUI (kBtu/ft^2·yr)	60.0	62.6	82.0	105
	Low-Energy (IP units)	EUI (kBtu/ft^2·yr)	30.0	31.3	39.1	49.7
	Low-Energy	Percent Energy Savings	50.0%	50.0%	52.4%	52.7%
High Plug Retail	Baseline (SI units)	EUI (MJ/m^2·yr)	903	915	1,080	1,290
	Low-Energy (SI units)	EUI (MJ/m^2·yr)	452	457	540	639
	Baseline (IP units)	EUI (kBtu/ft^2·yr)	79.5	80.6	95.3	114
	Low-Energy (IP units)	EUI (kBtu/ft^2·yr)	39.8	40.3	47.6	56.3
	Low-Energy	Percent Energy Savings	50.0%	50.0%	50.1%	50.6%

The economic performance of the low-energy models is shown inTable 4-18, Table 4-19, and Table 4-20. The data show that achieving 50% is much easier in the low plug load stores. In fact, ten of the low plug load, low-energy models are less expensive than their baseline counterparts, based on a five-year TLCC and our other economic parameters. None of the medium or high plug load low-energy models achieved this distinction, perhaps because of overly conservative plug load EDM cost estimates.

Table 4-18 Low-Energy Cost Summary: Humid Climates

Building Type	Building Name	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug Retail	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,180	1,200	1,180	1,160	1,170	1,150
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,160	1,170	1,150	1,150	1,160	1,160
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	110	112	109	108	109	107
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	108	108	107	107	107	108
Medium Plug Retail	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,220	1,240	1,210	1,190	1,210	1,170
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,220	1,240	1,300	1,300	1,290	1,250
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	113	115	113	110	112	109
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	114	115	121	121	120	116
High Plug Retail	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,250	1,280	1,260	1,220	1,250	1,200
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,300	1,510	1,360	1,380	1,420	1,350
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	116	119	117	113	116	111
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	121	140	126	129	132	125

Table 4-19 Low-Energy Cost Summary: Arid Climates

Building Type	Building Name	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug Retail	Baseline (SI units)	5-TLCC Intensity ($/m²)	1,190	1,170	1,180	1,130	1,130	1,150
	Low-Energy (SI units)	5-TLCC Intensity ($/m²)	1,160	1,140	1,160	1,130	1,130	1,150
	Baseline (IP units)	5-TLCC Intensity ($/ft²)	110	109	109	105	105	107
	Low-Energy (IP units)	5-TLCC Intensity ($/ft²)	108	106	107	105	105	107
Medium Plug Retail	Baseline (SI units)	5-TLCC Intensity ($/m²)	1,220	1,220	1,210	1,150	1,150	1,180
	Low-Energy (SI units)	5-TLCC Intensity ($/m²)	1,230	1,230	1,290	1,270	1,300	1,290
	Baseline (IP units)	5-TLCC Intensity ($/ft²)	113	113	113	107	107	110
	Low-Energy (IP units)	5-TLCC Intensity ($/ft²)	115	114	119	118	121	120
High Plug Retail	Baseline (SI units)	5-TLCC Intensity ($/m²)	1,250	1,260	1,250	1,180	1,180	1,210
	Low-Energy (SI units)	5-TLCC Intensity ($/m²)	1,240	1,310	1,350	1,320	1,370	1,430
	Baseline (IP units)	5-TLCC Intensity ($/ft²)	116	117	117	109	109	113
	Low-Energy (IP units)	5-TLCC Intensity ($/ft²)	116	121	126	123	128	133

Table 4-20 Low-Energy Cost Summary: Marine and Cold Climates

Building Type	Building Name	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug Retail	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,170	1,140	1,150	1,160
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,140	1,130	1,190	1,190
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	109	106	106	108
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	106	105	110	110
Medium Plug Retail	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,220	1,170	1,170	1,190
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,280	1,360	1,240	1,230
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	114	108	108	111
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	119	126	115	114
High Plug Retail	Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,280	1,200	1,190	1,230
	Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,360	1,460	1,310	1,270
	Baseline (IP units)	5-TLCC Intensity ($/ft^2)	119	111	110	114
	Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	126	135	122	118

For reference, we report the minimum and maximum monthly electric demand and electrical load factors for the baseline and low energy models, see Table 4-21, Table 4-22, and Table 4-23. Monthly electric demand is the maximum net electrical demand, taking credit for electricity produced by PV, computed for each month of the annual simulation. Monthly electrical load factor is the average net electrical demand (net kWh for the month divided by hours in the month) divided by the monthly electric demand. A higher electrical load factor represents a more uniform use of electrical energy at the building and is desirable from a utility's point of view. To capture the annual variations in electrical demand, we report the minimum and maximum for both metrics over the course of a year. For example, the smallest monthly electric demand for the low plug baseline building in Miami is 185 kW, which occurred on January 23 at 4:00 PM, and the largest is 217 kW, which occurred on June 27 at 4:45 PM.

In general, the low-energy models have lower electric demands than the corresponding baseline models, but also have lower electrical load factors. Although reduced demand is generally positive, the corresponding reduction in load factors is troublesome and points to grid issues that should be addressed in future studies.

Table 4-21 Low-Energy Electricity Demand Summary: Humid Climates

Building Type	Building Name	Metric	Humid					
			1A	2A	3A	4A	5A	6A
Low Plug Retail	Baseline	Monthly Electric Demand [min-max] (kW)	185–217	168–220	130–200	115–199	113–191	114–193
	Low-Energy	Monthly Electric Demand [min-max] (kW)	99.2–115	85.7–109	74.7–107	71.4–102	71.4–102	72.2–105
	Baseline	Monthly Electrical Load Factor [min-max]	0.476–0.521	0.408–0.513	0.442–0.499	0.417–0.559	0.432–0.569	0.393–0.578
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.351–0.420	0.332–0.402	0.325–0.442	0.334–0.472	0.346–0.482	0.308–0.492
Medium Plug Retail	Baseline	Monthly Electric Demand [min-max] (kW)	242–274	224–278	192–258	170–256	163–249	157–250
	Low-Energy	Monthly Electric Demand [min-max] (kW)	145–160	127–158	118–145	114–145	116–144	112–144
	Baseline	Monthly Electrical Load Factor [min-max]	0.501–0.535	0.440–0.530	0.474–0.518	0.442–0.530	0.441–0.554	0.431–0.583
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.414–0.465	0.358–0.458	0.383–0.430	0.398–0.464	0.417–0.468	0.403–0.503
High Plug Retail	Baseline	Monthly Electric Demand [min-max] (kW)	288–319	269–325	238–305	220–303	211–296	196–296
	Low-Energy	Monthly Electric Demand [min-max] (kW)	182–197	164–197	154–183	132–184	149–183	148–181
	Baseline	Monthly Electrical Load Factor [min-max]	0.556–0.580	0.501–0.578	0.532–0.575	0.504–0.561	0.499–0.582	0.492–0.624
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.435–0.479	0.414–0.458	0.408–0.455	0.381–0.500	0.397–0.475	0.404–0.484

Table 4-22 Low-Energy Electricity Demand Summary: Arid Climates

Building Type	Building Name	Metric	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Low Plug Retail	Baseline	Monthly Electric Demand [min-max] (kW)	156–253	138–162	134–215	116–185	116–176	114–172
	Low-Energy	Monthly Electric Demand [min-max] (kW)	74.6–118	72.4–87.2	74.0–112	74.4–98.5	73.1–95.2	73.0–93.7
	Baseline	Monthly Electrical Load Factor [min-max]	0.446–0.474	0.462–0.498	0.453–0.495	0.444–0.567	0.448–0.569	0.435–0.571
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.345–0.425	0.311–0.409	0.357–0.456	0.349–0.458	0.338–0.467	0.348–0.490
Medium Plug Retail	Baseline	Monthly Electric Demand [min-max] (kW)	213–314	194–219	192–276	165–245	162–236	158–232
	Low-Energy	Monthly Electric Demand [min-max] (kW)	129–168	115–129	105–158	105–137	117–137	116–135
	Baseline	Monthly Electrical Load Factor [min-max]	0.470–0.496	0.477–0.522	0.467–0.501	0.458–0.557	0.461–0.569	0.459–0.577
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.410–0.439	0.388–0.443	0.367–0.471	0.375–0.482	0.370–0.456	0.400–0.490
High Plug Retail	Baseline	Monthly Electric Demand [min-max] (kW)	258–363	239–265	238–324	213–293	209–284	203–280
	Low-Energy	Monthly Electric Demand [min-max] (kW)	160–200	152–167	137–197	135–176	137–170	151–172
	Baseline	Monthly Electrical Load Factor [min-max]	0.518–0.548	0.530–0.580	0.512–0.547	0.505–0.584	0.507–0.593	0.507–0.609
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.434–0.474	0.411–0.456	0.386–0.480	0.368–0.487	0.374–0.487	0.372–0.484

Table 4-23 Low-Energy Electricity Demand Summary: Marine and Cold Climates

Building Type	Building Name	Metric	Marine		Cold	
			3C	4C	7	8
Low Plug Retail	Baseline	Monthly Electric Demand [min-max] (kW)	118–163	110–175	113–178	111–153
	Low-Energy	Monthly Electric Demand [min-max] (kW)	68.8–87.0	68.8–92.5	69.0–100	68.9–89.8
	Baseline	Monthly Electrical Load Factor [min-max]	0.436–0.525	0.399–0.569	0.428–0.572	0.463–0.590
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.324–0.463	0.321–0.510	0.449–0.559	0.469–0.569
Medium Plug Retail	Baseline	Monthly Electric Demand [min-max] (kW)	177–221	154–233	157–235	154–209
	Low-Energy	Monthly Electric Demand [min-max] (kW)	106–124	101–130	110–140	109–139
	Baseline	Monthly Electrical Load Factor [min-max]	0.462–0.510	0.434–0.575	0.450–0.578	0.491–0.593
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.353–0.465	0.336–0.521	0.418–0.510	0.505–0.568
High Plug Retail	Baseline	Monthly Electric Demand [min-max] (kW)	224–268	188–281	192–281	189–255
	Low-Energy	Monthly Electric Demand [min-max] (kW)	141–161	131–167	146–175	149–172
	Baseline	Monthly Electrical Load Factor [min-max]	0.513–0.569	0.491–0.636	0.512–0.634	0.553–0.643
	Low-Energy	Monthly Electrical Load Factor [min-max]	0.379–0.462	0.352–0.532	0.416–0.501	0.498–0.543

The energy and cost performances are shown together in Figure 4-2 through Figure 4-7. Figure 4-2 though Figure 4-4 shows the baseline and low-energy models for each climate zone and each plug load scenario on a series of 5-TLCC versus net EUI plots. Each pair of models is connected with a line—the baseline models are the rightmost points of each pair, since their net EUIs are about twice as large as the low-energy models'. The locations whose connecting lines have a positive slope are able to achieve 50% energy savings at a cost lower than the baseline cost; negative slopes flag low-energy models that are more expensive than baseline. For instance, Figure 4-2 clearly demonstrates that most of the low plug load low-energy models are cost effective, and Figure 4-3 and Figure 4-4 go on to show that the cost premium for low-energy designs is positively correlated with plug load levels in most climate zones.

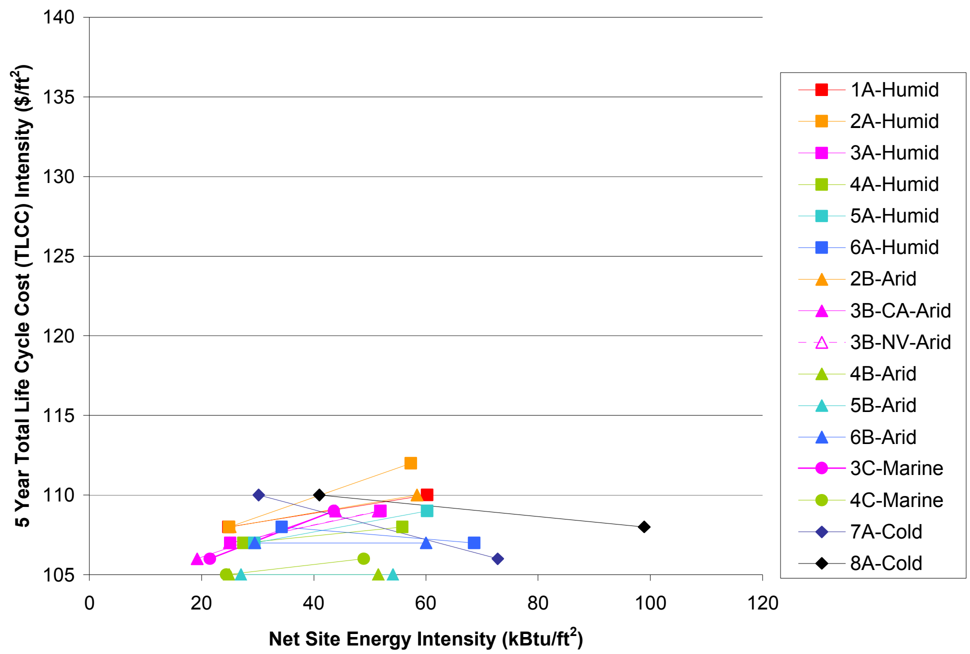

Figure 4-2 5-TLCC Intensity versus Net EUI: Low Plug Load Baseline and Low-Energy Models

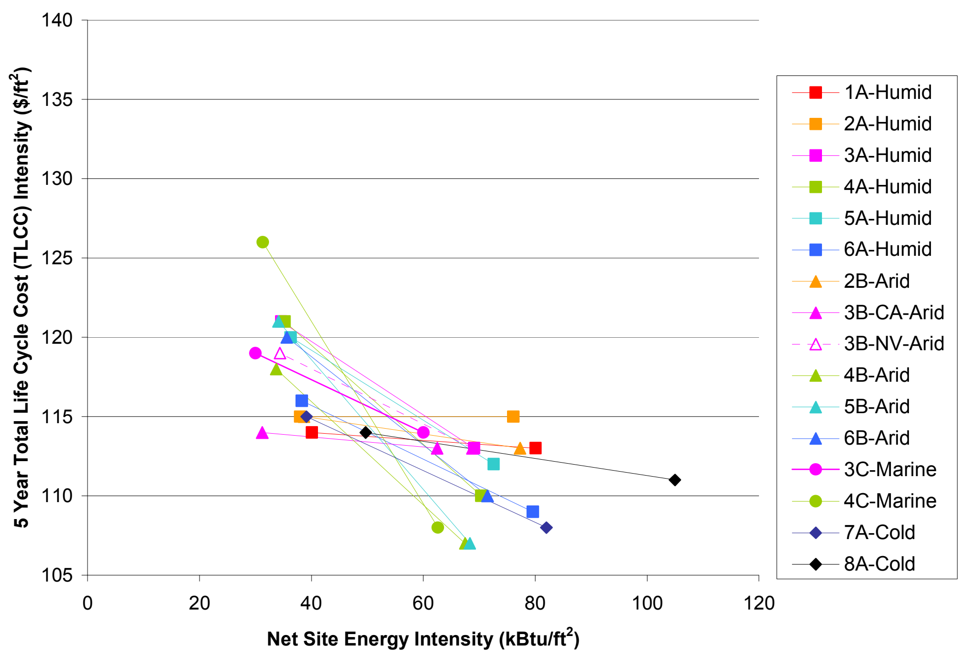

Figure 4-3 5-TLCC Intensity versus Net EUI: Medium Plug Load Baseline and Low-Energy Models

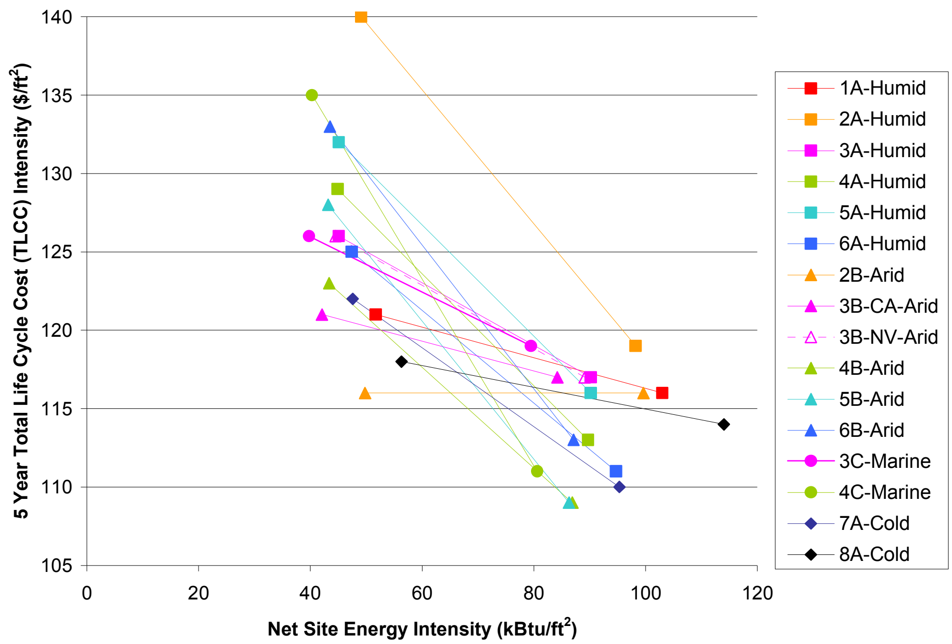

Figure 4-4 5-TLCC Intensity versus Net EUI: High Plug Load Baseline and Low-Energy Models

The Pareto fronts in Figure 4-5 through Figure 4-7 demonstrate the relative ease of achieving 50% in each climate zone location, and for the different plug load levels (see Section 2.2 for a description of Pareto points and fronts). For instance, Figure 4-5 shows that it was harder to reach 50% energy savings in climate zones 6 and 7 than elsewhere, and that it will likely be difficult to design zero energy buildings for climate zone 8. Although these curves provide a rough ranking of how easy it is to reach 50%, the limits on achievable percent energy savings that they imply are not fixed. The curves come directly from our analysis, which is fully dependent on the assumptions of Section 3. Given more EDMs (such as wind, radiant heating and cooling, or thermal storage) or improved cost-effectiveness of the current EDMs, the achievable percent savings will increase; even in the current plots, the linear positive slopes on the right sides of the curves can be extended further, since they represent the cost versus energy savings trade-off of PV electricity generation, and the end points are at 30% roof coverage. Even so, a great deal of work remains to move further along on the path to zero energy buildings—EDMs must be improved or added to cost-effectively achieve 70% energy savings in all climate zones and for all plug load levels.

