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Technical Support Document: Development of the Advanced Energy Design Guide for Grocery Stores—50% Energy Savings

Technical Report
NREL/TP-550-42829
September 2008

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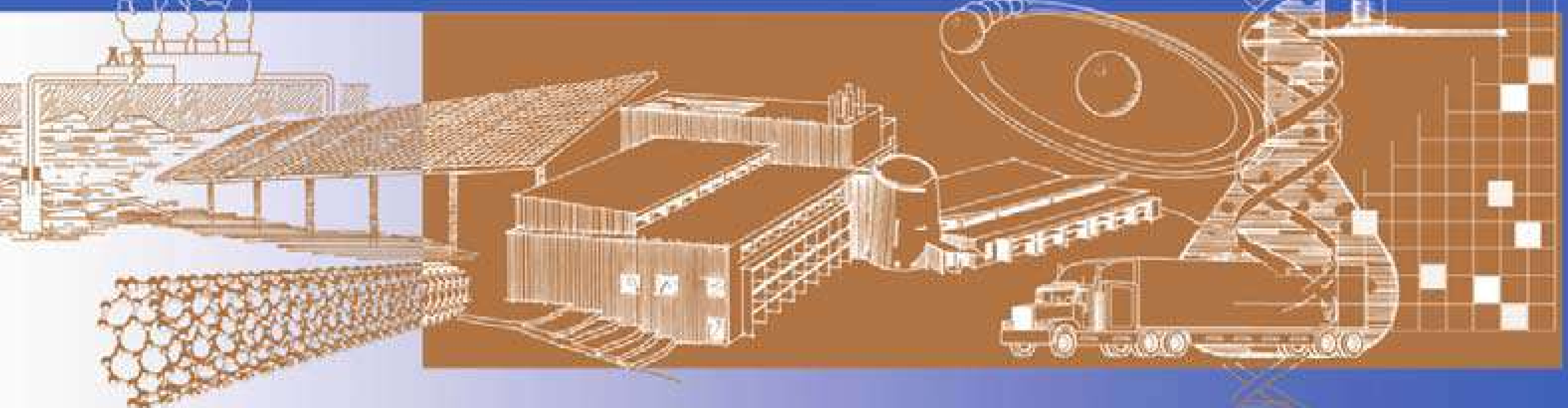

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A number of colleagues made this work possible. The authors greatly appreciate the assistance of Brent Griffith and the NREL EnergyPlus analysis and modeling team. Their simulation development and support allowed us to evaluate a number of energy efficiency technologies. We would also like to thank NREL's High Performance Computing Center's Wesley Jones and Jim Albin for their support in providing dedicated Linux cluster nodes for the large number of simulations needed for the analysis. Finally, we extend our thanks to those who helped edit and review the document: Stefanie Woodward, Michael Deru, and Ian Doebber (all of NREL).

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 grocery stores. It represents an initial step toward 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.
- Demonstrates sets of recommendations that meet, or exceed, the 50% goal. There are sixteen sets of recommendations, one for each climate zone location.

This technical support document (*TSD*), along with a sister document for medium box retail stores (Hale, Macumber 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 interorganizational 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 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 features not addressed by ASHRAE 90.1-2004) for typical grocery stores, thereby defining a prototype model.
- 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, 108,736 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. The prototype buildings are 45,000 ft^2, one-story rectangular buildings with a 1.5 aspect ratio. We assume 1,400 ft^2 of glazing on the façade, which gives a 27% window-to-wall ratio for that wall, and an 8% 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 nominal refrigerated case and walk-in cooler load is 973 kBtu/h (285 kW), split 68%/32% between medium and low temperature compressor racks, respectively. The EDMs considered in this work fall into the following categories:

- **Lighting technologies**. Reduced lighting power density (LPD), occupancy controls, and dayligthing controls.
- **Plug and process loads**. Reduced density.
- **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.
- **Refrigeration Equipment**. Higher efficiency refrigerated cases, and evaporatively cooled condensers.
- **Generation**. Photovoltaic (PV) electricity generation.

Findings

The results show that 50% net site energy savings can be achieved cost-effectively in grocery stores. Everywhere except Miami (climate zone 1A), buildings 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. The following energy design measures are recommended in all locations:

- Reduce LPD by 40%, and use occupancy sensors in the dry storage and office zones.
- Install efficient fans in all rooftop HVAC units.
- Replace all baseline frozen food and ice cream refrigerated cases with efficient vertical door models with hot gas defrost.
- Replace open multi-deck dairy/deli refrigerated cases with efficient vertical door models.

Three EDMs were not chosen for any location:

- Overhangs above the windows on the (south) façade.
- Infiltration reduction measures.
- Economizers.

Furthermore, skylights and increased amounts of window glazing were only used in Miami, and Miami was the only location without ERVs. We recognize that some of these findings are surprising, and that designing grocery store OA systems for energy recovery represents a significant deviation from current practice. Any future NREL grocery store studies will closely re-examine the model inputs associated with skylights, economizers, ERVs, and infiltration.

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; strategies to use waste heat from the refrigeration equipment; solar thermal technologies for service water heating and space conditioning; direct and indirect evaporative cooling; decreased pressure drop via improved duct design; secondary loop refrigeration; multiple compressor types; humidity control; under case HVAC return air; and state- or utility-specific rebate programs for PV.

Conclusions

This report finds that achieving 50% energy savings is possible for grocery stores in each climate zone in the United States. Reaching 50% is cost-effective for almost all stores; only in Miami does the low-energy model cost more than the baseline model. However, these findings depend on a willingness to put doors on a number of refrigerated cases—stores not willing to do this may be unable to reach high levels of energy efficiency cost effectively.

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	5-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
IESNA	Illuminating Engineering Society of North America
LPD	lighting power density
NREL	National Renewable Energy Laboratory
OA	outside air
O&M	operations and maintenance
OMB	Office of Management and Budget
PSZ	A package single zone DX rooftop unit
PV	photovoltaic
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
WWR	window-to-wall ratio
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 grocery store 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, commercial refrigeration and kitchen equipment, 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, Brandmuehl et al. 2006; Jarnagin, Watson 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, AIA et al. 2004; ASHRAE, AIA et al. 2006; Jarnagin, Liu et al. 2006; Liu, Jarnagin et al. 2006; Liu, Jarnagin et al. 2007; Pless, Torcellini et al. 2007; ASHRAE, AIA et al. 2008; ASHRAE, AIA 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, Long et al. 2007).
- The K-12 *AEDG TSD* describes a middle school design that achieves 50% savings (Pless, Torcellini 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 grocery stores 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 examples 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 medium box retail (Hale, Macumber et al. 2008). This work should reach its intended audience of architects, designers, contractors, developers, owners and lessees of grocery stores, 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 unregulated loads.
- **Develop recommendations that can assist a range of interested parties**. 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 grocery store characteristics.
3. Develop the baseline EnergyPlus grocery store models, one for each climate zone location.
4. Develop a list of EDMs that can be applied to the baseline models.
5. Present EnergyPlus grocery store models that achieve 50% savings over ASHRAE 90.1-2004.
6. Propose a formulation and analysis procedure for 50% AEDGs.
7. Discuss EDMs recommended for future studies.

1.2 Scope

This document provides recommendations and design assistance to designers, developers, and owners of grocery stores that will encourage steady progress toward net ZEBs. To ease the burden of the design and construction of energy-efficient retail stores, it describes a set of designs that reach the 50% energy savings target for each climate zone. The recommendations and discussion apply to grocery stores between 25,000 and 65,000 ft^2, with about 750 ft of refrigerated cases and 500 ft of walk-in coolers and freezers.

The *TSD* is not intended to substitute for rating systems or other references that address the full range of sustainable issues in grocery 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 grocery 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 grocery store designs that achieve 50% energy savings over ASHRAE 90.1-2004. Secondarily, we seek designs that are cost effective over a five-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 given 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, Brandmuehl et al. 2006; Liu, Jarnagin 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.

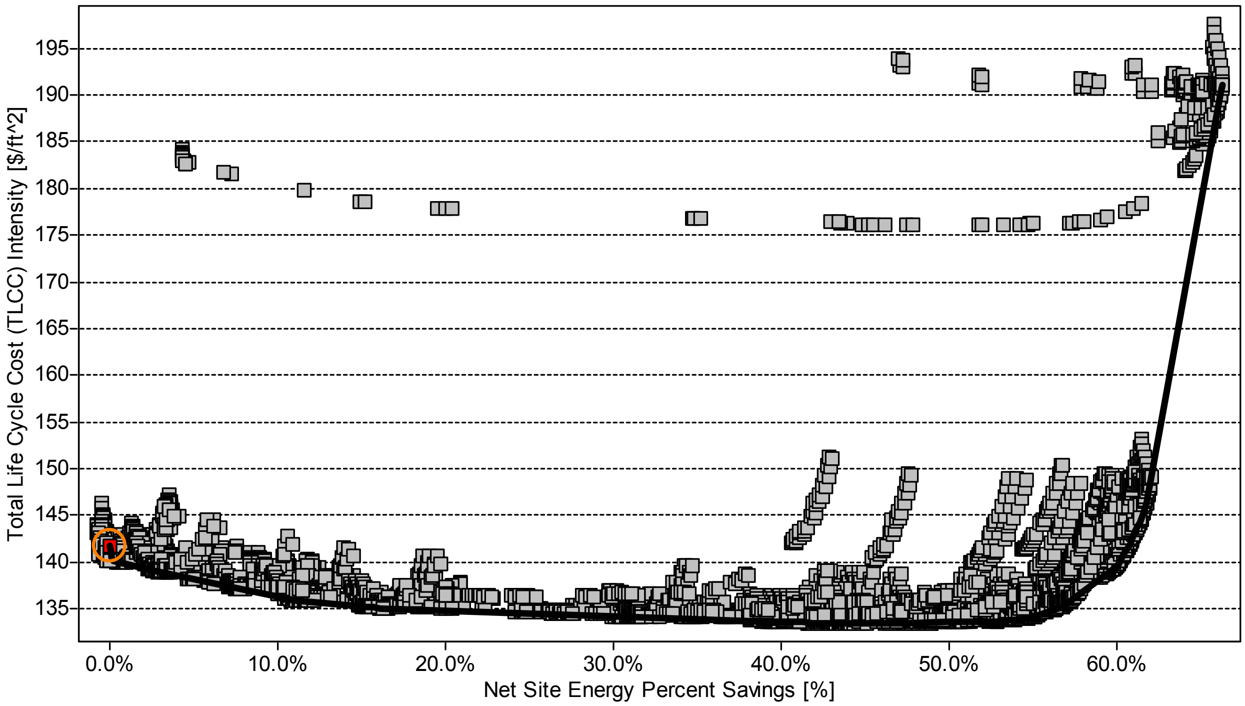

Figure 2-1 Example Opt-E-Plus Output

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 3.3 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 of 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 5,500 to 8,000 simulations, and each simulation took 5 to 10 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 models are 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.

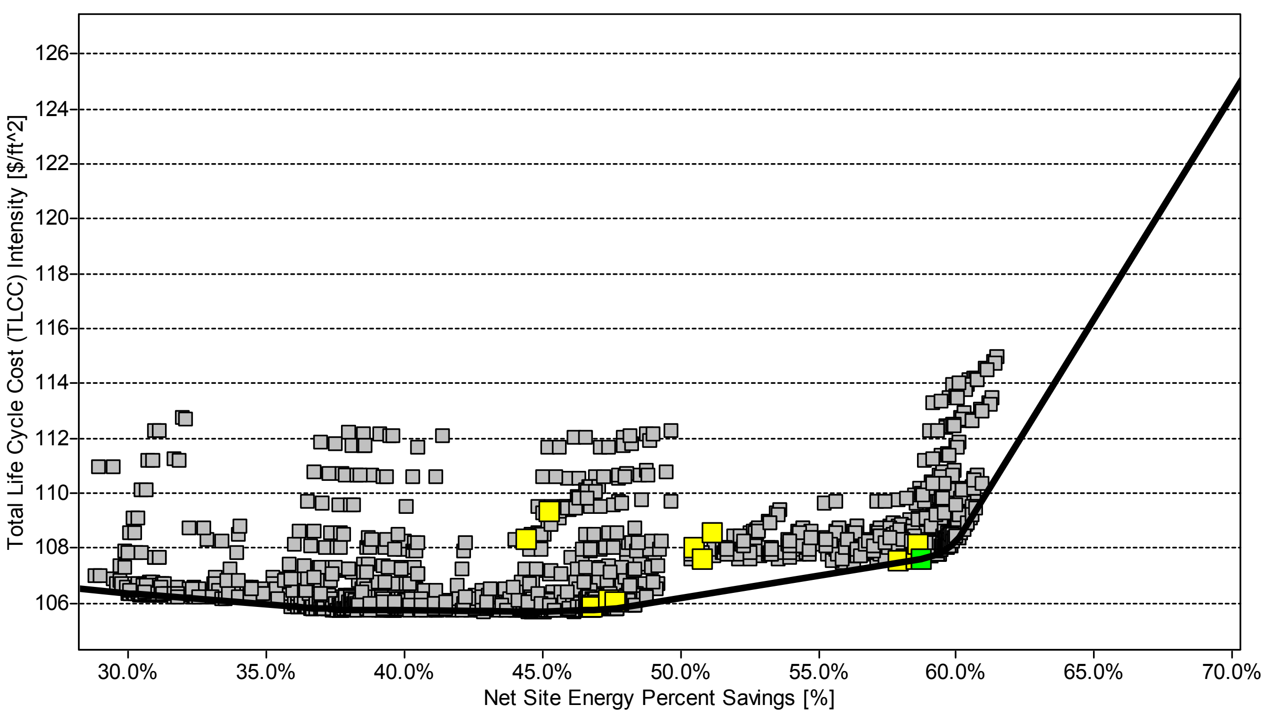

Figure 2-2 A Pareto Point that Achieves 50% Savings without PV

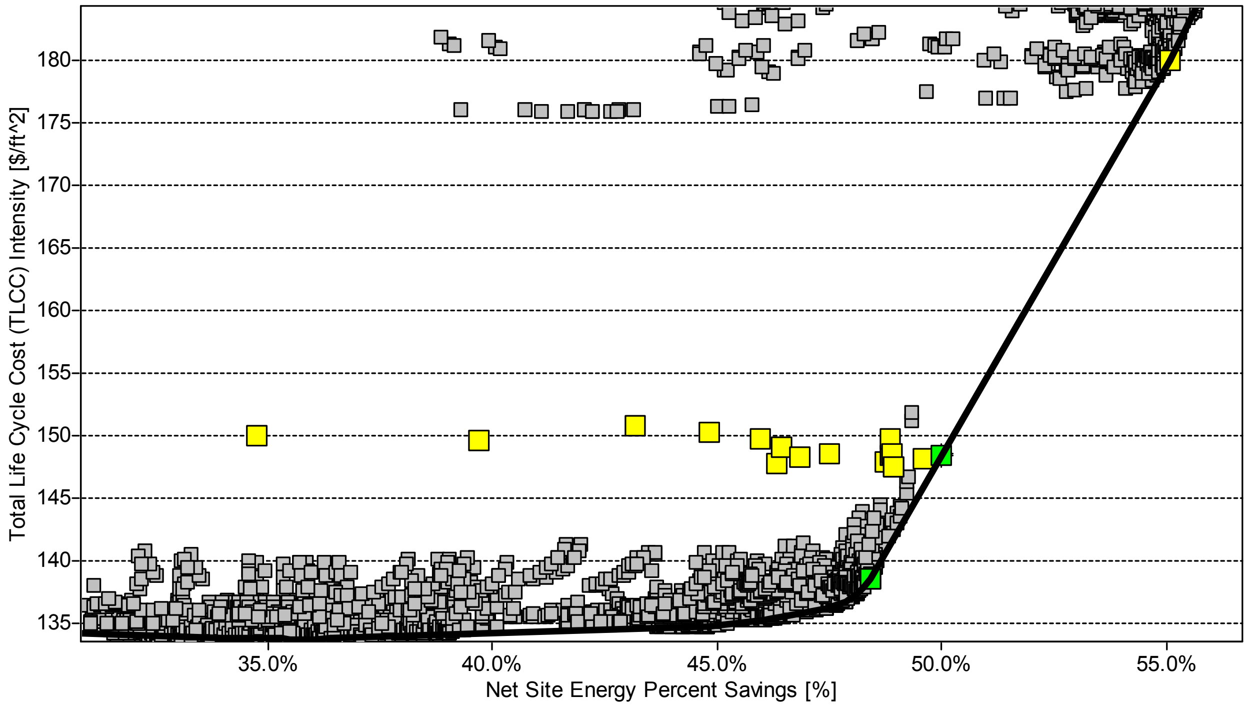

Figure 2-3 A Pareto Point with the Amount of PV Perturbed to Just Reach 50% Energy Savings

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 features not addressed by ASHRAE 90.1-2004) for typical grocery stores, thereby defining a prototype model.
2. Create baseline energy models for each climate zone that are elaborations of the prototype models and are minimally compliant with ASHRAE 90.1-2004.
3. Create a list of perturbations (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, Pless et al. 2006). Each metric has advantages and disadvantages in calculation and interpretation, and each favors different technologies and fuel types. The grocery store *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 used 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 did not limit our recommendations to the regulated loads, as was done in the 30% AEDGs.

2.3.3 ASHRAE Baseline

This report is intended to help owners and designers of grocery 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, Liu et al. 2006; Liu, Jarnagin et al. 2006; Pless, Torcellini 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 *AEDGs* 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 3-2. 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).

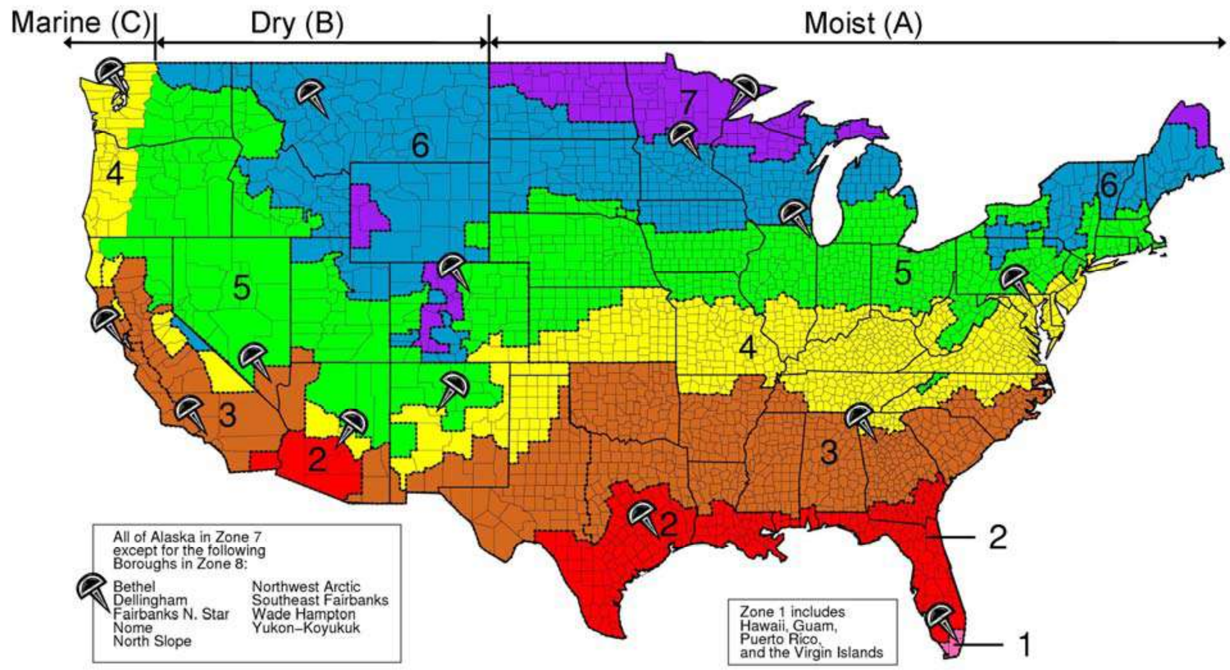

Figure 2-4 DOE Climate Zones and Representative Cities

To provide a concrete basis for analysis, the 16 specific locations (cities) used in the Benchmark Project (Deru, Griffith et al. 2008) are designated as representatives of their climate zones. The cities are marked in Figure 3-2 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 grocery store, and uses them to develop a high-level, prototype model. 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 grocery store characteristics and obtain estimates of grocery store energy performance. These include:

- *2003 Commercial Buildings Energy Consumption Survey* (*CBECS*) (EIA 2005)
- *DOE Commercial Building Research Benchmarks for Commercial Buildings* (Deru, Griffith et al. 2008)
- *Energy Savings Potential for Commercial Refrigeration Equipment* (Westphalen, Zogg et al. 1996)
- *Methodology for Modeling Building Energy Performance Across the Commercial Sector* (Griffith, Long et al. 2008)

After a brief description of each data source, the reasoning behind the prototype model assumptions is described in several functional groupings. The grocery store prototype models 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 grocery store 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 *2003 CBECS* statistics in this *TSD* are weighted by the aforementioned weighting factors multiplied by floor area.

The *2003 CBECS* includes 63 grocery stores/food markets, which represent 85,984 buildings and 715 million ft^2 (66.4 million m^2) of floor area nationwide (1% of the total area represented by the *2003 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 grocery stores 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 *2003 CBECS* grocery stores by year of construction is shown in Figure 3-1. The portion built since 1970 consists of 30 survey buildings representing 398 million ft^2 (37 million m^2) of floor area.

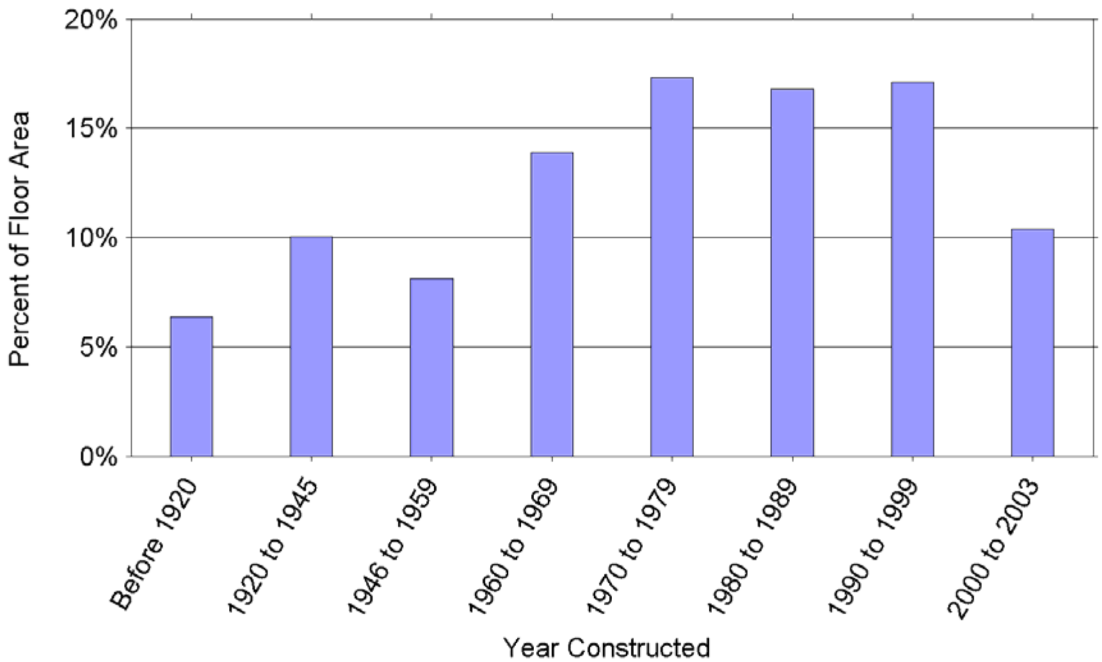

Figure 3-1 Area-Weighted Histogram of Grocery Store Vintage

3.1.1.2 DOE Commercial Building Research Benchmarks for Commercial Buildings

Concurrently with this TSD, DOE developed a new generation of subsector-specific benchmark building models (Deru, Griffith et al. 2008). Many aspects of our prototype model are derived from the benchmark supermarket model; we also collaborated with the benchmark project team.

3.1.1.3 Energy Savings Potential for Commercial Refrigeration Equipment

The benchmark supermarket model refrigeration system, and therefore the system modeled in this report, is largely based on a 1996 report prepared for the DOE Office of Building Technologies by Arthur D. Little, Inc. (Westphalen, Zogg et al. 1996). The size of the benchmark model's system (number of compressor racks, number of and type of cases) and the efficiency of the compressor racks were developed from the example grocery store presented in that report.