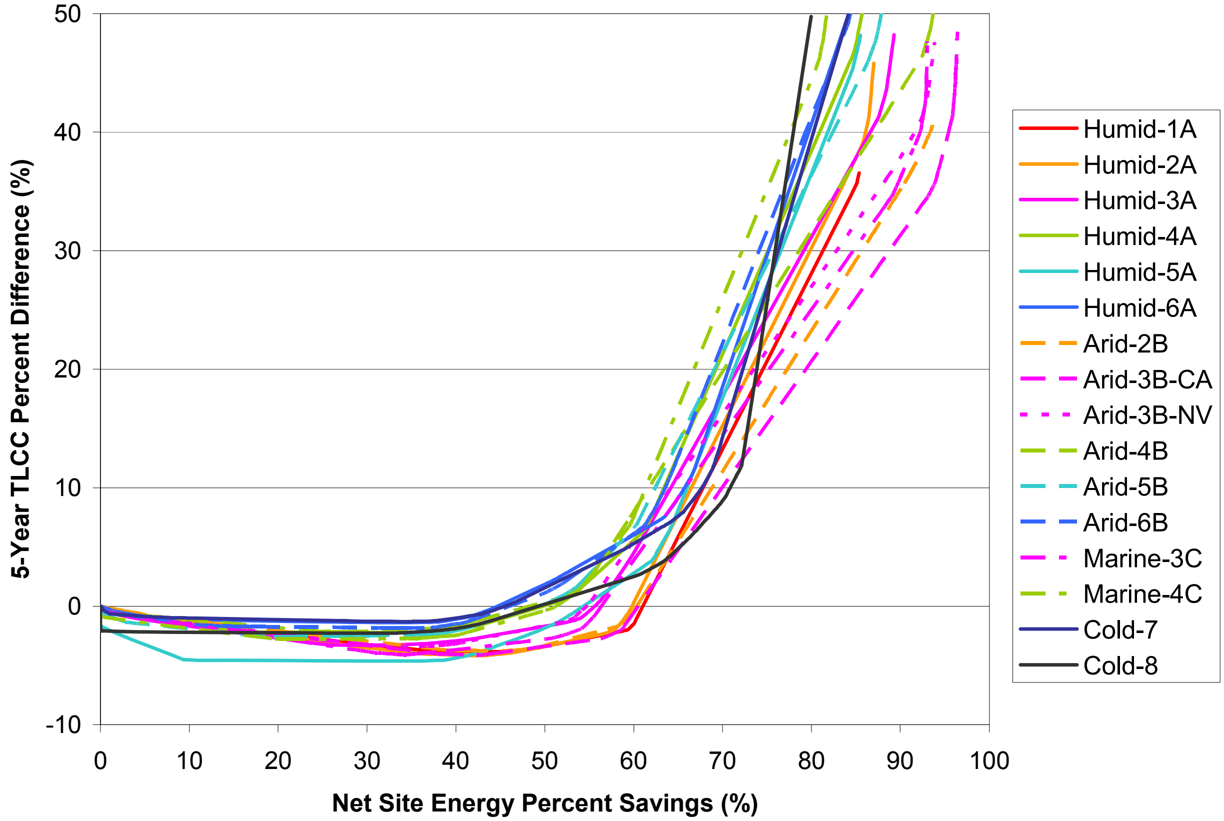

Figure 4-5 Low Plug Load Pareto Curves

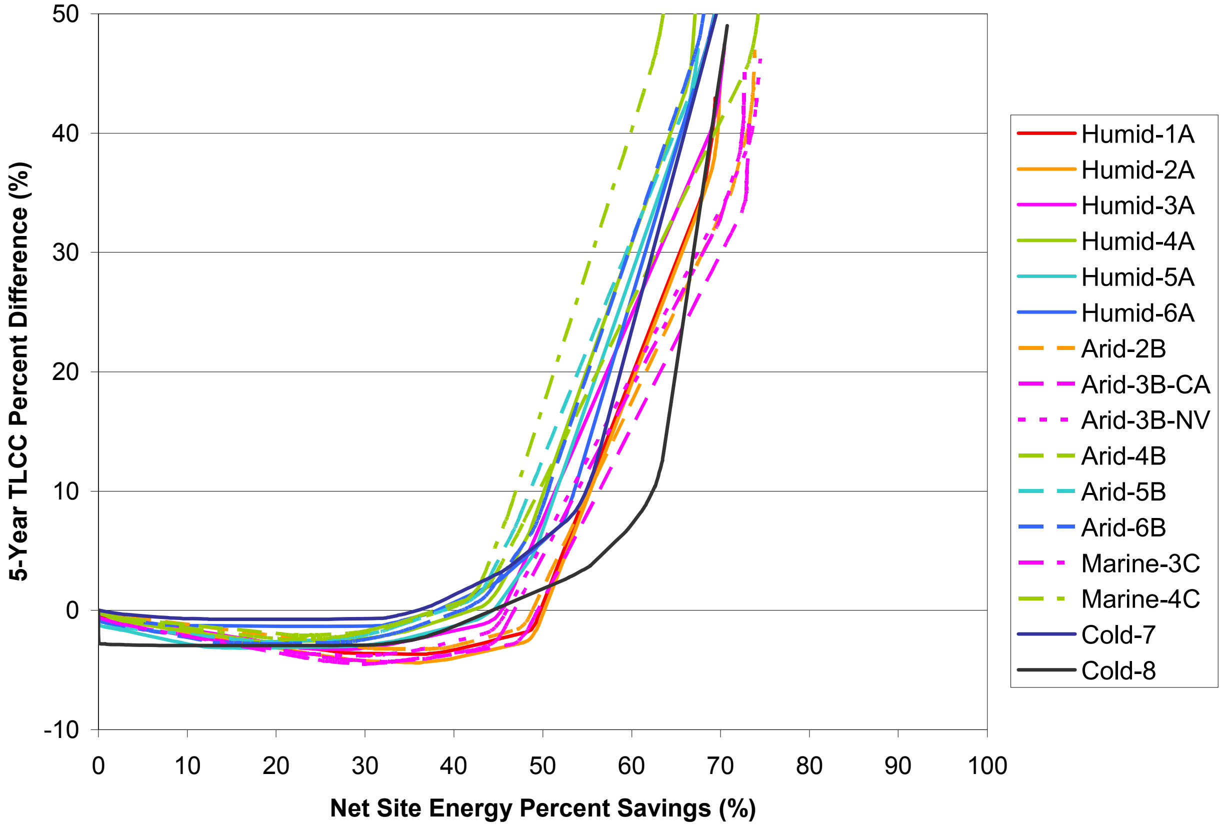

Figure 4-6 Medium Plug Load Pareto Curves

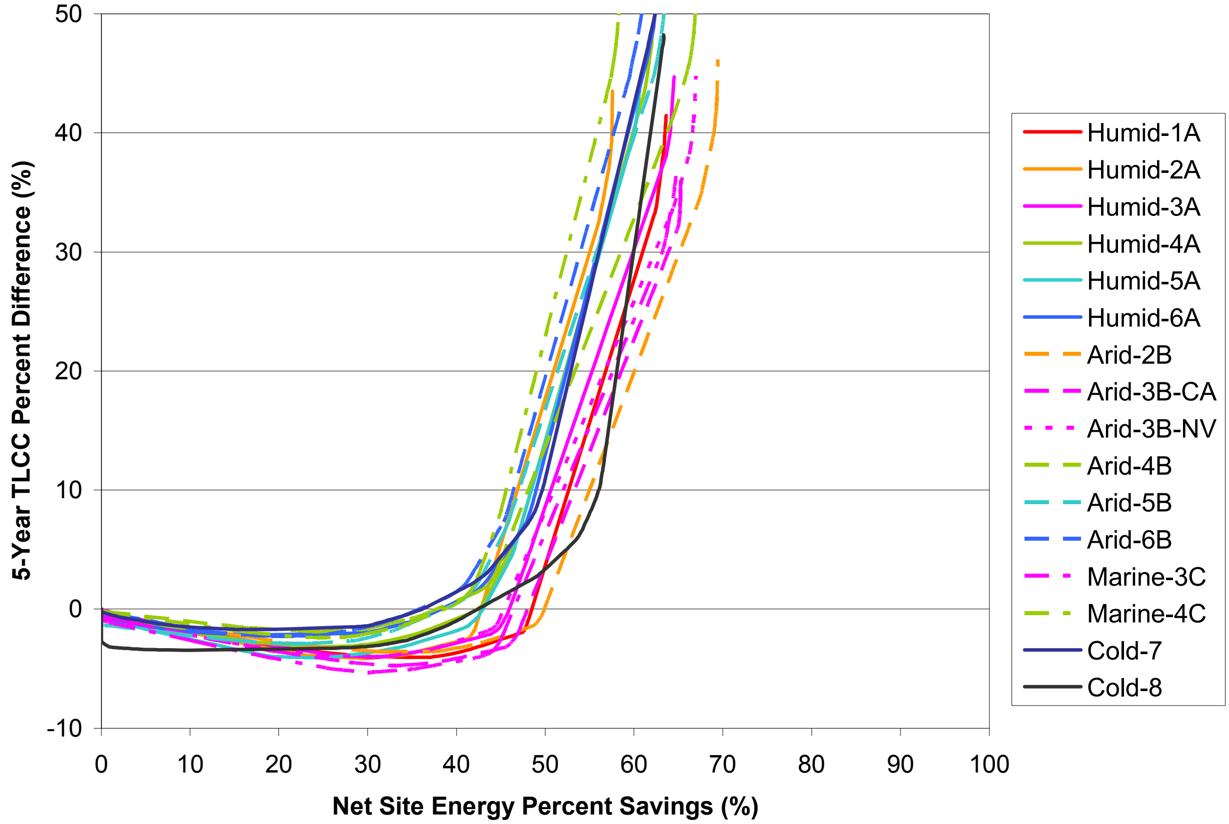

Figure 4-7 High Plug Load Pareto Curves

Finally, the breakdown of EUI by end use is depicted in Figure 4-8 through Figure 4-10. Six sets of data are shown per climate zone: baseline and low-energy model pairs for each plug load level. The expected variations by climate zone are evident, as are the increases in cooling loads, and often fan loads, that accompany higher plug load levels. For ease of reference, the data are shown in tabular form in Appendix C.

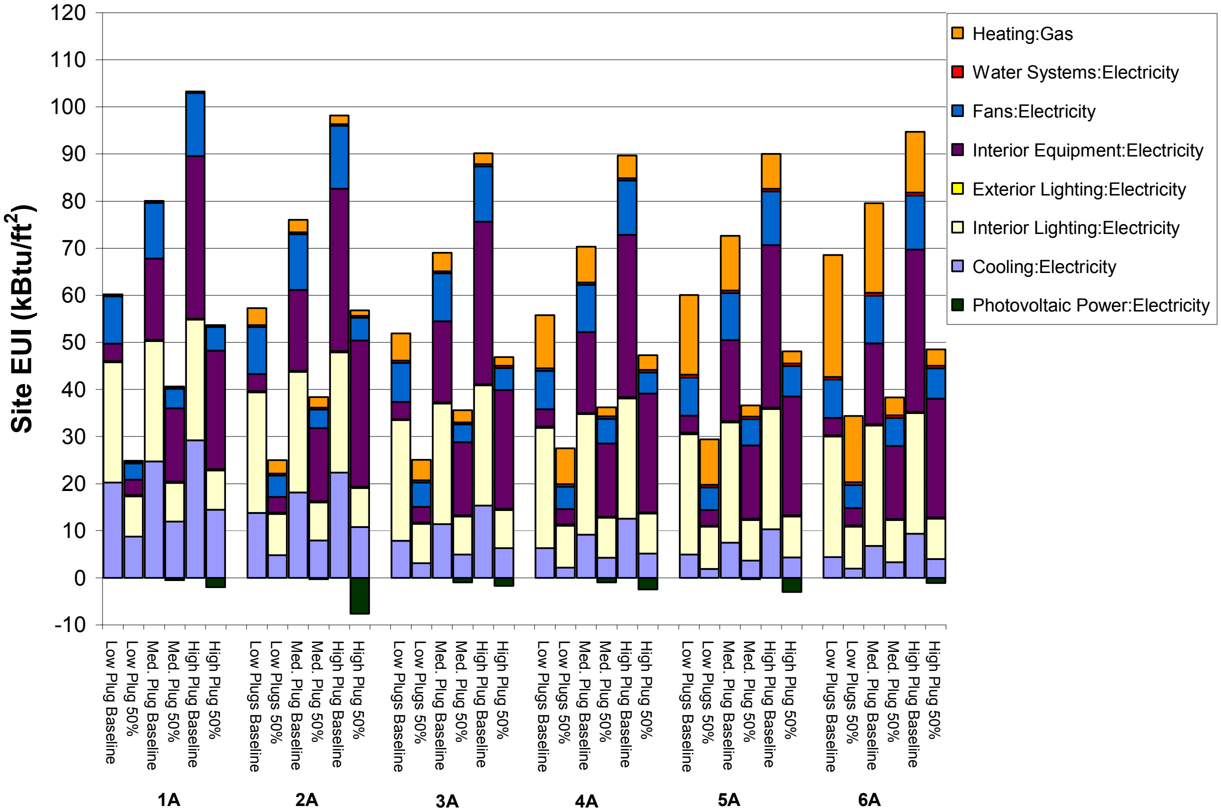

Figure 4-8 Detailed End Uses: Humid Climates

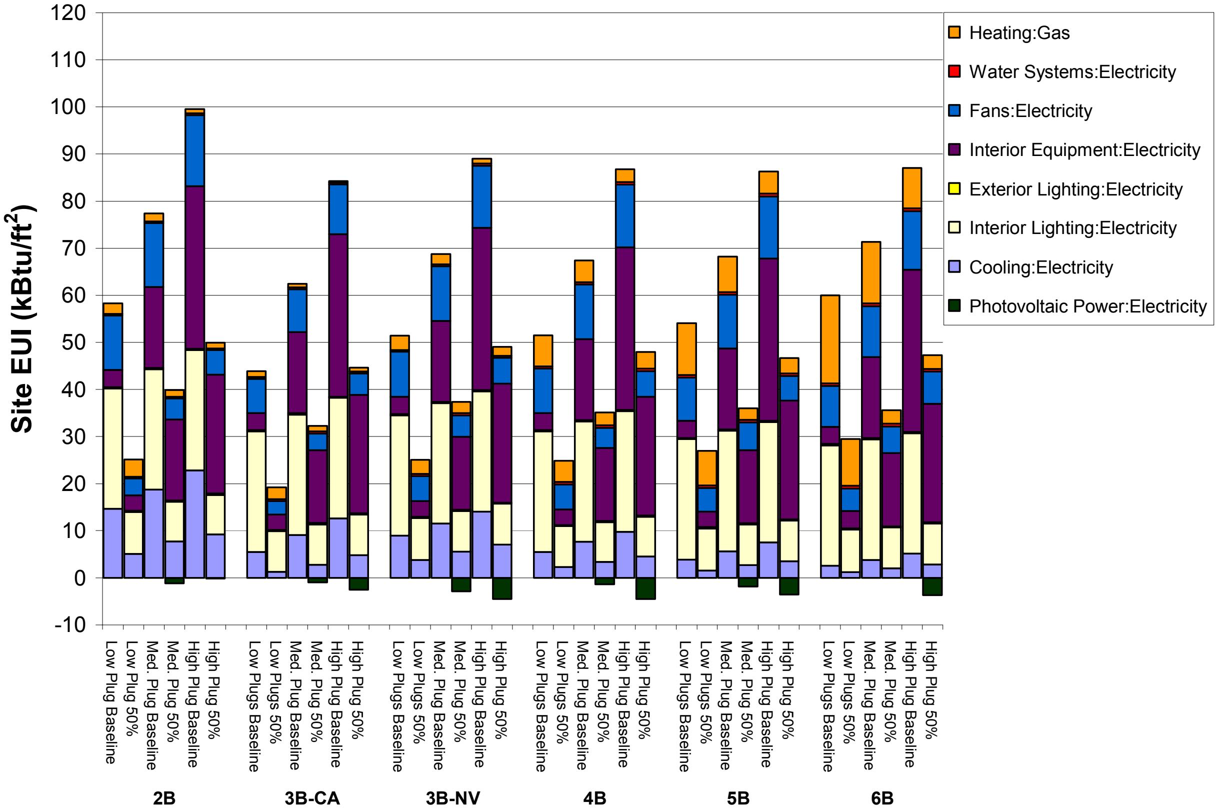

Figure 4-9 Detailed End Uses: Arid Climates

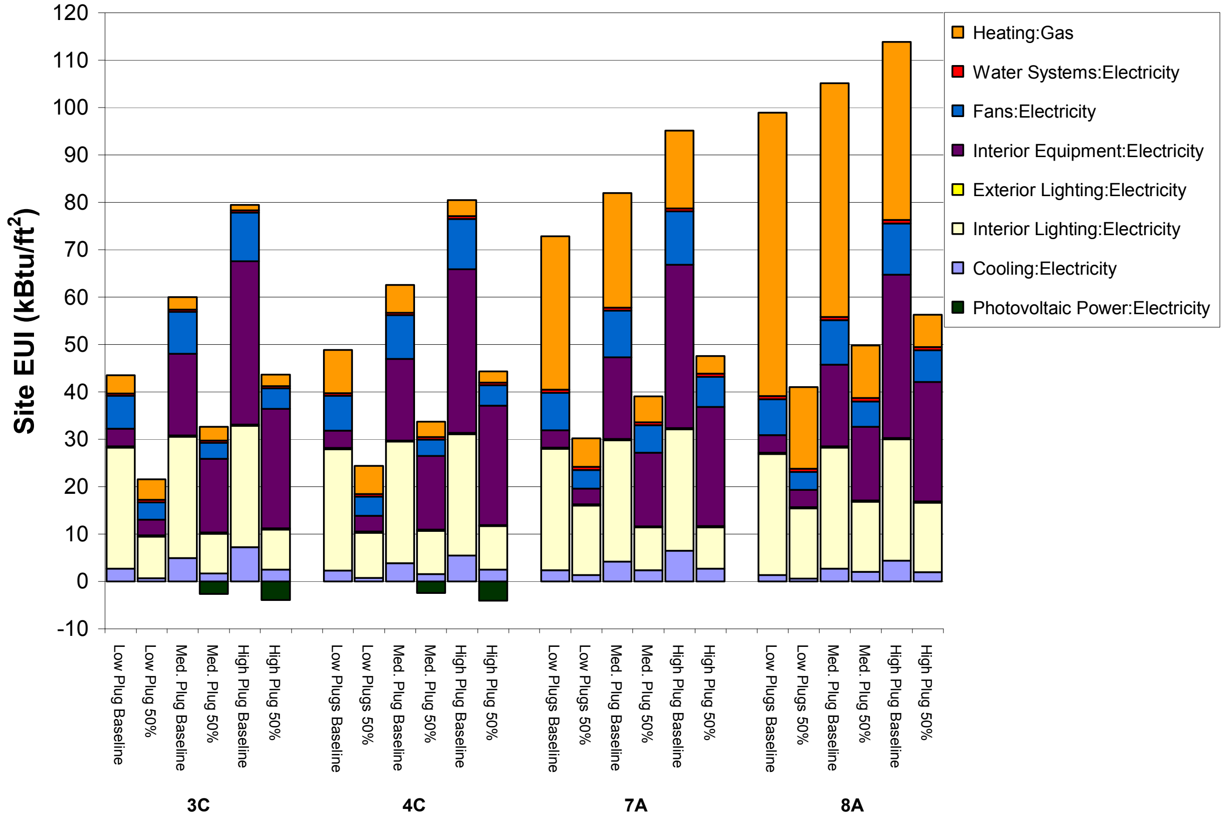

Figure 4-10 Detailed End Uses: Marine and Cold Climates

4.4 Sensitivity Analysis

To provide some idea of the relative importance of the EDMs chosen for each low-energy model, we conduct sensitivity analyses that remove sets of EDMs from each such model in turn. In all cases, the perturbations reset non-baseline to baseline values. For single EDM perturbations, if the baseline value persists in the low-energy model, the perturbation was not run and is not reported. Similarly, if a perturbation contains multiple EDMs, only those that differ from the baseline are actually perturbed. The perturbations are described in Table 4-24. The perturbation results are shown in Appendix B, along with detailed data describing each low-energy model. The perturbation tables report EUI and 5-TLCC in IP and SI units, as well as the percent energy savings of the low-energy model, and the difference in percent energy savings between each perturbation model and the low-energy model.

The significant interactions embedded in the integrated low-energy designs are reflected in the fact that the differences between the low-energy model percent savings and the non-overlapping perturbations' percent savings do not add up to 50%. Thus, removing some combinations of EDMs is likely to degrade the energy performance more than the sum of the first-order analyses would indicate.

Table 4-24 Sensitivity Analysis Perturbations

EDM Category	Perturbation Name	Description
Program	Daylighting Sensors	Removes all daylighting sensors
	Lighting Power Density	Returns to the baseline lighting power density
	Daylighting Sensors And Skylights	Removes all daylighting sensors and skylights
	Plug Loads	Returns to the baseline plug load density and schedule
	Photovoltaics	Removes all PV panels
Form	Glazing Quantity	Applies the baseline glazing amount to the façade, and removes skylights
	Overhangs	Removes overhangs from the façade
	Effective Aperture	Removes skylights and overhangs, and applies the baseline glazing amount to the façade
Fabric	Opaque Envelope Constructions	Sets the wall and roof insulation levels to baseline
	Infiltration	Removes the air barrier and vestibule EDMs
	Fenestration Constructions	Sets the window and skylight constructions to baseline
Equipment	Rooftop Unit	Applies the baseline rooftop unit (baseline COP, standard fans, and economizer based on climate zone)
	Energy Recovery	Removes the ERV systems
	Demand Control Ventilation	Removes the DCV systems
	Entire HVAC System	Applies the baseline rooftop unit and removes DCV and ERV

4.5 Suggestions for Future Work

As with any undertaking of this magnitude, we cannot answer the question at hand in a perfectly accurate or comprehensive manner. In this section we outline several types of improvements recommended for future 50% *AEDG* work.

4.5.1 Problem Formulation

On the path to zero energy, some climates—and some buildings—have it easier than others. The arbitrary selection of a goal based on percent savings from an uneven reference case leads to uneven outcomes in terms of how difficult it is to reach the goal in specific projects. If we continue to inflexibly follow the percent savings milestones, some building types in some climates are likely to fall short of percent savings goals greater than 50%. On the other hand, some building types in some climate zones can be designed to cost-effectively achieve 60% or 70% energy savings today.

One approach that would avoid falling short of the goal in some places and not realizing the best possible designs in others would be to base the milestones on a list of acceptable EDMs. Design recommendations could then be made using multi-criteria optimizations of appropriate objective functions. For instance, the Pareto curves found in this work are shown in Figure 4-5, Figure 4-6, and Figure 4-7. For each climate, they represent the best-case 5-TLCC/percent savings trade-offs available for the list of EDMs developed in Section 3.2.6. All that is needed to define a percent savings-independent set of low-energy models is a rule that defines an acceptable amount of effort. Four rules that could be used are 1) choose the minimum cost buildings, 2) choose the low-energy buildings that cost the same as their corresponding baselines, 3) choose the low-energy buildings that fall at some other percentage of the baseline 5-TLCC, or 4) choose the buildings at the knee of the curves, that is, at a mathematically defined compromise point where it becomes significantly more expensive to increase the percent energy savings.

Another possible approach would be to have EUI, rather than percent savings, targets. Some work would be required to determine how or if the EUI goals should vary across climate zones, but an advantage would be to decouple the path to zero energy buildings from the steadily moving 90.1 baseline.

To maintain the popular percent savings naming convention, one could ensure that the required percent savings is reached in a chosen flagship climate zone, or on a national average basis.

4.5.2 Economic Data

It is important to weigh capital and maintenance costs versus future energy costs 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 goal 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:

1. Ignore economics in all general analyses. Instead, work with a specified set of EDMs that are deemed to be reasonably mature and cost effective. Only recommend EDMs that have an appreciable impact on energy use.
2. Integrate algorithms and methodologies that can deal with data uncertainties into Opt-E-Plus, and exercise them by providing ranges, rather than single values, for highly uncertain economic and performance parameters.
3. 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.

4.5.3 Energy Modeling

A number of EDMs were not included in this report for lack of modeling capability (in EnergyPlus or the Opt-E-Plus platform) or reliable input data. Measures and model features we feel are deserving of increased attention are:

- Alternative HVAC systems

  For simplicity, we assumed that all HVAC needs were supplied with 10-ton rooftop DX units. Rooftop units are by far the most common HVAC systems used in medium box retail stores, but they are not necessarily the best choice. Future studies should consider the use of centralized systems, radiant heating and cooling, thermal storage systems, ground source heat pumps, and other technologies. Also, to obtain true comparisons with a baseline building that uses rooftop units, the dynamics of each system should be modeled 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 EnergyPlus team, and in acquiring accurate measured data.

- Air flow models

  Right now, the 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 like vestibules. For instance, infiltration is currently modeled on a whole building, ACH basis, but a more accurate model (EnergyPlus's AirFlowNetwork) would deal directly with infiltration through the envelope and the front entrance.

- Reduced static pressure drops via better rooftop unit 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. 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 rooftop units, but were unsatisfied with the modeling results. Since we could not dynamically model the effects of bypassing the indirect evaporative cooler when it was not needed, we are uncertain of our finding that evaporative cooling should not be used in any climate zone. Further refinement of both the EnergyPlus modeling methods and the input data are needed.

- Alternative service hot water systems

  We did not model solar or instantaneous hot water systems. The inclusion of solar or other waste heat water heating technologies would require modifications to the Opt-E-Plus platform to handle sizing and design issues.

- More aggressive plug load EDMs

  A detailed study of plug loads and plug load reduction measures in retail stores should be undertaken to establish realistic costs for a wider variety of plug load EDMs. For instance, we suspect that the 10% reduction modeled in this study is overpriced, and that larger reductions are possible.

- 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.

We also recommend the re-evaluation of some model inputs:

- ERVs

  Medium-sized retail stores' OA systems are not often designed for energy recovery, likely because it is difficult to design the proper routing of OA and relief air in such large one-story buildings. This issue should be studied in more detail to decide if ERVs are feasible, and if so, what the input data should be.

- Infiltration

  The baseline infiltration rates are likely lower than what is achieved in the field. To provide helpful design assistance, it may be better to model actual infiltration rates and add an infiltration EDM that describes good practice with regards to issues such as wall-ceiling connections.

4.5.4 Search Algorithms

Opt-E-Plus currently uses a sequential search routine to approximate the Pareto front associated with two design objectives. There are several drawbacks to this approach:

- The search routine is heuristic, and therefore not guaranteed to find the true Pareto curve.
- In this work, 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.
- Opt-E-Plus does not automatically provide sensitivity information or a meaningful list of designs that are close to optimal.
- 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.

Therefore, 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.), find near-optimal solutions, report sensitivity information, use continuous variables in early iterations, and propagate uncertainty information.

4.5.5 AEDG Format

The current *AEDG*s 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 and desires of specific projects, and are thus unable to provide truly integrated designs. If the development of low-energy design recommendations is automated using technologies like Opt-E-Plus, it would be possible to offer direct web-based or software-based assistance to individual building projects. One possible path would be to use the technical support document process to develop a list of acceptable EDMs for a given building type. The *AEDG*s would then be a portal through which designers could select those EDMs that are acceptable to their specific projects, enter basic geometric information, and obtain a customized set of recommendations.

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Appendix A. Baseline Schedules

A.1 Occupancy

The occupancy schedule for all zones is shown in Table A-1. The operating (open) hours can be extracted by excluding the hours for which the occupancy is 0 or 0.05 of peak, as described in Sections 3.1.2.3.1 and 3.1.2.3.2.

Table A-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	0	1	0	0
9	0.05	0.05	1	0	0
10	0.1	0.1	1	0	0.05
11	0.2	0.3	1	0	0.1
12	0.4	0.4	1	0	0.2
13	0.4	0.6	1	0	0.5
14	0.25	0.7	1	0	0.5
15	0.25	0.7	1	0	0.5
16	0.5	0.7	1	0	0.5
17	0.5	0.7	1	0	0.5
18	0.5	0.7	1	0	0.2
19	0.3	0.6	1	0	0.05
20	0.3	0.4	1	0	0
21	0.2	0.4	1	0	0
22	0.05	0.05	1	0	0
23	0	0	1	0	0
24	0	0	1	0	0
Total Hours/Day	4.000	6.400	24.00	0.0000	3.100
Total Hours/Week	29.50				
Total Hours/Year	1,538				

A.2 Lighting

Each zone in the baseline models uses the lighting schedule developed in Section 3.1.2.3.3 and shown in Table A-2.

Table A-2 Lighting Schedule

Hour	Weekdays, Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	0.1	1	0	0.1
2	0.1	1	0	0.1
3	0.1	1	0	0.1
4	0.1	1	0	0.1
5	0.1	1	0	0.1
6	0.1	1	0	0.1
7	0.1	1	0	0.1
8	0.1	1	0	0.1
9	0.5	1	0	0.1
10	0.95	1	0	0.5
11	0.95	1	0	0.95
12	0.95	1	0	0.95
13	0.95	1	0	0.95
14	0.95	1	0	0.95
15	0.95	1	0	0.95
16	0.95	1	0	0.95
17	0.95	1	0	0.95
18	0.95	1	0	0.95
19	0.95	1	0	0.5
20	0.95	1	0	0.1
21	0.95	1	0	0.1
22	0.5	1	0	0.1
23	0.1	1	0	0.1
24	0.1	1	0	0.1
Total Hours/Day	13.40	24.00	0.0000	10.00
Total Hours/Week	77.00			
Total Hours/Year	4,015			

A.3 Plug and Process Loads

Each zone in the low- and medium-level plug load baseline models uses the equipment schedules shown in Table A-3. The high-level plug load baseline models use the schedule shown in Table A-4. These schedules were developed in Section 3.1.2.3.4.

Table A-3 Low and Medium Plug Equipment Schedule

Hour	Weekdays, Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	0.15	1	0	0.15
2	0.15	1	0	0.15
3	0.15	1	0	0.15
4	0.15	1	0	0.15
5	0.15	1	0	0.15
6	0.15	1	0	0.15
7	0.15	1	0	0.15
8	0.15	1	0	0.15
9	0.5	1	0	0.15
10	0.9	1	0	0.5
11	0.9	1	0	0.9
12	0.9	1	0	0.9
13	0.9	1	0	0.9
14	0.9	1	0	0.9
15	0.9	1	0	0.9
16	0.9	1	0	0.9
17	0.9	1	0	0.9
18	0.9	1	0	0.9
19	0.9	1	0	0.5
20	0.9	1	0	0.15
21	0.9	1	0	0.15
22	0.5	1	0	0.15
23	0.15	1	0	0.15
24	0.15	1	0	0.15
Total Hours/Day	13.30	24.00	0.0000	10.30
Total Hours/Week	76.80			
Total Hours/Year	4,005			

Table A-4 High Plug Equipment Schedule

Hour	Weekdays, Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	0.4	1	0	0.4
2	0.4	1	0	0.4
3	0.4	1	0	0.4
4	0.4	1	0	0.4
5	0.4	1	0	0.4
6	0.4	1	0	0.4
7	0.4	1	0	0.4
8	0.4	1	0	0.4
9	0.65	1	0	0.4
10	0.9	1	0	0.65
11	0.9	1	0	0.9
12	0.9	1	0	0.9
13	0.9	1	0	0.9
14	0.9	1	0	0.9
15	0.9	1	0	0.9
16	0.9	1	0	0.9
17	0.9	1	0	0.9
18	0.9	1	0	0.9
19	0.9	1	0	0.65
20	0.9	1	0	0.4
21	0.9	1	0	0.4
22	0.65	1	0	0.4
23	0.4	1	0	0.4
24	0.4	1	0	0.4
Total Hours/Day	16.10	24.00	0.0000	14.10
Total Hours/Week	94.60			
Total Hours/Year	4,933			

A.4 Infiltration and HVAC

The HVAC operation schedules and infiltration schedules are shown in Table A-5 and Table A-6, respectively. The motorized damper schedules are the same as the HVAC operational schedules. During off hours, the HVAC system is shut off and only cycles “on” when the setback thermostat control calls for heating or cooling to maintain the setback temperature. The outdoor air (OA) is also “turned off” with motorized dampers during off hours, when motorized dampers are present and the system is not in economizing mode. In the baseline models, motorized dampers are used only when the HVAC system is equipped with an economizer. In the low-energy models, motorized dampers are added whenever an economizer, a DCV, or an ERV system is present. All other models use gravity damper OA systems, which bring in OA whenever the fans operate, even during night cycle operation.

Table A-5 HVAC Operation Schedule

Hour	Weekdays, Saturdays	Winter Design, Summer Design	Sundays, Holidays, Other
1	0	1	0
2	0	1	0
3	0	1	0
4	0	1	0
5	0	1	0
6	0	1	0
7	0	1	0
8	1	1	0
9	1	1	1
10	1	1	1
11	1	1	1
12	1	1	1
13	1	1	1
14	1	1	1
15	1	1	1
16	1	1	1
17	1	1	1
18	1	1	1
19	1	1	1
20	1	1	0
21	1	1	0
22	1	1	0
23	0	1	0
24	0	1	0
Total Hours/Day	15.00	24.00	11.00
Total Hours/Week	86.00		
Total Hours/Year	4,484		

Table A-6 Infiltration Schedule

Hour	Weekdays, Saturdays	Summer Design, Winter Design	Sundays, Holidays, Other
1	1	0.5	1
2	1	0.5	1
3	1	0.5	1
4	1	0.5	1
5	1	0.5	1
6	1	0.5	1
7	1	0.5	1
8	0.5	0.5	1
9	0.5	0.5	0.5
10	0.5	0.5	0.5
11	0.5	0.5	0.5
12	0.5	0.5	0.5
13	0.5	0.5	0.5
14	0.5	0.5	0.5
15	0.5	0.5	0.5
16	0.5	0.5	0.5
17	0.5	0.5	0.5
18	0.5	0.5	0.5
19	0.5	0.5	0.5
20	0.5	0.5	1
21	0.5	0.5	1
22	0.5	0.5	1
23	1	0.5	1
24	1	0.5	1
Total Hours/Day	16.50	12.00	18.50
Total Hours/Week	101.0		
Total Hours/Year	5,266		

A.5 Thermostat Set Points

Each zone in the baseline models uses the heating and cooling set point schedules shown in Table A-7 and Table A-8, 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 91ºF (33ºC) and setback to 55ºF (13ºC) is included in the models. Humidity is addressed indirectly by controlling supply air temperature, which is 57ºF (14ºC) during cooling, and 104ºF (40ºC) during heating.

Table A-7 Heating Set Point Schedule (ºC)

Hour	Weekdays, Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	13	13	21	13
2	13	13	21	13
3	13	13	21	13
4	13	13	21	13
5	13	13	21	13
6	13	13	21	13
7	13	13	21	13
8	21	13	21	13
9	21	13	21	21
10	21	13	21	21
11	21	13	21	21
12	21	13	21	21
13	21	13	21	21
14	21	13	21	21
15	21	13	21	21
16	21	13	21	21
17	21	13	21	21
18	21	13	21	21
19	21	13	21	21
20	21	13	21	13
21	21	13	21	13
22	21	13	21	13
23	13	13	21	13
24	13	13	21	13
Total Hours/Day	432.0	312.0	504.0	400.0
Total Hours/Week	2,560			
Total Hours/Year	133,500			

Table A-8 Cooling Set Point Schedule (ºC)

Hour	Weekdays, Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	33	24	33	33
2	33	24	33	33
3	33	24	33	33
4	33	24	33	33
5	33	24	33	33
6	33	24	33	33
7	33	24	33	33
8	24	24	33	33
9	24	24	33	24
10	24	24	33	24
11	24	24	33	24
12	24	24	33	24
13	24	24	33	24
14	24	24	33	24
15	24	24	33	24
16	24	24	33	24
17	24	24	33	24
18	24	24	33	24
19	24	24	33	24
20	24	24	33	33
21	24	24	33	33
22	24	24	33	33
23	33	24	33	33
24	33	24	33	33
Total Hours/Day	657.0	576.0	792.0	693.0
Total Hours/Week	3,978			
Total Hours/Year	207,400			

A.6 Service Water Heating

The service water heating schedules are adopted from ASHRAE 90.1-1989, and are shown in Table A-9.

Table A-9 Service Water Heating Schedule

Hour	Weekdays, Summer Design	Saturdays, Winter Design	Sundays, Holidays, Other
1	0.04	0.11	0.07
2	0.05	0.1	0.07
3	0.05	0.08	0.07
4	0.04	0.06	0.06
5	0.04	0.06	0.06
6	0.04	0.06	0.06
7	0.04	0.07	0.07
8	0.15	0.2	0.1
9	0.23	0.24	0.12
10	0.32	0.27	0.14
11	0.41	0.42	0.29
12	0.57	0.54	0.31
13	0.62	0.59	0.36
14	0.61	0.6	0.36
15	0.5	0.49	0.34
16	0.45	0.48	0.35
17	0.46	0.47	0.37
18	0.47	0.46	0.34
19	0.42	0.44	0.25
20	0.34	0.36	0.27
21	0.33	0.29	0.21
22	0.23	0.22	0.16
23	0.13	0.16	0.1
24	0.08	0.13	0.06
Total Hours/Day	6.620	6.900	4.590
Total Hours/Week	44.59		
Total Hours/Year	2,325		

Appendix B. Low-Energy Model and Sensitivity Analysis Data

B.1 Climate Zone 1A: Miami, Florida

Table B-1 1A Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	1A		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	1.1% of net roof area	4.1% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.991	0.991
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.187	1.06	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.9
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction	Baseline Skylight Construction	Baseline Skylight Construction
			SHGC (Ratio)	0.360	0.360	0.360
			VLT (Ratio)	0.457	0.457	0.457
			U-Factor (Btu/h·ft^2·°F)	1.22	1.22	1.22
			Materials Cost ($/ft^2)	$19.11	$19.11	$19.11
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Baseline Window Construction	Baseline Window Construction	Baseline Window Construction
			SHGC (Ratio)	0.250	0.250	0.250

Category	Subcategory	EDM Type	EDM Instance	1A		
				Plug 1	Plug 2	Plug 3
			VLT (Ratio)	0.250	0.250	0.250
			U-Factor (Btu/h·ft^2·°F)	1.21	1.21	1.21
			Materials Cost ($/ft^2)	$16.83	$16.83	$16.83
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
	Infiltration	Infiltration	EDM Key	Baseline	Baseline	Baseline
			Rate (ACH)	0.322	0.322	0.322
	Opaque Constructions	Walls	EDM Key	R-9.5 c.i.	R-20 c.i.	R-20 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.137	0.0633	0.0633
			Materials Cost ($/ft^2)	$3.99	$4.89	$4.89
			Installation Cost ($/ft^2)	$1.72	$2.11	$2.11
		Roof	EDM Key	R-20 c.i. with cool roof	R-25 c.i. with cool roof	R-25 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507	0.0405	0.0405
			Materials Cost ($/ft^2)	$3.43	$3.68	$3.68
			Installation Cost ($/ft^2)	$1.48	$1.58	$1.58
Equipment	HVAC System	System	EDM Key	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan
			Cooling COP (Ratio)	4.43	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	False
			Motorized Damper	False	False	False
			Fan Efficiency (%)	50.8	50.8	50.8
			Fan Static Pressure (In. w.c.)	1.53	1.53	1.53
			Materials Cost ($/ton)	$1,590.95	$1,590.95	$1,590.95
			Installation Cost ($/ton)	$171.00	$171.00	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	Installed	Installed	Installed
		ERV	EDM Key	None	None	None
			Sensible Effectiveness (%)	N/A	N/A	N/A
			Latent Effectiveness (%)	N/A	N/A	N/A

Category	Subcategory	EDM Type	EDM Instance	1A		
				Plug 1	Plug 2	Plug 3
			Pressure Drop (in. w.c.)	N/A	N/A	N/A

Table B-2 1A Low Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			684	1,180	60.2	110	N/A
Low-Energy			282	1,160	24.8	108	58.7%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	380	1,170	33.5	108	–14.4%
		Lighting Power Density	374	1,180	32.9	109	–13.5%
		Daylighting Sensors And Skylights	364	1,140	32.0	106	–12.0%
		Plug Loads	288	1,160	25.3	108	–0.8%
	Form	Effective Aperture	360	1,140	31.7	106	–11.4%
		Glazing Quantity	358	1,140	31.5	106	–11.1%
		Overhangs	283	1,160	25.0	108	–0.2%
	Fabric	Opaque Envelope Constructions	334	1,170	29.4	109	–7.6%
	Equipment	Entire HVAC System	338	1,160	29.8	108	–8.2%
		Rooftop Unit	336	1,160	29.6	108	–7.9%
		Demand Control Ventilation	283	1,160	24.9	108	–0.2%

Table B-3 1A Medium Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			910	1,220	80.1	113	N/A
Low-Energy			455	1,220	40.1	114	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	558	1,230	49.1	115	-11.3%
		Lighting Power Density	544	1,240	47.9	115	-9.8%
		Daylighting Sensors And Skylights	537	1,200	47.3	112	–9.0%
		Plug Loads	482	1,220	42.4	113	–2.9%
		Photovoltaics	461	1,210	40.6	112	–0.7%
	Form	Effective Aperture	533	1,200	46.9	112	–8.6%
		Glazing Quantity	531	1,200	46.8	112	-8.4%
		Overhangs	457	1,220	40.2	114	–0.2%
	Fabric	Opaque Envelope Constructions		1,230	45.3	114	–6.5%
	Equipment	Entire HVAC System	528	1,230	46.5	114	–8.0%
		Rooftop Unit	523	1,220	46.1	114	–7.5%
		Demand Control Ventilation	458	1,230	40.4	114	–0.4%

Table B-4 1A High Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,170	1,250	103	116	N/A
Low-Energy			587	1,300	51.7	121	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	713	1,300	62.7	121	–10.7%
		Daylighting Sensors	689	1,310	60.7	121	–8.7%
		Lighting Power Density	676	1,310	59.5	122	–7.6%
		Daylighting Sensors And Skylights	668	1,280	58.8	119	–6.9%
		Photovoltaics	610	1,240	53.7	115	–2.0%
	Form	Effective Aperture	664	1,280	58.5	119	–6.6%
		Glazing Quantity	662	1,280	58.3	119	–6.4%
		Overhangs	588	1,300	51.8	121	–0.1%
	Fabric	Opaque Envelope Constructions	646	1,300	56.9	121	–5.0%
	Equipment	Entire HVAC System	674	1,300	59.3	121	–7.4%
		Rooftop Unit	669	1,300	58.9	121	–7.0%
		Demand Control Ventilation	591	1,300	52.0	121	–0.3%

B.2 Climate Zone 2A: Houston, Texas

Table B-5 2A Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	2A		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	0.70% of net roof area	17% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupanc y sensors
			Power Density (W/ft^2)	0.989	0.991	0.989
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.187	1.06	1.74
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.9
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction	Double pane with low-e and high solar gain	Double pane with high solar gain
			SHGC (Ratio)	0.360	0.460	0.490
			VLT (Ratio)	0.457	0.584	0.622
			U-Factor (Btu/h·ft^2·°F)	1.22	0.451	0.580
			Materials Cost ($/ft^2)	$19.11	$14.19	$14.10

Category	Subcategory	EDM Type	EDM Instance	2A		
				Plug 1	Plug 2	Plug 3
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane with low-e and argon	Double pane with low-e2 and argon	Double pane with low-e2 and argon
			SHGC (Ratio)	0.564	0.416	0.416
			VLT (Ratio)	0.745	0.750	0.750
			U-Factor (Btu/h·ft^2·°F)	0.264	0.235	0.235
			Materials Cost ($/ft^2)	$19.63	$26.65	$26.65
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Baseline	Baseline
			Rate (ACH)	0.322	0.322	0.322
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.	R-31.3 c.i.	R-31.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0859	0.0399	0.0399
			Materials Cost ($/ft^2)	$4.41	$5.77	$5.77
			Installation Cost ($/ft^2)	$1.90	$2.49	$2.49
		Roof	EDM Key	R-20 c.i. with cool roof	Baseline Roof Construction, R-30 c.i. with cool roof	R-25 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507	0.0332	0.0405
			Materials Cost ($/ft^2)	$3.43	$3.95	$3.68
			Installation Cost ($/ft^2)	$1.48	$1.70	$1.58
Equipment	HVAC System	System	EDM Key	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with efficient fan
			Cooling COP (Ratio)	4.43	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	False
			Motorized Damper	False	False	False
			Fan Efficiency (%)	50.8	50.8	50.8

Category	Subcategory	EDM Type	EDM Instance	2A		
				Plug 1	Plug 2	Plug 3
			Fan Static Pressure (in. w.c.)	1.53	1.53	1.53
			Materials Cost ($/ton)	$1,590.95	$1,590.95	$1,590.95
			Installation Cost ($/ton)	$171.00	$171.00	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	Installed	Installed	Installed
		ERV	EDM Key	Low effectiveness	None	None
			Sensible Effectiveness (%)	60.0	N/A	N/A
			Latent Effectiveness (%)	50.0	N/A	N/A
			Pressure Drop (In. w.c.)	0.703	N/A	N/A
			Materials Cost ($/ton)	$68.97	$0.00	$0.00
			Installation Cost ($/ton)	$8.19	$0.00	$0.00

Table B-6 2A Low Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			651	1,200	57.3	112	N/A
Low-Energy			283	1,170	24.9	108	56.5%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	373	1,180	32.8	110	–13.7%
		Lighting Power Density	369	1,190	32.5	110	–13.2%
		Daylighting Sensors And Skylights	351	1,150	31.0	107	–10.5%
		Plug Loads	288	1,170	25.4	108	–0.8%
	Form	Effective Aperture	348	1,150	30.6	107	–9.9%
		Glazing Quantity	346	1,150	30.4	107	–9.6%
		Overhangs	285	1,170	25.1	109	–0.3%
	Fabric	Opaque Envelope Constructions	360	1,180	31.7	110	–11.8%
		Fenestration Constructions	287	1,170	25.2	108	–0.5%
	Equipment	Rooftop Unit	333	1,170	29.3	109	–7.6%
		Entire HVAC System	327	1,170	28.8	109	–6.7%
		Energy Recovery	297	1,170	26.2	108	–2.1%
		Demand Control Ventilation	283	1,170	24.9	109	0.1%

Table B-7 2A Medium Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			864	1,240	76.1	115	N/A
Low-Energy			432	1,240	38.0	115	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	533	1,260	46.9	117	–11.7%
		Lighting Power Density	511	1,260	45.0	117	–9.1%
		Daylighting Sensors And Skylights	508	1,220	44.7	114	–8.8%
		Plug Loads	456	1,240	40.1	115	–2.8%
		Photovoltaics	435	1,230	38.3	114	–0.4%
	Form	Effective Aperture	504	1,230	44.3	114	–8.3%
		Glazing Quantity	502	1,220	44.2	114	–8.1%
		Overhangs	433	1,240	38.1	115	–0.1%
	Fabric	Opaque Envelope Constructions	512	1,230	45.1	115	–9.3%
		Fenestration Constructions	441	1,240	38.8	115	–1.0%
	Equipment	Entire HVAC System	484	1,250	42.6	116	–6.1%
		Rooftop Unit	484	1,240	42.6	115	–6.0%
		Demand Control Ventilation	430	1,240	37.9	116	0.2%

Table B-8 2A High Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,120	1,280	98.2	119	N/A
Low-Energy			558	1,510	49.1	140	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed - Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	658	1,520	57.9	141	–9.0%
		Photovoltaics	645	1,260	56.8	117	–7.8%
		Lighting Power Density	641	1,530	56.5	142	–7.5%
		Daylighting Sensors And Skylights	632	1,510	55.7	140	–6.7%
		Plug Loads	606	1,500	53.4	140	–4.4%
	Form	Effective Aperture	628	1,510	55.3	140	–6.3%
		Glazing Quantity	626	1,510	55.1	140	–6.1%
		Overhangs	559	1,510	49.2	140	–0.1%
	Fabric	Opaque Envelope Constructions	633	1,510	55.7	140	–6.7%
		Fenestration Constructions	566	1,510	49.8	140	–0.7%
	Equipment	Entire HVAC System	630	1,510	55.5	141	–6.5%
		Rooftop Unit	626	1,510	55.1	140	–6.1%
		Demand Control Ventilation	560	1,510	49.3	140	–0.2%