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, Long 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.

3.1.2 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

The size distribution of grocery stores built since 1970, according to the *2003 CBECS*, is shown in Figure 3-2. The labels correspond to bin maxima. There are just 30 *CBECS* grocery stores built since 1970. Nonetheless, those buildings are most representative of the new construction we are trying to influence, and thus are the sole basis of the *CBECS* statistics presented in the remainder of this report.

Our prototype store is 45,000 ft^2 (4,181 m^2), a size that lies between the area-weighted mean and median of the 2003 *CBECS* post-1970 grocery stores, and matches that of the benchmark supermarket.

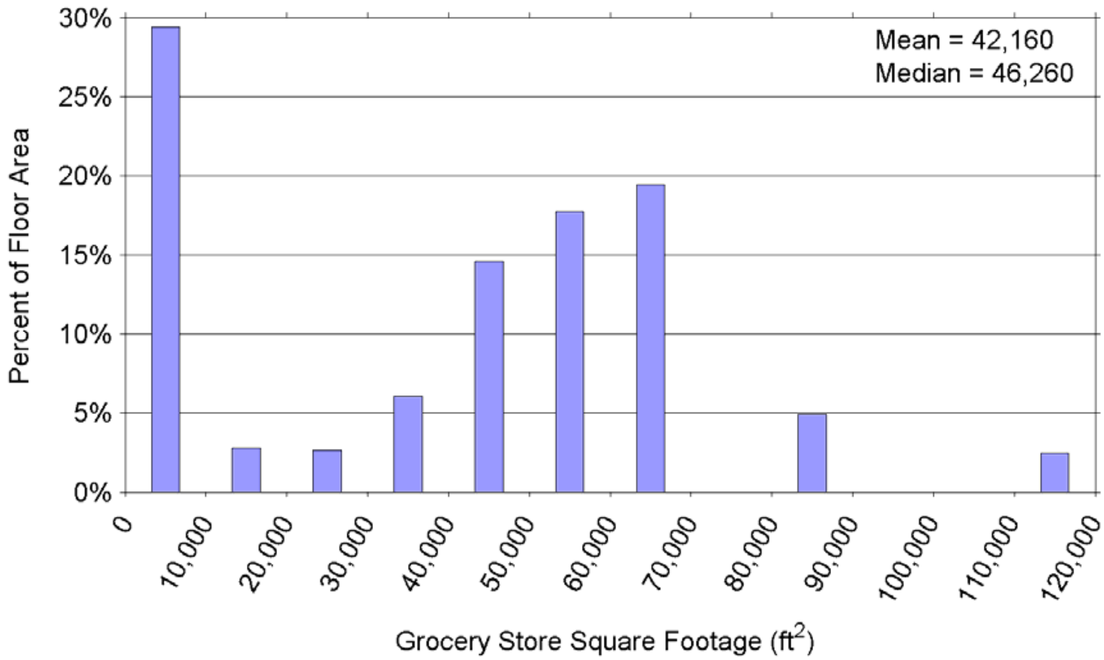

Figure 3-2 Area-Weighted Histogram of Post-1970 Grocery Store Size

3.1.2.2 Zones and Space Types

This project adopts most aspects of the benchmark project supermarket model (Deru, Griffith et al. 2008). That work states that the geometry and thermal zones were originally set by LBNL; NREL updated the model to reflect the larger supermarket sizes common in new construction. The layout contains six zones, whose names and sizes are shown in Table 3-1.

Table 3-1 Benchmark Project Supermarket Zones

Zone Name	Floor Area (ft^2)	Floor Area (m^2)	Percent of Total
Sales	25,029	2,325	56
Produce	7,658	711.5	17
Deli	2,419	224.7	5
Bakery	2,251	209.1	5
Dry Storage	6,694	621.9	15
Office	956	88.8	2
Total	45,000	4,181	100

3.1.2.3 Internal Load Densities and Schedules

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

3.1.2.3.1 Operating Hours

Two of the 30 post-1970 grocery stores in the *2003 CBECS* were vacant for three or more months during the survey year. These buildings are excluded from the reported statistics concerning operating characteristics, such as those discussed in this section.

More than 80% of the floor area represented by the 28 stores that were open for the entire survey year is in stores that are not operated 24 hours per day. Only 4% of the area is in stores that are not open every weekday, and all of the stores have weekend operating hours. The distribution of operating hours per week is shown in Figure 3-3.

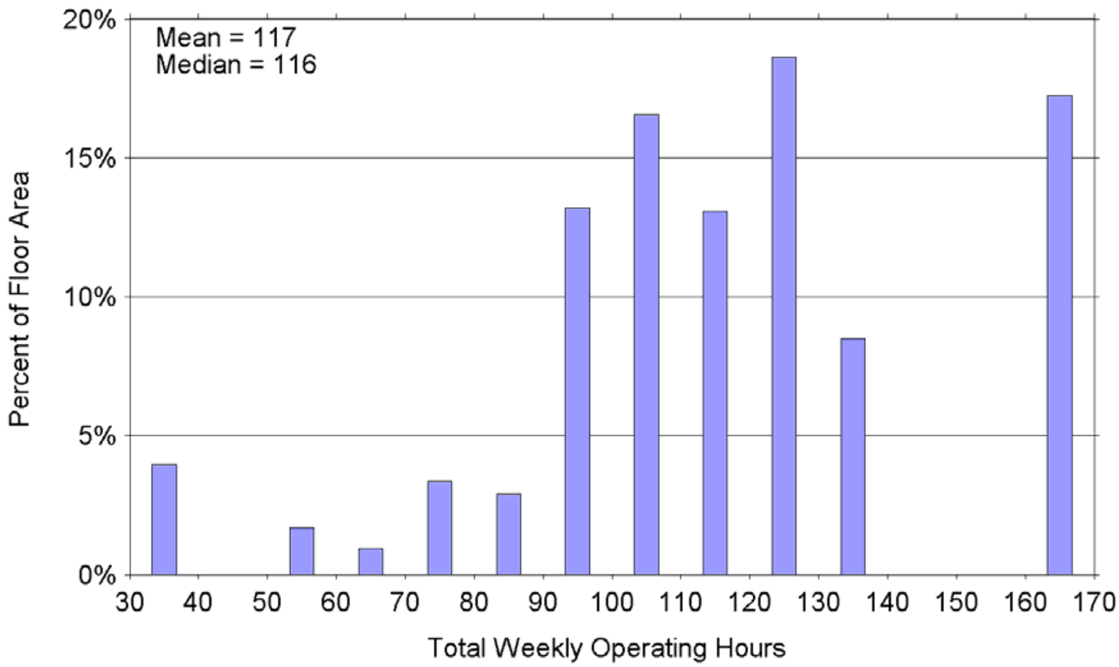

Figure 3-3 Area-Weighted Histogram of Post-1970 Grocery Store Weekly Operating Hours

As of this writing, the benchmark grocery store follows a 100 hours per week operating schedule: Monday through Friday 6:00 a.m. to 9:00 p.m.; Saturday, 6:00 a.m. to 10:00 p.m.; and Sunday, 8:00 a.m. to 5:00 p.m. To better match the *CBECS* data, we will assume open hours of 6:00 a.m. to 10:00 p.m. Sunday through Thursday and 6:00 a.m. to 12:00 a.m. Friday and Saturday, for a total of 116 hours per week.

3.1.2.3.2 Occupancy

The *2003 CBECS* provides little information about occupancy levels in grocery stores. It does report the number of employees during the main shift, however. Figure 3-4 shows those statistics normalized by building floor area.

ASHRAE Standard 62 lists peak occupant density in supermarkets as 8 people per 1,000 ft^2, whereas the Standard 90.1-2004 User's Manual does not provide any grocery store-specific guidelines. This work therefore assumes a peak density of 8 people/1000 ft^2 (8.61 people/100 m^2).

The benchmark grocery store has a peak people density of 3.34 people/1000 ft^2 (3.59 people/100 m^2), and uses the ASHRAE 90.1-1989 retail occupancy schedule.

Here we adapt the schedule developed for the medium box retail *TSD*, which is a blend of ASHRAE 90.1-1989 and the schedule developed for the small retail *TSD* (Hale, Macumber et al. 2008). We assume that there are one-hour transitional times before and after closing during which just staff is present, except Friday and Saturday evening, when the store is open until midnight. The schedule is listed in Table 3-2. The occupancy level before and after closing, 0.05, corresponds to 0.40 people/1000 ft^2 (0.43 people/100 m^2), which is a bit low compared to the main shift employee density reported by the *2003 CBECS*, but is reasonable if a reduced number of employees are present for opening and closing.

Figure 3-4 Area-Weighted Histogram of Post-1970 Grocery Store Employee Density

Table 3-2 Prototype Store Occupancy Schedule, in Fraction of Peak Occupancy

Hour	Monday through Thursday	Fridays and Saturdays	Sundays and Holidays
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0.05	0.05	0.05
7	0.10	0.10	0.10
8	0.10	0.10	0.10
9	0.10	0.10	0.10
10	0.20	0.20	0.10
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	0.30
19	0.30	0.60	0.30
20	0.30	0.40	0.20
21	0.20	0.40	0.10
22	0.10	0.20	0.10
23	0.05	0.10	0.05
24	0	0.10	0

3.1.2.3.3 Lighting

The *2003 CBECS* data indicate that almost no post-1970 grocery stores have independent lighting controls or sensors. However, all the surveyed grocery stores stated that an energy management control ballast fixtures. Figure 3-5 and Figure 3-6 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* sets lighting levels to 15% during unoccupied hours, 50% when only staff is present, and 95% during open hours.

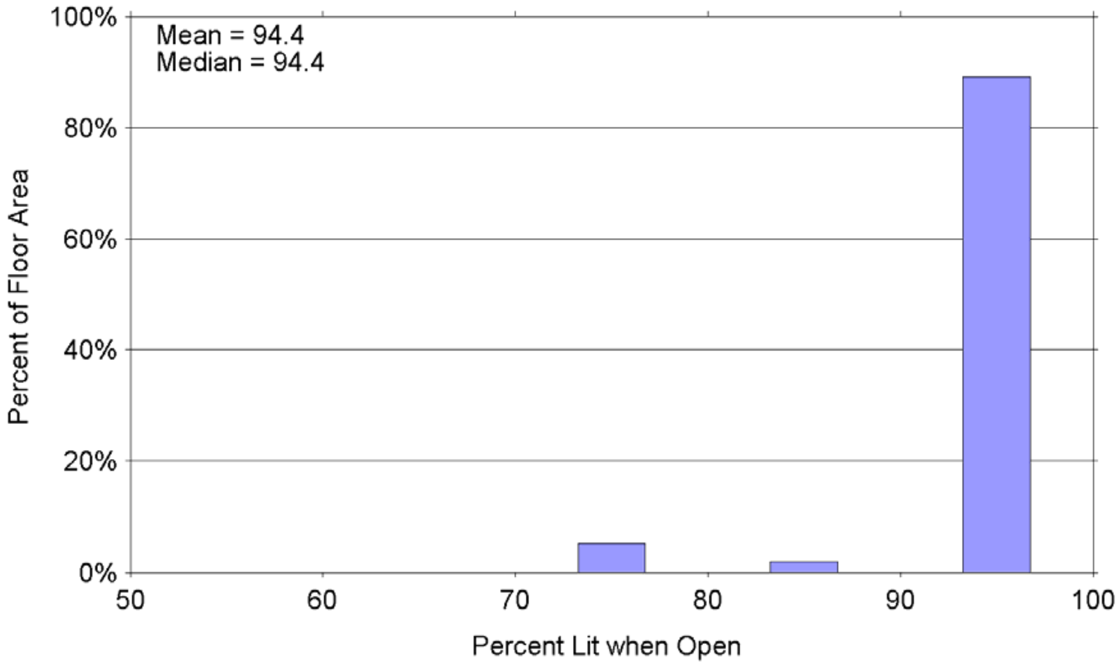

Figure 3-5 Area-Weighted Histogram of Post-1970 Grocery Store Open Hours Lighting Percentage

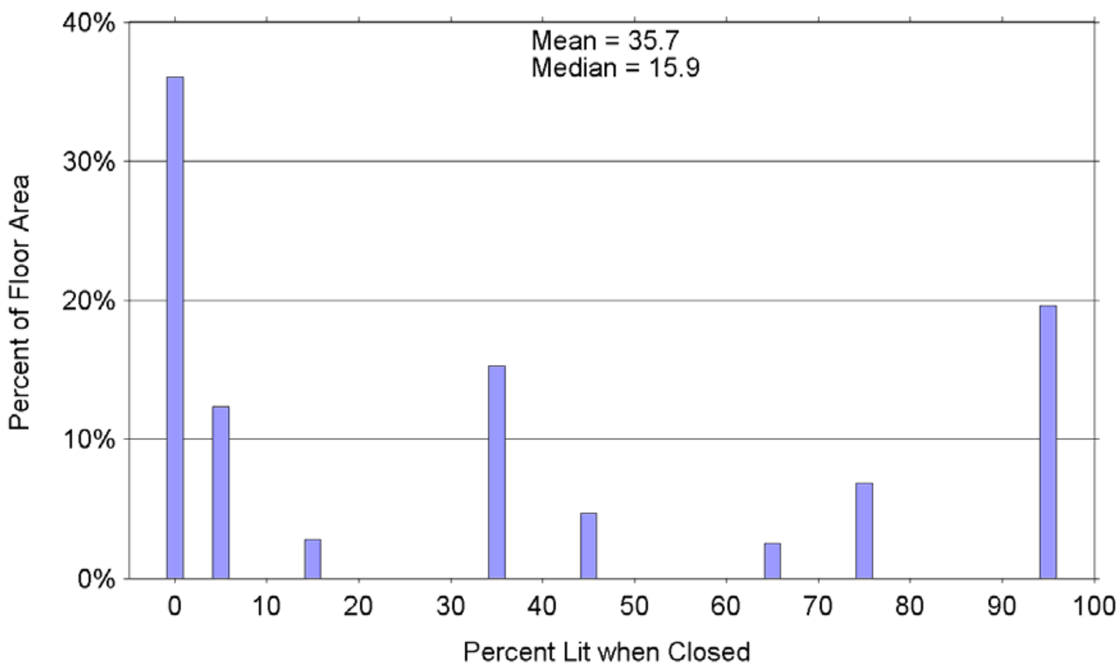

Figure 3-6 Area-Weighted Histogram of Post-1970 Grocery Store Closed Hours Lighting Percentage

3.1.2.3.4 Plug and Process Loads

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 electric plug load of 0.480 W/ft^2 (5.13 W/m^2) in the *2003 CBECS* grocery store models (with little variation—the loads ranged from 0.474 to 0.482 W/ft^2 [5.10 to 5.19 W/m^2]). The gas process loads for those buildings correspond to the EUI reported by the CEUS survey and were 0.35 W/ft^2 (3.74 W/m^2) operating on a constant, always on schedule.

The benchmark study has higher average electric and gas plug loads: 0.884 W/ft^2 (9.52 W/m^2) and 0.384 W/ft^2 (4.14 W/m^2), respectively. We use the benchmark study plug and process loads, since that study carefully modeled commercial kitchens. Similarly, we use their revised plug load schedules, updated for our operating hours (Deru, Griffith et al. 2008). The peak plug and process loads are listed by zone in Table 3-3. The plug load schedule is in Table 3-4.

Table 3-3 Peak Plug and Process Loads

Zone Name	Peak Electric Plug Load (W/ft^2)	Peak Electric Plug Load (W/m^2)	Peak Gas Process Load (W/ft^2)	Peak Gas Process Load (W/m^2)
Sales	0.50	5.4	0.0	0.0
Produce	0.50	5.4	0.0	0.0
Deli	5.0	54	2.5	27
Bakery	2.5	27	5.0	54
Dry Storage	0.75	8.1	0.0	0.0
Office	0.75	8.1	0.0	0.0
Average	0.88	9.5	0.38	4.1

Table 3-4 Plug and Process Load Schedule, in Fraction of Peak Load

Hour	Monday through Thursday	Fridays and Saturdays	Sundays and Holidays
1	0.20	0.15	0.15
2	0.20	0.15	0.15
3	0.20	0.15	0.15
4	0.20	0.15	0.15
5	0.20	0.15	0.15
6	0.20	0.15	0.15
7	0.40	0.30	0.30
8	0.40	0.30	0.30
9	0.70	0.50	0.30
10	0.90	0.80	0.30
11	0.90	0.90	0.60
12	0.90	0.90	0.60
13	0.90	0.90	0.80
14	0.90	0.90	0.80
15	0.90	0.90	0.80
16	0.90	0.90	0.80
17	0.90	0.90	0.80
18	0.90	0.90	0.60
19	0.80	0.70	0.40
20	0.80	0.50	0.40
21	0.70	0.50	0.40
22	0.40	0.30	0.40
23	0.20	0.30	0.15
24	0.20	0.30	0.15

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 3-7), the 45,000 ft^2 (4,181 m^2) prototype grocery store is a one-story rectangular building. The aspect ratio, footprint, and floor-to-floor height match those of the benchmark supermarket model: 1.5, 259.8 ft × 173.2 ft (79.2 m × 52.8 m), and 20 ft, respectively. The ceiling height is also 20 ft—there is no drop ceiling or plenum.

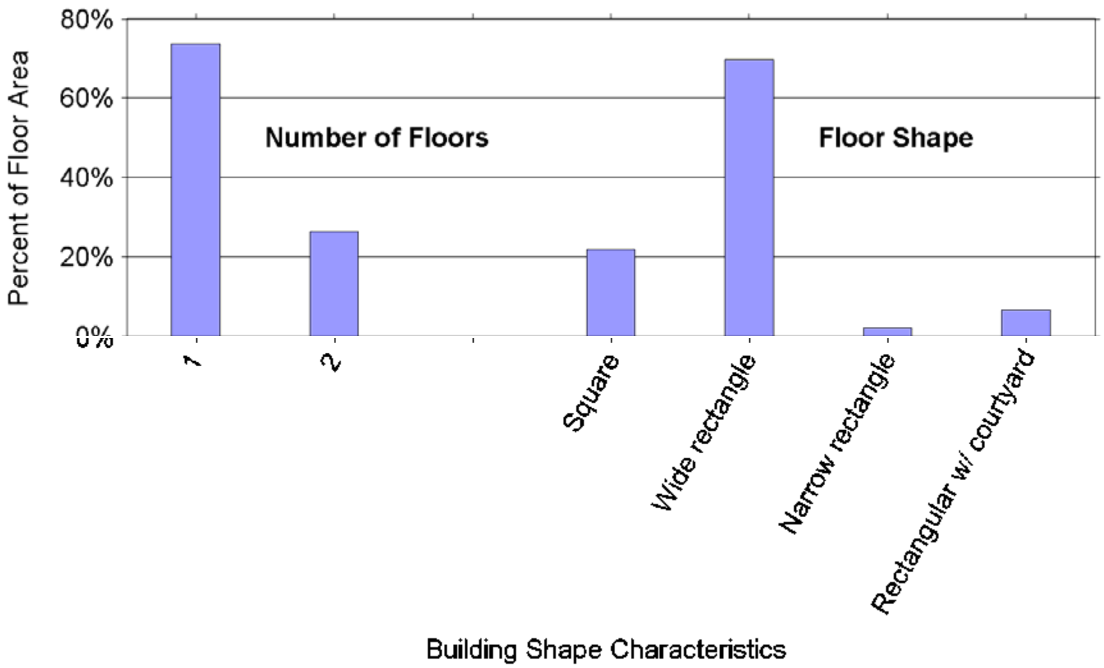

Figure 3-7 Area-Weighted Histogram of Post-1970 Grocery Store Shape Characteristics

3.1.3.2 Fenestration

The *2003 CBECS* reports on several aspects of fenestration form. Statistics on the amount and distribution of windows in grocery stores are shown in Figure 3-8; Figure 3-9 gives statistics on window shading (with awnings or overhangs), skylights, and what percentage of individual stores' floor area is daylit. These data indicate that our prototype store should have 10% or less of its wall area glazed. Based on experience, all the glazing is on the façade. Awnings and overhangs are common, but not dominant, and so they are not included in the prototype. The baseline store does not include skylights or daylighting controls.

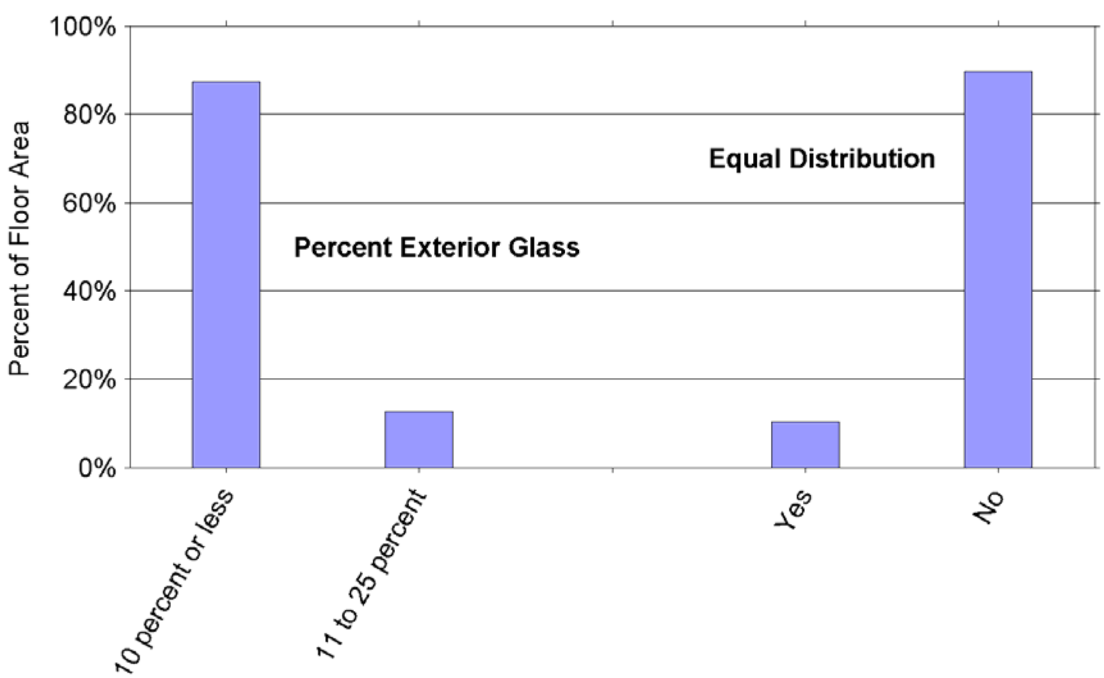

Figure 3-8 Area-Weighted Histograms of Post-1970 Grocery Store Fenestration Amounts

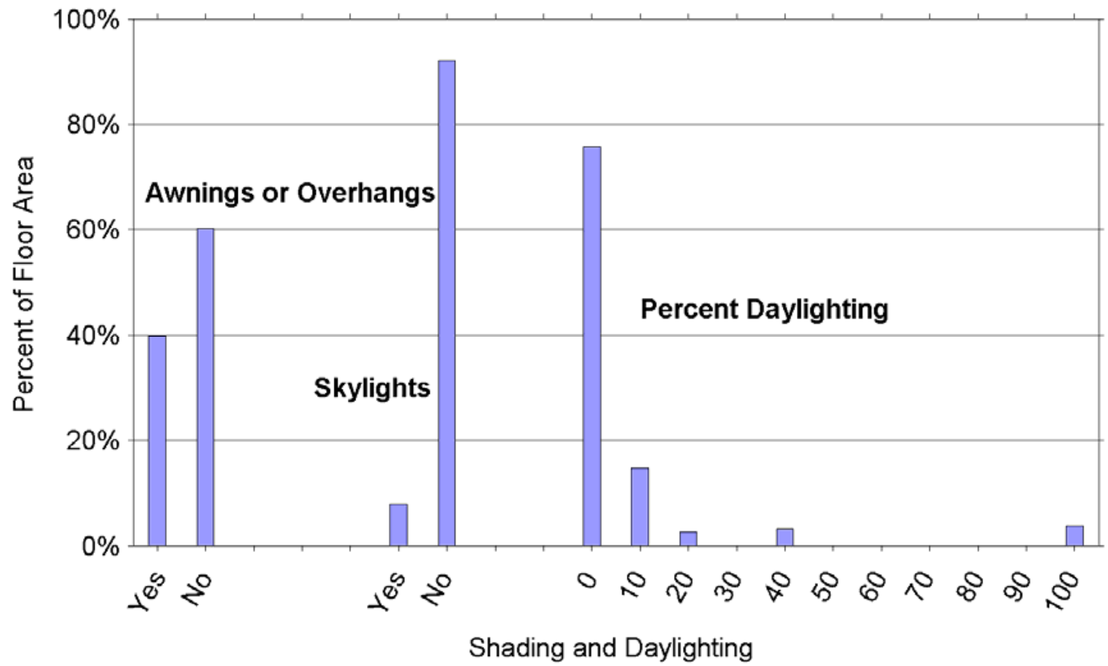

Figure 3-9 Area-Weighted Histogram of Post-1970 Grocery Store Sunlight Management

The benchmark study supermarket has 1,880 ft^2 (174 m^2) of glazing on the façade, for a total window-to-wall ratio (WWR) of 11%. This is slightly larger than what is supportable by *CBECS*, so this work uses an 8% WWR, that is 1,400 ft^2 (130 m^2) of glazing.