B.3 Climate Zone 2B: Phoenix, Arizona

Table B-9 2B Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	2B		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	2.1% of net roof area	0.28% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.989	0.989
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Baseline	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.187	1.17	1.74
Form	Shading	Shading Depth	EDM Key	Projection factor of 1.5	Projection factor of 0.9	Projection factor of 0.9
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.360	0.460	0.460
			VLT (Ratio)	0.457	0.584	0.584
			U-Factor (Btu/h·ft^2·°F)	1.22	0.451	0.451
			Materials	$19.11	$14.19	$14.19

Category	Subcategory	EDM Type	EDM Instance	2B		
				Plug 1	Plug 2	Plug 3
			Cost ($/ft^2)			
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane with low-e and argon	Double pane with low-e2 and tinted glass	Double pane with low-e2 and argon
			SHGC (Ratio)	0.564	0.282	0.416
			VLT (Ratio)	0.745	0.550	0.750
			U-Factor (Btu/h·ft^2·°F)	0.264	0.288	0.235
			Materials Cost ($/ft^2)	$19.63	$26.65	$26.65
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Baseline	Baseline
			Rate (ACH)	0.322	0.322	0.322
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.	R-31.3 c.i.	R-31.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0859	0.0399	0.0399
			Materials Cost ($/ft^2)	$4.41	$5.77	$5.77
			Installation Cost ($/ft^2)	$1.90	$2.49	$2.49
		Roof	EDM Key	R-20 c.i. with cool roof	R-25 c.i. with cool roof	R-25 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507	0.0405	0.0405
			Materials Cost ($/ft^2)	$3.43	$3.68	$3.68
			Installation Cost ($/ft^2)	$1.48	$1.58	$1.58
Equipment	HVAC System	System	EDM Key	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	4.43	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	True
			Motorized Damper	False	False	True
			Fan Efficiency (%)	50.8	50.8	52.6

Category	Subcategory	EDM Type	EDM Instance	2B		
				Plug 1	Plug 2	Plug 3
			Fan Static Pressure (in. w.c.)	1.53	1.53	1.62
			Materials Cost ($/ton)	$1,590.95	$1,590.95	$1,687.18
			Installation Cost ($/ton)	$171.00	$171.00	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	None	None	None
		ERV	EDM Key	None	None	None
			Sensible Effectiveness (%)	N/A	N/A	N/A
			Latent Effectiveness (%)	N/A	N/A	N/A
			Pressure Drop (in. w.c.)	N/A	N/A	N/A

Table B-10 2B Low Plug Perturbation Results

Building Name			EUI ($MJ/m^2\cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			664	1,190	58.4	110	N/A
Low-Energy			285	1,160	25.1	108	57.1%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI ($MJ/m^2\cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Daylighting Sensors	367	1,170	32.4	109	–12.4%
		Lighting Power Density	363	1,180	31.9	109	–11.7%
		Daylighting Sensors And Skylights	346	1,140	30.5	106	–9.2%
		Plug Loads	290	1,160	25.5	108	–0.7%
	Form	Effective Aperture	345	1,150	30.4	106	–9.0%
		Glazing Quantity	341	1,140	30.0	106	–8.4%
		Overhangs	289	1,160	25.4	108	–0.5%
	Fabric	Opaque Envelope Constructions	361	1,180	31.8	109	–11.5%
		Fenestration Constructions	290	1,160	25.6	108	–0.8%
	Equipment	Entire HVAC System	324	1,160	28.5	108	–5.8%
		Rooftop Unit	324	1,160	28.5	108	–5.8%

Table B-11 2B Medium Plug Perturbation Results

<table>
<tr><th colspan="3">Building Name</th><th>EUI (MJ/m²·yr)</th><th>5-TLCC Intensity ($/m²)</th><th>EUI (kBtu/ft²yr)</th><th>5-TLCC Intensity ($/ft²)</th><th>Percent Savings</th></tr>
<tr><td colspan="3">Baseline</td><td>878</td><td>1,220</td><td>77.3</td><td>113</td><td>N/A</td></tr>
<tr><td colspan="3">Low-Energy</td><td>439</td><td>1,230</td><td>38.7</td><td>115</td><td>50.0%</td></tr>
<tr><th></th><th>EDM Category</th><th>EDMs Reverted from Low-Energy to Baseline</th><th>EUI (MJ/m²·yr)</th><th>5-TLCC Intensity ($/m²)</th><th>EUI (kBtu/ft²yr)</th><th>5-TLCC Intensity ($/ft²)</th><th>Percent Savings Difference (Perturbed – Low Energy)</th></tr>
<tr><td rowspan="11">Removal Perturbation</td><td rowspan="4">Program</td><td>Daylighting Sensors</td><td>538</td><td>1,250</td><td>47.3</td><td>116</td><td>–11.2%</td></tr>
<tr><td>Lighting Power Density</td><td>523</td><td>1,250</td><td>46.1</td><td>116</td><td>–9.6%</td></tr>
<tr><td>Daylighting Sensors And Skylights</td><td>512</td><td>1,220</td><td>45.0</td><td>113</td><td>–8.2%</td></tr>
<tr><td>Photovoltaics</td><td>453</td><td>1,200</td><td>39.9</td><td>112</td><td>–1.6%</td></tr>
<tr><td rowspan="3">Form</td><td>Effective Aperture</td><td>508</td><td>1,220</td><td>44.8</td><td>114</td><td>–7.9%</td></tr>
<tr><td>Glazing Quantity</td><td>506</td><td>1,220</td><td>44.5</td><td>114</td><td>–7.6%</td></tr>
<tr><td>Overhangs</td><td>441</td><td>1,230</td><td>38.9</td><td>115</td><td>–0.2%</td></tr>
<tr><td rowspan="2">Fabric</td><td>Opaque Envelope Constructions</td><td>530</td><td>1,240</td><td>46.6</td><td>115</td><td>–10.3%</td></tr>
<tr><td>Fenestration Constructions</td><td>447</td><td>1,230</td><td>39.4</td><td>115</td><td>–0.9%</td></tr>
<tr><td rowspan="2">Equipment</td><td>Entire HVAC System</td><td>496</td><td>1,230</td><td>43.7</td><td>115</td><td>–6.5%</td></tr>
<tr><td>Rooftop Unit</td><td>496</td><td>1,230</td><td>43.7</td><td>115</td><td>–6.5%</td></tr>
</table>

Table B-12 2B Medium Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,130	1,250	99.6	116	N/A
Low-Energy			565	1,240	49.8	116	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	679	1,240	59.8	115	–10.1%
		Daylighting Sensors	663	1,260	58.4	117	–8.7%
		Lighting Power Density	648	1,260	57.1	117	–7.3%
		Daylighting Sensors And Skylights	638	1,230	56.2	114	–6.5%
		Photovoltaics	567	1,240	49.9	115	–0.2%
	Form	Effective Aperture	635	1,230	55.9	115	–6.2%
		Glazing Quantity	632	1,230	55.7	114	–5.9%
		Overhangs	568	1,250	50.0	116	–0.2%
	Fabric	Opaque Envelope Constructions	653	1,250	57.5	116	–7.8%
		Fenestration Constructions	573	1,240	50.5	116	–0.7%
	Equipment	Entire HVAC System	636	1,240	56.0	115	–6.2%
		Rooftop Unit	636	1,240	56.0	115	–6.2%

B.4 Climate Zone 3A: Atlanta, Georgia

Table B-13 3A Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	3A		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($\$/ft^2$)	$0.19	$0.19	$0.19
			Installation Cost ($\$/ft^2$)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	2.2% of net roof area	3.8% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.991	0.991
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.187	1.06	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.9	Projection factor of 0.9	Projection factor of 0.7
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.460	0.460	0.460
			VLT (Ratio)	0.584	0.584	0.584
			U-Factor ($Btu/h{\cdot}ft^2{\cdot}°F$)	0.451	0.451	0.451
			Materials Cost ($\$/ft^2$)	$14.19	$14.19	$14.19
			Installation Cost ($\$/ft^2$)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($\$/ft^2$)	$0.22	$0.22	$0.22

Category	Subcategory	EDM Type	EDM Instance	3A		
				Plug 1	Plug 2	Plug 3
		Windows	EDM Key	Double pane with low-e and argon	Double pane with low-e2 and argon	Double pane with low-e and argon
			SHGC (Ratio)	0.564	0.416	0.564
			VLT (Ratio)	0.745	0.750	0.745
			U-Factor (Btu/h·ft^2·°F)	0.264	0.235	0.264
			Materials Cost ($/ft^2)	$19.63	$26.65	$19.63
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Tighter envelope	Tighter envelope
			Rate (ACH)	0.322	0.132	0.132
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.	R-31.3 c.i.	R-31.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0859	0.0399	0.0399
			Materials Cost ($/ft^2)	$4.41	$5.77	$5.77
			Installation Cost ($/ft^2)	$1.90	$2.49	$2.49
		Roof	EDM Key	R-20 c.i. with cool roof	Baseline Roof Construction, R-30 c.i. with cool roof	R-30 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507	0.0332	0.0289
			Materials Cost ($/ft^2)	$3.43	$3.95	$4.19
			Installation Cost ($/ft^2)	$1.48	$1.70	$1.81
Equipment	HVAC System	System	EDM Key	10% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	4.06	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	True
			Motorized Damper	False	False	True
			Fan Efficiency (%)	50.8	50.8	52.6
			Fan Static Pressure (in. w.c.)	1.53	1.53	1.62
			Materials Cost ($/ton)	$1,539.07	$1,590.95	$1,687.18
			Installation	$164.00	$171.00	$171.00

Category	Subcategory	EDM Type	EDM Instance	3A		
				Plug 1	Plug 2	Plug 3
			Cost ($/ton)			
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	Installed	None	Installed
		ERV	EDM Key	High effectiveness	None	None
			Sensible Effectiveness (%)	80.0	N/A	N/A
			Latent Effectiveness (%)	70.0	N/A	N/A
			Pressure Drop (in. w.c.)	1.00	N/A	N/A
			Materials Cost ($/ton)	$103.43	$0.00	$0.00
			Installation Cost ($/ton)	$8.19	$0.00	$0.00

Table B-14 3A Low Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			590	1,180	51.9	109	N/A
Low-Energy			285	1,150	25.1	107	51.7%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	375	1,170	33.0	109	–15.3%
		Lighting Power Density	362	1,170	31.8	109	–13.0%
		Daylighting Sensors And Skylights	353	1,140	31.1	106	–11.5%
		Plug Loads	289	1,150	25.5	107	–0.8%
	Form	Effective Aperture	350	1,140	30.8	106	–11.1%
		Glazing Quantity	347	1,140	30.6	106	–10.6%
		Overhangs	287	1,160	25.3	107	–0.4%
	Fabric	Opaque Envelope Constructions	323	1,160	28.4	108	–6.5%
		Fenestration Constructions	298	1,160	26.2	107	–2.2%
	Equipment	Entire HVAC System	340	1,150	29.9	107	–9.4%
		Energy Recovery	333	1,150	29.4	107	–8.2%
		Rooftop Unit	326	1,160	28.7	107	–6.9%
		Demand Control Ventilation	285	1,160	25.1	108	0.1%

Table B-15 3A Medium Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			785	1,210	69.1	113	N/A
Low-Energy			393	1,300	34.6	121	50.0%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Daylighting Sensors	491	1,320	43.2	123	–12.5%
		Lighting Power Density	468	1,320	41.2	122	–9.6%
		Daylighting Sensors And Skylights	465	1,290	41.0	120	–9.3%
		Plug Loads	416	1,300	36.6	121	–2.9%
		Photovoltaics	404	1,270	35.6	118	–1.5%
	Form	Effective Aperture	462	1,290	40.7	120	–8.8%
		Glazing Quantity	460	1,290	40.5	120	–8.5%
		Overhangs	394	1,300	34.7	121	–0.2%
	Fabric	Opaque Envelope Constructions	441	1,290	38.8	120	–6.2%
		Infiltration	417	1,250	36.7	116	–3.1%
		Fenestration Constructions	403	1,300	35.5	121	–1.3%
	Equipment	Entire HVAC System	434	1,300	38.2	121	–5.3%
		Rooftop Unit	434	1,300	38.2	121	–5.3%

Table B-16 3A High Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,020	1,260	90.2	117	N/A
Low-Energy			512	1,360	45.1	126	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	624	1,360	54.9	126	–10.8%
		Daylighting Sensors	610	1,370	53.7	128	–9.5%
		Lighting Power Density	588	1,370	51.7	128	–7.3%
		Daylighting Sensors And Skylights	586	1,340	51.6	125	–7.1%
		Photovoltaics	532	1,300	46.9	121	–1.9%
	Form	Effective Aperture	582	1,350	51.3	125	–6.8%
		Glazing Quantity	580	1,350	51.1	125	–6.6%
		Overhangs	514	1,360	45.3	126	–0.2%
	Fabric	Opaque Envelope Constructions	559	1,340	49.3	124	–4.6%
		Infiltration	534	1,300	47.0	121	–2.1%
		Fenestration Constructions	521	1,360	45.9	126	–0.9%
	Equipment	Entire HVAC System	576	1,360	50.7	126	–6.2%
		Rooftop Unit	571	1,360	50.3	126	–5.7%
		Demand Control Ventilation	514	1,360	45.2	127	–0.1%

B.5 Climate Zone 3B-CA: Los Angeles, California

Table B-17 3B-CA Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	3B-CA Plug 1	3B-CA Plug 2	3B-CA Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	2.0% of net roof area	5.1% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.989	0.989
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.187	1.05	1.74
Form	Shading	Shading Depth	EDM Key	Projection factor of 1.5	Projection factor of 0.9	Projection factor of 0.9
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with high solar gain	Double pane with high solar gain
			SHGC (Ratio)	0.460	0.490	0.490
			VLT (Ratio)	0.584	0.622	0.622
			U-Factor (Btu/h·ft^2·°F)	0.451	0.580	0.580
			Materials Cost ($/ft^2)	$14.19	$14.10	$14.10
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Single pane	Baseline	Baseline

Category	Subcategory	EDM Type	EDM Instance	3B-CA		
				Plug 1	Plug 2	Plug 3
				with clear glass	Window Construction	Window Construction
			SHGC (Ratio)	0.810	0.250	0.250
			VLT (Ratio)	0.881	0.318	0.318
			U-Factor (Btu/h·ft^2·°F)	1.08	0.570	0.570
			Materials Cost ($/ft^2)	$12.61	$22.63	$22.63
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.22	$0.22
	Infiltration	Infiltration	EDM Key	Baseline	Baseline	Baseline
			Rate (ACH)	0.322	0.322	0.322
	Opaque Constructions	Walls	EDM Key	R-9.5 c.i.	R-20 c.i.	R-13.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.137	0.0633	0.0859
			Materials Cost ($/ft^2)	$3.99	$4.89	$4.41
			Installation Cost ($/ft^2)	$1.72	$2.11	$1.90
		Roof	EDM Key	R-20 c.i. with cool roof	R-25 c.i. with cool roof	R-25 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507	0.0405	0.0405
			Materials Cost ($/ft^2)	$3.43	$3.68	$3.68
			Installation Cost ($/ft^2)	$1.48	$1.58	$1.58
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	3.69	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	True
			Motorized Damper	False	False	True
			Fan Efficiency (%)	53.8	53.8	55.8
			Fan Static Pressure (in. w.c.)	1.62	1.62	1.72
			Materials Cost ($/ton)	$1,487.27	$1,590.95	$1,687.18
			Installation Cost ($/ton)	$157.98	$171.00	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	None	Installed	Installed
		ERV	EDM Key	None	None	None

Category	Subcategory	EDM Type	EDM Instance	3B-CA		
				Plug 1	Plug 2	Plug 3
			Sensible Effectiveness (%)	N/A	N/A	N/A
			Latent Effectiveness (%)	N/A	N/A	N/A
			Pressure Drop (in. w.c.)	N/A	N/A	N/A

Table B-18 3B-CA Low Plug Perturbation Results

<table>
<tr><th colspan="3">Building Name</th><th>EUI (MJ/m^2·yr)</th><th>5-TLCC Intensity ($/m^2)</th><th>EUI (kBtu/ft^{2}yr)</th><th>5-TLCC Intensity ($/ft^2)</th><th>Percent Savings</th></tr>
<tr><td colspan="3">Baseline</td><td>499</td><td>1,170</td><td>43.9</td><td>109</td><td>N/A</td></tr>
<tr><td colspan="3">Low-Energy</td><td>218</td><td>1,140</td><td>19.2</td><td>106</td><td>56.3%</td></tr>
<tr><th></th><th>EDM Category</th><th>EDMs Reverted from Low-Energy to Baseline</th><th>EUI (MJ/m^2·yr)</th><th>5-TLCC Intensity ($/m^2)</th><th>EUI (kBtu/ft^{2}yr)</th><th>5-TLCC Intensity ($/ft^2)</th><th>Percent Savings Difference (Perturbed – Low Energy)</th></tr>
<tr><td rowspan="11">Removal Perturbation</td><td rowspan="4">Program</td><td>Daylighting Sensors</td><td>302</td><td>1,150</td><td>26.6</td><td>107</td><td>–16.9%</td></tr>
<tr><td>Lighting Power Density</td><td>296</td><td>1,160</td><td>26.1</td><td>107</td><td>–15.7%</td></tr>
<tr><td>Daylighting Sensors And Skylights</td><td>287</td><td>1,120</td><td>25.3</td><td>104</td><td>–13.8%</td></tr>
<tr><td>Plug Loads</td><td>222</td><td>1,140</td><td>19.6</td><td>105</td><td>–0.9%</td></tr>
<tr><td rowspan="3">Form</td><td>Effective Aperture</td><td>292</td><td>1,130</td><td>25.7</td><td>105</td><td>–14.9%</td></tr>
<tr><td>Glazing Quantity</td><td>282</td><td>1,120</td><td>24.8</td><td>104</td><td>–12.9%</td></tr>
<tr><td>Overhangs</td><td>227</td><td>1,140</td><td>20.0</td><td>106</td><td>–1.8%</td></tr>
<tr><td rowspan="2">Fabric</td><td>Opaque Envelope Constructions</td><td>237</td><td>1,140</td><td>20.9</td><td>106</td><td>–3.8%</td></tr>
<tr><td>Fenestration Constructions</td><td>223</td><td>1,140</td><td>19.6</td><td>106</td><td>–1.0%</td></tr>
<tr><td rowspan="2">Equipment</td><td>Entire HVAC System</td><td>239</td><td>1,140</td><td>21.0</td><td>106</td><td>–4.1%</td></tr>
<tr><td>Rooftop Unit</td><td>239</td><td>1,140</td><td>21.0</td><td>106</td><td>–4.1%</td></tr>
</table>

Table B-19 3B-CA Medium Plug Perturbation Results

Building Name			EUI ($MJ/m^2\cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			709	1,220	62.5	113	N/A
Low-Energy			355	1,230	31.2	114	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2\cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	447	1,240	39.4	115	–13.0%
		Lighting Power Density	439	1,250	38.7	116	–11.9%
		Daylighting Sensors And Skylights	427	1,210	37.6	113	–10.1%
		Plug Loads	379	1,220	33.4	114	–3.5%
		Photovoltaics	366	1,200	32.3	111	–1.6%
	Form	Effective Aperture	425	1,220	37.4	113	–9.9%
		Glazing Quantity	421	1,220	37.1	113	–9.4%
		Overhangs	357	1,230	31.5	114	–0.4%
	Fabric	Opaque Envelope Constructions	381	1,220	33.6	114	–3.8%
		Fenestration Constructions	357	1,230	31.4	114	–0.3%
	Equipment	Entire HVAC System	395	1,220	34.8	114	–5.7%
		Rooftop Unit	391	1,230	34.4	114	–5.1%
		Demand Control Ventilation	358	1,220	31.5	114	–0.4%

Table B-20 3B-CA High Plug Perturbation Results

Building Name			EUI ($MJ/m^2\cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			957	1,260	84.2	117	N/A
Low-Energy			478	1,310	42.1	121	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2\cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	595	1,310	52.4	122	–12.2%
		Daylighting	571	1,320	50.3	123	–9.7%

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			957	1,260	84.2	117	N/A
Low-Energy			478	1,310	42.1	121	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
		Sensors					
		Lighting Power Density	563	1,330	49.6	124	–8.9%
		Daylighting Sensors And Skylights	550	1,300	48.5	120	–7.5%
		Photovoltaics	507	1,230	44.7	115	–3.0%
	Form	Effective Aperture	548	1,300	48.3	121	–7.3%
		Glazing Quantity	545	1,300	48.0	121	–7.0%
		Overhangs	481	1,310	42.3	122	–0.3%
	Fabric	Opaque Envelope Constructions	503	1,310	44.3	121	–2.5%
		Fenestration Constructions	480	1,310	42.2	121	–0.2%
	Equipment	Entire HVAC System	531	1,300	46.7	121	–5.5%
		Rooftop Unit	527	1,310	46.4	122	–5.1%
		Demand Control Ventilation	482	1,300	42.5	121	–0.4%

B.6 Climate Zone 3B-NV: Las Vegas, Nevada

Table B-21 3B-NV Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	3B-NV		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	5.1% of net roof area	8.0% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.991	0.991
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.187	1.06	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 1.5	Projection factor of 0.9	Projection factor of 0.9
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.460	0.460	0.460
			VLT (Ratio)	0.584	0.584	0.584
			U-Factor (Btu/h·ft^2·°F)	0.451	0.451	0.451
			Materials Cost ($/ft^2)	$14.19	$14.19	$14.19
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17

Category	Subcategory	EDM Type	EDM Instance	3B-NV		
				Plug 1	Plug 2	Plug 3
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon
			SHGC (Ratio)	0.564	0.564	0.564
			VLT (Ratio)	0.745	0.745	0.745
			U-Factor (Btu/h·ft^2·°F)	0.264	0.264	0.264
			Materials Cost ($/ft^2)	$19.63	$19.63	$19.63
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Baseline	Baseline
			Rate (ACH)	0.322	0.322	0.322
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.	R-31.3 c.i.	R-31.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0859	0.0399	0.0399
			Materials Cost ($/ft^2)	$4.41	$5.77	$5.77
			Installation Cost ($/ft^2)	$1.90	$2.49	$2.49
		Roof	EDM Key	R-20 c.i. with cool roof	Baseline Roof Construction, R-30 c.i. with cool roof	R-25 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507	0.0332	0.0405
			Materials Cost ($/ft^2)	$3.43	$3.95	$3.68
			Installation Cost ($/ft^2)	$1.48	$1.70	$1.58
Equipment	HVAC System	System	EDM Key	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	4.43	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	True	True
			Motorized Damper	False	True	True
			Fan Efficiency (%)	53.8	55.8	55.8
			Fan Static Pressure (in. w.c.)	1.62	1.72	1.72
			Materials Cost ($/ton)	$1,590.95	$1,687.18	$1,687.18

Category	Subcategory	EDM Type	EDM Instance	3B-NV		
				Plug 1	Plug 2	Plug 3
			Installation Cost ($/ton)	$171.00	$171.00	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	None	None	None
		ERV	EDM Key	Low effectiveness	None	None
			Sensible Effectiveness (%)	60.0	N/A	N/A
			Latent Effectiveness (%)	50.0	N/A	N/A
			Pressure Drop (in. w.c.)	0.703	N/A	N/A
			Materials Cost ($/ton)	$68.97	$0.00	$0.00
			Installation Cost ($/ton)	$8.19	$0.00	$0.00

Table B-22 3B-NV Low Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			584	1,180	51.5	109	N/A
Low-Energy			284	1,160	25.0	107	51.3%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Daylighting Sensors	368	1,170	32.4	109	–14.3%
		Lighting Power Density	368	1,170	32.4	109	–14.3%
		Daylighting Sensors And Skylights	347	1,140	30.5	106	–10.7%
		Plug Loads	289	1,150	25.5	107	–0.8%
	Form	Effective Aperture	347	1,140	30.5	106	–10.6%
		Glazing Quantity	342	1,140	30.1	106	–9.8%
		Overhangs	289	1,160	25.4	107	–0.8%
	Fabric	Opaque Envelope Constructions	323	1,160	28.4	108	–6.6%
		Fenestration Constructions	295	1,160	26.0	108	–1.8%
	Equipment	Rooftop Unit	347	1,160	30.5	108	–10.6%
		Entire HVAC System	328	1,150	28.9	107	–7.4%
		Energy Recovery	294	1,150	25.9	107	–1.7%

Table B-23 3B-NV Medium Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			781	1,210	68.8	113	N/A
Low-Energy			390	1,290	34.4	119	50.0%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Daylighting Sensors	481	1,300	42.3	121	–11.6%
		Lighting Power Density	470	1,300	41.3	121	–10.1%

Building Name			EUI (MJ/m^2·yr)	5-TLCC Intensity (\$/m^2)	EUI (kBtu/ft^{2}yr)	5-TLCC Intensity (\$/ft^2)	Percent Savings
Baseline			781	1,210	68.8	113	N/A
Low-Energy			390	1,290	34.4	119	50.0%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m^2·yr)	5-TLCC Intensity (\$/m^2)	EUI (kBtu/ft^{2}yr)	5-TLCC Intensity (\$/ft^2)	Percent Savings Difference (Perturbed – Low Energy)
		Daylighting Sensors And Skylights	455	1,270	40.1	118	–8.3%
		Photovoltaics	424	1,210	37.3	113	–4.3%
		Plug Loads	413	1,280	36.4	119	–2.9%
	Form	Effective Aperture	453	1,280	39.9	119	–8.1%
		Glazing Quantity	450	1,280	39.6	118	–7.6%
		Overhangs	393	1,290	34.6	120	–0.4%
	Fabric	Opaque Envelope Constructions	440	1,280	38.7	119	–6.3%
		Fenestration Constructions	398	1,290	35.1	120	–1.0%
	Equipment	Entire HVAC System	437	1,280	38.5	119	–5.9%
		Rooftop Unit	437	1,280	38.5	119	–5.9%

Table B-24 3B-NV High Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,010	1,250	89.1	117	N/A
Low-Energy			506	1,350	44.5	126	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	614	1,360	54.0	126	–10.7%
		Daylighting Sensors	596	1,370	52.5	127	–9.0%
		Lighting Power Density	587	1,370	51.7	127	–8.0%
		Daylighting Sensors And Skylights	570	1,340	50.2	125	–6.3%
		Photovoltaics	558	1,240	49.1	115	–5.1%
	Form	Effective Aperture	568	1,350	50.0	125	–6.1%
		Glazing Quantity	564	1,340	49.7	125	–5.8%
		Overhangs	509	1,350	44.8	126	–0.3%
	Fabric	Opaque Envelope Constructions	551	1,350	48.5	125	–4.5%
		Fenestration Constructions	512	1,360	45.1	126	–0.6%
	Equipment	Entire HVAC System	564	1,350	49.7	126	–5.8%
		Rooftop Unit	564	1,350	49.7	126	–5.8%

B.7 Climate Zone 3C: San Francisco, California

Table B-25 3C Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	3C		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	5.5% of net roof area	8.2% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.991	0.991
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.187	1.06	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 1.5	Projection factor of 0.9	Projection factor of 0.9
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.460	0.460	0.460
			VLT (Ratio)	0.584	0.584	0.584
			U-Factor (Btu/h·ft^2·°F)	0.451	0.451	0.451
			Materials Cost ($/ft^2)	$14.19	$14.19	$14.19
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M	$0.22	$0.22	$0.22

Category	Subcategory	EDM Type	EDM Instance	3C		
				Plug 1	Plug 2	Plug 3
			Cost ($/ft^2)			
		Windows	EDM Key	Single pane with clear glass	Double pane with low-e and argon	Double pane with low-e and argon
			SHGC (Ratio)	0.810	0.564	0.564
			VLT (Ratio)	0.881	0.745	0.745
			U-Factor (Btu/h·ft^2·°F)	1.08	0.264	0.264
			Materials Cost ($/ft^2)	$12.61	$19.63	$19.63
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Baseline	Baseline
			Rate (ACH)	0.322	0.322	0.322
	Opaque Constructions	Walls	EDM Key	R-9.5 c.i.	R-20 c.i.	R-20 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.137	0.0633	0.0633
			Materials Cost ($/ft^2)	$3.99	$4.89	$4.89
			Installation Cost ($/ft^2)	$1.72	$2.11	$2.11
		Roof	EDM Key	R-20 c.i. with cool roof	Baseline Roof Construction, R-30 c.i. with cool roof	R-25 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507	0.0332	0.0405
			Materials Cost ($/ft^2)	$3.43	$3.95	$3.68
			Installation Cost ($/ft^2)	$1.48	$1.70	$1.58
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	3.69	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	True
			Motorized Damper	False	False	True
			Fan Efficiency (%)	53.8	53.8	55.8
			Fan Static Pressure (in. w.c.)	1.62	1.62	1.72

Category	Subcategory	EDM Type	EDM Instance	3C		
				Plug 1	Plug 2	Plug 3
			Materials Cost ($/ton)	$1,487.27	$1,590.95	$1,687.18
			Installation Cost ($/ton)	$157.98	$171.00	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	None	None	Installed
		ERV	EDM Key	Low effectiveness	None	None
			Sensible Effectiveness (%)	60.0	N/A	N/A
			Latent Effectiveness (%)	50.0	N/A	N/A
			Pressure Drop (in. w.c.)	0.703	N/A	N/A
			Materials Cost ($/ton)	$68.97	$0.00	$0.00
			Installation Cost ($/ton)	$8.19	$0.00	$0.00

Table B-26 3C Low Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			495	1,170	43.6	109	N/A
Low-Energy			245	1,140	21.5	106	50.5%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Daylighting Sensors	321	1,150	28.3	107	–15.5%
		Lighting Power Density	319	1,160	28.1	108	–15.0%
		Daylighting Sensors And Skylights	307	1,130	27.1	105	–12.7%
		Plug Loads	249	1,140	21.9	106	–0.8%
	Form	Effective Aperture	319	1,140	28.1	106	–15.1%
		Glazing Quantity	304	1,130	26.8	105	–12.0%
		Overhangs	259	1,150	22.8	107	–2.8%
	Fabric	Opaque Envelope Constructions	264	1,140	23.3	106	–4.0%
		Fenestration Constructions	250	1,140	22.0	106	–1.0%
	Equipment	Rooftop Unit	293	1,140	25.8	106	–9.7%
		Entire HVAC System	280	1,140	24.6	106	–7.1%
		Energy Recovery	267	1,140	23.5	106	–4.5%

Table B-27 3C Medium Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			682	1,220	60.0	114	N/A
Low-Energy			341	1,280	30.0	119	50.0%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Daylighting Sensors	430	1,300	37.8	120	–13.1%
		Lighting Power	418	1,300	36.8	121	–11.3%

Building Name			EUI (MJ/m^2·yr)	5-TLCC Intensity (\$/m^2)	EUI (kBtu/ft^{2}yr)	5-TLCC Intensity (\$/ft^2)	Percent Savings
Baseline			682	1,220	60.0	114	N/A
Low-Energy			341	1,280	30.0	119	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m^2·yr)**	**5-TLCC Intensity (\$/m^2)**	**EUI (kBtu/ft^{2}yr)**	**5-TLCC Intensity (\$/ft^2)**	**Percent Savings Difference (Perturbed – Low Energy)**
		Density					
		Daylighting Sensors And Skylights	409	1,270	36.1	118	–10.1%
		Photovoltaics	370	1,200	32.6	112	–4.4%
		Plug Loads	363	1,280	32.0	119	–3.3%
	Form	Effective Aperture	414	1,280	36.5	119	–10.8%
		Glazing Quantity	405	1,270	35.6	118	–9.3%
		Overhangs	348	1,280	30.6	119	–1.1%
	Fabric	Opaque Envelope Constructions	373	1,270	32.9	118	–4.7%
		Fenestration Constructions	348	1,280	30.7	119	–1.1%
	Equipment	Entire HVAC System	369	1,280	32.5	119	–4.1%
		Rooftop Unit	369	1,280	32.5	119	–4.1%

Table B-28 3C High Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			903	1,280	79.5	119	N/A
Low-Energy			452	1,360	39.8	126	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	555	1,370	48.9	127	–11.4%
		Daylighting Sensors	539	1,370	47.5	128	–9.7%
		Lighting Power Density	527	1,380	46.4	128	–8.4%
		Daylighting Sensors And Skylights	520	1,350	45.8	126	–7.5%
		Photovoltaics	496	1,250	43.7	116	–4.9%
	Form	Effective Aperture	523	1,360	46.0	126	–7.9%
		Glazing Quantity	515	1,350	45.3	126	–7.0%
		Overhangs	457	1,360	40.3	127	–0.6%
	Fabric	Opaque Envelope Constructions	478	1,350	42.1	126	–2.9%
		Fenestration Constructions	458	1,360	40.4	126	–0.8%
	Equipment	Entire HVAC System	493	1,360	43.4	126	–4.5%
		Rooftop Unit	489	1,360	43.0	126	–4.1%
		Demand Control Ventilation	455	1,350	40.1	126	–0.4%

B.8 Climate Zone 4A: Baltimore, Maryland

Table B-29 4A Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	4A Plug 1	4A Plug 2	4A Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft²)	$0.19	$0.19	$0.19
			Installation Cost ($/ft²)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	2.5% of net roof area	6.0% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft²)	0.989	0.991	0.991
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft²)	0.187	1.06	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.7	Projection factor of 0.7	Projection factor of 0.5
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.460	0.460	0.460
			VLT (Ratio)	0.584	0.584	0.584
			U-Factor (Btu/h·ft²·°F)	0.451	0.451	0.451
			Materials Cost ($/ft²)	$14.19	$14.19	$14.19
			Installation Cost ($/ft²)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft²)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane with low-e and argon	Double pane with low-e2 and argon	Double pane with low-e and

Category	Subcategory	EDM Type	EDM Instance	4A		
				Plug 1	Plug 2	Plug 3
						argon
			SHGC (Ratio)	0.564	0.416	0.564
			VLT (Ratio)	0.745	0.750	0.745
			U-Factor (Btu/h·ft²·°F)	0.264	0.235	0.264
			Materials Cost ($/ft²)	$19.63	$26.65	$19.63
			Installation Cost ($/ft²)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft²)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Tighter envelope	Tighter envelope
			Rate (ACH)	0.322	0.132	0.132
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.	R-31.3 c.i.	R-43.8 c.i.
			U-Factor (Btu/h·ft²·°F)	0.0859	0.0399	0.0304
			Materials Cost ($/ft²)	$4.41	$5.77	$6.65
			Installation Cost ($/ft²)	$1.90	$2.49	$2.86
		Roof	EDM Key	R-25 c.i. with cool roof	R-35 c.i. with cool roof	R-30 c.i. with cool roof
			U-Factor (Btu/h·ft²·°F)	0.0405	0.0289	0.0289
			Materials Cost ($/ft²)	$3.68	$4.19	$4.19
			Installation Cost ($/ft²)	$1.58	$1.81	$1.81
Equipment	HVAC System	System	EDM Key	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	4.43	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	True
			Motorized Damper	False	False	True
			Fan Efficiency (%)	50.8	50.8	52.6
			Fan Static Pressure (in. w.c.)	1.53	1.53	1.62
			Materials Cost ($/ton)	$1,590.95	$1,590.95	$1,687.18
			Installation Cost ($/ton)	$171.00	$171.00	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	Installed	Installed	None
		ERV	EDM Key	High effectiveness	Low effectiveness	None
			Sensible Effectiveness (%)	80.0	60.0	N/A

Category	Subcategory	EDM Type	EDM Instance	4A		
				Plug 1	Plug 2	Plug 3
			Latent Effectiveness (%)	70.0	50.0	N/A
			Pressure Drop (in. w.c.)	1.00	0.703	N/A
			Materials Cost ($/ton)	$103.43	$68.97	$0.00
			Installation Cost ($/ton)	$8.19	$8.19	$0.00

Table B-30 4A Low Plug Perturbation Results

Building Name			EUI ($MJ/m^2\cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			634	1,160	55.8	108	N/A
Low-Energy			312	1,150	27.5	107	50.7%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2\cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	386	1,160	33.9	108	–11.6%
		Lighting Power Density	380	1,170	33.4	109	–10.7%
		Daylighting Sensors And Skylights	368	1,130	32.4	105	–8.8%
		Plug Loads	316	1,150	27.8	107	–0.6%
	Form	Effective Aperture	367	1,140	32.3	106	–8.6%
		Glazing Quantity	363	1,140	32.0	106	–8.0%
		Overhangs	315	1,160	27.8	107	–0.5%
	Fabric	Opaque Envelope Constructions	364	1,150	32.1	107	–8.2%
		Fenestration Constructions	320	1,160	28.2	107	–1.2%
	Equipment	Energy Recovery	415	1,150	36.5	107	–16.2%
		Entire HVAC System	405	1,150	35.6	107	–14.6%
		Rooftop Unit	345	1,150	30.4	107	–5.2%
		Demand Control Ventilation	309	1,160	27.2	108	0.4%

Table B-31 4A Medium Plug Perturbation Results

Building Name			EUI ($MJ/m^2 \cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			799	1,190	70.4	110	N/A
Low-Energy			400	1,300	35.2	121	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2 \cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	496	1,310	43.7	121	–12.1%
		Lighting Power Density	484	1,310	42.6	122	–10.6%
		Daylighting Sensors And Skylights	466	1,280	41.0	119	–8.3%
		Plug Loads	424	1,290	37.3	120	–3.0%
		Photovoltaics	411	1,260	36.2	117	–1.5%
	Form	Effective Aperture	464	1,280	40.8	119	–8.0%
		Glazing Quantity	461	1,280	40.6	119	–7.6%
		Overhangs	402	1,300	35.4	121	–0.3%
	Fabric	Opaque Envelope Constructions	463	1,280	40.7	119	–7.9%
		Infiltration	429	1,250	37.8	116	–3.7%
		Fenestration Constructions	404	1,300	35.6	121	–0.6%
	Equipment	Rooftop Unit	453	1,300	39.9	121	–6.7%
		Entire HVAC System	445	1,300	39.2	121	–5.6%
		Energy Recovery	426	1,300	37.5	121	–3.2%
		Demand Control Ventilation	402	1,300	35.4	121	–0.3%

Table B-32 4A High Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,020	1,220	89.7	113	N/A
Low-Energy			509	1,380	44.9	129	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	614	1,380	54.1	128	–10.3%
		Daylighting Sensors	598	1,400	52.6	130	–8.7%
		Lighting Power Density	584	1,400	51.4	130	–7.3%
		Daylighting Sensors And Skylights	575	1,370	50.6	127	–6.4%
		Photovoltaics	537	1,300	47.3	121	–2.7%
	Form	Effective Aperture	572	1,370	50.4	128	–6.1%
		Glazing Quantity	570	1,370	50.2	128	–5.9%
		Overhangs	511	1,390	45.0	129	–0.2%
	Fabric	Opaque Envelope Constructions	571	1,360	50.3	126	–6.0%
		Infiltration	543	1,330	47.8	124	–3.3%
		Fenestration Constructions	515	1,390	45.4	129	–0.6%
	Equipment	Entire HVAC System	564	1,380	49.7	128	–5.3%
		Rooftop Unit	564	1,380	49.7	128	–5.3%

B.9 Climate Zone 4B: Albuquerque, New Mexico

Table B-33 4B Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	4B		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft²)	$0.19	$0.19	$0.19
			Installation Cost ($/ft²)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	2.5% of net roof area	8.1% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft²)	0.989	0.991	0.991
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft²)	0.187	1.06	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.9	Projection factor of 0.5	Projection factor of 0.5
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.460	0.460	0.460
			VLT (Ratio)	0.584	0.584	0.584
			U-Factor (Btu/h·ft²·°F)	0.451	0.451	0.451
			Materials Cost ($/ft²)	$14.19	$14.19	$14.19
			Installation Cost ($/ft²)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft²)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane with low-e	Double pane with low-e	Double pane with

Category	Subcategory	EDM Type	EDM Instance	4B		
				Plug 1	Plug 2	Plug 3
				and argon	and argon	low-e and argon
			SHGC (Ratio)	0.564	0.564	0.564
			VLT (Ratio)	0.745	0.745	0.745
			U-Factor (Btu/h·ft^2·°F)	0.264	0.264	0.264
			Materials Cost ($/ft^2)	$19.63	$19.63	$19.63
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Tighter envelope	Baseline
			Rate (ACH)	0.322	0.132	0.322
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.	R-31.3 c.i.	R-31.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0859	0.0399	0.0399
			Materials Cost ($/ft^2)	$4.41	$5.77	$5.77
			Installation Cost ($/ft^2)	$1.90	$2.49	$2.49
		Roof	EDM Key	R-25 c.i. with cool roof	Baseline Roof Construction, R-30 c.i. with cool roof	R-30 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0405	0.0332	0.0289
			Materials Cost ($/ft^2)	$3.68	$3.95	$4.19
			Installation Cost ($/ft^2)	$1.58	$1.70	$1.81
Equipment	HVAC System	System	EDM Key	10% increased COP with efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	4.06	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	True	True
			Motorized Damper	False	True	True
			Fan Efficiency (%)	53.8	55.8	55.8
			Fan Static Pressure (in. w.c.)	1.62	1.72	1.72
			Materials Cost ($/ton)	$1,539.07	$1,687.18	$1,687.18
			Installation Cost ($/ton)	$164.00	$171.00	$171.00
			Fixed O&M	$131.99	$131.99	$131.99

Category	Subcategory	EDM Type	EDM Instance	4B		
				Plug 1	Plug 2	Plug 3
			Cost ($/ton)			
	Outdoor Air	DCV	EDM Key	None	None	None
		ERV	EDM Key	High effectiveness	None	None
			Sensible Effectiveness (%)	80.0	N/A	N/A
			Latent Effectiveness (%)	70.0	N/A	N/A
			Pressure Drop (in. w.c.)	1.00	N/A	N/A
			Materials Cost ($/ton)	$103.43	$0.00	$0.00
			Installation Cost ($/ton)	$8.19	$0.00	$0.00

Table B-34 4B Low Plug Perturbation Results

Building Name			EUI (MJ/m^2·yr)	5-TLCC Intensity ($/m^2)	EUI (kBtu/ft^{2}yr)	5-TLCC Intensity ($/ft^2)	Percent Savings
Baseline			585	1,130	51.5	105	N/A
Low-Energy			283	1,130	24.9	105	51.7%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m^2·yr)**	**5-TLCC Intensity ($/m^2)**	**EUI (kBtu/ft^{2}yr)**	**5-TLCC Intensity ($/ft^2)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	368	1,140	32.4	106	–14.5%
		Lighting Power Density	362	1,140	31.9	106	–13.5%
		Daylighting Sensors And Skylights	345	1,110	30.3	103	–10.6%
		Plug Loads	287	1,130	25.3	105	–0.8%
	Form	Effective Aperture	344	1,110	30.3	103	–10.4%
		Glazing Quantity	339	1,110	29.9	103	–9.7%
		Overhangs	287	1,130	25.3	105	–0.7%
	Fabric	Opaque Envelope Constructions	336	1,130	29.6	105	–9.1%
		Fenestration Constructions	287	1,130	25.3	105	–0.8%
	Equipment	Rooftop Unit	344	1,130	30.3	105	–10.5%
		Entire HVAC System	342	1,130	30.1	105	–10.1%
		Energy Recovery	322	1,130	28.4	105	–6.8%

Table B-35 4B Medium Plug Perturbation Results

Building Name			EUI (MJ/m^2·yr)	5-TLCC Intensity ($/m^2)	EUI (kBtu/ft^{2}yr)	5-TLCC Intensity ($/ft^2)	Percent Savings
Baseline			766	1,150	67.5	107	N/A
Low-Energy			383	1,270	33.7	118	50.0%
	EDM Category	**EDMs Reverted From Low-Energy to Baseline**	**EUI (MJ/m^2·yr)**	**5-TLCC Intensity ($/m^2)**	**EUI (kBtu/ft^{2}yr)**	**5-TLCC Intensity ($/ft^2)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	472	1,280	41.6	119	–11.6%
		Lighting Power	458	1,280	40.3	119	–9.7%