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 3-10. The prototype building has masonry wall construction (which includes brick, stucco, and the two concrete constructions) and a roof with all insulation above deck (which includes the built-up and plastic/rubber/synthetic sheeting categories).

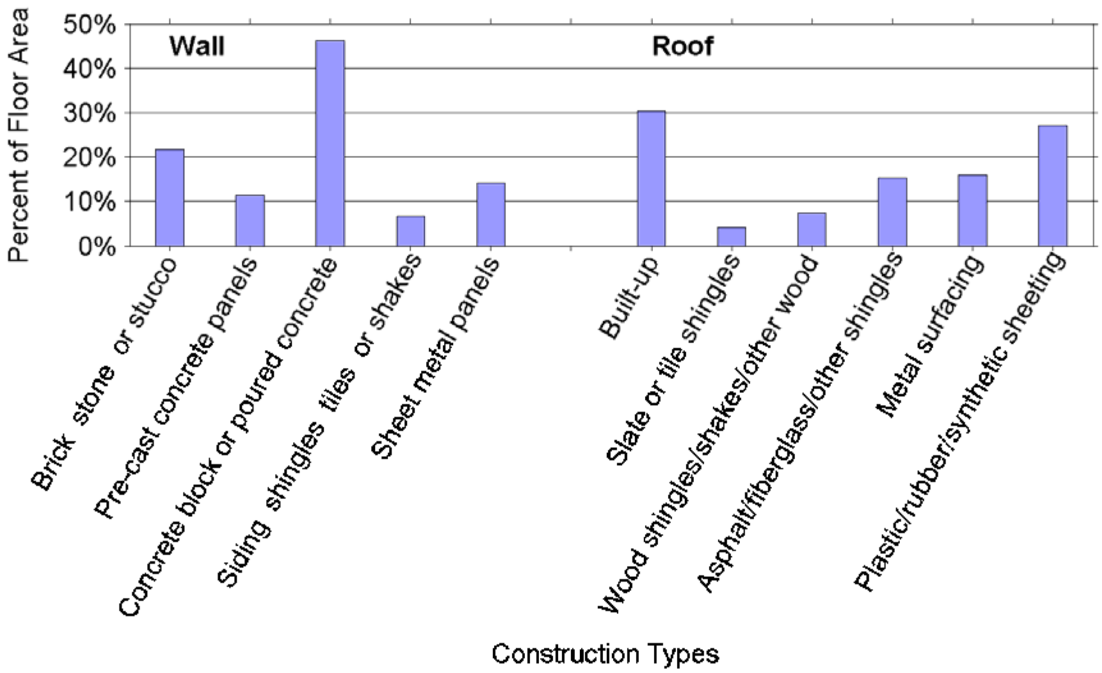

Figure 3-10 Area-Weighted Histograms of Post-1970 Grocery Store Construction Types

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 90,000 ft^2 (8,361 m^2) of 6-in. (0.15-m) thick wood.

3.1.5 Equipment

This section specifies the types of HVAC, refrigeration and service water heating equipment used in the prototype and baseline models. Performance and cost data are discussed in Sections 3.2.5, 3.2.6, and 3.2.7.

3.1.5.1 Heating, Ventilating, and Air-Conditioning

According to the *2003 CBECS*, all stores have some heating and all but 2.8% of floor area has some cooling. More than 80% of floor area is in stores that are 100% heated; about 32% of floor area is in stores that are 100% cooled (78% is in stores that are at least 70% cooled). We therefore assume that the prototype is fully heated and cooled.

Figure 3-11 summarizes the *2003 CBECS* statistics on what types of heating and cooling equipment are used in grocery stores. All cooling is electric; the types of fuel used for heating are shown in Figure 3-12. Most stores (about 73% 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 (DX) coils with air-cooled condensers for cooling. The units do not have variable air volume (VAV) systems because *CBECS* reports that only 24% of grocery store floor area uses them. Economizers are applied as per Standard 90.1-2004.

Most stores (more than 60% of the floor area) do not attenuate their heating or cooling set points over the course of a day, see Figure 3-13. We therefore set the HVAC schedule to always-on.

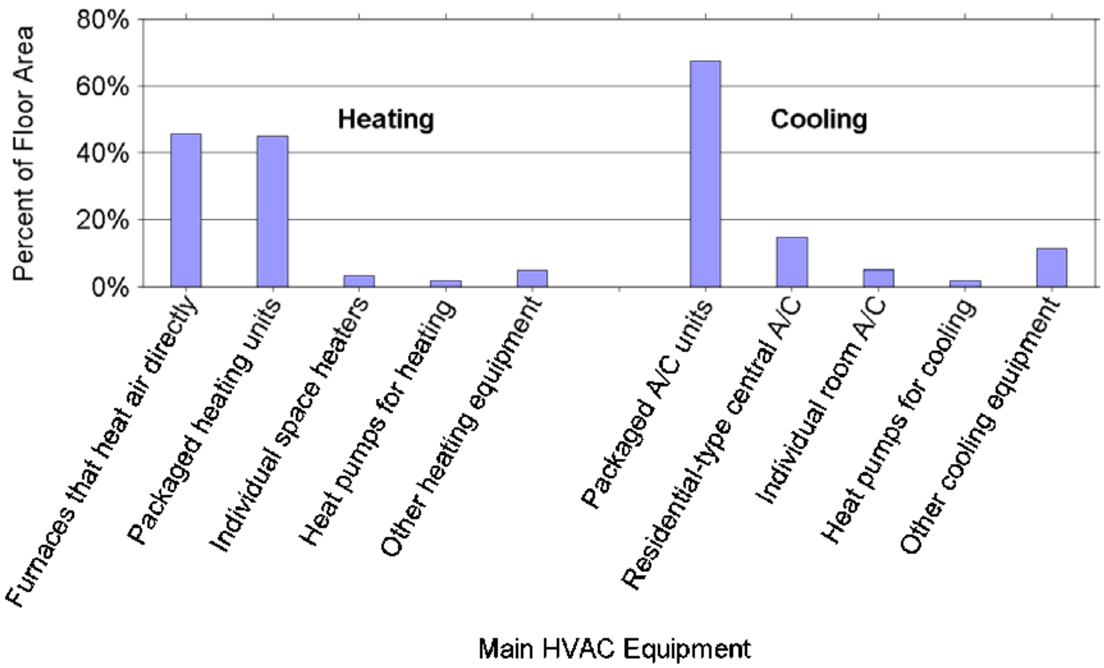

Figure 3-11 Area-Weighted Histogram of Post-1970 Grocery Store Heating and Cooling Equipment

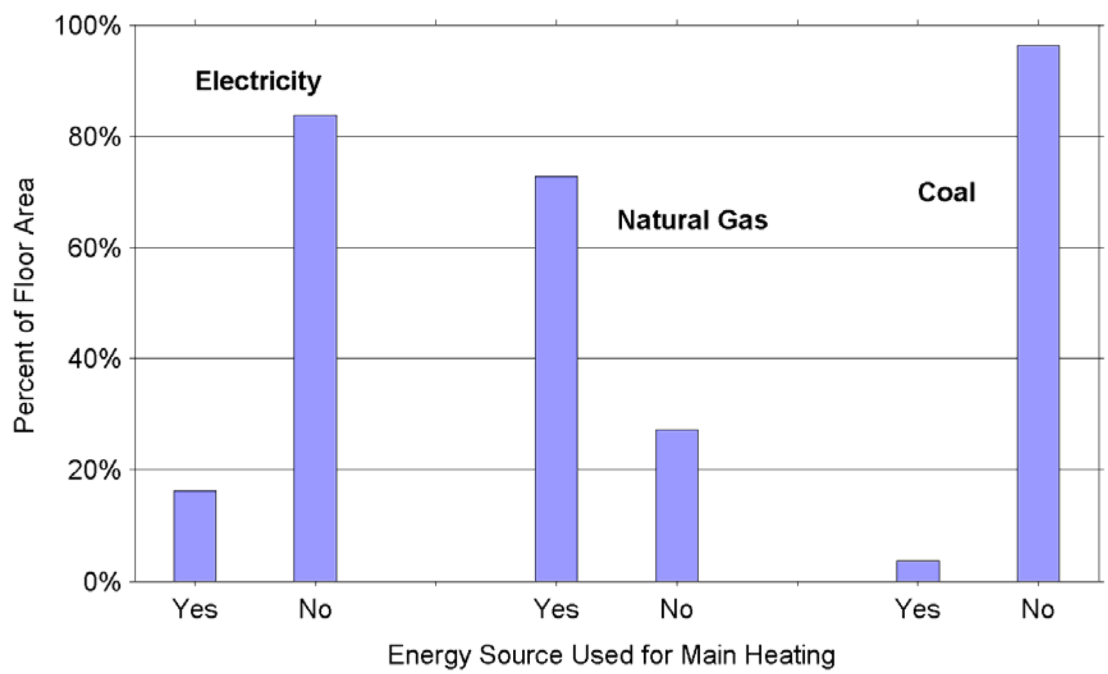

Figure 3-12 Area-Weighted Histogram of Post-1970 Grocery Stores Main Heating Source

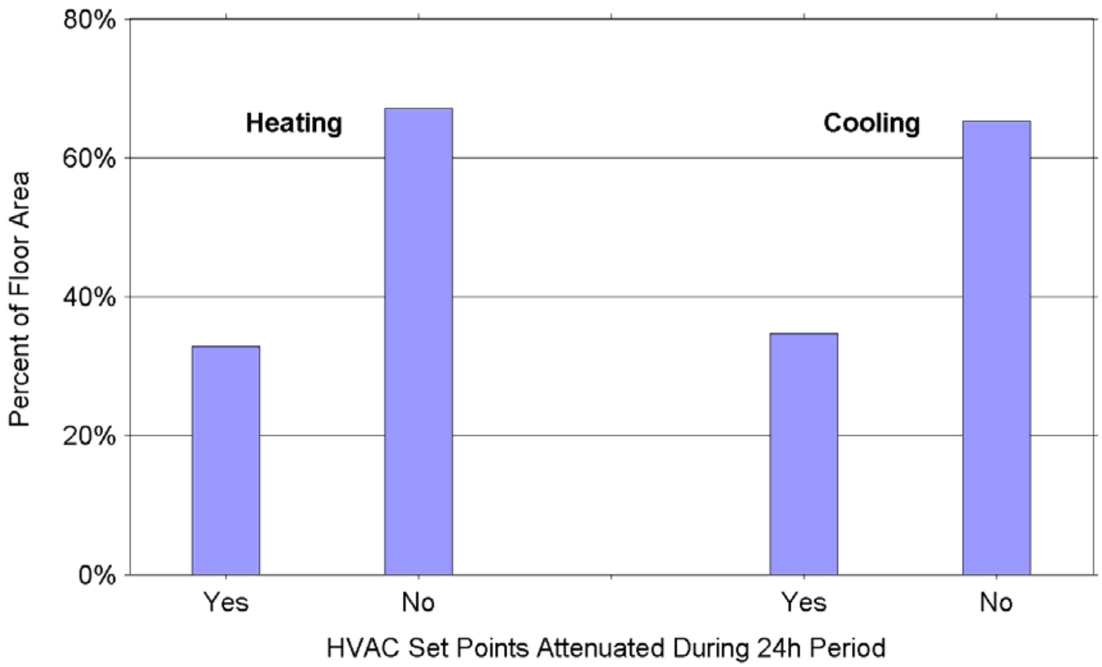

Figure 3-13 Area-Weighed Histograms of Post-1970 Grocery Store Setback and Setup Practices

3.1.5.2 Refrigeration

The prototype refrigeration system is adapted from the benchmark supermarket model system, which itself is largely based on an example in Westphalen et al. (1996) (Deru, Griffith et al. 2008). There are four compressor racks: two low-temperature racks (serving frozen food cases, ice cream cases, and walk-in freezers), and two medium-temperature racks (serving meat cases, dairy/deli cases, and walk-in coolers). The heat from the compressor racks is rejected by air-cooled condensers. The types, sizes, and number of cases and walk-in units are listed in Table 3-5. Technical details and cost estimates are provided in Section 3.2.6.

Table 3-5 Refrigerated Cases and Walk-In Units by Zone

Zone Name	Case/Walk-in Type	Case Length	Number of Units	Total Length
Sales	Island Single Deck Meat	12 ft (3.66 m)	9	108 ft (32.92 m)
Sales	Multi-Deck Dairy/Deli	12 ft (3.66 m)	13	156 ft (47.55 m)
Sales	Vertical Frozen Food with Doors	15 ft (4.57 m)	18	270 ft (82.30 m)
Sales	Island Single Deck Ice Cream	12 ft (3.66 m)	10	120 ft (36.58 m)
Sales	Walk-In Cooler (Medium Temperature)	N/A	2	351 ft (107 m)
Sales	Walk-In Freezer (Low Temperature)	N/A	1	125 ft (38.1 m)
Produce	Multi-Deck Dairy/Deli	12 ft (3.66 m)	8	96 ft (29.26 m)
Deli	Multi-Deck Dairy/Deli	12 ft (3.66 m)	1	12 ft (3.66 m)
Deli	Walk-In Cooler (Medium Temperature)	N/A	1	15.8 ft (4.8 m)
Bakery	Walk-In Cooler (Medium Temperature)	N/A	1	7.9 ft (2.4 m)

3.1.5.3 Service Water Heating

Figure 3-14 summarizes much of the *2003 CBECS* information on service hot water in post-1970 grocery stores. No stores reported using instant hot water. Thus, our prototype model will have a centralized natural gas water heater. The size of the system is determined based on the ASHRAE *HVAC Applications Handbook*, Chapter 49 (ASHRAE 2003), see Section 3.2.7.

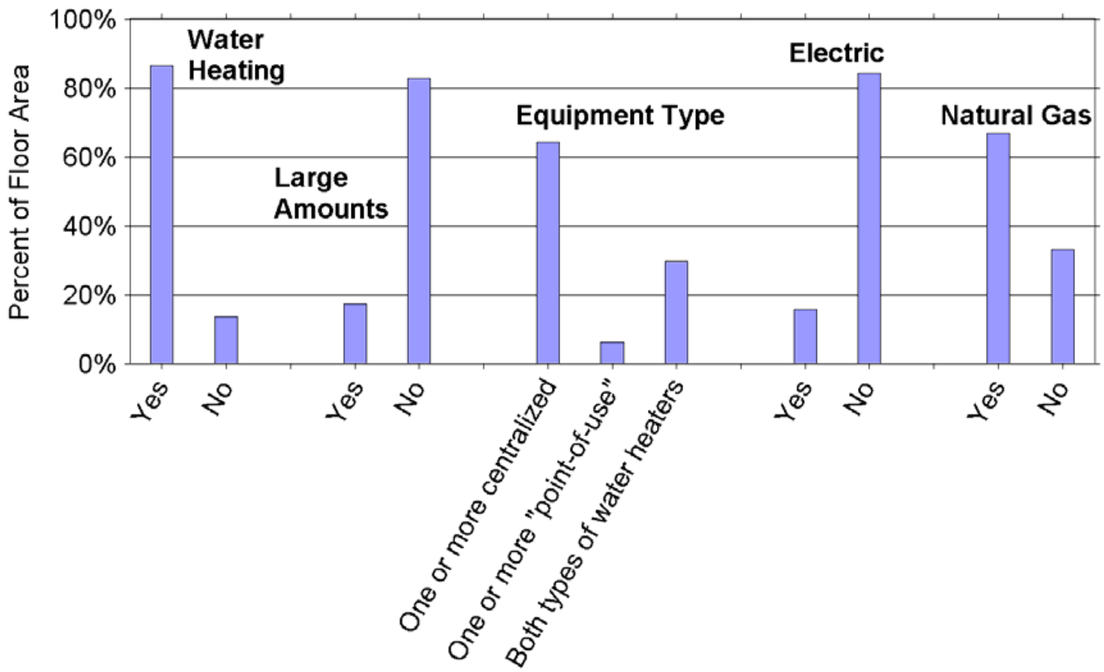

Figure 3-14 Area-Weighted Histograms of Post-1970 Grocer Store Service Hot Water Characteristics

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 30 *2003 CBECS* post-1970 grocery stores are shown by ASHRAE climate zone in Table 3-6. Two sets of EUI data are included: those from Griffith et al.'s EnergyPlus models, and those calculated directly from the *CBECS* (using just 28 stores, since two were not occupied for the full survey year), assuming the same TMY2 locations as Griffith et al. (2008). Table 3-6 also shows how many of those *2003 CBECS* buildings are in each climate zone: there are none in climate zones 1, 6, or 8.

Table 3-6 Area-Weighted Average Site EUI by ASHRAE Climate Zone, Post-1970 Grocery Stores

ASHRAE Climate Zone	Sector Model			CBECS		
	Number of CBECS Grocery Stores	EUI ($kBtu/ft^2$)	EUI (MJ/m^2)	Number of CBECS Grocery Stores Fully Occupied	EUI ($kBtu/ft^2$)	EUI (MJ/m^2)
1	0	–	–	0	–	–
2	2	182.1	2069	2	166.1	1887
3	10	183.2	2081	9	213.6	2427
4	2	188.6	2142	2	153.9	1749
5	13	196.4	2231	12	197.8	2247
6	0	–	–	0	–	–
7	3	211.5	2403	3	258.4	2937
8	0	–	–	0	–	–
All	30	191.6	2176	28	201.9	2295

The national area-weighted average site EUI is 191.6 $kBtu/ft^2$ (2176 MJ/m^2), according to Griffith et al. (2008), and 201.9 $kBtu/ft^2$ (2295 MJ/m^2) according to the *2003 CBECS*. The by climate zone data are depicted graphically in Figure 3-15. The sector model data show a positive correlation between EUI and climate zone number; the *CBECS* data are more erratic, but concur that the highest EUIs are in climate zone 7.

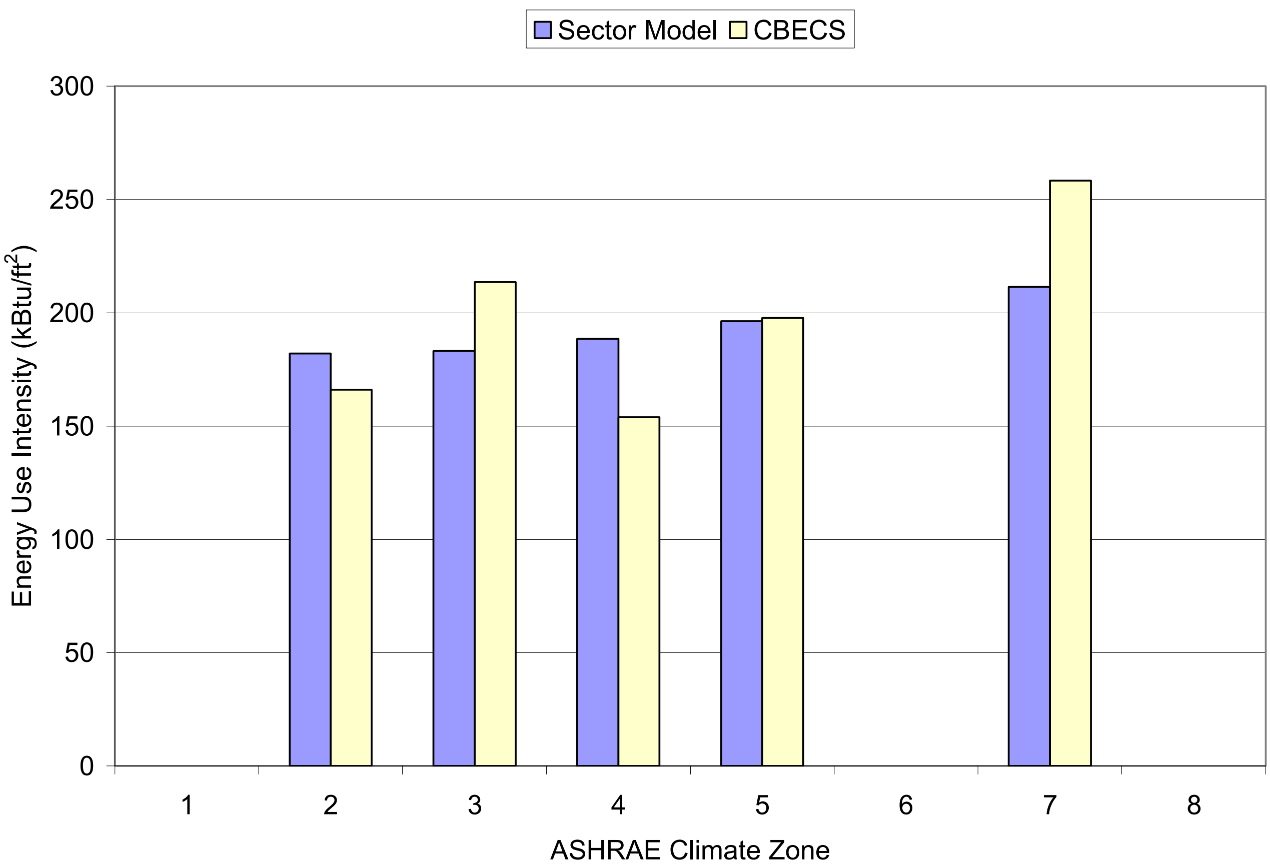

Figure 3-15 *2003 CBECS* Site EUI by Climate Zone, Post-1970 Grocery Stores

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 were 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 3-7, 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 3-7 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 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 that 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, Jarnagin et al. 2006; Liu, Jarnagin et al. 2007), and other sources (Westphalen, Zogg et al. 1996; Emmerich, McDowell 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 supermarkets (Balboni 2005). The adjustment is made before regional adjustments, contractor fees, and architecture fees are applied, excludes all refrigeration equipment, and results in an approximate baseline cost of $58.96/ft^2 in 2005 dollars. This cost assumes stucco on concrete block, bearing exterior walls; a floor area of 45,000 ft^2; a perimeter of 866 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 Energy Information Administration 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 3-8. 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 so they are also listed in that table.

Table 3-8 Utility Data Sources by Climate Zone Location

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

*AK = Alaska; AZ = Arizona; CA = California; CO = Colorado; FL = Florida; IN = Indiana; TX = Texas; GA = Georgia; IL = Illinois; MD = Maryland; MN; Minnesota; MT = Montana; NM = New Mexico; NV = Nevada; VA = Virginia; 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 *Five-Year Total Life Cycle Cost* (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 whole analysis period. The equation to calculate the annual cash flows is shown in Equation 3-1.

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

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 grocery store prototype model. 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 code-compliant baseline and low-energy models. Many characteristics are summarized in Table 3-9, the space type sizes are in Table 3-10, and the floor plan is in Figure 3-16.