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			766	1,150	67.5	107	N/A
Low-Energy			383	1,270	33.7	118	50.0%
	EDM Category	EDMs Reverted From Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
		Density					
		Daylighting Sensors And Skylights	448	1,250	39.5	116	–8.5%
		Plug Loads	405	1,260	35.7	117	–2.8%
		Photovoltaics	399	1,230	35.1	115	–2.0%
	Form	Effective Aperture	445	1,250	39.2	116	–8.0%
		Glazing Quantity	443	1,250	39.0	116	–7.8%
		Overhangs	384	1,270	33.9	118	–0.2%
	Fabric	Opaque Envelope Constructions	438	1,260	38.5	117	–7.1%
		Infiltration	411	1,210	36.2	113	–3.6%
		Fenestration Constructions	388	1,270	34.1	118	–0.6%
	Equipment	Entire HVAC System	421	1,270	37.0	118	–4.9%
		Rooftop Unit	421	1,270	37.0	118	–4.9%

Table B-36 4B High Plug Perturbation Results

Building Name			EUI (MJ/m^2·yr)	5-TLCC Intensity (\$/m^2)	EUI (kBtu/ft^{2}yr)	5-TLCC Intensity (\$/ft^2)	Percent Savings
Baseline			987	1,180	86.9	109	N/A
Low-Energy			493	1,320	43.4	123	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m^2·yr)**	**5-TLCC Intensity (\$/m^2)**	**EUI (kBtu/ft^{2}yr)**	**5-TLCC Intensity (\$/ft^2)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	595	1,320	52.4	122	–10.3%
		Daylighting Sensors	585	1,330	51.5	124	–9.3%
		Lighting Power Density	569	1,330	50.1	124	–7.7%
		Daylighting Sensors And Skylights	560	1,310	49.3	121	–6.7%
		Photovoltaics	545	1,210	48.0	112	–5.2%
	Form	Effective Aperture	557	1,310	49.0	122	–6.4%
		Glazing Quantity	554	1,310	48.8	122	–6.2%
		Overhangs	495	1,320	43.6	123	–0.2%
	Fabric	Opaque Envelope Constructions	549	1,310	48.3	121	–5.6%
		Fenestration Constructions	498	1,330	43.9	123	–0.5%
	Equipment	Entire HVAC System	543	1,320	47.8	122	–5.0%
		Rooftop Unit	543	1,320	47.8	122	–5.0%

B.10 Climate Zone 4C: Seattle, Washington

Table B-37 4C Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	4C		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	7.3% of net roof area	12% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.991	0.991
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.187	1.06	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.9	Projection factor of 0.7	Projection factor of 0.7
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.460	0.460	0.460
			VLT (Ratio)	0.584	0.584	0.584
			U-Factor (Btu/h·ft^2·°F)	0.451	0.451	0.451
			Materials Cost ($/ft^2)	$14.19	$14.19	$14.19
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane with low-e	Double pane with	Double pane with low-e and

Category	Subcategory	EDM Type	EDM Instance	4C		
				Plug 1	Plug 2	Plug 3
				and argon	low-e and argon	argon
			SHGC (Ratio)	0.564	0.564	0.564
			VLT (Ratio)	0.745	0.745	0.745
			U-Factor (Btu/h·ft^2·°F)	0.264	0.264	0.264
			Materials Cost (\$/ft^2)	\$19.63	\$19.63	\$19.63
			Installation Cost (\$/ft^2)	\$27.17	\$27.17	\$27.17
			Fixed O&M Cost (\$/ft^2)	\$0.19	\$0.19	\$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Tighter envelope	Tighter envelope
			Rate (ACH)	0.322	0.132	0.132
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.	R-43.8 c.i.	R-43.8 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0859	0.0304	0.0304
			Materials Cost (\$/ft^2)	\$4.41	\$6.65	\$6.65
			Installation Cost (\$/ft^2)	\$1.90	\$2.86	\$2.86
		Roof	EDM Key	R-25 c.i. with cool roof	R-35 c.i. with cool roof	R-30 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0405	0.0289	0.0289
			Materials Cost (\$/ft^2)	\$3.68	\$4.19	\$4.19
			Installation Cost (\$/ft^2)	\$1.58	\$1.81	\$1.81
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	3.69	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	True	True
			Motorized Damper	False	True	True
			Fan Efficiency (%)	53.8	55.8	55.8
			Fan Static Pressure (In. w.c.)	1.62	1.72	1.72
			Materials Cost (\$/ton)	\$1,487.27	\$1,687.18	\$1,687.18
			Installation Cost (\$/ton)	\$157.98	\$171.00	\$171.00
			Fixed O&M Cost (\$/ton)	\$131.99	\$131.99	\$131.99
	Outdoor Air	DCV	EDM Key	None	None	None

Category	Subcategory	EDM Type	EDM Instance	4C		
				Plug 1	Plug 2	Plug 3
		ERV	EDM Key	High effectiveness	None	None
			Sensible Effectiveness (%)	80.0	N/A	N/A
			Latent Effectiveness (%)	70.0	N/A	N/A
			Pressure Drop (in. w.c.)	1.00	N/A	N/A
			Materials Cost ($/ton)	$103.43	$0.00	$0.00
			Installation Cost ($/ton)	$8.19	$0.00	$0.00

Table B-38 4C Low Plug Perturbation Results

Building Name			EUI ($MJ/m^2 \cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2 yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			555	1,140	48.9	106	N/A
Low-Energy			277	1,130	24.4	105	50.1%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2 \cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2 yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Lighting Power Density	350	1,150	30.8	107	–13.1%
		Daylighting Sensors	345	1,140	30.3	106	–12.2%
		Daylighting Sensors And Skylights	326	1,120	28.7	104	–8.8%
		Plug Loads	281	1,130	24.7	105	–0.6%
	Form	Effective Aperture	332	1,120	29.2	104	–9.8%
		Glazing Quantity	322	1,120	28.3	104	–8.0%
		Overhangs	285	1,140	25.1	106	–1.5%
	Fabric	Opaque Envelope Constructions	326	1,130	28.7	105	–8.8%
		Fenestration Constructions	284	1,140	25.0	106	–1.3%
	Equipment	Rooftop Unit	366	1,140	32.2	106	–16.0%
		Entire HVAC System	362	1,130	31.8	105	–15.2%
		Energy Recovery	353	1,130	31.1	105	–13.7%

Table B-39 4C Medium Plug Perturbation Results

Building Name			EUI ($MJ/m^2 \cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2 yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			711	1,170	62.6	108	N/A
Low-Energy			356	1,360	31.3	126	50.0%
	EDM Category	**EDMs Reverted From Low-Energy to Baseline**	**EUI ($MJ/m^2 \cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2 yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	432	1,370	38.0	127	–10.7%
		Lighting Power	430	1,370	37.8	128	–10.4%

Building Name			EUI ($MJ/m^2 \cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			711	1,170	62.6	108	N/A
Low-Energy			356	1,360	31.3	126	50.0%
	EDM Category	**EDMs Reverted From Low-Energy to Baseline**	**EUI ($MJ/m^2 \cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
		Density					
		Daylighting Sensors And Skylights	412	1,350	36.3	125	–8.0%
		Photovoltaics	383	1,250	33.7	117	–3.9%
		Plug Loads	376	1,350	33.1	126	–2.9%
	Form	Effective Aperture	412	1,350	36.3	126	–8.0%
		Glazing Quantity	408	1,350	35.9	125	–7.3%
		Overhangs	359	1,360	31.6	127	–0.4%
	Fabric	Opaque Envelope Constructions	417	1,330	36.7	123	–8.6%
		Infiltration	387	1,300	34.1	121	–4.4%
		Fenestration Constructions	361	1,360	31.8	127	–0.8%
	Equipment	Entire HVAC System	380	1,360	33.5	126	–3.5%
		Rooftop Unit	380	1,360	33.5	126	–3.5%

Table B-40 4C High Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			915	1,200	80.6	111	N/A
Low-Energy			457	1,460	40.3	135	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	563	1,450	49.6	135	–11.5%
		Lighting Power Density	536	1,470	47.2	137	–8.6%
		Daylighting Sensors	536	1,460	47.2	136	–8.6%
		Daylighting Sensors And Skylights	515	1,450	45.4	134	–6.3%
		Photovoltaics	504	1,280	44.3	119	–5.0%
	Form	Effective Aperture	514	1,450	45.3	135	–6.2%
		Glazing Quantity	511	1,450	45.0	135	–5.8%
		Overhangs	460	1,460	40.5	136	–0.3%
	Fabric	Opaque Envelope Constructions	510	1,420	44.9	132	–5.8%
		Infiltration	478	1,400	42.1	130	–2.3%
		Fenestration Constructions	462	1,460	40.7	135	–0.5%
	Equipment	Entire HVAC System	492	1,450	43.3	135	–3.7%
		Rooftop Unit	492	1,450	43.3	135	–3.7%

B.11 Climate Zone 5A: Chicago, Illinois

Table B-41 5A Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	5A		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	0.72% of net roof area	7.8% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.991	0.991
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.187	1.06	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.5	Projection factor of 0.5	Projection factor of 0.5
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.460	0.460	0.460
			VLT (Ratio)	0.584	0.584	0.584
			U-Factor (Btu/h·ft^2·°F)	0.451	0.451	0.451
			Materials Cost ($/ft^2)	$14.19	$14.19	$14.19
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22

Category	Subcategory	EDM Type	EDM Instance	5A		
				Plug 1	Plug 2	Plug 3
		Windows	EDM Key	Double pane with low-e and argon	Double pane with low-e2 and argon	Quadruple layer with low-e polyester films and krypton
			SHGC (Ratio)	0.564	0.416	0.461
			VLT (Ratio)	0.745	0.750	0.624
			U-Factor (Btu/h·ft^2·°F)	0.264	0.235	0.136
			Materials Cost ($/ft^2)	$19.63	$26.65	$35.42
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Tighter envelope	Tighter envelope
			Rate (ACH)	0.322	0.132	0.132
	Opaque Constructions	Walls	EDM Key	R-20 c.i.	R-43.8 c.i.	R-43.8 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0633	0.0304	0.0304
			Materials Cost ($/ft^2)	$4.89	$6.65	$6.65
			Installation Cost ($/ft^2)	$2.11	$2.86	$2.86
		Roof	EDM Key	R-30 c.i.	R-35 c.i. with cool roof	R-30 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0332	0.0289	0.0289
			Materials Cost ($/ft^2)	$3.95	$4.19	$4.19
			Installation Cost ($/ft^2)	$1.70	$1.81	$1.81
Equipment	HVAC System	System	EDM Key	20% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	4.43	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	True
			Motorized Damper	False	False	True
			Fan Efficiency (%)	50.8	50.8	52.6
			Fan Static Pressure (in. w.c.)	1.53	1.53	1.62
			Materials Cost ($/ton)	$1,590.95	$1,590.95	$1,687.18
			Installation Cost ($/ton)	$171.00	$171.00	$171.00

Category	Subcategory	EDM Type	EDM Instance	5A		
				Plug 1	Plug 2	Plug 3
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	Installed	Installed	Installed
		ERV	EDM Key	High effectiveness	Medium effectiveness	Low effectiveness
			Sensible Effectiveness (%)	80.0	70.0	60.0
			Latent Effectiveness (%)	70.0	60.0	50.0
			Pressure Drop (in. w.c.)	1.00	0.863	0.703
			Materials Cost ($/ton)	$103.43	$82.76	$68.97
			Installation Cost ($/ton)	$8.19	$8.19	$8.19

Table B-42 5A Low Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			683	1,170	60.2	109	N/A
Low-Energy			334	1,160	29.4	107	51.1%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	401	1,160	35.3	108	–9.8%
		Lighting Power Density	396	1,180	34.8	110	–9.1%
		Daylighting Sensors And Skylights	382	1,140	33.7	106	–7.1%
		Plug Loads	337	1,150	29.7	107	–0.5%
	Form	Effective Aperture	383	1,140	33.7	106	–7.2%
		Glazing Quantity	378	1,140	33.3	106	–6.4%
		Overhangs	338	1,160	29.7	108	–0.6%
	Fabric	Opaque Envelope Constructions	407	1,160	35.8	107	–10.7%
		Fenestration Constructions	345	1,160	30.4	108	–1.6%
	Equipment	Energy Recovery	475	1,160	41.8	108	–20.7%
		Entire HVAC System	453	1,160	39.9	107	–17.5%
		Rooftop Unit	363	1,170	32.0	108	–4.3%
		Demand Control Ventilation	329	1,160	29.0	108	0.7%

Table B-43 5A Medium Plug Perturbation Results

Building Name			EUI ($MJ/m^2\cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2 yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			825	1,210	72.6	112	N/A
Low-Energy			412	1,290	36.3	120	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2\cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2 yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	506	1,300	44.5	121	–11.3%
		Lighting Power Density	498	1,300	43.8	121	–10.4%
		Daylighting Sensors And Skylights	475	1,270	41.8	118	–7.6%
		Plug Loads	436	1,280	38.4	119	–2.9%
		Photovoltaics	416	1,280	36.6	119	–0.4%
	Form	Effective Aperture	473	1,280	41.7	119	–7.4%
		Glazing Quantity	470	1,270	41.4	118	–7.0%
		Overhangs	415	1,290	36.5	120	–0.3%
	Fabric	Opaque Envelope Constructions	483	1,260	42.6	117	–8.6%
		Infiltration	452	1,230	39.8	115	–4.8%
		Fenestration Constructions	419	1,290	36.9	120	–0.8%
	Equipment	Entire HVAC System	472	1,290	41.6	119	–7.3%
		Energy Recovery	472	1,280	41.6	119	–7.2%
		Rooftop Unit	466	1,290	41.0	120	–6.5%
		Demand Control Ventilation	415	1,290	36.5	120	–0.3%

Table B-44 5A High Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,020	1,250	90.2	116	N/A
Low-Energy			512	1,420	45.1	132	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	619	1,430	54.5	133	–10.5%
		Daylighting Sensors	601	1,440	53.0	133	–8.7%
		Lighting Power Density	594	1,440	52.3	133	–8.0%
		Daylighting Sensors And Skylights	573	1,410	50.4	131	–5.9%
		Photovoltaics	547	1,310	48.1	122	–3.4%
	Form	Effective Aperture	571	1,420	50.3	132	–5.8%
		Glazing Quantity	568	1,420	50.0	131	–5.5%
		Overhangs	514	1,420	45.3	132	–0.2%
	Fabric	Opaque Envelope Constructions	578	1,400	50.9	130	–6.5%
		Infiltration	548	1,370	48.2	127	–3.5%
		Fenestration Constructions	520	1,420	45.8	132	–0.8%
	Equipment	Rooftop Unit	585	1,420	51.5	132	–7.1%
		Entire HVAC System	563	1,420	49.6	132	–5.0%
		Energy Recovery	530	1,420	46.7	132	–1.8%
		Demand Control Ventilation	514	1,430	45.3	132	–0.2%

B.12 Climate Zone 5B: Denver, Colorado

Table B-45 5B Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	5B		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	4.0% of net roof area	7.7% of net roof area
			Materials Cost ($/W)	$0.00	$9.54	$9.54
			Installation Cost ($/W)	$0.00	$1.06	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.991	0.991
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.187	1.06	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.7	Projection factor of 0.5	Projection factor of 0.5
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.460	0.460	0.460
			VLT (Ratio)	0.584	0.584	0.584
			U-Factor (Btu/h·ft^2·°F)	0.451	0.451	0.451
			Materials Cost ($/ft^2)	$14.19	$14.19	$14.19
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane with low-e	Double pane with low-e2	Double pane with

Category	Subcategory	EDM Type	EDM Instance	5B		
				Plug 1	Plug 2	Plug 3
				and argon	and argon	low-e and argon
			SHGC (Ratio)	0.564	0.416	0.564
			VLT (Ratio)	0.745	0.750	0.745
			U-Factor (Btu/h·ft^2·°F)	0.264	0.235	0.264
			Materials Cost ($/ft^2)	$19.63	$26.65	$19.63
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Tighter envelope	Tighter envelope
			Rate (ACH)	0.322	0.132	0.132
	Opaque Constructions	Walls	EDM Key	R-20 c.i.	R-31.3 c.i.	R-31.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0633	0.0399	0.0399
			Materials Cost ($/ft^2)	$4.89	$5.77	$5.77
			Installation Cost ($/ft^2)	$2.11	$2.49	$2.49
		Roof	EDM Key	R-25 c.i. with cool roof	R-35 c.i. with cool roof	R-30 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0405	0.0289	0.0289
			Materials Cost ($/ft^2)	$3.68	$4.19	$4.19
			Installation Cost ($/ft^2)	$1.58	$1.81	$1.81
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	3.69	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	True	True
			Motorized Damper	False	True	True
			Fan Efficiency (%)	53.8	55.8	55.8
			Fan Static Pressure (in. w.c.)	1.62	1.72	1.72
			Materials Cost ($/ton)	$1,487.27	$1,687.18	$1,687.18
			Installation Cost ($/ton)	$157.98	$171.00	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	None	None	None

Category	Subcategory	EDM Type	EDM Instance	5B		
				Plug 1	Plug 2	Plug 3
		ERV	EDM Key	High effectiveness	Low effectiveness	None
			Sensible Effectiveness (%)	80.0	60.0	N/A
			Latent Effectiveness (%)	70.0	50.0	N/A
			Pressure Drop (in. w.c.)	1.00	0.703	N/A
			Materials Cost ($/ton)	$103.43	$68.97	$0.00
			Installation Cost ($/ton)	$8.19	$8.19	$0.00

Table B-46 5B Low Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			614	1,130	54.1	105	N/A
Low-Energy			306	1,130	27.0	105	50.2%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Daylighting Sensors	382	1,140	33.6	106	–12.3%
		Lighting Power Density	378	1,140	33.3	106	–11.6%
		Daylighting Sensors And Skylights	362	1,110	31.9	103	–9.1%
		Plug Loads	310	1,130	27.3	105	–0.6%
	Form	Effective Aperture	363	1,120	32.0	104	–9.2%
		Glazing Quantity	357	1,110	31.4	103	–8.2%
		Overhangs	312	1,130	27.4	105	–0.9%
	Fabric	Opaque Envelope Constructions	366	1,130	32.2	105	–9.7%
		Fenestration Constructions	315	1,140	27.7	105	–1.4%
	Equipment	Entire HVAC System	390	1,130	34.4	105	–13.7%
		Energy Recovery	378	1,130	33.3	105	–11.7%
		Rooftop Unit	361	1,130	31.8	105	–8.9%

Table B-47 5B Medium Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			775	1,150	68.3	107	N/A
Low-Energy			388	1,300	34.1	121	50.0%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Daylighting Sensors	478	1,310	42.1	121	–11.6%
		Lighting Power	469	1,310	41.3	122	–10.5%

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			775	1,150	68.3	107	N/A
Low-Energy			388	1,300	34.1	121	50.0%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
		Density					
		Daylighting Sensors And Skylights	450	1,280	39.6	119	–8.0%
		Plug Loads	411	1,290	36.2	120	–3.0%
		Photovoltaics	409	1,240	36.0	115	–2.7%
	Form	Effective Aperture	447	1,280	39.4	119	–7.7%
		Glazing Quantity	444	1,280	39.1	119	–7.3%
		Overhangs	390	1,300	34.4	121	–0.3%
	Fabric	Opaque Envelope Constructions	451	1,280	39.7	119	–8.2%
		Infiltration	420	1,240	37.0	116	–4.2%
		Fenestration Constructions	394	1,300	34.7	121	–0.8%
	Equipment	Rooftop Unit	436	1,300	38.4	120	–6.2%
		Entire HVAC System	423	1,290	37.2	120	–4.5%
		Energy Recovery	392	1,300	34.5	121	–0.5%

Table B-48 5B High Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			980	1,180	86.3	109	N/A
Low-Energy			490	1,370	43.2	128	50.0%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Plug Loads	592	1,370	52.2	127	–10.4%
		Daylighting Sensors	576	1,380	50.7	128	–8.7%
		Lighting Power Density	566	1,380	49.8	129	–7.7%
		Daylighting Sensors and	551	1,360	48.5	126	–6.2%

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			980	1,180	86.3	109	N/A
Low-Energy			490	1,370	43.2	128	50.0%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
		Skylights					
		Photovoltaics	530	1,260	46.7	117	–4.1%
	Form	Effective Aperture	548	1,360	48.3	126	–6.0%
		Glazing Quantity	546	1,360	48.0	126	–5.7%
		Overhangs	492	1,370	43.3	128	–0.2%
	Fabric	Opaque Envelope Constructions	548	1,350	48.3	126	–5.9%
		Infiltration	522	1,320	46.0	122	–3.3%
		Fenestration Constructions	496	1,380	43.7	128	–0.6%
	Equipment	Entire HVAC System	533	1,370	47.0	127	–4.4%
		Rooftop Unit	533	1,370	47.0	127	–4.4%

B.13 Climate Zone 6A: Minneapolis, Minnesota

Table B-49 6A Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	6A Plug 1	6A Plug 2	6A Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	None	2.8% of net roof area
			Materials Cost ()	$0.00	$0.00	$9.54
			Installation Cost ()	$0.00	$0.00	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.989	0.991
	Plug Loads	Plug Loads	EDM Key	Baseline	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.207	1.05	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.5	Projection factor of 0.7	Projection factor of 0.5
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.460	0.460	0.460
			VLT (Ratio)	0.584	0.584	0.584
			U-Factor (Btu/h·ft^2·°F)	0.451	0.451	0.451
			Materials Cost ($/ft^2)	$14.19	$14.19	$14.19
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17

Category	Subcategory	EDM Type	EDM Instance	6A		
				Plug 1	Plug 2	Plug 3
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane with low-e and argon	Double pane with low-e and argon	Quadruple layer with low-e polyester films and krypton
			SHGC (Ratio)	0.564	0.564	0.461
			VLT (Ratio)	0.745	0.745	0.624
			U-Factor (Btu/h·ft^2·°F)	0.264	0.264	0.136
			Materials Cost ($/ft^2)	$19.63	$19.63	$35.42
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Tighter envelope	Tighter envelope and front door vestibule
			Rate (ACH)	0.322	0.132	0.103
	Opaque Constructions	Walls	EDM Key	R-20 c.i.	R-31.3 c.i.	R-43.8 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0633	0.0399	0.0304
			Materials Cost ($/ft^2)	$4.89	$5.77	$6.65
			Installation Cost ($/ft^2)	$2.11	$2.49	$2.86
		Roof	EDM Key	R-30 c.i.	Baseline Roof Construction, R-30 c.i. with cool roof	R-30 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0332	0.0332	0.0289
			Materials Cost ($/ft^2)	$3.95	$3.95	$4.19
			Installation Cost ($/ft^2)	$1.70	$1.70	$1.81
Equipment	HVAC System	System	EDM Key	10% increased COP with efficient fan	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	4.06	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	True
			Motorized Damper	False	False	True

Category	Subcategory	EDM Type	EDM Instance	6A		
				Plug 1	Plug 2	Plug 3
			Fan Efficiency (%)	50.8	50.8	52.6
			Fan Static Pressure (in. w.c.)	1.53	1.53	1.62
			Materials Cost ($/ton)	$1,539.07	$1,590.95	$1,687.18
			Installation Cost ($/ton)	$164.00	$171.00	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	None	Installed	Installed
		ERV	EDM Key	High effectiveness	High effectiveness	Low effectiveness
			Sensible Effectiveness (%)	80.0	80.0	60.0
			Latent Effectiveness (%)	70.0	70.0	50.0
			Pressure Drop (in. w.c.)	1.00	1.00	0.703
			Materials Cost ($/ton)	$103.43	$103.43	$68.97
			Installation Cost ($/ton)	$8.19	$8.19	$8.19

Table B-50 6A Low Plug Perturbation Results

Building Name			EUI ($MJ/m^2\cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			780	1,150	68.6	107	N/A
Low-Energy			389	1,160	34.3	108	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2\cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	457	1,170	40.2	108	–8.6%
		Lighting Power Density	445	1,170	39.2	109	–7.1%
		Daylighting Sensors and Skylights	435	1,140	38.3	106	–5.8%
	Form	Effective Aperture	437	1,150	38.5	107	–6.1%
	Fabric	Opaque Envelope Constructions	474	1,150	41.8	107	–10.9%
		Fenestration Constructions	405	1,160	35.6	108	–2.0%
	Equipment	HVAC System	548	1,160	48.2	108	–20.3%
		Energy Recovery	535	1,160	47.1	108	–18.7%

Table B-51 6A Medium Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			904	1,170	79.6	109	N/A
Low-Energy			435	1,250	38.3	116	51.9%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	521	1,250	45.9	116	–9.5%
		Lighting Power Density	519	1,260	45.7	117	–9.3%
		Daylighting Sensors and Skylights	493	1,220	43.4	114	–6.4%
		Plug Loads	458	1,240	40.3	115	–2.5%
	Form	Effective Aperture	495	1,230	43.6	114	–6.6%
		Glazing Quantity	488	1,230	43.0	114	–5.9%
		Overhangs	440	1,250	38.7	116	–0.5%
	Fabric	Opaque Envelope Constructions	509	1,230	44.9	114	–8.2%
		Infiltration	496	1,190	43.7	111	–6.8%
		Fenestration Constructions	444	1,250	39.1	116	–1.0%
	Equipment	Energy Recovery	551	1,250	48.5	116	–12.8%
		Entire HVAC System	534	1,240	47.1	115	–11.0%
		Rooftop Unit	487	1,240	42.9	116	–5.8%
		Demand Control Ventilation	436	1,250	38.4	116	–0.1%

Table B-52 6A High Plug Perturbation Results

Building Name			EUI (MJ/m^2·yr)	5-TLCC Intensity (\$/m^2)	EUI (kBtu/ft^{2}yr)	5-TLCC Intensity (\$/ft^2)	Percent Savings
Baseline			1,080	1,200	94.7	111	N/A
Low-Energy			538	1,350	47.4	125	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m^2·yr)**	**5-TLCC Intensity (\$/m^2)**	**EUI (kBtu/ft^{2}yr)**	**5-TLCC Intensity (\$/ft^2)**	**Percent Savings Difference (Perturbed - Low Energy)**
Removal Perturbation	Program	Plug Loads	642	1,340	56.6	125	-9.7%
		Daylighting Sensors	627	1,350	55.2	126	-8.3%
		Lighting Power Density	616	1,360	54.3	126	-7.3%
		Daylighting Sensors And Skylights	597	1,320	52.6	123	-5.5%
		Photovoltaics	550	1,310	48.5	121	-1.2%
	Form	Effective Aperture	596	1,330	52.5	124	-5.4%
		Glazing Quantity	592	1,330	52.1	123	-5.1%
		Overhangs	541	1,350	47.6	125	-0.3%
	Fabric	Opaque Envelope Constructions	615	1,320	54.1	123	-7.2%
		Infiltration	605	1,280	53.2	119	-6.2%
		Fenestration Constructions	549	1,350	48.3	125	-1.0%
	Equipment	Entire HVAC System	606	1,340	53.4	125	-6.4%
		Rooftop Unit	607	1,340	53.4	125	-6.4%
		Energy Recovery	593	1,350	52.2	125	-5.2%
		Demand Control Ventilation	538	1,350	47.4	125	-0.0%

B.14 Climate Zone 6B: Helena, Montana

Table B-53 6B Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	6B		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	None	9.4% of net roof area
			Materials Cost ($/W)	$0.00	$0.00	$9.54
			Installation Cost ($/W)	$0.00	$0.00	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.989	0.991	0.991
	Plug Loads	Plug Loads	EDM Key	Baseline	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.207	1.06	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.7	Projection factor of 0.5	Projection factor of 0.5
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.460	0.460	0.460
			VLT (Ratio)	0.584	0.584	0.584
			U-Factor (Btu/h·ft^2·°F)	0.451	0.451	0.451
			Materials Cost ($/ft^2)	$14.19	$14.19	$14.19
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane	Double pane	Quadruple

Category	Subcategory	EDM Type	EDM Instance	6B		
				Plug 1	Plug 2	Plug 3
				with low-e and argon	with low-e and argon	layer with low-e polyester films and krypton
			SHGC (Ratio)	0.564	0.564	0.461
			VLT (Ratio)	0.745	0.745	0.624
			U-Factor (Btu/h·ft^2·°F)	0.264	0.264	0.136
			Materials Cost ($/ft^2)	$19.63	$19.63	$35.42
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Baseline	Tighter envelope and front door vestibule	Tighter envelope
			Rate (ACH)	0.322	0.103	0.132
	Opaque Constructions	Walls	EDM Key	R-31.3 c.i.	R-43.8 c.i.	R-43.8 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0399	0.0304	0.0304
			Materials Cost ($/ft^2)	$5.77	$6.65	$6.65
			Installation Cost ($/ft^2)	$2.49	$2.86	$2.86
		Roof	EDM Key	R-30 c.i.	R-40 c.i.	R-30 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0332	0.0229	0.0289
			Materials Cost ($/ft^2)	$3.95	$4.54	$4.19
			Installation Cost ($/ft^2)	$1.70	$1.95	$1.81
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan	20% increased COP with economizer and efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	3.69	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	True	True
			Motorized Damper	False	True	True
			Fan Efficiency (%)	53.8	55.8	55.8
			Fan Static Pressure (in. w.c.)	1.62	1.72	1.72
			Materials Cost ($/ton)	$1,487.27	$1,687.18	$1,687.18
			Installation	$157.98	$171.00	$171.00

Category	Subcategory	EDM Type	EDM Instance	6B		
				Plug 1	Plug 2	Plug 3
			Cost ($/ton)			
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	None	None	None
		ERV	EDM Key	High effectiveness	Low effectiveness	Low effectiveness
			Sensible Effectiveness (%)	80.0	60.0	60.0
			Latent Effectiveness (%)	70.0	50.0	50.0
			Pressure Drop (in. w.c.)	1.00	0.703	0.703
			Materials Cost ($/ton)	$103.43	$68.97	$68.97
			Installation Cost ($/ton)	$8.19	$8.19	$8.19

Table B-54 6B Low Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			682	1,150	60.0	107	N/A
Low-Energy			335	1,150	29.5	107	50.8%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Daylighting Sensors	406	1,160	35.8	108	–10.4%
		Lighting Power Density	397	1,170	35.0	109	–9.1%
		Daylighting Sensors And Skylights	384	1,140	33.8	106	–7.1%
	Form	Effective Aperture	388	1,140	34.1	106	–7.7%
		Glazing Quantity	379	1,140	33.4	106	–6.4%
		Overhangs	343	1,160	30.2	108	–1.1%
	Fabric	Opaque Envelope Constructions	425	1,140	37.4	106	–13.2%
		Fenestration Constructions	348	1,160	30.7	108	–1.9%
	Equipment	Entire HVAC System	457	1,160	40.2	107	–17.8%
		Energy Recovery	451	1,160	39.7	107	–17.0%
		Rooftop Unit	388	1,160	34.1	108	–7.7%

Table B-55 6B Medium Plug Perturbation Results

Building Name			EUI (MJ/m^2·yr)	5-TLCC Intensity (\$/m^2)	EUI (kBtu/ft^{2}yr)	5-TLCC Intensity (\$/ft^2)	Percent Savings
Baseline			812	1,180	71.5	110	N/A
Low-Energy			404	1,290	35.6	120	50.2%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m^2·yr)**	**5-TLCC Intensity (\$/m^2)**	**EUI (kBtu/ft^{2}yr)**	**5-TLCC Intensity (\$/ft^2)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Daylighting Sensors	491	1,300	43.2	121	–10.7%
		Lighting Power Density	481	1,310	42.4	121	–9.5%
		Daylighting Sensors And Skylights	464	1,270	40.8	118	–7.4%
	Form	Effective Aperture	465	1,270	40.9	118	–7.5%
		Glazing Quantity	459	1,270	40.4	118	–6.7%
		Overhangs	409	1,290	36.0	120	–0.7%
	Fabric	Opaque Envelope Constructions	483	1,260	42.5	117	–9.7%
		Infiltration	461	1,220	40.6	113	–7.0%
		Fenestration Constructions	413	1,290	36.3	120	–1.1%
	Equipment	Entire HVAC System	454	1,280	40.0	119	–6.2%
		Rooftop Unit	446	1,290	39.3	120	–5.2%
		Energy Recovery	429	1,290	37.8	119	–3.1%

Table B-56 6B High Plug Perturbation Results

Building Name			EUI ($MJ/m^2 \cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			989	1,210	87.1	113	N/A
Low-Energy			495	1,430	43.5	133	50.0%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2 \cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	600	1,430	52.8	133	–10.6%
		Daylighting Sensors	583	1,440	51.3	134	–8.9%
		Lighting Power Density	575	1,450	50.6	135	–8.1%
		Daylighting Sensors And Skylights	555	1,420	48.8	132	–6.1%
		Photovoltaics	537	1,300	47.2	120	–4.2%
	Form	Effective Aperture	554	1,420	48.8	132	–6.0%
		Glazing Quantity	549	1,420	48.4	132	–5.5%
		Overhangs	499	1,430	43.9	133	–0.4%
	Fabric	Opaque Envelope Constructions	562	1,410	49.5	131	–6.8%
		Infiltration	532	1,370	46.9	128	–3.8%
		Fenestration Constructions	504	1,430	44.3	133	–0.9%
	Equipment	Rooftop Unit	549	1,430	48.4	133	–5.6%
		Entire HVAC System	537	1,420	47.3	132	–4.3%
		Energy Recovery	504	1,430	44.3	133	–0.9%

B.15 Climate Zone 7: Duluth, Minnesota

Table B-57 7 Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	7		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	None	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.947	0.989	0.991
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.206	1.05	1.75
Form	Shading	Shading Depth	EDM Key	Projection factor of 0.5	Projection factor of 0.5	Projection factor of 0.5
	Skylights	Skylight Fraction	EDM Key	None	3% of roof area in non-sidelit zones	4% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction	Double pane with low-e and high solar gain	Double pane with low-e and high solar gain
			SHGC (Ratio)	0.490	0.460	0.460
			VLT (Ratio)	0.490	0.584	0.584
			U-Factor (Btu/h·ft^2·°F)	0.690	0.451	0.451
			Materials Cost ($/ft^2)	$20.05	$14.19	$14.19
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane with low-e and argon	Double pane with low-e and argon	Quadruple layer with low-e polyester films and krypton

Category	Subcategory	EDM Type	EDM Instance	7		
				Plug 1	Plug 2	Plug 3
			SHGC (Ratio)	0.564	0.564	0.461
			VLT (Ratio)	0.745	0.745	0.624
			U-Factor (Btu/h·ft^2·°F)	0.264	0.264	0.136
			Materials Cost ($/ft^2)	$19.63	$19.63	$35.42
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Tighter envelope	Tighter envelope	Tighter envelope and front door vestibule
			Rate (ACH)	0.132	0.132	0.103
	Opaque Constructions	Walls	EDM Key	R-31.3 c.i.	R-31.3 c.i.	R-62.5 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0399	0.0399	0.0228
			Materials Cost ($/ft^2)	$5.77	$5.77	$7.98
			Installation Cost ($/ft^2)	$2.49	$2.49	$3.44
		Roof	EDM Key	R-30 c.i.	R-25 c.i. with cool roof	R-30 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0332	0.0405	0.0289
			Materials Cost ($/ft^2)	$3.95	$3.68	$4.19
			Installation Cost ($/ft^2)	$1.70	$1.58	$1.81
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan	20% increased COP with efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	3.69	4.43	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	True
			Motorized Damper	False	False	True
			Fan Efficiency (%)	50.8	50.8	52.6
			Fan Static Pressure (in. w.c.)	1.53	1.53	1.62
			Materials Cost ($/ton)	$1,487.27	$1,590.95	$1,687.18
			Installation Cost ($/ton)	$157.98	$171.00	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	None	None	None

Category	Subcategory	EDM Type	EDM Instance	7		
				Plug 1	Plug 2	Plug 3
		ERV	EDM Key	High effectiveness	High effectiveness	Low effectiveness
			Sensible Effectiveness (%)	80.0	80.0	60.0
			Latent Effectiveness (%)	70.0	70.0	50.0
			Pressure Drop (in. w.c.)	1.00	1.00	0.703
			Materials Cost ($/ton)	$103.43	$103.43	$68.97
			Installation Cost ($/ton)	$8.19	$8.19	$8.19

Table B-58 7 Low Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			827	1,150	72.8	106	N/A
Low-Energy			343	1,190	30.2	110	58.6%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Lighting Power Density	462	1,200	40.7	112	–14.4%
		Daylighting Sensors and Skylights	348	1,190	30.6	110	–0.7%
		Daylighting Sensors	348	1,190	30.6	110	–0.7%
		Plug Loads	346	1,190	30.5	110	–0.5%
	Form	Effective Aperture	350	1,190	30.8	111	–0.9%
		Overhangs	347	1,190	30.6	111	–0.6%
		Glazing Quantity	343	1,190	30.2	111	–0.1%
	Fabric	Infiltration	440	1,140	38.8	106	–11.8%
		Opaque Envelope Constructions	436	1,180	38.4	109	–11.2%
		Fenestration Constructions	349	1,190	30.7	110	–0.7%
	Equipment	Entire HVAC System	497	1,190	43.7	110	–18.6%
		Energy Recovery	490	1,190	43.2	111	–17.8%
		Rooftop Unit	365	1,190	32.2	110	–2.7%

Table B-59 7 Medium Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			931	1,170	82.0	108	N/A
Low-Energy			444	1,240	39.1	115	52.4%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Lighting Power Density	524	1,250	46.2	116	–8.7%
		Daylighting Sensors	525	1,240	46.2	115	–8.7%
		Daylighting Sensors and Skylights	498	1,210	43.9	113	–5.9%
		Plug Loads	465	1,230	41.0	114	–2.3%
	Form	Effective Aperture	500	1,220	44.0	113	–6.1%
		Glazing Quantity	494	1,220	43.5	113	–5.4%
		Overhangs	448	1,240	39.4	115	–0.5%
	Fabric	Infiltration	523	1,180	46.1	110	–8.6%
		Opaque Envelope Constructions	514	1,230	45.2	114	–7.5%
		Fenestration Constructions	459	1,240	40.4	115	–1.7%
	Equipment	Entire HVAC System	567	1,230	49.9	114	–13.2%
		Energy Recovery	550	1,240	48.4	115	–11.5%
		Rooftop Unit	490	1,230	43.1	115	–5.0%

Table B-60 7 High Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,080	1,190	95.3	110	N/A
Low-Energy			540	1,310	47.6	122	50.1%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Plug Loads	644	1,310	56.7	121	–9.6%
		Daylighting Sensors	627	1,320	55.2	123	–8.0%

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,080	1,190	95.3	110	N/A
Low-Energy			540	1,310	47.6	122	50.1%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI (MJ/m²·yr)**	**5-TLCC Intensity ($/m²)**	**EUI (kBtu/ft²yr)**	**5-TLCC Intensity ($/ft²)**	**Percent Savings Difference (Perturbed – Low Energy)**
		Lighting Power Density	620	1,320	54.6	123	–7.3%
		Daylighting Sensors And Skylights	600	1,290	52.8	120	–5.5%
	Form	Effective Aperture	599	1,300	52.8	120	–5.4%
		Glazing Quantity	595	1,290	52.4	120	–5.0%
		Overhangs	543	1,310	47.8	122	–0.3%
	Fabric	Opaque Envelope Constructions	620	1,270	54.6	118	–7.4%
		Infiltration	613	1,240	54.0	115	–6.7%
		Fenestration Constructions	556	1,310	49.0	122	–1.5%
	Equipment	Entire HVAC System	618	1,300	54.5	121	–7.2%
		Rooftop Unit	612	1,310	53.9	121	–6.6%
		Energy Recovery	581	1,310	51.1	122	–3.7%

B.16 Climate Zone 8: Fairbanks, Alaska

Table B-61 8 Low-Energy Model Descriptions

Category	Subcategory	EDM Type	EDM Instance	8		
				Plug 1	Plug 2	Plug 3
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point	400 lux set point	400 lux set point
			Materials Cost ($/ft^2)	$0.19	$0.19	$0.19
			Installation Cost ($/ft^2)	$0.22	$0.22	$0.22
	Generation	PV	EDM Key	None	None	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.947	0.947	0.947
	Plug Loads	Plug Loads	EDM Key	Baseline	Peak plug loads reduced 10%	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.229	0.973	1.58
Form	Shading	Shading Depth	EDM Key	Projection factor of 1.1	Projection factor of 1.1	Projection factor of 0.9
	Skylights	Skylight Fraction	EDM Key	None	None	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing	80% of baseline glazing	80% of baseline glazing
			South Window-to-Wall Ratio (%)	16.0	16.0	16.0
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction	Baseline Skylight Construction	Baseline Skylight Construction
			SHGC (Ratio)	0.490	0.490	0.490
			VLT (Ratio)	0.490	0.490	0.490
			U-Factor (Btu/h·ft^2·°F)	0.580	0.580	0.580
			Materials Cost ($/ft^2)	$23.87	$23.87	$23.87
			Installation Cost ($/ft^2)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft^2)	$0.22	$0.22	$0.22
		Windows	EDM Key	Double pane with low-e and argon	Double pane with low-e and argon	Double pane with low-e and argon
			SHGC (Ratio)	0.564	0.564	0.564
			VLT (Ratio)	0.745	0.745	0.745
			U-Factor	0.264	0.264	0.264

Category	Subcategory	EDM Type	EDM Instance	8		
				Plug 1	Plug 2	Plug 3
			(Btu/h·ft²·°F)			
			Materials Cost ($/ft²)	$19.63	$19.63	$19.63
			Installation Cost ($/ft²)	$27.17	$27.17	$27.17
			Fixed O&M Cost ($/ft²)	$0.19	$0.19	$0.19
	Infiltration	Infiltration	EDM Key	Tighter envelope	Tighter envelope	Tighter envelope
			Rate (ACH)	0.132	0.132	0.132
	Opaque Constructions	Walls	EDM Key	R-31.3 c.i.	R-31.3 c.i.	R-31.3 c.i.
			U-Factor (Btu/h·ft²·°F)	0.0399	0.0399	0.0399
			Materials Cost ($/ft²)	$5.77	$5.77	$5.77
			Installation Cost ($/ft²)	$2.49	$2.49	$2.49
		Roof	EDM Key	R-25 c.i. with cool roof	R-25 c.i. with cool roof	R-30 c.i. with cool roof
			U-Factor (Btu/h·ft²·°F)	0.0405	0.0405	0.0289
			Materials Cost ($/ft²)	$3.68	$3.68	$4.19
			Installation Cost ($/ft²)	$1.58	$1.58	$1.81
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan	Baseline COP with efficient fan	20% increased COP with economizer and efficient fan
			Cooling COP (Ratio)	3.69	3.69	4.43
			Heating Efficiency (%)	80.0	80.0	80.0
			Economizer	False	False	True
			Motorized Damper	False	False	True
			Fan Efficiency (%)	50.8	50.8	52.6
			Fan Static Pressure (in. w.c.)	1.53	1.53	1.62
			Materials Cost ($/ton)	$1,487.27	$1,487.27	$1,687.18
			Installation Cost ($/ton)	$157.98	$157.98	$171.00
			Fixed O&M Cost ($/ton)	$131.99	$131.99	$131.99
	Outdoor Air	DCV	EDM Key	None	None	None
		ERV	EDM Key	High effectiveness	High effectiveness	High effectiveness
			Sensible Effectiveness (%)	80.0	80.0	80.0

Category	Subcategory	EDM Type	EDM Instance	8		
				Plug 1	Plug 2	Plug 3
			Latent Effectiveness (%)	70.0	70.0	70.0
			Pressure Drop (in. w.c.)	1.00	1.00	1.00
			Materials Cost ($/ton)	$103.43	$103.43	$103.43
			Installation Cost ($/ton)	$8.19	$8.19	$8.19

Table B-62 8 Low Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,120	1,160	98.9	108	N/A
Low-Energy			465	1,190	41.0	110	58.6%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Lighting Power Density	546	1,210	48.1	112	–7.2%
		Daylighting Sensors And Skylights	469	1,190	41.3	110	–0.3%
		Daylighting Sensors	469	1,190	41.3	110	–0.3%
	Form	Effective Aperture	475	1,200	41.8	111	–0.9%
		Overhangs	471	1,190	41.5	111	–0.5%
		Glazing Quantity	467	1,190	41.1	111	–0.1%
	Fabric	Infiltration	668	1,140	58.8	106	–18.1%
		Opaque Envelope Constructions	538	1,180	47.3	110	–6.4%
		Fenestration Constructions	473	1,190	41.7	110	–0.7%
	Equipment	Entire HVAC System	733	1,190	64.6	110	–23.9%
		Energy Recovery	730	1,190	64.3	110	–23.6%
		Rooftop Unit	478	1,190	42.1	110	–1.1%