Table 3-9 Grocery *TSD* Prototype Characteristics and Data Sources

Grocery Store Characteristic	Grocery TSD Prototype	Source
Program		
Size	45,000 ft^2 (4181 m^2)	*2003 CBECS*; DOE Benchmark Supermarket
Space Types	See Table 3-10.	DOE Benchmark Supermarket
Operating Hours	Sunday through Thursday 6:00 a.m. to 10:00 p.m., Friday and Saturday 6:00 a.m. to 12:00 a.m.	*2003 CBECS*; Assumption
Occupancy	Peak density of 8 people/1000 ft^2 (8.61 people/m^2), see Table 3-2 for schedule	ASHRAE 62.1-2004; Assumption
Lighting	15%/50%/95% on during unoccupied/staff-only/operating hours	*2003 CBECS*; Assumption
Plug and Process	See Table 3-3 and Table 3-4.	DOE Benchmark Supermarket
Form		
Number of Floors	1	*2003 CBECS*
Aspect Ratio	1.5	*2003 CBECS*; DOE Benchmark Supermarket
Floor-to-Floor Height	20 ft (6.10 m)	DOE Benchmark Supermarket
Window Area	1400 ft^2 (130 m^2, 0.08 WWR)	*2003 CBECS*; Assumption
Floor Plan	See Figure 3-16	DOE Benchmark Supermarket
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 (8,360 m^2) of 6” wood	Assumption
Equipment		
HVAC System Type	Unitary rooftop units with DX coils, natural gas heating, and constant volume fans; Economizer as per 90.1	*2003 CBECS*
HVAC Unit Size	10 tons (35 kW) cooling	Assumption
HVAC Controls	No thermostat setback	2003 CBECS
Refrigeration	2 medium-temperature and 2 low-temperature compressor racks; air-cooled condensers; cases and walk-in units listed in Table 3-5.	DOE Benchmark Supermarket; Arthur D. Little Report
Service Hot Water	Natural gas heating with storage tank	*2003 CBECS*

3.1.8.1 Space Type Sizes and Layout

The prototype model zones are listed in Table 3-10 along with their sizes, and their classification by space type, which determines baseline lighting power density (LPD) and ventilation rates. The zones and sizes are identical to what is shown in Table 3-1 for the benchmark supermarket. The floor plan for the grocery store prototype model is shown in Figure 3-16.

Table 3-10 Space Types and Sizes in the Grocery Store Prototype Model

Zone Name	Space Type	Floor Area (ft^2)	Floor Area (m^2)	Percent of Total
Sales	Retail Sales	25,029	2,325.3	56
Produce	Retail Sales	7,658	711.5	17
Deli	Food Preparation	2,419	224.7	5
Bakery	Food Preparation	2,251	209.1	5
Dry Storage	Active Storage	6,694	621.9	15
Office	Enclosed Office	956	88.8	2
Total		45,000	4,181	100

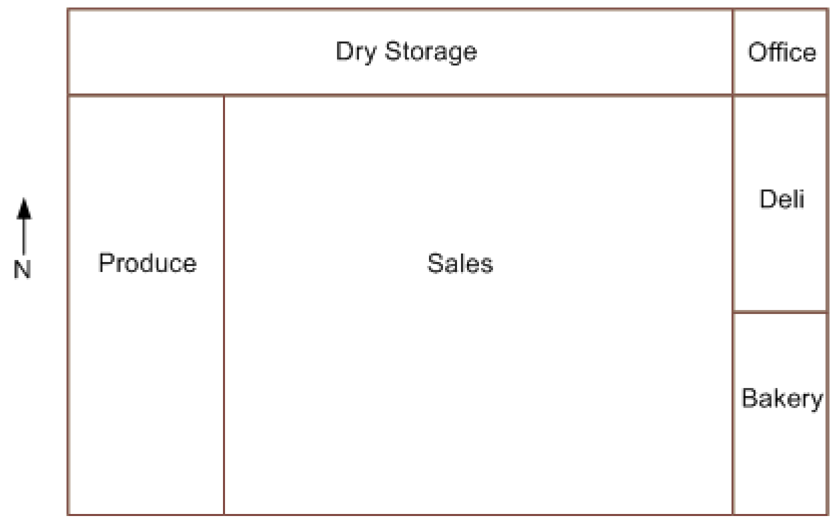

Figure 3-16 Grocery Store Prototype Model Floor Plan

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 grocery 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 as documented in the previous section together with a few modeling assumptions are used to generate the baseline models' form and floor plate. The baseline models do not include plenums or overhangs.

Form and floor plate parameters are listed in Table 3-11. A rendering of the grocery store baseline model is shown in Figure 3-17, which shows an isometric view from the southwest.

Table 3-11 Selected Baseline Modeling Assumptions

Model Parameters	Value
Floor area	45,000 ft^2 (4,181 m^2)
Aspect ratio	1.5
Ceiling height	20 ft (6.096 m)
Fraction of fenestration to gross wall area	8%
Glazing sill height	3.609 ft (1.1 m)

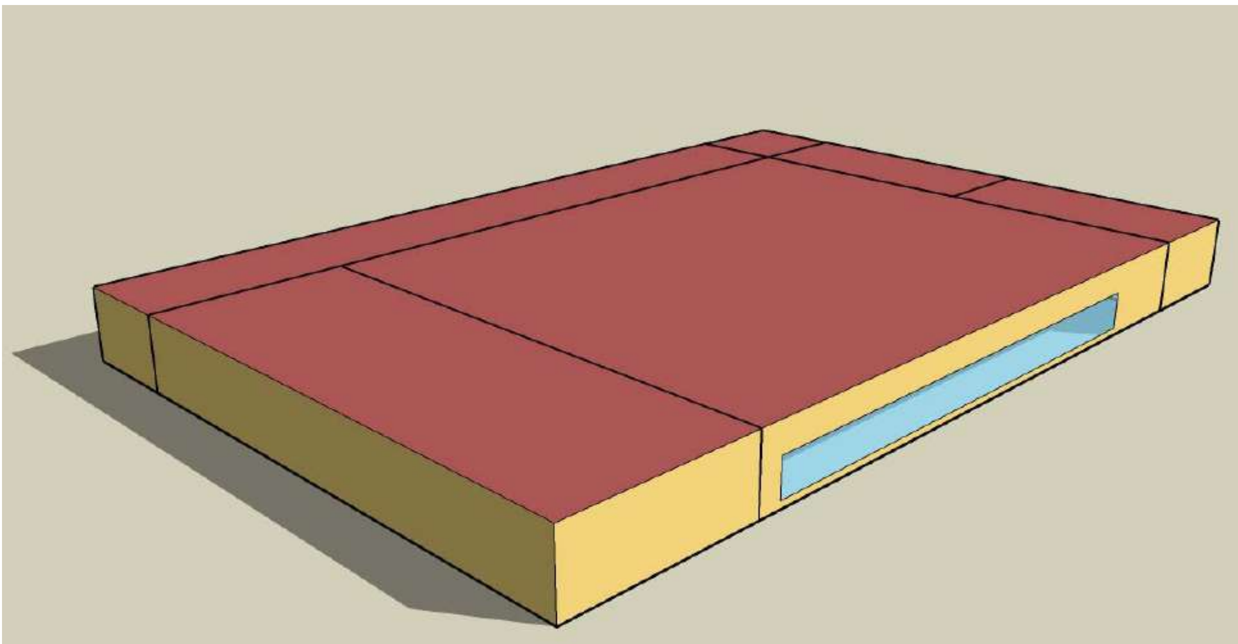

Figure 3-17 Grocery Store Baseline Model Rendering: View from Southwest

3.2.2 Envelope

Based on the *2003 CBECS* and engineering experience, we assume that grocery 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 grocery 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 3-12. 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 3-12 Baseline Exterior Wall Constructions

EDM Properties	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

* continuous insulation

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 c.i. 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 3-13. The costs are based on personal communication with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007).

Table 3-13 Baseline Roof Constructions

EDM Properties	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 grocery stores' fenestration systems are modeled as a single window on the façade totaling 1,400 ft^2 (130 m^2) of glazing area. Windows are collected into a single object per zone and frames are not explicitly modeled to reduce model complexity and make the EnergyPlus simulations run faster. However, the U-factors and solar heat gain coefficients (SHGC) are whole-assembly values that include frames. Those performance criteria were 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 just match the required assembly performance level. The baseline window constructions and costs are summarized in Table 3-14. The costs are based on personal communication with the ASHRAE 90.1 Envelope Subcommittee (ASHRAE 2007).

Table 3-14 Baseline Window Constructions

EDM Properties	Climate Zone						
	1	2	3	4	5 and 6	7	8
EDM Key	Baseline Window	Baseline Window	Baseline Window	Baseline Window	Baseline Window	Baseline Window	Baseline Window
SHGC	0.190	0.170	0.190	0.250	0.260	0.360	0.491
VLT	0.190	0.170	0.241	0.318	0.330	0.360	0.626
U-Factor (Btu/h·ft^2·°F)	1.21	1.21	0.460	0.460	0.460	0.460	0.573
Materials Cost ($/$ft^2$)	$16.83	$16.83	$25.98	$24.91	$24.91	$24.31	$16.65
Installation Cost ($/$ft^2$)	$27.17	$27.17	$27.17	$27.17	$27.17	$27.17	$23.23
Fixed O&M Cost ($/$ft^2$)	$0.22	$0.22	$0.22	$0.22	$0.22	$0.22	$0.19

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 3-15. Costs based on personal communication with the ASHRAE 90.1 Envelope Subcommittee are also listed (ASHRAE 2007).

Table 3-15 Baseline Skylight Constructions

EDM Properties	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

3.2.2.5 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, we model a constant 0.161 ACH since the HVAC system is always 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).

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 3.1.2.3.4. Plug load schedules, occupancy schedules, and lighting schedules are documented in Appendix A.

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 ASHRAE 90.1-2004 (ASHRAE 2004). The baseline LPDs and peak occupancy are shown in Table 3-16. For the location of each space type, see Figure 3-16.

Table 3-16 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	1.7	18.3	8	8.6
Food Preparation: Deli	1.2	12.9	8	8.6
Food Preparation: Bakery	1.2	12.9	8	8.6
Active Storage	0.8	8.6	8	8.6
Enclosed Office	1.1	11.8	8	8.6
Weighted Average	1.5	16.2	8	8.6

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 $283,500, and the baseline maintenance costs are about $12,825/yr.

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 grocery stores 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

The ventilation rates are shown in Table 3-17. The rates for the retail sales and office spaces are based on ASHRAE 62.1-2004 (ASHRAE 2004).

For the buildings with motorized dampers, OA is always available since the motorized dampers follow the same schedule as the HVAC system, which is always on. Buildings without motorized dampers used gravity dampers, which open whenever the fans operate.

Individual zones with exhaust fans receive more OA than the minimum to make up for the exhaust rates.

Table 3-17 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
Food Preparation	–	–	0.34	1.7
All Other	7.5	3.8	0.12	0.6

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 coefficient of performance (COP) values, and then use them to calculate fan efficiency. As stated above, the EER is 10.1. We assume a compressor/condenser COP of 3.69, based on publically available industrial spec sheets for EER 10.1 units.

3.2.5.5 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 3-18 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).

Table 3-18 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*	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

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

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%.

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 3-19 summarizes the primary HVAC performance characteristics and cost data for the baseline grocery stores.

Table 3-19 Baseline HVAC Models Summary

HVAC Input	ASHRAE 90.1-2004 Baseline PSZ DX, Furnace, No Economizer	ASHRAE 90.1-2004 Baseline PSZ DX, Furnace, With Economizer
System EER	10.1	10.1
COP of compressor/condenser	3.69	3.69
Heating efficiency	80%	80%
Fan power	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 Refrigeration

This section augments the Section 3.1.5.2 refrigeration system description with performance and cost data.

3.2.6.1 Refrigerated Cases

Four types of refrigerated cases are modeled: Island Single-Deck Meat, Multi-Deck Dairy/Deli, Vertical Frozen Food with Doors, and Island Single-Deck Ice Cream. The energy models for these cases are developed from publically available manufacturers' data; the costs are estimated from industry quotes and RSMeans (Waier 2005). The baseline lighting levels for each case are somewhat arbitrary, in line with a personal communication indicating that installed lighting varies tremendously from customer to customer. The rated performance conditions for all cases are 75°F (24°C) and 55% relative humidity, per ARI Standard 1200-2002 (ARI 2002).

Table 3-20 and Table 3-21 summarize the performance and cost data of the baseline refrigerated cases in IP and SI units, respectively. The rated capacity is the cooling load of the case at rated conditions, which includes fan, lighting, and anti-sweat heater power, and heat transfer from the store. The heat transfer from the store can be decomposed into an infiltration load caused by the mixing of store and case air, transfer from the surrounding air through the case walls, and radiant heat transfer. The infiltration load includes sensible and latent components. The infiltration ratio is the proportion of the rated capacity caused by infiltration; the latent heat ratio is the proportion of the rated capacity caused just by the latent component. EnergyPlus uses the latent heat ratio directly to calculate latent load; we use the infiltration ratio to reduce the baseline EnergyPlus case credit schedules during the summer design day. In Section 3.3.4.6.1 the infiltration ratio is used to estimate the effects of adding night covers or case doors.

The operating temperature is the temperature inside the case. The restocking load and schedule attempt to model the periodic additional cooling loads that result from placing new product in the cases. These loads are estimated by assuming the average specific heat and density of the product, the temperature difference of the product before and after loading, the proportion of case volume filled with product, and volumetric proportion of product restocked per day. These inputs are summarized in Table 3-22.

Time-off defrost always uses all allotted defrost time. Electric defrost with temperature termination may end early, depending on the relative humidity of the store. Whenever we use temperature termination, this feature is modeled in EnergyPlus with the case temperature method and the coefficients provided in Howell and Adams (1991) for horizontal and vertical cases, see the EnergyPlus documentation for Case:Refrigerated (DOE 2008).

Table 3-20 Baseline Refrigerated Case Characteristics (IP Units)

Characteristic	Island Single-Deck Meat	Multi-Deck Dairy/Deli	Vertical Frozen Food with Doors	Island Single-Deck Ice Cream
Rated Capacity (Btu/h·ft)	770	1500	538	740
Operating Temperature (°F)	28.5	41.0	–1.5	–13.0
Latent Heat Ratio	0.361	0.241	0.061	0.147
Infiltration Ratio	0.686	0.579	0.152	0.412
Fan Power (Btu/h·ft)	38.7	42.6	40.9	29.0
Lighting Power (Btu/h·ft)	0	215	92.8	255
Anti-Sweat Heater Power (Btu/h·ft)	37.0	0	259	135
Defrost Type	Time-off	Time-off	Electric with temperature termination	Electric with temperature termination
Defrost Power (Btu/h·ft)	0	0	1311	1032
Maximum Defrost Time (min)	45	42	46	60
Drip-Down Time (min)	8	8	15	15
Defrost Start Time(s)	6:00 a.m. 2:00 p.m. 10:00 p.m.	1:00 a.m. 7:00 a.m. 1:00 p.m. 7:00 p.m.	10:00 p.m.	10:00 p.m.
Restocking Load (Btu/h·ft) and Schedule	65 from 1:00 p.m. to 4:00 p.m.	325 from 9:00 a.m. to 12:00 p.m.	16.0 from 6:00 p.m. to 9:00 p.m.	27.4 from 7:00 a.m. to 10:00 a.m.
Materials Cost ($/ft)	656.23	501.40	559.92	674.83
Installation Cost ($/ft)	22.40	23.84	23.60	22.41

Table 3-21 Baseline Refrigerated Case Characteristics (SI Units)

Characteristic	Island Single-Deck Meat	Multi-Deck Dairy/Deli	Vertical Frozen Food with Doors	Island Single-Deck Ice Cream
Rated Capacity (W/m)	740	1442	517	712
Operating Temperature (°C)	–1.9	5.0	–18.6	–25.0
Latent Heat Ratio	0.361	0.241	0.061	0.147
Infiltration Ratio	0.686	0.579	0.152	0.412
Fan Power (W/m)	37.2	41.0	39.4	27.9
Lighting Power (W/m)	0	207	89.2	246
Anti-Sweat Heater Power (W/m)	35.5	0	249	130
Defrost Type	Time-off	Time-off	Electric with temperature termination	Electric with temperature termination
Defrost Power (W/m)	0	0	1260	992
Maximum Defrost Time (min)	45	42	46	60
Drip-Down Time (min)	8	8	15	15
Defrost Start Time(s)	6:00 a.m. 2:00 p.m. 10:00 p.m.	1:00 a.m. 7:00 a.m. 1:00 p.m. 7:00 p.m.	10:00 p.m.	10:00 p.m.
Restocking Load (W/m) and Schedule	62 from 1:00 p.m. to 4:00 p.m.	312.5 from 9:00 a.m. to 12:00 p.m.	15.4 from 6:00 p.m. to 9:00 p.m.	26.4 from 7:00 a.m. to 10:00 a.m.
Materials Cost ($/m)	2,153	1,645	1,837	2,214
Installation Cost ($/m)	73.50	78.20	77.43	73.54

Table 3-22 Refrigerated Case Restocking Assumptions

Case Type	Case Volume/ft (ft^3/ft)	Volume Filled by Product (%)	Volume of Product Restocked (%)	Specific Heat of Product (Btu/lb·°F)	Density of Product (lb/ft^3)	Temp. Difference (°F)	Daily Restocking Load (Btu/ft·day)
Island Single-Deck Meat	1.67	30	20	0.75	60	43	194
Multi-Deck Dairy/Deli	13.1	50	40	0.75	62	8	975
Vertical Frozen Food with Doors	13.5	50	5	0.50	57	5	48.1
Island Single-Deck Ice Cream	6.35	70	10	0.65	57	5	82.3

3.2.6.2 Walk-In Coolers and Freezers

Under the assumption that walk-in coolers and freezers are already designed for energy efficiency, we directly adopt the benchmark project models for these units, and do not develop any EDMs for these units. For completeness, their performance characteristics are summarized in Table 3-23. See Section 3.2.6.1 for a discussion of the listed characteristics.

Table 3-23 Walk-In Cooler and Freezer Characteristics (Dual Units)

Characteristic	Walk-In Cooler (IP Units)	Walk-In Freezer (IP Units)	Walk-In Cooler (SI Units)	Walk-In Freezer (SI Units)
Rated Capacity (Btu/h·ft or W/m)	480.0	640.0	461.5	615.4
Operating Temperature (°F or °C)	36	-10	2.2	-23.3
Latent Heat Ratio	0.1	0.1	0.1	0.1
Fan Power (Btu/h·ft or W/m)	101	109	97.1	105
Lighting Power (Btu/h·ft or W/m)	27.30	27.30	26.25	26.25
Anti-Sweat Heater Power (Btu/h·ft or W/m)	0	0	0	0
Defrost Type	Electric	Electric	Electric	Electric
Defrost Power (Btu/h·ft or W/m)	532.26	791.58	511.8	761.15
Max. Defrost Time (min)	20	20	20	20
Drip-Down Time (min)	10	10	10	10
Defrost Start Time(s)	11:00 a.m. 11:00 p.m.	11:00 a.m. 11:00 p.m.	11:00 a.m. 11:00 p.m.	11:00 a.m. 11:00 p.m.
Restocking Load (Btu/ft or kJ/m)	1,489 on Tuesdays and Fridays; 690.4 all other days	1,489 on Tuesdays and Fridays; 690.4 all other days	5,155 on Tuesdays and Fridays; 2,390 all other days	5,155 on Tuesdays and Fridays; 2,390 all other days

3.2.6.3 Compressor racks

EnergyPlus assumes that compressor racks can always satisfy the case load connected to them. It also models compressor racks and their associated condensers as one unit. Air-cooled condensers are assumed for the baseline models.

The COPs at rated conditions (104°F [40°C] condensing temperature) are assumed to be 2.5 and 1.3 for the medium- and low-temperature racks, respectively, based on Westphalen et al. (1996). The fan power for each rack is estimated using the sum of the rated case loads connected to that rack, the rated rack COPs, and the statistic that 55% and 7% of the refrigeration electricity in a typical grocery store is used to power the compressors and the condenser fans, respectively (Westphalen, Zogg et al. 1996). This results in a total of 19,000 W of condenser fan power, with 11,860 W for the medium-temperature racks, and 7,140 W for the low-temperature racks.

The variation of COP and condenser fan power with temperature is modeled using the normalized curves in the EnergyPlus Supermarket example files. Overall, the low-temperature rack COPs are modeled as

$$COP = 1.5\left(1.7603 - 0.0377\,T + 0.0004\,T^2\right),$$

and the medium-temperature rack COPs are

$$COP = 2.8\left(1.7603 - 0.0377\,T + 0.0004\,T^2\right),$$

where T is the condensing (outdoor) temperature in °C. The fan power for the low-temperature racks is

$$P_{fan} = 0.0286\,T \cdot P_{fan,rated},$$

and the medium-temperature racks use

$$P_{fan} = \left(0.3 + 0.02\,T\right)P_{fan,rated}.$$

The cost of the racks and condensers is based on the cost of an entire refrigeration system ($1 million to $1.1 million) and the percentage of that cost that is dedicated to compressor racks, condensers, and installation, as described in Westphalen et al. (1996). The compressor and condenser equipment is 16% of the total cost, which, after applying a 24% increase for inflation (to 2005 dollars), is $200,000. The total installation cost comes out to $260,000. After subtracting $30,000 for case and walk-in installation, $230,000 is attributed to compressor rack and condenser installation.

Finally, Westphalen et al. (1996) estimated $75/100 ft^2·yr to maintain the refrigeration system. After converting to 2005 dollars and multiplying by the size of the store, we estimate $42,000/yr for O&M costs for the whole system.

3.2.7 Service Water Heating

As discussed in Section 3.1.5.3, the baseline service water heating system for the grocery stores is a gas-fired storage water heater that meets the ASHRAE 90.1-2004 requirements. We assume a thermal efficiency of 80% to meet the requirements for units with rated input power greater than 75,000 Btu/h (22 kW) and expending less than 4000 Btu/h·gal.

The baseline grocery stores' peak hot water consumption rate is modeled as 116 gph (0.44 m^3/h), based on the statement in the ASHRAE *HVAC Applications Handbook* that grocery stores typically use 300–1000 gallons of hot water per day (ASHRAE 2003). The storage tank has a volume of 250 gallons (0.95 m^3). The consumption schedule as a fraction of peak load is shown in Table A-4. It dictates usages of 768, 800, and 532 gallons per day on weekdays, Saturdays, and Sundays, respectively. The hot water outlet temperature is assumed to be 110ºF (43.3ºC). 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 and process load densities
- 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
- Higher efficiency refrigerated cases
- Evaporatively cooled refrigeration condensers

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.

3.3.1 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 dry storage and office zones. 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 17% 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 eight 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 3-24.

Table 3-24 Lighting Power Density EDMs

EDM Key	Power Density (W/ft^2)	Materials Cost ($/kW)	Installation Cost ($/kW)	Fixed O&M Cost ($/kW·yr)
Baseline	1.50	$2,268.00	$1,932.00	$190.00
Occupancy sensors	1.49	$2,302.00	$1,957.00	$191.90
20% LPD reduction and occupancy sensors	1.19	$2,904.00	$2,452.00	$240.50
40% LPD reduction and occupancy sensors	0.885	$3,916.00	$3,284.00	$322.00

3.3.1.2 Plug and Process Loads

The only measure affecting peak plug and process load densities, which here include electrical equipment and gas loads such as cooking, reduces them by 10%. We assume that such a reduction is achievable in most situations, perhaps by installing energy-efficient equipment that meets or exceeds the ENERGY STAR® requirements.

Without analyzing individual plug and process loads in detail, it is difficult to capture an accurate cost for this design measure. We therefore choose fairly high cost numbers: $3,600 for materials and $900 for installation per kilowatt of peak plug load reduced. For comparison, Table 3-25 lists estimated capital and maintenance costs per kilowatt of peak plug load saved for some 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 3-25 Capital and Maintenance Costs per Kilowatt 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 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 3-26. The sill height remains constant for each EDM.

Table 3-26 South Window Fractions EDMs

EDM Key	South WWR (%)
80% of baseline glazing	21.5
120% of baseline glazing	32.3

Another set of EDMs add 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 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. The zoning of the sales area is not ideal for daylighting, however, since the windows at the front of the store cannot light the whole space, but preclude the application of skylights in that 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 a skylight is 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 daylighting 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, Jarnagin 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 increased by 15%. These EDMs are summarized in Table 3-27.

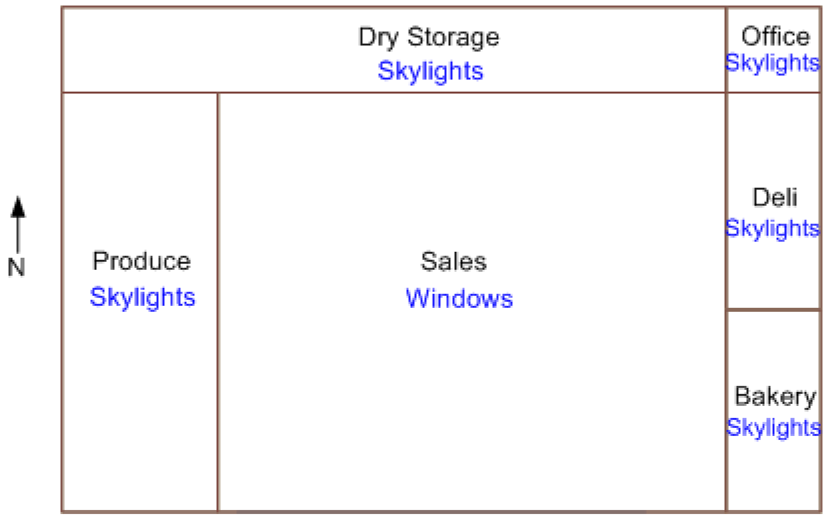

Figure 3-18 Potential Daylight Sources for Each Zone

Table 3-27 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 3-28, 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 would 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 3-28 Exterior Wall EDMs

EDM Key	U-Factor (Btu/h·ft^2·°F)	Materials Cost ($/ft^2)	Installation Cost ($/ft^2)
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 3-29, 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 3-29 Roof EDMs

EDM Key	U-Factor (Btu/h·ft^2·°F)	Materials Cost ($/ft^2)	Installation Cost ($/ft^2)
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 3-30 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 3-30 South 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 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 3-31.

Table 3-31 Skylight 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 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/ft^2 ($13.92/m^2) of exterior wall area (Emmerich, McDowell 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 ft^2 (18 m^2), 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 1, 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 (VAV) 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 3-32.

Table 3-32 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 *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.

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 3-33). In general, more effective ERVs have higher pressure drops. The pressure drops listed in Table 3-33 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 3-33 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 future 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), 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.

3.3.4.6 *Refrigeration Equipment*

This *TSD* includes EDMs for the refrigerated cases and the refrigeration condensers. We place more emphasis on the refrigerated cases, because the primary criterion for their selection is typically not energy efficiency. There is one EDM for the compressor rack/condenser systems: evaporatively cooled condensers.

3.3.4.6.1 Refrigerated Cases

Several EDMs are available for each refrigerated case type. Most are not single changes, but are combinations of one or more of the following recommendations:

- High-efficiency fans
- Reduced lighting power
- Anti-sweat heater controls
- High-efficiency anti-sweat heaters
- Alternative defrost systems. The medium-temperature cases can use time-off defrost or electric defrost with temperature termination. The low-temperature cases can use electric defrost with temperature termination or hot gas defrost with temperature termination.
- Adding night covers or doors, or switching to a vertical case with doors.

The performance and cost data for each baseline and EDM case are presented in Table 3-34 through Table 3-41, two tables per case type (one in IP and one in SI units). The relative costs of the EDM cases compared to the baseline cases are determined using data from Waier (2005), Westphalen et al. (1996), and industry quotes. Most of the table entries are described in Section 3.2.6.1. We now describe the new entries and EDM-specific details.

In the brief descriptions of the EDMs found in the table headings, high-efficiency fans are listed as *Eff. Fans*, anti-sweat heater controls are *A-S Controls*, and groups of measures are identified and referred to using the notations *#1* and *#2*. The rated capacities reflect the impact of reduced fan, lighting and anti-sweat heater power, but do not reflect schedule or control changes. Values that differ from the baseline are highlighted in green.

Anti-sweat heater controls are modeled using the Dewpoint Method, which assumes that the actual anti-sweat heater power is equal to the power at rated conditions multiplied by the ratio

$$\frac{T_{dp,store} - T_{case}}{T_{dp,rated} - T_{case}},$$

where $T_{dp,store}$ is the dew point of the store, $T_{dp,rated}$ is the dew point at rated conditions, and T_{case} is the operating temperature of the refrigerated case. The cost is modeled assuming one sensor for every 30 to 36 ft of cases.

The case credit schedules determine how much of the rated heat load from the store, sensible and latent, should be applied to the case at any one time. Temperature and relative humidity effects are modeled in other ways—the schedule is primarily available to indicate when the case is and is not exposed to full infiltration loads. Because the rated capacities of the models with doors already include the effects of door openings, the baseline cases and most of the EDM cases have a case credit schedule that is always equal to 1.0. However, for the single-deck meat case EDMs with night covers and doors, this schedule is used to reduce infiltration loads.

The nighttime loads of the single-deck meat cases with night covers and doors are set to the minimum possible value, which is obtained by subtracting the fraction of the sensible and latent loads caused by infiltration from 1.0. The infiltration load is equal to the infiltration ratio times the rated capacity; the total sensible and latent loads are equal to the rated capacity minus all the electrical equipment loads. The night cover EDM models the placement of insulated panels over the refrigerated case openings. Thus, the daytime case credits are set to 1.0, and the schedule is set to the average of the daytime and nighttime values during the employee-only transition hours. The sliding door EDM has a daytime case credit schedule based on the assumption that the doors are opened for 10 seconds 6 times per hour.

For cases with LED lighting, the maximum lighting power is listed in the tables, but the implemented power is equal to one-half of this value to model the effects of occupancy sensors.

It is difficult to find accurate data on the energy delivered to refrigerated cases by hot gas defrost. Based on the recommendation of the EnergyPlus documentation, we assume that the total energy delivered during the hot gas defrost cycle is equal to that delivered by an electric defrost cycle. Because hot gas defrost cycles are typically shorter than the corresponding electric defrost cycles, the listed defrost powers are higher in the former case. Note that hot gas defrost is achieved by rerouting hot gases coming off of the compressors, and so there is no extra energy penalty for generating the heat used to defrost the coils, as there is with electric defrost.

The total length of each category of cases remains constant when the EDMs are applied, except when the single-deck ice cream cases are replaced with efficient vertical door models. In this situation, based on the useful volumes of the two types of cases, we assume that only 0.659 ft of efficient vertical cases are required for every 1 ft of baseline single-deck cases.

Table 3-34 Island Single-Deck Meat Case EDMs (IP Units)

Characteristic	Baseline	Electric Defrost	#1: Eff. Fans and A-S Controls	#1 with Electric Defrost	#2: #1 and Covered at Night	#2 with Electric Defrost	#3: #1 and Sliding Doors	#3 with Electric Defrost
Rated Capacity (Btu/h·ft)	770	770	756	756	756	756	756	756
Operating Temperature (°F)	28.5	28.5	28.5	28.5	28.5	28.5	28.5	28.5
Latent Heat Ratio	0.361	0.361	0.367	0.367	0.367	0.367	0.367	0.367
Infiltration Ratio	0.686	0.686	0.698	0.698	0.698	0.698	0.698	0.698
Fan Power (Btu/h·ft)	38.7	38.7	25.0	25.0	25.0	25.0	25.0	25.0
Lighting Power (Btu/h·ft)	0	0	0	0	0	0	0	0
Anti-Sweat Heater Power (Btu/h·ft)	37.0	37.0	37.0	37.0	37.0	37.0	79.7	79.7
Anti-Sweat Heater Control Method	None	None	Dewpoint Method	Dewpoint Method	Dewpoint Method	Dewpoint Method	Dewpoint Method	Dewpoint Method
Defrost Type	Time-off	Electric w/Temp. Term.	Time-off	Electric w/Temp. Term.	Time-off	Electric w/Temp. Term.	Time-off	Electric w/ Temp. Term.
Defrost Power (Btu/h·ft)	0	427	0	427	0	427	0	427
Maximum Defrost Time (min)	45	40	45	40	45	40	45	40
Drip-Down Time (min)	8	8	8	8	8	8	8	8
Defrost Start Time(s)	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.
Restocking Load (Btu/h·ft) and Schedule	65 from 1:00 p.m. to 4:00 p.m.	65 from 1:00 p.m. to 4:00 p.m.	65 from 1:00 p.m. to 4:00 p.m.	65 from 1:00 p.m. to 4:00 p.m.	65 from 1:00 p.m. to 4:00 p.m.	65 from 1:00 p.m. to 4:00 p.m.	65 from 1:00 p.m. to 4:00 p.m.	65 from 1:00 p.m. to 4:00 p.m.
Case Credit Schedule	All Days, 1.0	All Days, 1.0	All Days, 1.0	All Days, 1.0	Night, 0.24; Open Hrs, 1.0	Night, 0.24; Open Hrs, 1.0	Night, 0.19; Open Hrs, 0.20	Night, 0.19; Open Hrs, 0.20
Materials Cost ($/ft)	656.23	660.20	684.88	690.07	701.65	705.61	789.13	793.09
Installation Cost ($/ft)	22.40	22.81	31.01	31.42	31.01	31.42	31.01	31.42
Maintenance Cost ($/ft·yr)	0	0	0	0	16.67	16.67	0	0

Table 3-35 Island Single-Deck Meat Case EDMs (SI Units)

Characteristic	Baseline	Electric Defrost	#1: Eff. Fans and A-S Controls	#1 with Electric Defrost	#2: #1 and Covered at Night	#2 with Electric Defrost	#3: #1 and Sliding Doors	#3 with Electric Defrost
Rated Capacity (W/m)	740	740	727	727	727	727	727	727
Operating Temperature (°C)	–1.9	–1.9	–1.9	–1.9	–1.9	–1.9	–1.9	–1.9
Latent Heat Ratio	0.361	0.361	0.367	0.367	0.367	0.367	0.367	0.367
Infiltration Ratio	0.686	0.686	0.698	0.698	0.698	0.698	0.698	0.698
Fan Power (W/m)	37.2	37.2	24.0	24.0	24.0	24.0	24.0	24.0
Lighting Power (W/m)	0	0	0	0	0	0	0	0
Anti-Sweat Heater Power (W/m)	35.5	35.5	35.5	35.5	35.5	35.5	76.6	76.6
Anti-Sweat Heater Control Method	None	None	Dewpoint Method	Dewpoint Method	Dewpoint Method	Dewpoint Method	Dewpoint Method	Dewpoint Method
Defrost Type	Time-off	Electric w/ Temp. Term.	Time-off	Electric w/ Temp. Term.	Time-off	Electric w/ Temp. Term.	Time-off	Electric w/ Temp. Term.
Defrost Power (W/m)	0	411	0	411	0	411	0	411
Maximum Defrost Time (min)	45	40	45	40	45	40	45	40
Drip-Down Time (min)	8	8	8	8	8	8	8	8
Defrost Start Time(s)	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.	6:00 a.m. 2:00 p.m. 10:00 p.m.
Restocking Load (W/m) and Schedule	62 from 1:00 p.m. to 4:00 p.m.	62 from 1:00 p.m. to 4:00 p.m.	62 from 1:00 p.m. to 4:00 p.m.	62 from 1:00 p.m. to 4:00 p.m.	62 from 1:00 p.m. to 4:00 p.m.	62 from 1:00 p.m. to 4:00 p.m.	62 from 1:00 p.m. to 4:00 p.m.	62 from 1:00 p.m. to 4:00 p.m.
Case Credit Schedule	All Times, 1.0	All Times, 1.0	All Times, 1.0	All Times, 1.0	Night, 0.24; Open Hrs, 1.0	Night, 0.24; Open Hrs, 1.0	Night, 0.19; Open Hrs, 0.20	Night, 0.19; Open Hrs, 0.20
Materials Cost ($/m)	2,153	2,166	2,247	2,261	2,302	2,315	2,589	2,602
Installation Cost ($/m)	73.50	74.83	101.75	103.08	101.75	103.08	101.75	103.08
Maintenance Cost ($/m·yr)	0	0	0	0	54.68	54.68	0	0

Table 3-36 Multi-Deck Dairy/Deli Case EDMs (IP Units)

Characteristic	Baseline	Baseline with Electric Defrost	#1: Eff. Fans and Standard Lighting	#1 with Electric Defrost	Replace w/ Eff. Vertical Door Model
Rated Capacity (Btu/h·ft)	1500	1500	1285	1285	272
Operating Temperature (°F)	41.0	41.0	41.0	41.0	2.8
Latent Heat Ratio	0.241	0.241	0.281	0.281	0.100
Infiltration Ratio	0.579	0.579	0.676	0.676	0.250
Fan Power (Btu/h·ft)	42.6	42.6	19.9	19.9	12.6
Lighting Power (Btu/h·ft)	215	215	23.9	23.9	62.1
Anti-Sweat Heater Power (Btu/h·ft)	0	0	0	0	79.7
Anti-Sweat Heater Control Method	None	None	None	None	Dewpoint Method
Defrost Type	Time-off	Electric w/ Temp. Term.	Time-off	Electric w/ Temp. Term.	Electric w/ Temp. Term.
Defrost Power (Btu/h·ft)	0	341	0	341	445
Maximum Defrost Time (min)	42	32	42	32	30
Drip-Down Time (min)	8	8	8	8	20
Defrost Start Time(s)	1:00 a.m., 7:00 a.m., 1:00 p.m., 7:00 p.m.	1:00 a.m., 7:00 a.m., 1:00 p.m., 7:00 p.m.	1:00 a.m., 7:00 a.m., 1:00 p.m., 7:00 p.m.	1:00 a.m., 7:00 a.m., 1:00 p.m., 7:00 p.m.	1:00 a.m.
Restocking Load (Btu/h·ft) and Schedule	325 from 9:00 a.m. to 12:00 p.m.	325 from 9:00 a.m. to 12:00 p.m.	325 from 9:00 a.m. to 12:00 p.m.	325 from 9:00 a.m. to 12:00 p.m.	312.5 from 9:00 a.m. to 12:00 p.m.
Materials Cost ($/ft)	501.40	511.45	425.20	435.25	636.12
Installation Cost ($/ft)	23.84	24.83	23.84	24.83	39.15

Table 3-37 Multi-Deck Dairy/Deli Case EDMs (SI Units)

Characteristic	Baseline	Baseline with Electric Defrost	#1: Eff. Fans and Standard Lighting	#1 with Electric Defrost	Replace w/ Eff. Vertical Door Model
Rated Capacity (W/m)	1442	1442	1236	1236	262
Operating Temperature (°C)	5.0	5.0	5.0	5.0	2.8
Latent Heat Ratio	0.241	0.241	0.281	0.281	0.100
Infiltration Ratio	0.579	0.579	0.676	0.676	0.250
Fan Power (W/m)	41.0	41.0	19.1	19.1	12.1
Lighting Power (W/m)	207	207	23	23	59.7
Anti-Sweat Heater Power (W/m)	0	0	0	0	76.6
Anti-Sweat Heater Control Method	None	None	None	None	Dewpoint Method
Defrost Type	Time-off	Electric w/ Temp. Term.	Time-off	Electric w/ Temp. Term.	Electric w/ Temp. Term.
Defrost Power (W/m)	0	328	0	328	428
Maximum Defrost Time (min)	42	32	42	32	30
Drip-Down Time (min)	8	8	8	8	20
Defrost Start Time(s)	1:00 a.m., 7:00 a.m., 1:00 p.m., 7:00 p.m.	1:00 a.m., 7:00 a.m., 1:00 p.m., 7:00 p.m.	1:00 a.m., 7:00 a.m., 1:00 p.m., 7:00 p.m.	1:00 a.m., 7:00 a.m., 1:00 p.m., 7:00 p.m.	1:00 a.m.
Restocking Load (W/m) and Schedule	312.5 from 9:00 a.m. to 12:00 p.m.	312.5 from 9:00 a.m. to 12:00 p.m.	312.5 from 9:00 a.m. to 12:00 p.m.	312.5 from 9:00 a.m. to 12:00 p.m.	312.5 from 9:00 a.m. to 12:00 p.m.
Materials Cost ($/m)	1,645	1,678	1,395	1,428	2,087
Installation Cost ($/m)	78.20	81.47	78.20	81.47	128.46

Table 3-38 Vertical Frozen Food with Doors Case EDMs (IP Units)

Characteristic	Baseline	Baseline with Hot Gas Defrost	#1: Eff. Fans and A-S Controls	#1 with Hot Gas Defrost	#2: #1, Eff. A-S Heaters and LEDs	#2 with Hot Gas Defrost
Rated Capacity (Btu/h·ft)	538	538	510	510	317	317
Operating Temperature (°F)	–1.5	–1.5	–1.5	–1.5	–1.5	–1.5
Latent Heat Ratio	0.061	0.061	0.064	0.064	0.103	0.103
Infiltration Ratio	0.152	0.152	0.160	0.160	0.257	0.257
Fan Power (Btu/h·ft)	40.9	40.9	12.6	12.6	12.6	12.6
Lighting Power (Btu/h·ft)	92.8	92.8	92.8	92.8	62.1	62.1
Anti-Sweat Heater Power (Btu/h·ft)	259	259	259	259	97	97
Anti-Sweat Heater Control Method	None	None	Dewpoint Method	Dewpoint Method	Dewpoint Method	Dewpoint Method
Defrost Type	Electric with temperature termination	Hot Gas with Temp. Term.	Electric with temperature termination	Hot Gas with Temp. Term.	Electric with temperature termination	Hot Gas with Temp. Term.
Defrost Power (Btu/h·ft)	1311	2491	1311	2491	1311	2491
Maximum Defrost Time (min)	46	24	46	24	46	24
Drip-Down Time (min)	15	15	15	15	15	15
Defrost Start Time(s)	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.
Restocking Load (Btu/h·ft) and Schedule	16.0 from 6:00 p.m. to 9:00 p.m.	15.4 from 6:00 p.m. to 9:00 p.m.	16.0 from 6:00 p.m. to 9:00 p.m.	15.4 from 6:00 p.m. to 9:00 p.m.	16.0 from 6:00 p.m. to 9:00 p.m.	15.4 from 6:00 p.m. to 9:00 p.m.
Materials Cost ($/ft)	559.92	566.32	581.25	587.65	681.53	688.24
Installation Cost ($/ft)	23.60	25.22	33.93	35.56	42.09	43.72

Table 3-39 Vertical Frozen Food with Doors Case EDMs (SI Units)

Characteristic	Baseline	Baseline with Hot Gas Defrost	#1: Eff. Fans and A-S Controls	#1 with Hot Gas Defrost	#2: #1, Eff. A-S Heaters and LEDs	#2 with Hot Gas Defrost
Rated Capacity (W/m)	517	517	490	490	305	305
Operating Temperature (°C)	–18.6	–18.6	–18.6	–18.6	–18.6	–18.6
Latent Heat Ratio	0.061	0.061	0.064	0.064	0.103	0.103
Infiltration Ratio	0.152	0.152	0.160	0.160	0.257	0.257
Fan Power (W/m)	39.4	39.4	12.1	12.1	12.1	12.1
Lighting Power (W/m)	89.2	89.2	89.2	89.2	59.7	59.7
Anti-Sweat Heater Power (W/m)	249	249	249	249	93.4	93.4
Anti-Sweat Heater Control Method	None	None	Dewpoint Method	Dewpoint Method	Dewpoint Method	Dewpoint Method
Defrost Type	Electric w/ Temp. Term.	Hot Gas with Temp. Term.	Electric w/ Temp. Term.	Hot Gas w/ Temp. Term.	Electric w/ Temp. Term.	Hot Gas w/ Temp. Term.
Defrost Power (W/m)	1260	2395	1260	2395	1260	2395
Maximum Defrost Time (min)	46	24	46	24	46	24
Drip-Down Time (min)	15	15	15	15	15	15
Defrost Start Time(s)	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.
Restocking Load (W/m) and Schedule	15.4 from 6:00 p.m. to 9:00 p.m.	15.4 from 6:00 p.m. to 9:00 p.m.	15.4 from 6:00 p.m. to 9:00 p.m.	15.4 from 6:00 p.m. to 9:00 p.m.	15.4 from 6:00 p.m. to 9:00 p.m.	15.4 from 6:00 p.m. to 9:00 p.m.
Materials Cost ($/m)	1,837	1,858	1,907	1,928	2,236	2,258
Installation Cost ($/m)	77.43	82.76	111.33	116.66	138.10	143.43

Table 3-40 Island Single-Deck Ice Cream Case EDMs (IP Units)

Characteristic	Baseline	Baseline with Hot Gas Defrost	#1: Eff. Fans, A-S Control and No Lighting	#1 with Hot Gas Defrost	Replace with Eff. Vert. Model, Elec. Def.	Replace with Eff. Vert. Model, Hot Gas
Rated Capacity (Btu/h·ft)	740	740	474	474	341	341
Operating Temperature (°F)	–13.0	–13.0	–13.0	–13.0	–6.5	–6.5
Total Length (ft)	120	120	120	120	79	79
Latent Heat Ratio	0.147	0.147	0.230	0.230	0.111	0.111
Infiltration Ratio	0.412	0.412	0.643	0.643	0.280	0.280
Fan Power (Btu/h·ft)	29.0	29.0	18.7	18.7	12.6	12.6
Lighting Power (Btu/h·ft)	255	255	0	0	62.1	62.1
Anti-Sweat Heater Power (Btu/h·ft)	135	135	135	135	97.1	97.1
Anti-Sweat Heater Control Method	None	None	Dewpoint Method	Dewpoint Method	Dewpoint Method	Dewpoint Method
Defrost Type	Electric w/ Temp. Term.	Hot Gas w/ Temp. Term.	Electric w/ Temp. Term.	Hot Gas w/ Temp. Term.	Electric w/ Temp. Term.	Hot Gas w/ Temp. Term.
Defrost Power (Btu/h·ft)	1032	3079	1032	3079	1310	2491
Maximum Defrost Time (min)	60	20	60	20	46	24
Drip-Down Time (min)	15	15	15	15	15	15
Defrost Start Time(s)	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.
Restocking Load (Btu/h·ft) and Schedule	27.4 from 7:00 a.m. to 10:00 a.m.	27.4 from 7:00 a.m. to 10:00 a.m.	27.4 from 7:00 a.m. to 10:00 a.m.	27.4 from 7:00 a.m. to 10:00 a.m.	27.4 from 7:00 a.m. to 10:00 a.m.	27.4 from 7:00 a.m. to 10:00 a.m.
Materials Cost ($/ft)	674.83	675.44	582.78	583.08	681.53	688.24
Installation Cost ($/ft)	22.41	24.04	31.03	32.65	42.09	43.72

Table 3-41 Island Single-Deck Ice Cream Case EDMs (SI Units)

Characteristic	Baseline	Baseline with Hot Gas Defrost	#1: Eff. Fans, A-S Control and No Lighting	#1 with Hot Gas Defrost	Replace with Eff. Vert. Model, Elec. Def.	Replace with Eff. Vert. Model, Hot Gas
Rated Capacity (W/m)	712	712	456	456	328	328
Operating Temperature (°C)	–25.0	–25.0	–25.0	–25.0	–21.4	–21.4
Total Length (m)	36.6	36.6	36.6	36.6	24.1	24.1
Latent Heat Ratio	0.147	0.147	0.230	0.230	0.111	0.111
Infiltration Ratio	0.412	0.412	0.643	0.643	0.280	0.280
Fan Power (W/m)	27.9	27.9	18.0	18.0	12.1	12.1
Lighting Power (W/m)	246	246	0	0	59.7	59.7
Anti-Sweat Heater Power (W/m)	130	130	130	130	93.4	93.4
Anti-Sweat Heater Control Method	None	None	Dewpoint Method	Dewpoint Method	Dewpoint Method	Dewpoint Method
Defrost Type	Electric w/ Temp. Term.	Hot Gas w/ Temp. Term.	Electric w/ Temp. Term.	Hot Gas w/ Temp. Term.	Electric w/ Temp. Term.	Hot Gas w/ Temp. Term.
Defrost Power (W/m)	992	2961	992	2961	1260	2395
Maximum Defrost Time (min)	60	20	60	20	46	24
Drip-Down Time (min)	15	15	15	15	15	15
Defrost Start Time(s)	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.	10:00 p.m.
Restocking Load (W/m) and Schedule	26.4 from 7:00 a.m. to 10:00 a.m.	26.4 from 7:00 a.m. to 10:00 a.m.	26.4 from 7:00 a.m. to 10:00 a.m.	26.4 from 7:00 a.m. to 10:00 a.m.	26.4 from 7:00 a.m. to 10:00 a.m.	26.4 from 7:00 a.m. to 10:00 a.m.
Materials Cost ($/m)	2,214	2,216	1,912	1,913	2,236	2,258
Installation Cost ($/m)	73.54	78.87	101.79	107.12	138.10	143.43

3.3.4.6.2 Compressor Racks and Condensers

Commercial refrigeration compressor racks and condensers are designed for energy efficiency. We therefore limit our efforts in this area to the replacement of air-cooled condensers with evaporative condensers. Other measures that could be explored in subsequent studies are discussed in Section 4.5.