Table B-63 8 Medium Plug Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			1,190	1,190	105	111	N/A
Low-Energy			564	1,230	49.7	114	52.7%
	EDM Category	EDMs Reverted from Low-Energy to Baseline	EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings Difference (Perturbed – Low Energy)
Removal Perturbation	Program	Lighting Power Density	676	1,250	59.6	116	–9.4%
		Plug Loads	582	1,220	51.3	114	–1.5%
		Daylighting	568	1,230	50.0	114	–0.3%

Building Name			EUI ($MJ/m^2 \cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2 yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			1,190	1,190	105	111	N/A
Low-Energy			564	1,230	49.7	114	52.7%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2 \cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2 yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
		Sensors					
		Daylighting Sensors And Skylights	568	1,230	50.0	114	–0.3%
	Form	Effective Aperture	575	1,240	50.7	115	–0.9%
		Overhangs	572	1,230	50.3	114	–0.6%
		Glazing Quantity	566	1,230	49.9	114	–0.2%
	Fabric	Infiltration	734	1,170	64.7	109	–14.2%
		Opaque Envelope Constructions	632	1,220	55.7	113	–5.7%
		Fenestration Constructions	572	1,230	50.4	114	–0.6%
	Equipment	Entire HVAC System	790	1,220	69.5	114	–18.8%
		Energy Recovery	781	1,220	68.7	114	–18.1%
		Rooftop Unit	594	1,230	52.3	114	–2.5%

Table B-64 8 High Plug Perturbation Results

Building Name			EUI ($MJ/m^2 \cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2 yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			1,290	1,230	114	114	N/A
Low-Energy			639	1,270	56.3	118	50.6%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2 \cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2 yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
Removal Perturbation	Program	Lighting Power Density	764	1,300	67.3	120	–9.7%
		Plug Loads	733	1,270	64.5	118	–7.2%
		Daylighting Sensors	643	1,270	56.6	118	–0.3%
		Daylighting Sensors And Skylights	643	1,270	56.6	118	–0.3%
	Form	Effective	649	1,280	57.1	119	–0.7%

Building Name			EUI ($MJ/m^2 \cdot yr$)	5-TLCC Intensity ($\$/m^2$)	EUI ($kBtu/ft^2yr$)	5-TLCC Intensity ($\$/ft^2$)	Percent Savings
Baseline			1,290	1,230	114	114	N/A
Low-Energy			639	1,270	56.3	118	50.6%
	EDM Category	**EDMs Reverted from Low-Energy to Baseline**	**EUI ($MJ/m^2 \cdot yr$)**	**5-TLCC Intensity ($\$/m^2$)**	**EUI ($kBtu/ft^2yr$)**	**5-TLCC Intensity ($\$/ft^2$)**	**Percent Savings Difference (Perturbed – Low Energy)**
		Aperture					
		Overhangs	645	1,280	56.8	119	–0.5%
		Glazing Quantity	641	1,270	56.4	118	–0.1%
	Fabric	Infiltration	765	1,220	67.4	113	–9.7%
		Opaque Envelope Constructions	715	1,250	63.0	116	–5.9%
		Fenestration Constructions	646	1,270	56.9	118	–0.5%
	Equipment	Entire HVAC System	819	1,260	72.1	117	–13.9%
		Energy Recovery	791	1,270	69.6	118	–11.7%
		Rooftop Unit	710	1,270	62.5	118	–5.5%

Appendix C. Detailed End Use Data

Table C-1 Detailed End Uses, Absolute EUIs: Humid Climates

kBtu/ft^2		1A		2A		3A		4A		5A		6A	
		Base	50%	Base	50%	Base	50%	Base	50%	Base	50%	Base	50%
Low Plug	Heating:Gas	0.1	0.2	3.6	2.8	5.8	4.4	11.3	7.6	17.0	9.6	25.9	14.1
	Water Sys.:Elec.	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6
	Fans:Elec.	10.1	3.5	10.0	4.6	8.3	5.2	8.2	4.8	8.1	4.8	8.2	4.9
	Int. Equip.:Elec.	3.7	3.3	3.7	3.3	3.7	3.3	3.7	3.3	3.7	3.3	3.7	3.7
	Ext. Light:Elec.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Int. Light:Elec.	25.6	8.5	25.6	8.7	25.6	8.4	25.6	8.9	25.6	9.0	25.6	8.9
	Cooling:Elec.	20.2	8.8	13.8	4.8	7.8	3.1	6.3	2.2	4.9	1.8	4.4	1.9
	PV:Elec.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Med. Plug	Heating:Gas	0.1	0.1	2.7	2.2	3.9	2.6	7.6	1.9	11.6	2.4	19.1	3.8
	Water Sys.:Elec.	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6
	Fans:Elec.	11.9	4.2	11.8	4.0	10.2	3.8	10.0	5.3	10.0	5.6	10.1	5.9
	Int. Equip.:Elec.	17.2	15.5	17.2	15.5	17.2	15.5	17.2	15.5	17.2	15.5	17.2	15.5
	Ext. Light:Elec.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Int. Light:Elec.	25.6	8.3	25.6	8.1	25.6	8.1	25.6	8.5	25.6	8.7	25.6	8.9
	Cooling:Elec.	24.7	11.9	18.1	7.9	11.4	5.0	9.1	4.2	7.4	3.6	6.8	3.3
	PV:Elec.	0.0	-0.5	0.0	-0.3	0.0	-1.0	0.0	-1.0	0.0	-0.3	0.0	0.0
High Plug	Heating:Gas	0.0	0.1	1.8	1.2	2.3	1.9	4.8	3.2	7.5	2.6	12.9	3.4
	Water Sys.:Elec.	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6
	Fans:Elec.	13.4	5.0	13.3	4.8	11.7	4.7	11.5	4.5	11.4	6.5	11.5	6.4
	Int. Equip.:Elec.	34.5	25.2	34.5	31.1	34.5	25.2	34.5	25.2	34.5	25.2	34.5	25.2
	Ext. Light:Elec.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Int. Light:Elec.	25.6	8.3	25.6	8.3	25.6	8.1	25.6	8.5	25.6	8.7	25.6	8.6
	Cooling:Elec.	29.2	14.5	22.3	10.8	15.3	6.3	12.5	5.1	10.3	4.3	9.4	4.0
	PV:Elec.	0.0	-2.0	0.0	-7.7	0.0	-1.8	0.0	-2.5	0.0	-3.0	0.0	-1.1

Table C-2 Detailed End Uses, Percent of Total EUI: Humid Climates

Percentages		1A		2A		3A		4A		5A		6A	
		Base	50%	Base	50%	Base	50%	Base	50%	Base	50%	Base	50%
Low Plug	Heating:Gas	0.1	0.7	6.2	11.4	11.2	17.6	20.3	27.6	28.3	32.8	37.8	41.1
	Water Sys.:Elec.	0.5	1.3	0.7	1.6	0.9	1.8	0.9	1.8	0.9	1.8	0.8	1.7
	Fans:Elec.	16.8	14.0	17.4	18.5	15.9	20.7	14.7	17.5	13.5	16.5	11.9	14.3
	Int. Equip.:Elec.	6.1	13.2	6.4	13.2	7.0	13.1	6.5	12.0	6.1	11.2	5.3	10.6
	Ext. Light:Elec.	0.4	1.1	0.5	1.1	0.5	1.1	0.5	1.0	0.4	0.9	0.4	0.8
	Int. Light:Elec.	42.5	34.4	44.7	35.0	49.3	33.3	45.9	32.2	42.6	30.6	37.3	26.0
	Cooling:Elec.	33.5	35.2	24.1	19.4	15.1	12.4	11.2	7.9	8.2	6.2	6.5	5.6
	PV:Elec.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Med. Plug	Heating:Gas	0.1	0.2	3.5	5.8	5.7	7.4	10.8	5.5	16.0	6.5	24.0	9.9
	Water Sys.:Elec.	0.4	0.8	0.5	1.0	0.7	1.3	0.7	1.4	0.7	1.5	0.7	1.5
	Fans:Elec.	14.9	10.5	15.5	10.4	14.8	10.8	14.2	15.0	13.7	15.5	12.7	15.5
	Int. Equip.:Elec.	21.5	38.7	22.6	40.8	24.9	44.8	24.5	44.1	23.7	42.7	21.6	40.5
	Ext. Light:Elec.	0.3	0.7	0.4	0.7	0.4	0.8	0.4	0.8	0.4	0.7	0.3	0.7
	Int. Light:Elec.	32.0	20.7	33.7	21.3	37.1	23.3	36.4	24.2	35.3	24.0	32.2	23.3
	Cooling:Elec.	30.9	29.7	23.8	20.8	16.5	14.4	13.0	12.0	10.2	9.9	8.5	8.6
	PV:Elec.	0.0	-1.3	0.0	-0.8	0.0	-3.0	0.0	-2.9	0.0	-0.8	0.0	0.0
High Plug	Heating:Gas	0.0	0.1	1.9	2.4	2.6	4.1	5.4	7.1	8.3	5.8	13.6	7.2
	Water Sys.:Elec.	0.3	0.6	0.4	0.8	0.5	1.0	0.6	1.1	0.6	1.2	0.6	1.2
	Fans:Elec.	13.0	9.7	13.5	9.7	13.0	10.4	12.8	10.1	12.7	14.4	12.1	13.6
	Int. Equip.:Elec.	33.4	48.8	35.1	63.3	38.3	55.9	38.5	56.2	38.3	55.9	36.4	53.2
	Ext. Light:Elec.	0.3	0.5	0.3	0.5	0.3	0.6	0.3	0.6	0.3	0.6	0.3	0.6
	Int. Light:Elec.	24.8	16.1	26.1	16.8	28.4	17.9	28.5	19.0	28.4	19.3	27.0	18.2
	Cooling:Elec.	28.3	28.1	22.7	22.0	17.0	14.0	13.9	11.4	11.4	9.6	9.9	8.4
	PV:Elec.	0.0	-3.9	0.0	-15.6	0.0	-3.9	0.0	-5.5	0.0	-6.7	0.0	-2.3

Table C-3 Detailed End Uses, Absolute EUIs: Arid Climates

		1A		2A		3A		4A		5A		6A	
	kBtu/ft^2	Base	50%	Base	50%	Base	50%	Base	50%	Base	50%	Base	50%
Low Plug	Heating:Gas	2.2	3.6	1.2	2.5	3.0	3.0	6.6	4.6	11.0	7.4	18.7	10.0
	Water Sys.:Elec.	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6
	Fans:Elec.	11.6	3.6	7.2	2.8	9.6	5.3	9.4	5.3	9.2	5.1	8.7	4.8
	Int. Equip.:Elec.	3.7	3.3	3.7	3.3	3.7	3.3	3.7	3.3	3.7	3.3	3.7	3.7
	Ext. Light:Elec.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Int. Light:Elec.	25.6	8.9	25.6	8.6	25.6	8.9	25.6	8.7	25.6	8.9	25.6	9.1
	Cooling:Elec.	14.6	5.1	5.5	1.3	8.9	3.8	5.5	2.3	3.8	1.5	2.5	1.2
	PV:Elec.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Med. Plug	Heating:Gas	1.7	1.4	0.7	1.2	2.2	2.4	4.6	2.7	7.6	2.4	13.1	2.9
	Water Sys.:Elec.	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6
	Fans:Elec.	13.6	4.5	9.1	3.6	11.6	4.6	11.6	4.3	11.4	5.9	10.8	5.7
	Int. Equip.:Elec.	17.2	17.2	17.2	15.5	17.2	15.5	17.2	15.5	17.2	15.5	17.2	15.5
	Ext. Light:Elec.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Int. Light:Elec.	25.6	8.5	25.6	8.6	25.6	8.7	25.6	8.4	25.6	8.6	25.6	8.7
	Cooling:Elec.	18.7	7.7	9.1	2.8	11.5	5.6	7.6	3.4	5.6	2.7	3.8	2.0
	PV:Elec.	0.0	-1.2	0.0	-1.0	0.0	-2.9	0.0	-1.4	0.0	-1.8	0.0	0.0
High Plug	Heating:Gas	0.9	1.2	0.2	0.8	1.1	2.0	2.8	3.5	4.7	3.3	8.6	2.9
	Water Sys.:Elec.	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6
	Fans:Elec.	15.1	5.3	10.6	4.5	13.2	5.5	13.4	5.5	13.2	5.2	12.4	6.8
	Int. Equip.:Elec.	34.5	25.2	34.5	25.2	34.5	25.2	34.5	25.2	34.5	25.2	34.5	25.2
	Ext. Light:Elec.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Int. Light:Elec.	25.6	8.4	25.6	8.6	25.6	8.7	25.6	8.4	25.6	8.6	25.6	8.7
	Cooling:Elec.	22.8	9.2	12.6	4.9	14.0	7.1	9.8	4.6	7.5	3.5	5.1	2.8
	PV:Elec.	0.0	-0.2	0.0	-2.6	0.0	-4.6	0.0	-4.5	0.0	-3.6	0.0	-3.7

Table C-4 Detailed End Uses, Percent of Total EUI: Arid Climates

	Percentages	1A		2A		3A		4A		5A		6A	
		Base	50%	Base	50%	Base	50%	Base	50%	Base	50%	Base	50%
Low Plug	Heating:Gas	3.8	14.5	2.7	13.0	5.9	12.1	12.8	18.3	20.3	27.3	31.2	33.9
	Water Sys.:Elec.	0.6	1.4	1.0	2.3	0.8	1.6	1.0	2.0	1.0	2.0	1.0	2.0
	Fans:Elec.	19.9	14.3	16.5	14.5	18.6	21.3	18.2	21.4	17.0	18.7	14.4	16.1
	Int. Equip.:Elec.	6.3	13.1	8.3	17.1	7.1	13.1	7.1	13.2	6.8	12.2	6.1	12.4
	Ext. Light:Elec.	0.5	1.1	0.6	1.4	0.5	1.1	0.5	1.1	0.5	1.0	0.4	0.9
	Int. Light:Elec.	43.9	35.4	58.3	45.0	49.8	35.7	49.7	34.9	47.3	33.1	42.7	30.7
	Cooling:Elec.	25.0	20.2	12.5	6.6	17.3	15.1	10.7	9.2	7.1	5.7	4.2	4.1
	PV:Elec.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Med. Plug	Heating:Gas	2.1	3.6	1.2	3.7	3.2	6.9	6.8	8.1	11.1	7.1	18.4	8.1
	Water Sys.:Elec.	0.5	0.9	0.7	1.4	0.6	1.2	0.7	1.5	0.8	1.6	0.8	1.6
	Fans:Elec.	17.6	11.6	14.6	11.4	16.9	13.3	17.2	12.9	16.7	17.4	15.1	15.9
	Int. Equip.:Elec.	22.2	44.5	27.6	49.6	25.0	45.1	25.5	45.9	25.2	45.4	24.1	43.6
	Ext. Light:Elec.	0.3	0.7	0.4	0.9	0.4	0.8	0.4	0.8	0.4	0.8	0.4	0.8
	Int. Light:Elec.	33.1	21.9	41.0	27.4	37.2	25.2	38.0	24.9	37.5	25.3	35.9	24.4
	Cooling:Elec.	24.2	19.9	14.5	8.9	16.7	16.1	11.3	10.0	8.3	7.8	5.4	5.6
	PV:Elec.	0.0	-3.1	0.0	-3.2	0.0	-8.5	0.0	-4.1	0.0	-5.4	0.0	0.0
High Plug	Heating:Gas	0.9	2.4	0.2	2.0	1.2	4.4	3.2	8.1	5.4	7.7	9.9	6.6
	Water Sys.:Elec.	0.4	0.7	0.5	1.0	0.5	0.9	0.6	1.1	0.6	1.3	0.7	1.3
	Fans:Elec.	15.2	10.6	12.6	10.7	14.8	12.4	15.4	12.6	15.3	12.1	14.2	15.7
	Int. Equip.:Elec.	34.7	50.6	41.0	59.8	38.8	56.6	39.7	58.0	40.0	58.4	39.6	57.9
	Ext. Light:Elec.	0.3	0.5	0.3	0.6	0.3	0.6	0.3	0.6	0.3	0.6	0.3	0.6
	Int. Light:Elec.	25.7	16.9	30.4	20.4	28.8	19.4	29.5	19.3	29.7	20.0	29.4	20.0
	Cooling:Elec.	22.9	18.5	15.0	11.5	15.7	15.9	11.3	10.5	8.7	8.1	5.8	6.4
	PV:Elec.	0.0	-0.3	0.0	-6.1	0.0	-10.2	0.0	-10.4	0.0	-8.3	0.0	-8.5

Table C-5 Detailed End Uses, Absolute EUIs: Marine and Cold Climates

	kBtu/ft^2	3C		4C		7		8	
		Base	50%	Base	50%	Base	50%	Base	50%
Low Plug	Heating:Gas	3.9	4.3	9.2	6.0	32.4	6.0	59.8	17.2
	Water Sys.:Elec.	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7
	Fans:Elec.	7.0	3.7	7.4	4.1	7.9	4.0	7.6	3.8
	Int. Equip.:Elec.	3.7	3.3	3.7	3.3	3.7	3.3	3.7	3.7
	Ext. Light:Elec.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Int. Light:Elec.	25.6	8.8	25.6	9.5	25.6	14.7	25.6	14.8
	Cooling:Elec.	2.7	0.7	2.3	0.8	2.4	1.3	1.3	0.6
	PV:Elec.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Med. Plug	Heating:Gas	2.6	2.9	5.9	3.3	24.2	5.5	49.3	11.1
	Water Sys.:Elec.	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7
	Fans:Elec.	8.9	3.4	9.2	3.5	9.9	5.8	9.4	5.4
	Int. Equip.:Elec.	17.2	15.5	17.2	15.5	17.2	15.5	17.2	15.5
	Ext. Light:Elec.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Int. Light:Elec.	25.6	8.5	25.6	9.1	25.6	9.0	25.6	14.8
	Cooling:Elec.	4.9	1.6	3.9	1.5	4.2	2.4	2.7	2.0
	PV:Elec.	0.0	-2.6	0.0	-2.4	0.0	0.0	0.0	0.0
High Plug	Heating:Gas	1.1	2.4	3.4	2.4	16.4	3.8	37.6	6.8
	Water Sys.:Elec.	0.5	0.5	0.5	0.5	0.6	0.6	0.7	0.7
	Fans:Elec.	10.3	4.3	10.7	4.3	11.3	6.3	10.8	6.7
	Int. Equip.:Elec.	34.5	25.2	34.5	25.2	34.5	25.2	34.5	25.2
	Ext. Light:Elec.	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Int. Light:Elec.	25.6	8.5	25.6	9.1	25.6	8.7	25.6	14.7
	Cooling:Elec.	7.2	2.5	5.5	2.5	6.4	2.7	4.4	1.9
	PV:Elec.	0.0	-3.9	0.0	-4.1	0.0	0.0	0.0	0.0

Table C-6 Detailed End Uses, Percent of Total EUI: Marine and Cold Climates

Percentages		3C Base	3C 50%	4C Base	4C 50%	7 Base	7 50%	8 Base	8 50%
Low Plug	Heating:Gas	8.9	20.1	18.8	24.6	44.5	20.0	60.5	42.0
	Water Sys.:Elec.	1.1	2.3	1.1	2.2	0.9	2.1	0.7	1.7
	Fans:Elec.	16.1	17.2	15.1	16.6	10.9	13.1	7.7	9.3
	Int. Equip.:Elec.	8.4	15.3	7.5	13.5	5.0	10.9	3.7	8.9
	Ext. Light:Elec.	0.6	1.2	0.5	1.1	0.4	0.9	0.3	0.6
	Int. Light:Elec.	58.8	40.7	52.4	38.9	35.1	48.7	25.9	36.1
	Cooling:Elec.	6.1	3.2	4.7	3.2	3.2	4.3	1.3	1.4
	PV:Elec.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Med. Plug	Heating:Gas	4.4	9.5	9.4	10.5	29.5	14.0	46.9	22.3
	Water Sys.:Elec.	0.8	1.6	0.8	1.7	0.8	1.6	0.7	1.4
	Fans:Elec.	14.8	11.4	14.8	11.1	12.1	14.9	9.0	10.8
	Int. Equip.:Elec.	28.7	51.7	27.5	49.5	21.0	39.7	16.4	31.1
	Ext. Light:Elec.	0.4	0.9	0.4	0.9	0.3	0.7	0.3	0.5
	Int. Light:Elec.	42.7	28.2	40.9	29.2	31.2	23.1	24.3	29.7
	Cooling:Elec.	8.2	5.4	6.2	4.9	5.1	6.0	2.5	4.1
	PV:Elec.	0.0	-8.7	0.0	-7.8	0.0	0.0	0.0	0.0
High Plug	Heating:Gas	1.4	6.1	4.3	6.0	17.2	7.9	33.0	12.1
	Water Sys.:Elec.	0.6	1.2	0.7	1.3	0.7	1.3	0.6	1.3
	Fans:Elec.	13.0	10.9	13.3	10.7	11.9	13.3	9.5	11.9
	Int. Equip.:Elec.	43.4	63.4	42.9	62.6	36.3	53.0	30.3	44.8
	Ext. Light:Elec.	0.3	0.7	0.3	0.7	0.3	0.6	0.2	0.5
	Int. Light:Elec.	32.2	21.3	31.8	22.7	26.9	18.3	22.5	26.1
	Cooling:Elec.	9.0	6.2	6.8	6.2	6.8	5.6	3.9	3.4
	PV:Elec.	0.0	-9.8	0.0	-10.1	0.0	0.0	0.0	0.0

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This report provides recommendations that architects, designers, contractors, developers, owners, and lessees of medium box retail buildings can use to achieve whole-building energy savings of at least 50% over ASHRAE Standard 90.1-2004. The recommendations are given by climate zone and address building envelope, fenestration, lighting systems, HVAC systems, building automation and controls, outside air treatment, service water heating, plug loads, and photovoltaic systems. The report presents several paths to 50% savings, which correspond to different levels of integrated design. These are recommendations only, and are not part of a code or standard. The recommendations are not exhaustive, but we do try to emphasize the benefits of integrated building design, that is, a design approach that analyzes a building as a whole system, rather than as a disconnected collection of individually engineered subsystems.

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