As modeled in this report, evaporative condensers apply water to the air-cooled heat exchanger coils to lower the temperature on the outside of the coils, and thus improve efficiency. We assume that the temperature on the outside of the coils is equal to the air wet-bulb temperature, and that evaporative cooling is available at all times in all climates.

Installing evaporative condensers instead of basic air-cooled condensers costs about $8,800 less on a whole-store basis, but requires about $4,464/yr more in maintenance costs (Westphalen, Zogg et al. 1996). Split evenly across the four racks, we obtain per-rack costs of $47,800 in materials, $57,500 in installation, and $11,616/yr in maintenance. For reference, the baseline per-rack costs are $50,000 in materials, $57,500 in installation, and $10,500/yr in 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* data shown in 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 baseline EUIs are significantly higher than the sector model (Griffith, Long et al. 2008) and the *2003 CBECS* data. Some of the disagreement in the national averages can be attributed a lack of cold climate grocery stores in *CBECS*. The differences within climate zones may be caused by the inclusion of small grocery stores in the sector model and *CBECS* statistics, an oversized baseline refrigeration system, small *CBECS* sample size, under-reporting of setback and setup thermostat schedules in *CBECS*, or a mismatch in operating hours.

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.

Table 4-1 Baseline Model Performance Summary: Humid Climates

Units	Metric	Humid					
		1A	2A	3A	4A	5A	6A
SI	EUI (MJ/m^2·yr)	2,560	2,740	2,820	3,040	3,200	3,380
	5-TLCC Intensity ($/m^2)	1,540	1,610	1,600	1,520	1,620	1,490
IP	EUI (kBtu/ft^2·yr)	225	242	248	267	282	298
	5-TLCC Intensity ($/ft^2)	143	150	149	141	150	138

Table 4-2 Baseline Model Performance Summary: Arid Climates

Units	Metric	Arid					
		2B	3B-CA	3B-NV	4B	5B	6B
SI	EUI (MJ/m^2·yr)	2,680	2,590	2,680	2,830	3,010	3,230
	5-TLCC Intensity ($/m^2)	1,520	1,620	1,560	1,420	1,430	1,530
IP	EUI (kBtu/ft^2·yr)	236	228	236	249	265	285
	5-TLCC Intensity ($/ft^2)	141	151	145	132	133	142

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

Units	Metric	Marine		Cold	
		3C	4C	7	8
SI	EUI (MJ/m^2·yr)	2,800	2,990	3,580	4,140
	5-TLCC Intensity ($/m^2)	1,670	1,500	1,490	1,560
IP	EUI (kBtu/ft^2·yr)	246	264	315	364
	5-TLCC Intensity ($/ft^2)	156	140	139	145

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

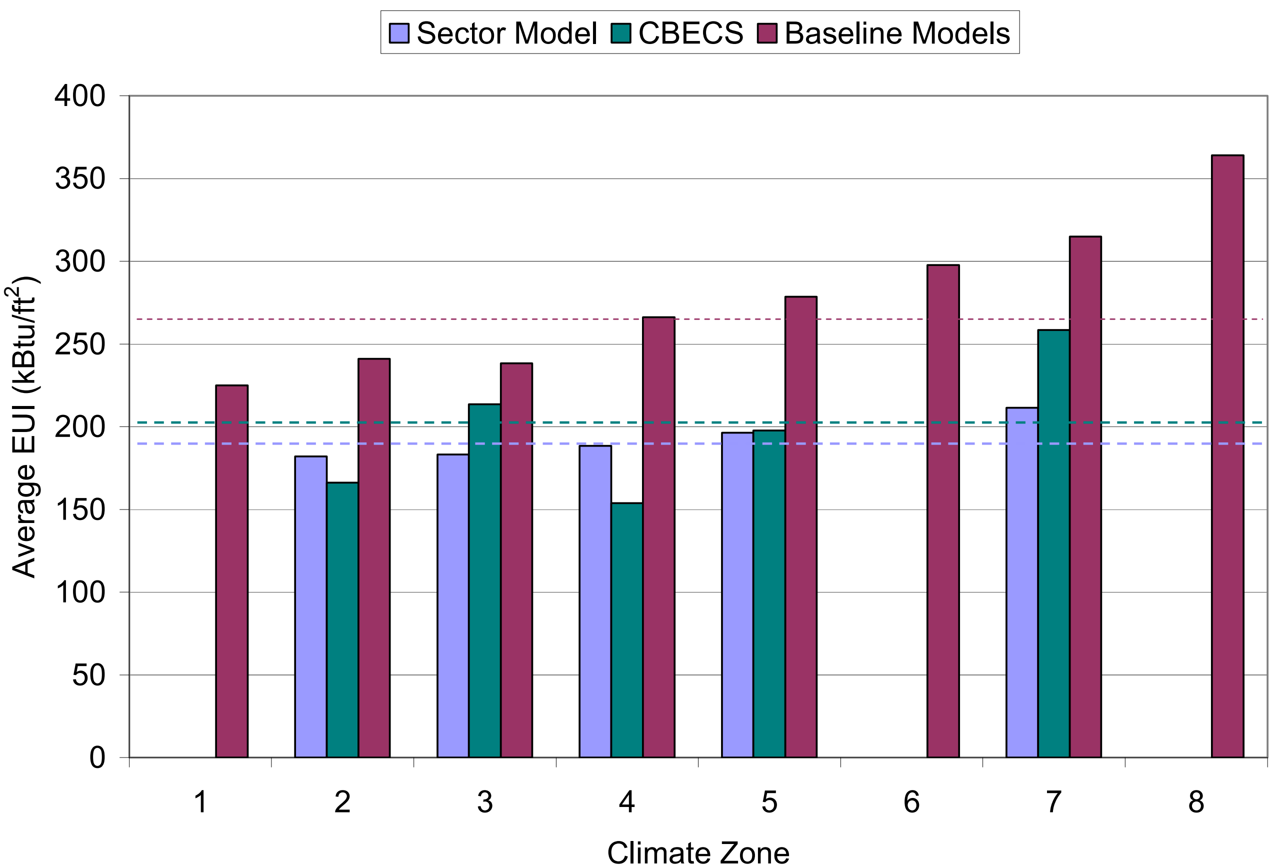

Figure 4-1 Baseline EUIs Compared to Sector Model and 2003 CBECS Data

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 4-5, Table 4-6, and Table 4-7. Examining all of the data listed there reveals that several options were chosen in all climate zones, namely:

- LPD is reduced by 40%, and occupancy sensors are placed in the dry storage and office zones.
- The rooftop HVAC units are equipped with efficient fans.
- All baseline frozen food and ice cream refrigerated cases are replaced with the same efficient model with hot gas defrost.
- All dairy/deli refrigerated cases are replaced with vertical cases that have doors.

Three EDMs were not chosen for any location:

- Overhangs above the windows on the (south) façade.
- Infiltration reduction measures.
- Economizers.

For several reasons, the store in Miami (climate zone 1A) can be contrasted with all of the other low-energy models: Miami is the only store with PV, skylights, and increased window glazing, and the only store without ERVs. It also has better windows and higher levels of insulation than the other locations, relative to the corresponding baselines. Plug load reductions and increased rooftop unit COP were also limited to hot and humid climates: the former to 1A and 2A, and the later to 1A, 2A and 3A. Some other general trends are:

- Daylighting sensors (with 400 lux set points) are applied in climate zones 1 through 4.
- Single pane clear glass is used in many of the warmer climate zones, likely to counteract the effects of the refrigerated cases.
- Cool roofs are recommended in most climate zones.
- Low effectiveness ERVs are sufficient in warm, arid climates (2B and 3B), but high effectiveness ERVs are needed elsewhere.
- The baseline island meat case is chosen for the coldest climates. Everywhere else efficient fans and anti-sweat heater controls are added. Night covers or doors are included in some climate zones, but this addition does not follow a simple pattern.
- DCV is applied in most climate zones. The only exceptions are 4B and 5B.
- Evaporative condensing is common in all but the coldest climates (zones 6 to 8).
- 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.

We recognize that some of these findings are surprising, that designing grocery store OA systems for energy recovery represents a significant deviation from current practice, and that single pane clear glass may not be acceptable from a comfort perspective. Any future NREL grocery store studies will closely re-examine the model inputs associated with skylights, windows, economizers, ERVs, and infiltration.

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. 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 4-5 Description of the Low-Energy Models: 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	None	None
	Generation	PV	7.2% of net roof area	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%	Baseline	Baseline	Baseline	Baseline
Form	Shading	Shading Depth	None	None	None	None	None	None
	Skylights	Skylight Fraction	3% of roof area in non-sidelit zones	None	None	None	None	None
	Vertical Glazing	South Window Fraction	120% 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	N/A	N/A	N/A	N/A	N/A
		Windows	Double pane with low-e and argon	Single pane with clear glass	Single pane with clear glass	Single pane with clear glass	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-31.3 c.i.	R-13.3 c.i.	R-13.3 c.i.	R-9.5 c.i.	R-13.3 c.i.	R-13.3 c.i.
		Roof	R-25 c.i. with cool roof	R-25 c.i. with cool roof	R-20 c.i. with cool roof	R-20 c.i. with cool roof	R-20 c.i. with cool roof	R-20 c.i.
Equipment	HVAC System	System	20% increased 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	Baseline COP with efficient fan
	Outdoor Air	DCV	Installed	Installed	Installed	Installed	Installed	Installed

Category	Subcategory	EDM Type	Humid					
			1A	2A	3A	4A	5A	6A
		ERV	None	High effectiveness	High effectiveness	High effectiveness	High effectiveness	High effectiveness
Refrigeration	Low Temp	Ice Cream	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost
		Frozen Food	#2 with hot gas defrost	#2 with hot gas defrost	#2 with hot gas defrost	#2 with hot gas defrost	#2 with hot gas defrost	#2 with hot gas defrost
		Low Temp. Rack	Evaporative condenser	Evaporative condenser	Evaporative condenser	Evaporative condenser	Evaporative condenser	Baseline
	Med Temp	Dairy/Deli	Replace with efficient vertical door model	Replace with efficient vertical door model	Replace with efficient vertical door model	Replace with efficient vertical door model	Replace with efficient vertical door model	Replace with efficient vertical door model
		Meat Display	#2: #1 plus covered at night	#3: #1 plus sliding doors	#3: #1 plus sliding doors	#3: #1 plus sliding doors	#1: Efficient fans and anti-sweat heater controls	Baseline
		Med. Temp. Rack	Evaporative condenser	Evaporative condenser	Evaporative condenser	Baseline	Evaporative condenser	Baseline

Table 4-6 Description of the Low-Energy Models: 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	None	None
	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	Baseline	Baseline	Baseline	Baseline	Baseline	Baseline
Form	Shading	Shading Depth	None	None	None	None	None	None
	Skylights	Skylight Fraction	None	None	None	None	None	None
	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	N/A	N/A	N/A	N/A	N/A	N/A
		Windows	Single pane with clear glass	Single pane with clear glass	Single pane with clear glass	Single pane with clear glass	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.	Baseline Wall Construction, R-5.7 c.i.	R-9.5 c.i.	R-9.5 c.i.	R-9.5 c.i.	R-13.3 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-20 c.i. with cool roof	R-20 c.i. with cool roof	R-20 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	Baseline COP with efficient fan	Baseline COP with efficient fan
	Outdoor Air	DCV	Installed	Installed	Installed	None	None	Installed
		ERV	Low effectiveness	Low effectiveness	Low effectiveness	High effectiveness	High effectiveness	High effectiveness

Category	Subcategory	EDM Type	Arid					
			2B	3B-CA	3B-NV	4B	5B	6B
Refrigeration	Low Temp	Ice Cream	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost
		Frozen Food	#2 with hot gas defrost	#2 with hot gas defrost	#2 with hot gas defrost	#2 with hot gas defrost	#2 with hot gas defrost	#2 with hot gas defrost
		Low Temp. Rack	Evaporative condenser	Evaporative condenser	Evaporative condenser	Evaporative condenser	Evaporative condenser	Evaporative condenser
	Med Temp	Dairy/Deli	Replace with efficient vertical door model	Replace with efficient vertical door model	Replace with efficient vertical door model	Replace with efficient vertical door model	Replace with efficient vertical door model	Replace with efficient vertical door model
		Meat Display	#1: Efficient fans and anti-sweat heater controls	#3: #1 plus sliding doors	#1: Efficient fans and anti-sweat heater controls	#3: #1 plus sliding doors	#3: #1 plus sliding doors	Baseline
		Med. Temp. Rack	Evaporative condenser	Evaporative condenser	Evaporative condenser	Evaporative condenser	Evaporative condenser	Baseline

Table 4-7 Description of the Low-Energy Models: 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	None	None
	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	Baseline	Baseline	Baseline	Baseline
Form	Shading	Shading Depth	None	None	None	None
	Skylights	Skylight Fraction	None	None	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	N/A	N/A	N/A	N/A
		Windows	Single pane with clear glass	Single pane with clear glass	Double pane with low-e and argon	Baseline Window Construction
	Infiltration	Infiltration	Baseline	Baseline	Baseline	Baseline
	Opaque Constructions	Walls	Baseline Wall Construction, R-5.7 c.i.	R-9.5 c.i.	Baseline Wall Construction, R-11.4 c.i.	R-13.3 c.i.
		Roof	R-20 c.i. with cool roof	R-20 c.i. with cool roof	R-20 c.i.	R-20 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	Installed	Installed	Installed	Installed
		ERV	High effectiveness	High effectiveness	High effectiveness	High effectiveness
Refrigeration	Low Temp	Ice Cream	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost	Replace with efficient vertical door model, hot gas defrost
		Frozen Food	#2 with hot gas defrost	#2 with hot gas defrost	#2 with hot gas defrost	#2 with hot gas defrost
		Low Temp. Rack	Evaporative condenser	Baseline	Baseline	Baseline

Category	Subcategory	EDM Type	Marine		Cold	
			3C	4C	7	8
	Med Temp	Dairy/Deli	Replace with efficient vertical door model	Replace with efficient vertical door model	Replace with efficient vertical door model	Replace with efficient vertical door model
		Meat Display	#1: Efficient fans and anti-sweat heater controls	#3: #1 plus sliding doors	Baseline	Baseline
		Med. Temp. Rack	Evaporative condenser	Baseline	Baseline	Baseline

4.3 Selected Low-Energy Models: Performance

The energy performance of the low-energy models is shown in Table 4-8, Table 4-9, and Table 4-10. The energy performance levels are largely dictated by the baseline EUIs, as the percent energy savings range between 50.0% and 51.8%.

Table 4-8 Low-Energy EUI Performance Summary: Humid Climates

Building Name	Metric	Humid					
		1A	2A	3A	4A	5A	6A
Baseline (SI units)	EUI (MJ/m^2·yr)	2,560	2,740	2,820	3,040	3,200	3,380
Low-Energy (SI units)	EUI (MJ/m^2·yr)	1,280	1,360	1,400	1,500	1,590	1,680
Baseline (IP units)	EUI (kBtu/ft^2·yr)	225	242	248	267	282	298
Low-Energy (IP units)	EUI (kBtu/ft^2·yr)	113	120	124	132	140	148
Low-Energy	Percent Energy Savings	50.0%	50.3%	50.2%	50.7%	50.3%	50.3%

Table 4-9 Low-Energy EUI Performance Summary: Arid Climates

Building Name	Metric	Arid					
		2B	3B-CA	3B-NV	4B	5B	6B
Baseline (SI units)	EUI (MJ/m^2·yr)	2,680	2,590	2,680	2,830	3,010	3,230
Low-Energy (SI units)	EUI (MJ/m^2·yr)	1,330	1,290	1,340	1,370	1,470	1,600
Baseline (IP units)	EUI (kBtu/ft^2·yr)	236	228	236	249	265	285
Low-Energy (IP units)	EUI (kBtu/ft^2·yr)	117	114	118	120	130	141
Low-Energy	Percent Energy Savings	50.5%	50.0%	50.1%	51.8%	51.1%	50.4%

Table 4-10 Low-Energy EUI Performance Summary: Marine and Cold Climates

Building Name	Metric	Marine		Cold	
		3C	4C	7	8
Baseline (SI units)	EUI (MJ/m²·yr)	2,800	2,990	3,580	4,140
Low-Energy (SI units)	EUI (MJ/m²·yr)	1,380	1,440	1,750	2,020
Baseline (IP units)	EUI (kBtu/ft²·yr)	246	264	315	364
Low-Energy (IP units)	EUI (kBtu/ft²·yr)	122	127	154	177
Low-Energy	Percent Energy Savings	50.6%	51.8%	51.3%	51.3%

The economic performance of the low-energy models is shown in Table 4-11, Table 4-12, and Table 4-13. Those data indicate that achieving 50% energy savings in grocery stores is largely cost effective: the low-energy buildings cost less than the baseline buildings everywhere but Miami (based on 5-TLCC and our other economic parameters). However, the low-energy models require putting doors on a number of refrigerated cases. Stores not willing to put more products behind glass may be unable to reach high levels of energy efficiency.

Table 4-11 Low-Energy Cost Summary: Humid Climates

Building Name	Metric	Humid					
		1A	2A	3A	4A	5A	6A
Baseline (SI units)	5-TLCC Intensity ($/m²)	1,540	1,610	1,600	1,520	1,620	1,490
Low-Energy (SI units)	5-TLCC Intensity ($/m²)	1,600	1,500	1,480	1,430	1,480	1,410
Baseline (IP units)	5-TLCC Intensity ($/ft²)	143	150	149	141	150	138
Low-Energy (IP units)	5-TLCC Intensity ($/ft²)	148	139	137	133	137	131

Table 4-12 Low-Energy Cost Summary: Arid Climates

Building Name	Metric	Arid					
		2B	3B-CA	3B-NV	4B	5B	6B
Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,520	1,620	1,560	1,420	1,430	1,530
Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,440	1,490	1,450	1,380	1,380	1,440
Baseline (IP units)	5-TLCC Intensity ($/ft^2)	141	151	145	132	133	142
Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	133	138	135	128	129	134

Table 4-13 Low-Energy Cost Summary: Marine and Cold Climates

Building Name	Metric	Marine		Cold	
		3C	4C	7	8
Baseline (SI units)	5-TLCC Intensity ($/m^2)	1,670	1,500	1,490	1,560
Low-Energy (SI units)	5-TLCC Intensity ($/m^2)	1,510	1,420	1,420	1,460
Baseline (IP units)	5-TLCC Intensity ($/ft^2)	156	140	139	145
Low-Energy (IP units)	5-TLCC Intensity ($/ft^2)	140	132	132	136

For reference, we report the minimum and maximum monthly electric demand and electrical load factors for the baseline and low energy models, see Table 4-14, Table 4-15, and Table 4-16. 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 baseline building in Miami is 414 kW, which occurred on December 15 at 10:45 PM, and the largest is 447 kW, which occurred on May 20 at 9:45 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 4-14 Low-Energy Electricity Demand Summary: Humid Climates

Building Name	Metric	Humid					
		1A	2A	3A	4A	5A	6A
Baseline	Monthly Electric Demand [min-max] (kW)	414–447	398–452	360–428	351–440	350–452	349–437
Low-Energy	Monthly Electric Demand [min-max] (kW)	228–257	238–264	229–263	216–280	225–283	226–287
Baseline	Monthly Electrical Load Factor [min-max]	0.706–0.769	0.631–0.765	0.684–0.732	0.648–0.718	0.648–0.714	0.661–0.717
Low-Energy	Monthly Electrical Load Factor [min-max]	0.616–0.681	0.556–0.687	0.555–0.682	0.551–0.657	0.531–0.622	0.571–0.637

Table 4-15 Low-Energy Electricity Demand Summary: Arid Climates

Building Name	Metric	Arid					
		2B	3B-CA	3B-NV	4B	5B	6B
Baseline	Monthly Electric Demand [min-max] (kW)	379–460	376–407	363–442	352–414	354–417	352–408
Low-Energy	Monthly Electric Demand [min-max] (kW)	220–267	221–249	212–268	213–254	224–269	227–262
Baseline	Monthly Electrical Load Factor [min-max]	0.689–0.767	0.678–0.705	0.681–0.741	0.681–0.731	0.673–0.714	0.677–0.721
Low-Energy	Monthly Electrical Load Factor [min-max]	0.579–0.674	0.597–0.643	0.589–0.641	0.583–0.657	0.577–0.620	0.585–0.627

Table 4-16 Low-Energy Electricity Demand Summary: Marine and Cold Climates

Building Name	Metric	Marine		Cold	
		3C	4C	7	8
Baseline	Monthly Electric Demand [min-max] (kW)	354–399	348–399	349–420	350–387
Low-Energy	Monthly Electric Demand [min-max] (kW)	219–236	219–245	224–283	224–258
Baseline	Monthly Electrical Load Factor [min-max]	0.670–0.710	0.670–0.716	0.675–0.718	0.699–0.722
Low-Energy	Monthly Electrical Load Factor [min-max]	0.582–0.627	0.573–0.658	0.570–0.603	0.579–0.631

The energy and cost performances are shown together in Figure 4-2 and Figure 4-3. Figure 4-2 shows the baseline and low-energy models for each climate zone on a 5-TLCC versus net EUI plot. Each pair of models is connected with a line—the baseline models are the rightmost points of each pair, as their net EUIs are about twice as large as the low-energy models'. The locations whose connecting lines have 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. Thus, we again see that the low-energy Miami store is the only one that costs more than its baseline.

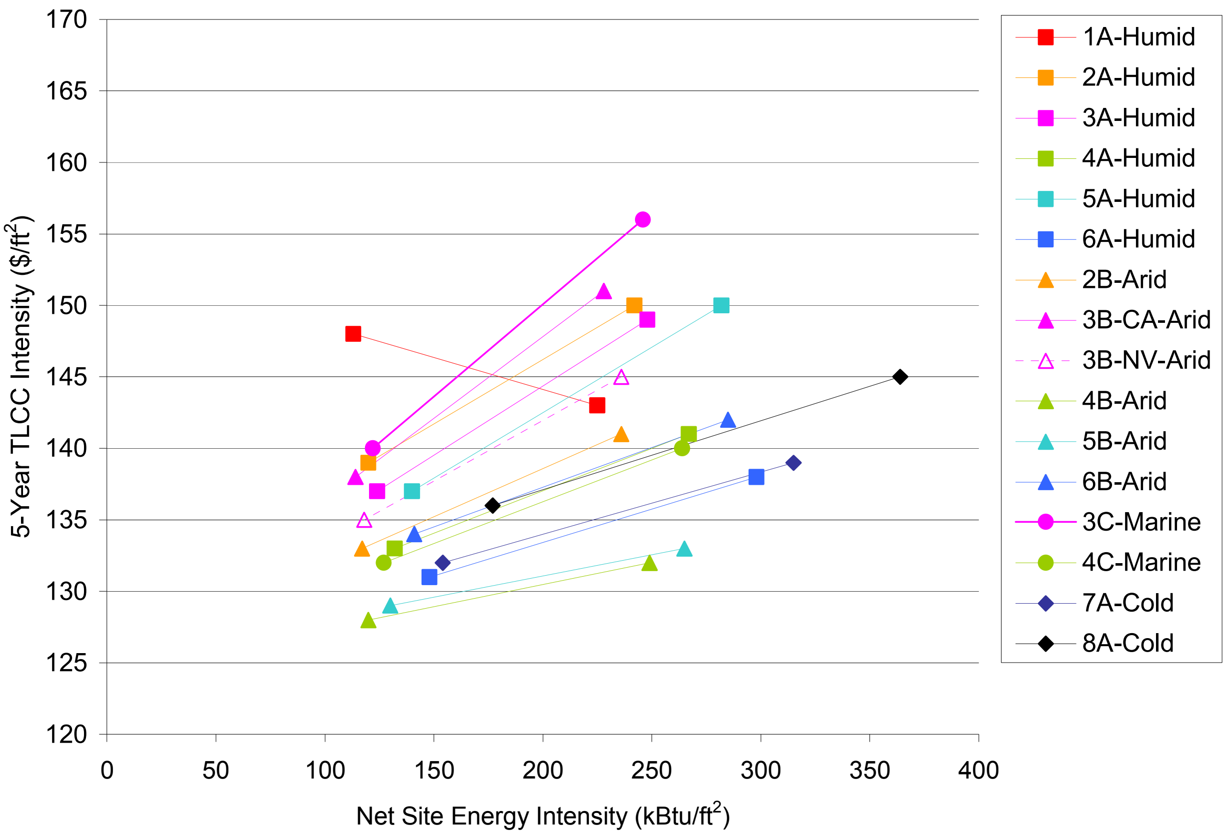

Figure 4-2 5-TLCC Intensity versus Net EUI of the Baseline and Low-Energy Models

The Pareto curves in Figure 4-3 demonstrate the relative ease of achieving 50% energy savings in each climate zone location (see Section 2.2 for a description of Pareto points and curves). For instance, Figure 4-3 shows that it is hardest to reach 50% in Miami, and easiest in San Francisco. The curves also imply that it will likely be difficult to design zero energy grocery stores. One should not read too much into this, however, since the maximum achievable percent energy savings 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, and thermal storage) or improved cost-effectiveness of the current EDMs, the achievable percent savings will increase; even in the current plot, 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.

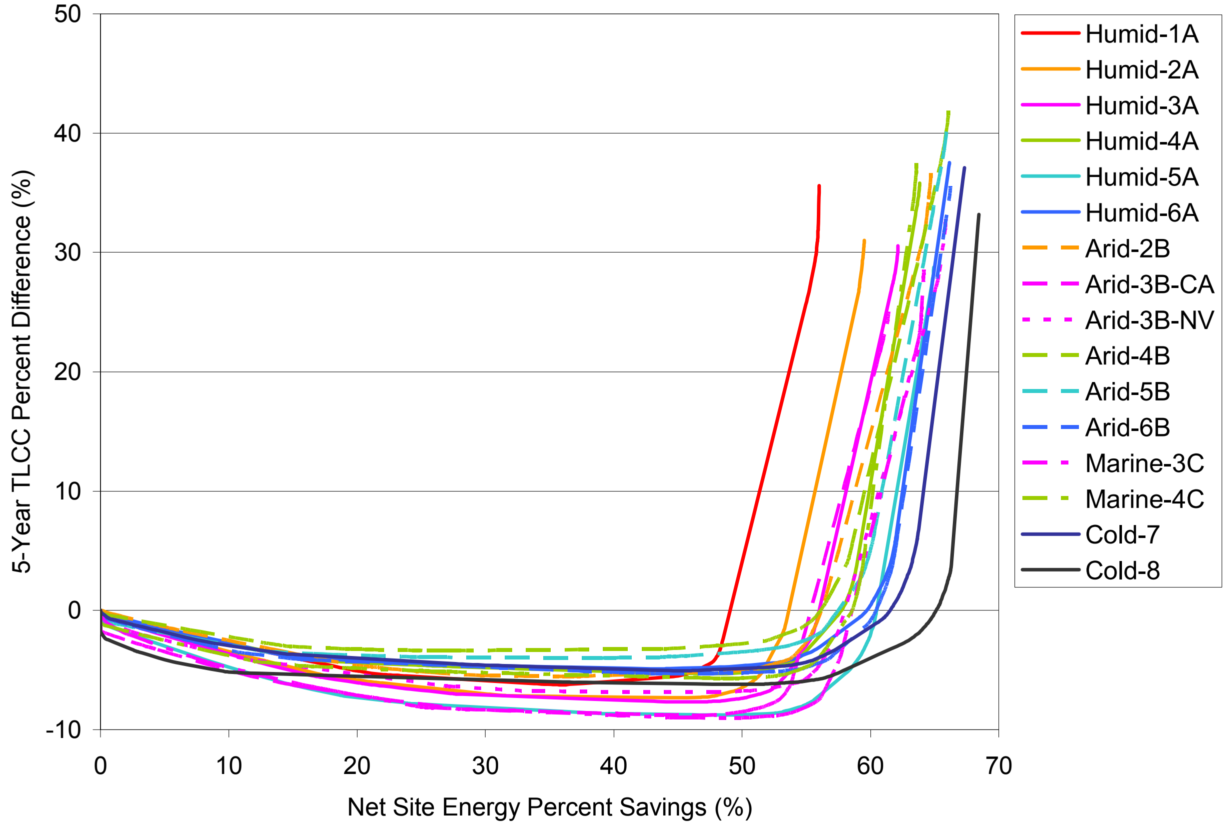

Figure 4-3 Pareto Curves

Finally, the breakdown of EUI by end use is depicted in Figure 4-4. The primary climatic variation is the amount of cooling and heating needed in each climate zone. As expected, the baseline stores in colder climates require a great deal of heating to counter the effects of the refrigerated cases, and this more than negates the benefits they receive in reduced refrigeration effort. For ease of reference, the data in Figure 4-4 are shown in tabular form in Appendix C.

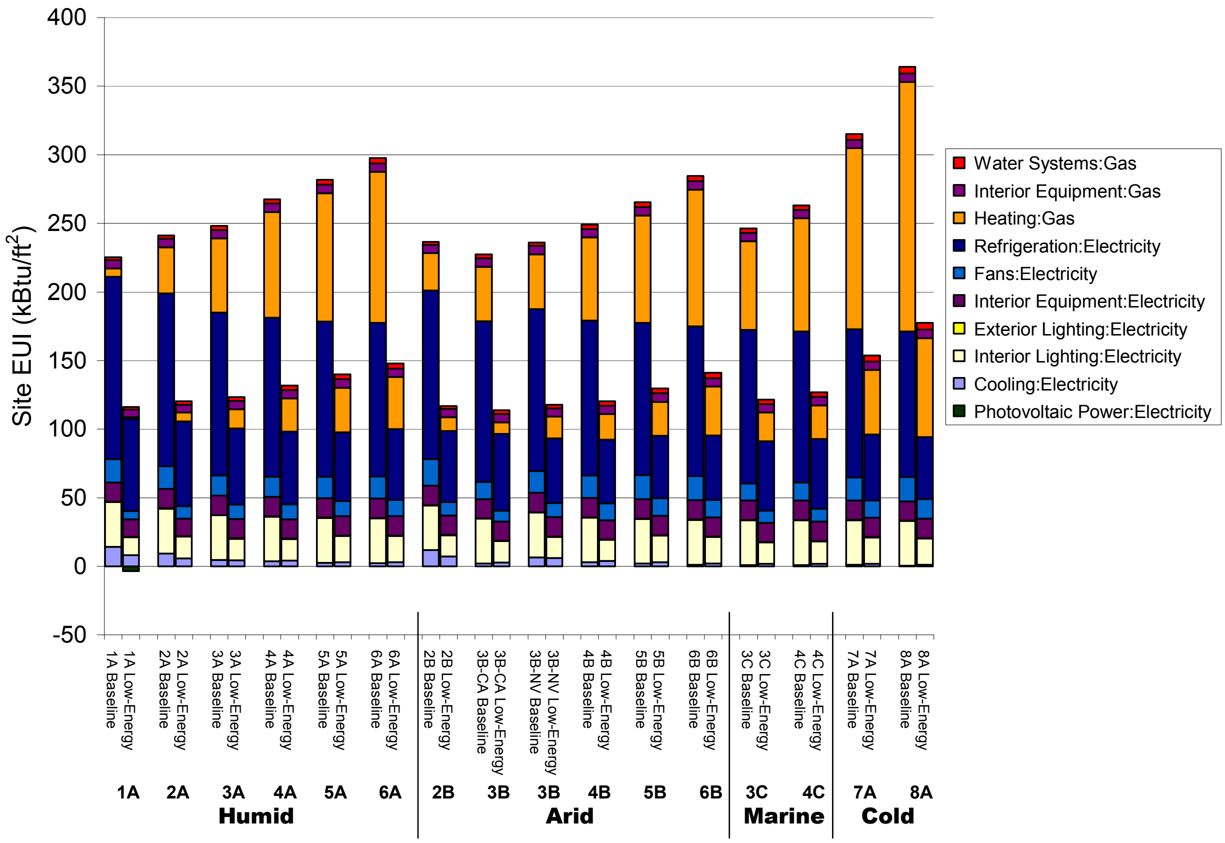

Figure 4-4 Detailed End Uses

4.4 Sensitivity Analyses

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 is not run and is not reported. Similarly, if a perturbation contains multiple EDMs, only those that are different from the baseline are actually perturbed. The perturbations are described in Table 4-17. 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 4-17 Sensitivity Analysis Perturbations

EDM Category	Perturbation Name	Description
Program	Daylighting Sensors	Removes all daylighting sensors
	Lighting Power Density	Returns to the baseline LPD
	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
Refrigeration	Meat Cases	Reverts to the baseline meat cases
	Dairy and Deli Cases	Reverts to the baseline dairy and deli cases
	Frozen Food Cases	Reverts to the baseline frozen food cases
	Ice Cream Cases	Reverts to the baseline ice cream cases
	Refrigeration Compressors	Reverts to air-cooled, rather than evaporatively cooled, condensers

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 4-3. For each climate, they represent the best-case 5-TLCC/percent savings trade-offs available for the list of EDMs developed in Section 3.3. 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.
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 ZEBs 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, both for the whole building and for individual EDMs. However, doing so is difficult. Today's costs for basic building materials, new technologies, and energy are constantly moving targets; future energy costs cannot be predicted with reasonable accuracy; economic parameters such as discount rates and acceptable payback periods vary by building owner; and one of the goals of the Energy Alliances is to provide enough buying power to drive the underlying economics, thereby rendering the current costs moot.

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

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) and/or reliable input data. Measures 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 grocery 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.

- Integrated HVAC and Refrigeration

  The heating loads in grocery stores, which are exacerbated by refrigerated cases, could be partially offset by using waste heat from the compressors for space heating. There are several ways to do this using some of the HVAC types listed above. Such integration may be necessary to achieve 70% and 100% net site energy savings.

- 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 grocery 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.

- Case type distribution

  Given the discrepancy between our baseline models' EUIs and the *2003 CBECS*, we suspect that our refrigeration system may be too large. The size of this system can be traced back to the types and numbers of cases and walk-in units included in the models. We therefore recommend a detailed study to characterize the typical grocery store refrigeration system.

- Secondary loop refrigeration

  An emerging trend in commercial refrigeration is the use of a secondary refrigerant loop on the case side of the system. The primary driver for this change is the subsequent reduction in refrigerant charge. It is not clear if these systems can be more energy efficient than traditional systems, but some studies show that they can be as efficient, and substantially reduce climate change and ozone depleting effects.

- Multiple compressor types

  The efficiency of compressors varies significantly with condensing temperature, and the shapes of those efficiency curves differ depending on the compressor type. The next grocery store study should develop the input data needed to model several types of compressors, determine which type should be used in which climate zone, and compare that determination to current practice.

- Under-case HVAC return air

  Pulling HVAC return air under refrigerated cases is a common practice for reducing the amount of cold air that enters the refrigerated case isles. Reliable input data are needed to model this HVAC system feature and quantify its benefits.

- Humidity control

  Refrigerated case loads are sensitive to humidity levels. In particular, anti-sweat heaters and defrost heaters must work harder at higher humidity levels, and higher humidity implies larger latent loads. Grocery stores are therefore good targets for dehumidification technologies. Although this was addressed implicitly by including ERV EDMs, the ERVs were not configured to provide precise humidity control, so we do not know if dehumidification played a significant role in our low-energy models. Along the same lines, additional dehumidification technologies should be considered.

- Walk-in coolers and freezers

  It is unlikely that a redesign of walk-in coolers and freezers will result in significant energy savings, but their quantity, distribution, and input data should be revisited.

- Alternative business models

  If more groceries were delivered after being ordered online or over the phone, some sales space could be replaced with storage space, and some refrigerated cases could be replaced with walk-in cooler capacity. Alternatively, building grocery stores with smaller footprints provides faster shopping trips and less energy use at the expense of reducing customer choice. Such design measures are well beyond the scope of this study, but could have a large impact on grocery store design and sector energy efficiency.

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

- Skylights

  The thermal zoning of the baseline grocery store was not conducive to full daylighting, because Opt-E-Plus never placed skylights in the Sales zone. To fix this problem, a 15-ft wide zone at the front of the store should be split off from the main Sales zone. Then the front zone can be daylit with windows, and the core of the Sales zone can be daylit with skylights.

- Economizers

  This report finds that economizers are not needed to reach 50% energy savings in any climate zone. We are unsure if this is an accurate finding, and suggest that the model inputs be re-examined in any subsequent grocery store studies. One factor may be the placement of refrigerated cases in large thermal zones, rather than smaller zones that would localize their effects.

- ERVs

  Grocery 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 Advanced Energy Design Guide 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

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

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	Mondays, Tuesdays, Wednesdays, Thursdays	Fridays, 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	0.05	0.05	1	0	0.05
7	0.1	0.1	1	0	0.1
8	0.1	0.1	1	0	0.1
9	0.1	0.1	1	0	0.1
10	0.2	0.2	1	0	0.1
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	0.3
19	0.3	0.6	1	0	0.3
20	0.3	0.4	1	0	0.2
21	0.2	0.4	1	0	0.1
22	0.1	0.2	1	0	0.1
23	0.05	0.1	1	0	0.05
24	0	0.1	1	0	0
Total Hours/Day	4.500	7.150	24.00	0.0000	4.300
Total Hours/Week	20.45				
Total Hours/Year	1,066				

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	Fridays, Saturdays	Summer Design	Winter Design	Mondays, Tuesdays, Wednesdays, Thursdays, 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	0.5	1	0	0.5
7	0.95	1	0	0.95
8	0.95	1	0	0.95
9	0.95	1	0	0.95
10	0.95	1	0	0.95
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	0.95
20	0.95	1	0	0.95
21	0.95	1	0	0.95
22	0.95	1	0	0.95
23	0.95	1	0	0.5
24	0.95	1	0	0.15
Total Hours/Day	18.35	24.00	0.0000	17.10
Total Hours/Week	52.55			
Total Hours/Year	2,740			

A.3 Plug and Process Loads

Each zone in the baseline models uses the equipment schedules shown in Table A-3, which were developed in Section 3.1.2.3.4.

Table A-3 Equipment Schedule

Hour	Mondays, Tuesdays, Wednesdays, Thursdays	Fridays, Saturdays	Summer Design	Winter Design	Sundays, Holidays, Other
1	0.2	0.15	1	0	0.15
2	0.2	0.15	1	0	0.15
3	0.2	0.15	1	0	0.15
4	0.2	0.15	1	0	0.15
5	0.2	0.15	1	0	0.15
6	0.2	0.15	1	0	0.15
7	0.4	0.3	1	0	0.3
8	0.4	0.3	1	0	0.3
9	0.7	0.5	1	0	0.3
10	0.9	0.8	1	0	0.3
11	0.9	0.9	1	0	0.6
12	0.9	0.9	1	0	0.6
13	0.9	0.9	1	0	0.8
14	0.9	0.9	1	0	0.8
15	0.9	0.9	1	0	0.8
16	0.9	0.9	1	0	0.8
17	0.9	0.9	1	0	0.8
18	0.9	0.9	1	0	0.6
19	0.8	0.7	1	0	0.4
20	0.8	0.5	1	0	0.4
21	0.7	0.5	1	0	0.4
22	0.4	0.3	1	0	0.4
23	0.2	0.3	1	0	0.15
24	0.2	0.3	1	0	0.15
Total Hours/Day	13.90	12.60	24.00	0.0000	9.800
Total Hours/Week	50.20				
Total Hours/Year	2,618				

A.4 Infiltration and HVAC

The HVAC operation schedules and infiltration schedules are always on, and always half-on, respectively. The motorized damper schedules follow the HVAC operational schedules, and so are also always on. 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 dampers.

A.5 Thermostat Set Points

Each zone in the baseline models uses constant heating and cooling set points. 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. No thermostat setup or setback is included based on the *2003 CBECS* data summarized in Section 3.1.5.1, but the summer design day heating set point is 55ºF (13ºC), and the winter design day cooling set point is 91ºF (33ºC). Humidity is addressed indirectly by controlling supply air temperature, which is 57ºF (14ºC) during cooling, and 104ºF (40ºC) during heating.

A.6 Service Water Heating

The service water heating schedules are adopted from ASHRAE 90.1-1989, and are shown in Table A-4.

Table A-4 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 Selected Results

Category	Subcategory	EDM Type	EDM Instance	1A
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point
			Materials Cost ($\$/ft^2$)	$0.19
			Installation Cost ($\$/ft^2$)	$0.22
	Generation	PV	EDM Key	7.2% of net roof area
			Materials Cost ($/W)	$9.54
			Installation Cost ($/W)	$1.06
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.796
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	3% of roof area in non-sidelit zones
	Vertical Glazing	South Window Fraction	EDM Key	120% of baseline glazing
			South Window-to-Wall Ratio (%)	32.3
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.360
			VLT (Ratio)	0.457
			U-Factor ($Btu/h{\cdot}ft^2{\cdot}°F$)	1.22
			Materials Cost ($\$/ft^2$)	$19.11
			Installation Cost ($\$/ft^2$)	$27.17
			Fixed O&M Cost ($\$/ft^2{\cdot}yr$)	$0.22
		Windows	EDM Key	Double pane with low-e and argon
			SHGC (Ratio)	0.564
			VLT (Ratio)	0.745

Category	Subcategory	EDM Type	EDM Instance	1A
			U-Factor (Btu/h·ft^2·°F)	0.264
			Materials Cost ($/ft^2)	$19.63
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque Constructions	Walls	EDM Key	R-31.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0399
			Materials Cost ($/ft^2)	$5.77
			Installation Cost ($/ft^2)	$2.49
		Roof	EDM Key	R-25 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0405
			Materials Cost ($/ft^2)	$3.68
			Installation Cost ($/ft^2)	$1.58
Equipment	HVAC System	System	EDM Key	20% increased COP with efficient fan
			Cooling COP (Ratio)	4.43
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	50.8
			Fan Static Pressure (in. w.c.)	1.53
			Materials Cost ($/ton)	$1,590.95
			Installation Cost ($/ton)	$171.00
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	None
			Sensible Effectiveness (%)	N/A
			Latent Effectiveness (%)	N/A
			Pressure Drop (in. w.c.)	N/A

Category	Subcategory	EDM Type	EDM Instance	1A
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#2: #1 plus covered at night
			Length (ft)	10.0
			Materials Cost ($/ft)	$701.65
			Installation Cost ($/ft)	$31.01
			Variable O&M Cost ($/ft/yr)	$16.67
		Med. Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	2.80
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00

Table B-2 1A Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			2,560	1,540	225	143	N/A
Low-Energy			1,280	1,600	113	148	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	Lighting Power Density	1,410	1,620	124	150	–5.2%
		Daylighting Sensors	1,370	1,600	121	149	–3.6%
		Daylighting Sensors and Skylights	1,360	1,600	120	148	–3.1%
		Photovoltaics	1,320	1,490	116	138	–1.6%
		Plug Loads	1,310	1,590	115	148	–1.2%
	Form	Effective Aperture	1,310	1,590	115	148	–1.1%
		Glazing Quantity	1,310	1,590	115	148	–1.1%
	Fabric	Opaque Envelope Constructions	1,370	1,590	121	148	–3.7%
		Fenestration Constructions	1,310	1,600	115	148	–1.1%
	Equipment	Entire HVAC System	1,380	1,610	122	150	–4.0%
		Rooftop Unit	1,340	1,600	118	149	–2.5%
		Demand Control Ventilation	1,310	1,610	115	150	–1.1%
	Refrigeration	Dairy and Deli Cases	1,670	1,610	147	150	–15.3%
		Frozen Food Cases	1,540	1,610	136	150	–10.3%
		Ice Cream Cases	1,450	1,620	128	151	–6.8%
		Refrigeration Compressors	1,310	1,600	115	148	–1.1%
		Meat Cases	1,290	1,590	114	148	–0.4%

B.2 Climate Zone 2A: Houston, Texas

Table B-3 2A Selected Results

Category	Subcategory	EDM Type	EDM Instance	2A
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point
			Materials Cost ($/ft^2)	$0.19
			Installation Cost ($/ft^2)	$0.22
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Peak plug loads reduced 10%
			Power Density (W/ft^2)	0.796
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.360
			VLT (Ratio)	0.457
			U-Factor (Btu/h·ft^2·°F)	1.22
			Materials Cost ($/ft^2)	$19.11
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.22
		Windows	EDM Key	Single pane with clear glass
			SHGC (Ratio)	0.810
			VLT (Ratio)	0.881
			U-Factor (Btu/h·ft^2·°F)	1.08
			Materials Cost ($/ft^2)	$12.61
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322

Category	Subcategory	EDM Type	EDM Instance	2A
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0859
			Materials Cost ($/ft^2)	$4.41
			Installation Cost ($/ft^2)	$1.90
		Roof	EDM Key	R-25 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0405
			Materials Cost ($/ft^2)	$3.68
			Installation Cost ($/ft^2)	$1.58
Equipment	HVAC System	System	EDM Key	20% increased COP with efficient fan
			Cooling COP (Ratio)	4.43
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	50.8
			Fan Static Pressure (in. w.c.)	1.53
			Materials Cost ($/ton)	$1,590.95
			Installation Cost ($/ton)	$171.00
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19

Category	Subcategory	EDM Type	EDM Instance	2A
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#3: #1 plus sliding doors
			Length (ft)	10.0
			Materials Cost ($/ft)	$789.15
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	2.80
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00

Table B-4 2A Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			2,740	1,610	242	150	N/A
Low-Energy			1,360	1,500	120	139	50.3%
	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	Lighting Power Density	1,510	1,530	133	142	–5.4%
		Daylighting Sensors	1,410	1,510	124	140	–1.5%
		Daylighting Sensors and Skylights	1,410	1,510	124	140	–1.5%
		Plug Loads	1,400	1,500	123	139	–1.2%
	Form	Glazing Quantity	1,360	1,500	120	140	0.1%
		Effective Aperture	1,360	1,500	120	140	0.1%
	Fabric	Opaque Envelope Constructions	1,500	1,510	132	141	–5.1%
		Fenestration Constructions	1,400	1,510	123	140	–1.2%
	Equipment	Entire HVAC System	1,530	1,520	135	141	–5.9%
		Rooftop Unit	1,440	1,510	127	140	–2.8%
		Energy Recovery	1,420	1,500	125	139	–1.9%
		Demand Control Ventilation	1,400	1,520	123	141	–1.2%
	Refrigeration	Dairy and Deli Cases	1,830	1,530	161	142	–17.1%
		Frozen Food Cases	1,630	1,520	143	141	–9.6%
		Ice Cream Cases	1,540	1,530	136	142	–6.4%
		Refrigeration Compressors	1,390	1,500	122	140	–0.8%
		Meat Cases	1,390	1,500	122	139	–1.0%

B.3 Climate Zone 2B: Phoenix, Arizona

Table B-5 2B Selected Results

Category	Subcategory	EDM Type	EDM Instance	2B
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point
			Materials Cost ($/ft^2)	$0.19
			Installation Cost ($/ft^2)	$0.22
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.360
			VLT (Ratio)	0.457
			U-Factor (Btu/h·ft^2·°F)	1.22
			Materials Cost ($/ft^2)	$19.11
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.22
		Windows	EDM Key	Single pane with clear glass
			SHGC (Ratio)	0.810
			VLT (Ratio)	0.881
			U-Factor (Btu/h·ft^2·°F)	1.08
			Materials Cost ($/ft^2)	$12.61
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque	Walls	EDM Key	R-13.3 c.i.

Category	Subcategory	EDM Type	EDM Instance	2B
	Constructions		U-Factor (Btu/h·ft^2·°F)	0.0859
			Materials Cost ($/ft^2)	$4.41
			Installation Cost ($/ft^2)	$1.90
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507
			Materials Cost ($/ft^2)	$3.43
			Installation Cost ($/ft^2)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	50.8
			Fan Static Pressure (in. w.c.)	1.53
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	Low effectiveness
			Sensible Effectiveness (%)	60.0
			Latent Effectiveness (%)	50.0
			Pressure Drop (in. w.c.)	0.703
			Materials Cost ($/ton)	$68.97
			Installation Cost ($/ton)	$8.19

Category	Subcategory	EDM Type	EDM Instance	2B
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#1: Efficient fans and anti-sweat heater controls
			Length (ft)	10.0
			Materials Cost ($/ft)	$684.99
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	2.80
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00

Table B-6 2B Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			2,680	1,520	236	141	N/A
Low-Energy			1,330	1,440	117	133	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	Lighting Power Density	1,460	1,450	129	135	–4.9%
		Daylighting Sensors	1,370	1,440	121	134	–1.7%
		Daylighting Sensors and Skylights	1,370	1,440	121	134	–1.7%
	Form	Glazing Quantity	1,330	1,440	117	134	0.1%
		Effective Aperture	1,330	1,440	117	134	0.1%
	Fabric	Opaque Envelope Constructions	1,470	1,460	130	135	–5.4%
		Fenestration Constructions	1,370	1,440	121	134	–1.5%
	Equipment	Entire HVAC System	1,450	1,440	127	134	–4.4%
		Rooftop Unit	1,390	1,440	122	134	–2.3%
		Energy Recovery	1,360	1,440	120	133	–1.3%
		Demand Control Ventilation	1,350	1,440	119	134	–0.8%
	Refrigeration	Dairy and Deli Cases	1,810	1,450	159	135	–17.9%
		Frozen Food Cases	1,600	1,440	141	134	–10.1%
		Ice Cream Cases	1,500	1,460	132	136	–6.5%
		Refrigeration Compressors	1,390	1,440	122	134	–2.3%
		Meat Cases	1,340	1,440	118	133	–0.4%

B.4 Climate Zone 3A: Atlanta, Georgia

Table B-7 3A Selected Results

Category	Subcategory	EDM Type	EDM Instance	3A
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point
			Materials Cost ($/ft^2)	$0.19
			Installation Cost ($/ft^2)	$0.22
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.360
			VLT (Ratio)	0.457
			U-Factor (Btu/h·ft^2·°F)	1.22
			Materials Cost ($/ft^2)	$19.11
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.22
		Windows	EDM Key	Single pane with clear glass
			SHGC (Ratio)	0.810
			VLT (Ratio)	0.881
			U-Factor (Btu/h·ft^2·°F)	1.08
			Materials Cost ($/ft^2)	$12.61
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque	Walls	EDM Key	R-13.3 c.i.

Category	Subcategory	EDM Type	EDM Instance	3A
	Constructions		U-Factor (Btu/h·ft²·°F)	0.0859
			Materials Cost ($/ft²)	$4.41
			Installation Cost ($/ft²)	$1.90
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft²·°F)	0.0507
			Materials Cost ($/ft²)	$3.43
			Installation Cost ($/ft²)	$1.48
Equipment	HVAC System	System	EDM Key	10% increased COP with efficient fan
			Cooling COP (Ratio)	4.06
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	50.8
			Fan Static Pressure (in. w.c.)	1.53
			Materials Cost ($/ton)	$1,539.07
			Installation Cost ($/ton)	$164.00
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19

Category	Subcategory	EDM Type	EDM Instance	3A
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#3: #1 plus sliding doors
			Length (ft)	10.0
			Materials Cost ($/ft)	$789.15
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	2.80
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00

Table B-8 3A Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			2,820	1,600	248	149	N/A
Low-Energy			1,400	1,480	124	137	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	Lighting Power Density	1,520	1,500	134	139	–4.3%
		Daylighting Sensors	1,440	1,480	127	138	–1.2%
		Daylighting Sensors and Skylights	1,440	1,480	127	138	–1.2%
	Form	Glazing Quantity	1,400	1,480	123	138	0.1%
		Effective Aperture	1,400	1,480	123	138	0.1%
	Fabric	Opaque Envelope Constructions	1,460	1,480	128	138	–2.0%
		Fenestration Constructions	1,420	1,490	125	138	–0.7%
	Equipment	Entire HVAC System	1,610	1,490	142	139	–7.3%
		Energy Recovery	1,510	1,480	133	137	–3.8%
		Rooftop Unit	1,470	1,490	129	138	–2.2%
		Demand Control Ventilation	1,430	1,490	126	139	–0.9%
	Refrigeration	Dairy and Deli Cases	1,930	1,520	170	141	–18.8%
		Frozen Food Cases	1,670	1,500	147	139	–9.4%
		Ice Cream Cases	1,580	1,510	139	140	–6.2%
		Meat Cases	1,450	1,480	128	137	–1.6%
		Refrigeration Compressors	1,420	1,480	125	138	–0.8%

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

Table B-9 3B-CA Selected Results

Category	Subcategory	EDM Type	EDM Instance	3B-CA
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point
			Materials Cost ($/ft^2)	$0.19
			Installation Cost ($/ft^2)	$0.22
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.360
			VLT (Ratio)	0.457
			U-Factor (Btu/h·ft^2·°F)	1.22
			Materials Cost ($/ft^2)	$19.11
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.22
		Windows	EDM Key	Single pane with clear glass
			SHGC (Ratio)	0.810
			VLT (Ratio)	0.881
			U-Factor (Btu/h·ft^2·°F)	1.08
			Materials Cost ($/ft^2)	$12.61
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque	Walls	EDM Key	Baseline Wall

Category	Subcategory	EDM Type	EDM Instance	3B-CA
	Constructions			Construction, R-5.7 c.i.
			U-Factor (Btu/h·ft²·°F)	0.173
			Materials Cost ($/ft²)	$3.82
			Installation Cost ($/ft²)	$1.65
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft²·°F)	0.0507
			Materials Cost ($/ft²)	$3.43
			Installation Cost ($/ft²)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	53.8
			Fan Static Pressure (in. w.c.)	1.62
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	Low effectiveness
			Sensible Effectiveness (%)	60.0
			Latent Effectiveness (%)	50.0
			Pressure Drop (in. w.c.)	0.703
			Materials Cost ($/ton)	$68.97
			Installation Cost ($/ton)	$8.19

Category	Subcategory	EDM Type	EDM Instance	3B-CA
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#3: #1 plus sliding doors
			Length (ft)	10.0
			Materials Cost ($/ft)	$789.15
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	2.80
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00

Table B-10 3B-CA Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			2,590	1,620	228	151	N/A
Low-Energy			1,290	1,490	114	138	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	Lighting Power Density	1,420	1,510	125	141	–4.8%
		Daylighting Sensors	1,330	1,490	117	139	–1.5%
		Daylighting Sensors and Skylights	1,330	1,490	117	139	–1.5%
	Form	Glazing Quantity	1,290	1,490	114	138	0.1%
		Effective Aperture	1,290	1,490	114	138	0.1%
	Fabric	Opaque Envelope Constructions	1,320	1,490	116	139	–0.9%
		Fenestration Constructions	1,320	1,500	116	139	–0.9%
	Equipment	Entire HVAC System	1,380	1,490	121	138	–3.3%
		Rooftop Unit	1,360	1,490	120	139	–2.5%
		Energy Recovery	1,330	1,480	117	138	–1.3%
		Demand Control Ventilation	1,290	1,490	114	138	–0.0%
	Refrigeration	Dairy and Deli Cases	1,850	1,520	163	142	–21.5%
		Frozen Food Cases	1,550	1,510	137	140	–10.0%
		Ice Cream Cases	1,470	1,520	129	141	–6.8%
		Meat Cases	1,350	1,480	119	138	–2.1%
		Refrigeration Compressors	1,320	1,490	116	138	–0.9%

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

Table B-11 3B-NV Selected Results

Category	Subcategory	EDM Type	EDM Instance	3B-NV
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point
			Materials Cost ($\$/ft^2$)	$0.19
			Installation Cost ($\$/ft^2$)	$0.22
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.360
			VLT (Ratio)	0.457
			U-Factor ($Btu/h \cdot ft^2 \cdot °F$)	1.22
			Materials Cost ($\$/ft^2$)	$19.11
			Installation Cost ($\$/ft^2$)	$27.17
			Fixed O&M Cost ($\$/ft^2 \cdot yr$)	$0.22
		Windows	EDM Key	Single pane with clear glass
			SHGC (Ratio)	0.810
			VLT (Ratio)	0.881
			U-Factor ($Btu/h \cdot ft^2 \cdot °F$)	1.08
			Materials Cost ($\$/ft^2$)	$12.61
			Installation Cost ($\$/ft^2$)	$27.17
			Fixed O&M Cost ($\$/ft^2 \cdot yr$)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque	Walls	EDM Key	R-9.5 c.i.

Category	Subcategory	EDM Type	EDM Instance	3B-NV
	Constructions		U-Factor (Btu/h·ft^2·°F)	0.137
			Materials Cost (\$/ft^2)	\$3.99
			Installation Cost (\$/ft^2)	\$1.72
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507
			Materials Cost (\$/ft^2)	\$3.43
			Installation Cost (\$/ft^2)	\$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	53.8
			Fan Static Pressure (in. w.c.)	1.62
			Materials Cost (\$/ton)	\$1,487.27
			Installation Cost (\$/ton)	\$157.98
			Fixed O&M Cost (\$/ton·yr)	\$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	Low effectiveness
			Sensible Effectiveness (%)	60.0
			Latent Effectiveness (%)	50.0
			Pressure Drop (in. w.c.)	0.703
			Materials Cost (\$/ton)	\$68.97
			Installation Cost (\$/ton)	\$8.19

Category	Subcategory	EDM Type	EDM Instance	3B-NV
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#1: Efficient fans and anti-sweat heater controls
			Length (ft)	10.0
			Materials Cost ($/ft)	$684.99
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	2.80
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00

Table B-12 3B-NV Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			2,680	1,560	236	145	N/A
Low-Energy			1,340	1,450	118	135	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	Lighting Power Density	1,460	1,480	128	137	–4.4%
		Daylighting Sensors	1,380	1,460	121	136	–1.5%
		Daylighting Sensors and Skylights	1,380	1,460	121	136	–1.5%
	Form	Glazing Quantity	1,330	1,460	117	135	0.2%
		Effective Aperture	1,330	1,460	117	135	0.2%
	Fabric	Opaque Envelope Constructions	1,380	1,460	122	136	–1.7%
		Fenestration Constructions	1,370	1,460	120	136	–1.1%
	Equipment	Entire HVAC System	1,470	1,460	130	136	–5.0%
		Rooftop Unit	1,440	1,460	127	136	–3.9%
		Energy Recovery	1,400	1,450	123	135	–2.3%
		Demand Control Ventilation	1,350	1,460	119	135	–0.5%
	Refrigeration	Dairy and Deli Cases	1,860	1,480	164	138	–19.4%
		Frozen Food Cases	1,620	1,470	142	137	–10.4%
		Ice Cream Cases	1,520	1,480	133	138	–6.7%
		Refrigeration Compressors	1,400	1,460	123	136	–2.2%
		Meat Cases	1,350	1,450	119	135	–0.5%

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

Table B-13 3C Selected Results

Category	Subcategory	EDM Type	EDM Instance	3C
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point
			Materials Cost ($/ft^2)	$0.19
			Installation Cost ($/ft^2)	$0.22
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.610
			VLT (Ratio)	0.775
			U-Factor (Btu/h·ft^2·°F)	1.22
			Materials Cost ($/ft^2)	$15.49
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.22
		Windows	EDM Key	Single pane with clear glass
			SHGC (Ratio)	0.810
			VLT (Ratio)	0.881
			U-Factor (Btu/h·ft^2·°F)	1.08
			Materials Cost ($/ft^2)	$12.61
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322

Category	Subcategory	EDM Type	EDM Instance	3C
	Opaque Constructions	Walls	EDM Key	Baseline Wall Construction, R-5.7 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.173
			Materials Cost ($/ft^2)	$3.82
			Installation Cost ($/ft^2)	$1.65
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507
			Materials Cost ($/ft^2)	$3.43
			Installation Cost ($/ft^2)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	53.8
			Fan Static Pressure (in. w.c.)	1.62
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19

Category	Subcategory	EDM Type	EDM Instance	3C
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#1: Efficient fans and anti-sweat heater controls
			Length (ft)	10.0
			Materials Cost ($/ft)	$684.99
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	2.80
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00

Table B-14 3C Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			2,800	1,670	246	156	N/A
Low-Energy			1,380	1,510	122	140	50.6%
	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	1,460	1,540	129	143	–3.0%
		Daylighting Sensors	1,400	1,520	123	141	–0.8%
		Daylighting Sensors and Skylights	1,400	1,520	123	141	–0.8%
	Form	Glazing Quantity	1,380	1,510	121	141	0.1%
		Effective Aperture	1,380	1,510	121	141	0.1%
	Fabric	Fenestration Constructions	1,420	1,520	125	141	–1.4%
		Opaque Envelope Constructions	1,390	1,510	123	141	–0.5%
	Equipment	Entire HVAC System	1,610	1,520	141	141	–8.1%
		Energy Recovery	1,530	1,510	135	140	–5.4%
		Rooftop Unit	1,520	1,520	134	141	–5.1%
		Demand Control Ventilation	1,390	1,510	122	140	–0.2%
	Refrigeration	Dairy and Deli Cases	2,010	1,560	177	145	–22.6%
		Frozen Food Cases	1,640	1,540	145	143	–9.4%
		Ice Cream Cases	1,570	1,550	138	144	–6.6%
		Refrigeration Compressors	1,400	1,510	123	140	–0.6%
		Meat Cases	1,390	1,510	123	140	–0.4%

B.8 Climate Zone 4A: Baltimore, Maryland

Table B-15 4A Selected Results

Category	Subcategory	EDM Type	EDM Instance	4A
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point
			Materials Cost ($\$/ft^2$)	$0.19
			Installation Cost ($\$/ft^2$)	$0.22
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.490
			VLT (Ratio)	0.622
			U-Factor ($Btu/h \cdot ft^2 \cdot °F$)	0.690
			Materials Cost ($\$/ft^2$)	$20.06
			Installation Cost ($\$/ft^2$)	$27.17
			Fixed O&M Cost ($\$/ft^2 \cdot yr$)	$0.22
		Windows	EDM Key	Single pane with clear glass
			SHGC (Ratio)	0.810
			VLT (Ratio)	0.881
			U-Factor ($Btu/h \cdot ft^2 \cdot °F$)	1.08
			Materials Cost ($\$/ft^2$)	$12.61
			Installation Cost ($\$/ft^2$)	$27.17
			Fixed O&M Cost ($\$/ft^2 \cdot yr$)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque	Walls	EDM Key	R-9.5 c.i.

Category	Subcategory	EDM Type	EDM Instance	4A
	Constructions		U-Factor (Btu/h·ft^2·°F)	0.137
			Materials Cost ($/ft^2)	$3.99
			Installation Cost ($/ft^2)	$1.72
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507
			Materials Cost ($/ft^2)	$3.43
			Installation Cost ($/ft^2)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	50.8
			Fan Static Pressure (in. w.c.)	1.53
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19

Category	Subcategory	EDM Type	EDM Instance	4A
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#3: #1 plus sliding doors
			Length (ft)	10.0
			Materials Cost ($/ft)	$789.15
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Baseline
			COP (Ratio)	2.80
			Materials Cost ($/each)	$50,000.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$10,500.00

Table B-16 4A Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			3,040	1,520	267	141	N/A
Low-Energy			1,500	1,430	132	133	50.7%
	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	1,600	1,440	140	134	–3.3%
		Daylighting Sensors	1,520	1,430	134	133	–0.9%
		Daylighting Sensors and Skylights	1,520	1,430	134	133	–0.9%
	Form	Glazing Quantity	1,490	1,440	132	133	0.1%
		Effective Aperture	1,490	1,440	132	133	0.1%
	Fabric	Opaque Envelope Constructions	1,540	1,430	136	133	–1.6%
		Fenestration Constructions	1,510	1,440	133	134	–0.4%
	Equipment	Entire HVAC System	1,810	1,450	160	135	–10.5%
		Energy Recovery	1,690	1,440	149	134	–6.4%
		Demand Control Ventilation	1,540	1,450	136	134	–1.5%
		Rooftop Unit	1,550	1,430	136	133	–1.6%
	Refrigeration	Dairy and Deli Cases	2,060	1,460	182	136	–18.7%
		Frozen Food Cases	1,760	1,440	155	133	–8.8%
		Ice Cream Cases	1,670	1,450	147	135	–5.9%
		Meat Cases	1,560	1,430	137	133	–2.0%
		Refrigeration Compressors	1,510	1,430	133	133	–0.3%

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

Table B-17 4B Selected Results

Category	Subcategory	EDM Type	EDM Instance	4B
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point
			Materials Cost ($/ft^2)	$0.19
			Installation Cost ($/ft^2)	$0.22
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.490
			VLT (Ratio)	0.622
			U-Factor (Btu/h·ft^2·°F)	0.690
			Materials Cost ($/ft^2)	$20.06
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.22
		Windows	EDM Key	Single pane with clear glass
			SHGC (Ratio)	0.810
			VLT (Ratio)	0.881
			U-Factor (Btu/h·ft^2·°F)	1.08
			Materials Cost ($/ft^2)	$12.61
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque	Walls	EDM Key	R-9.5 c.i.

Category	Subcategory	EDM Type	EDM Instance	4B
	Constructions		U-Factor (Btu/h·ft^2·°F)	0.137
			Materials Cost ($/ft^2)	$3.99
			Installation Cost ($/ft^2)	$1.72
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507
			Materials Cost ($/ft^2)	$3.43
			Installation Cost ($/ft^2)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	53.8
			Fan Static Pressure (in. w.c.)	1.62
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	None
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19

Category	Subcategory	EDM Type	EDM Instance	4B
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#3: #1 plus sliding doors
			Length (ft)	10.0
			Materials Cost ($/ft)	$789.15
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	2.80
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00

Table B-18 4B 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			2,830	1,420	249	132	N/A
Low-Energy			1,370	1,380	120	128	51.8%
	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	Lighting Power Density	1,470	1,390	129	129	–3.6%
		Daylighting Sensors	1,400	1,380	123	128	–1.3%
		Daylighting Sensors and Skylights	1,400	1,380	123	128	–1.3%
	Form	Effective Aperture	1,360	1,380	120	128	0.1%
		Glazing Quantity	1,360	1,380	120	128	0.1%
	Fabric	Opaque Envelope Constructions	1,400	1,380	123	128	–1.2%
		Fenestration Constructions	1,390	1,380	122	128	–0.7%
	Equipment	Entire HVAC System	1,570	1,380	138	128	–7.0%
		Energy Recovery	1,540	1,380	136	128	–6.3%
		Rooftop Unit	1,490	1,380	131	128	–4.5%
	Refrigeration	Dairy and Deli Cases	1,920	1,390	169	129	–19.5%
		Frozen Food Cases	1,640	1,380	144	128	–9.6%
		Ice Cream Cases	1,540	1,400	135	130	–6.1%
		Meat Cases	1,430	1,370	126	128	–2.2%
		Refrigeration Compressors	1,400	1,380	123	128	–1.2%

B.10 Climate Zone 4C: Seattle, Washington

Table B-19 4C Selected Results

Category	Subcategory	EDM Type	EDM Instance	4C
Program	Daylighting	Daylighting Controls	EDM Key	400 lux set point
			Materials Cost ($/ft^2)	$0.19
			Installation Cost ($/ft^2)	$0.22
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.490
			VLT (Ratio)	0.622
			U-Factor (Btu/h·ft^2·°F)	0.690
			Materials Cost ($/ft^2)	$20.06
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.22
		Windows	EDM Key	Single pane with clear glass
			SHGC (Ratio)	0.810
			VLT (Ratio)	0.881
			U-Factor (Btu/h·ft^2·°F)	1.08
			Materials Cost ($/ft^2)	$12.61
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque	Walls	EDM Key	R-9.5 c.i.

Category	Subcategory	EDM Type	EDM Instance	4C
	Constructions		U-Factor (Btu/h·ft^2·°F)	0.137
			Materials Cost ($/ft^2)	$3.99
			Installation Cost ($/ft^2)	$1.72
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507
			Materials Cost ($/ft^2)	$3.43
			Installation Cost ($/ft^2)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	53.8
			Fan Static Pressure (in. w.c.)	1.62
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19

Category	Subcategory	EDM Type	EDM Instance	4C
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Baseline
			COP (Ratio)	1.50
			Materials Cost ($/each)	$50,000.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$10,500.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#3: #1 plus sliding doors
			Length (ft)	10.0
			Materials Cost ($/ft)	$789.15
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Baseline
			COP (Ratio)	2.80
			Materials Cost ($/each)	$50,000.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$10,500.00

Table B-20 4C Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			2,990	1,500	264	140	N/A
Low-Energy			1,440	1,420	127	132	51.8%
	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	Lighting Power Density	1,520	1,430	134	133	–2.8%
		Daylighting Sensors	1,460	1,420	129	132	–0.7%
		Daylighting Sensors and Skylights	1,460	1,420	129	132	–0.7%
	Form	Glazing Quantity	1,440	1,420	127	132	–0.0%
		Effective Aperture	1,440	1,420	127	132	–0.0%
	Fabric	Opaque Envelope Constructions	1,480	1,420	131	132	–1.4%
		Fenestration Constructions	1,450	1,420	127	132	–0.1%
	Equipment	Entire HVAC System	1,750	1,430	154	133	–10.2%
		Energy Recovery	1,650	1,420	145	132	–6.8%
		Rooftop Unit	1,630	1,430	144	133	–6.3%
		Demand Control Ventilation	1,470	1,420	130	132	–1.0%
	Refrigeration	Dairy and Deli Cases	2,060	1,450	182	135	–20.8%
		Frozen Food Cases	1,710	1,430	150	133	–8.8%
		Ice Cream Cases	1,620	1,440	143	134	–6.1%
		Meat Cases	1,520	1,420	134	132	–2.6%
		Refrigeration Compressors	1,440	1,420	127	132	0.0%

B.11 Climate Zone 5A: Chicago, Illinois

Table B-21 5A Selected Results

Category	Subcategory	EDM Type	EDM Instance	5A
Program	Daylighting	Daylighting Controls	EDM Key	None
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.490
			VLT (Ratio)	0.622
			U-Factor (Btu/h·ft^2·°F)	0.690
			Materials Cost ($/ft^2)	$20.06
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.22
		Windows	EDM Key	Double pane with low-e and argon
			SHGC (Ratio)	0.564
			VLT (Ratio)	0.745
			U-Factor (Btu/h·ft^2·°F)	0.264
			Materials Cost ($/ft^2)	$19.63
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0859

Category	Subcategory	EDM Type	EDM Instance	5A
			Materials Cost ($/ft²)	$4.41
			Installation Cost ($/ft²)	$1.90
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft²·°F)	0.0507
			Materials Cost ($/ft²)	$3.43
			Installation Cost ($/ft²)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	50.8
			Fan Static Pressure (in. w.c.)	1.53
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost	$688.12

Category	Subcategory	EDM Type	EDM Instance	5A
			($/ft)	
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#1: Efficient fans and anti-sweat heater controls
			Length (ft)	10.0
			Materials Cost ($/ft)	$684.99
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	2.80
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00

Table B-22 5A 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			3,200	1,620	282	150	N/A
Low-Energy			1,590	1,480	140	137	50.3%
	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	Lighting Power Density	1,690	1,500	149	139	–3.1%
	Form	Effective Aperture	1,590	1,480	140	138	0.1%
		Glazing Quantity	1,590	1,480	140	138	0.1%
	Fabric	Opaque Envelope Constructions	1,650	1,480	145	137	–1.8%
		Fenestration Constructions	1,610	1,480	142	138	–0.6%
	Equipment	Entire HVAC System	2,010	1,500	177	139	–13.1%
		Energy Recovery	1,850	1,480	163	138	–8.2%
		Demand Control Ventilation	1,660	1,490	146	139	–2.2%
		Rooftop Unit	1,630	1,480	144	138	–1.2%
	Refrigeration	Dairy and Deli Cases	2,200	1,520	194	141	–19.0%
		Frozen Food Cases	1,860	1,500	164	139	–8.5%
		Ice Cream Cases	1,780	1,510	156	140	–5.8%
		Refrigeration Compressors	1,610	1,480	141	137	–0.5%
		Meat Cases	1,600	1,480	141	137	–0.3%

B.12 Climate Zone 5B: Denver, Colorado

Table B-23 5B Selected Results

Category	Subcategory	EDM Type	EDM Instance	5B
Program	Daylighting	Daylighting Controls	EDM Key	None
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.490
			VLT (Ratio)	0.622
			U-Factor ($Btu/h \cdot ft^2 \cdot °F$)	0.690
			Materials Cost ($\$/ft^2$)	$20.06
			Installation Cost ($\$/ft^2$)	$27.17
			Fixed O&M Cost ($\$/ft^2 \cdot yr$)	$0.22
		Windows	EDM Key	Double pane with low-e and argon
			SHGC (Ratio)	0.564
			VLT (Ratio)	0.745
			U-Factor ($Btu/h \cdot ft^2 \cdot °F$)	0.264
			Materials Cost ($\$/ft^2$)	$19.63
			Installation Cost ($\$/ft^2$)	$27.17
			Fixed O&M Cost ($\$/ft^2 \cdot yr$)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque Constructions	Walls	EDM Key	R-9.5 c.i.
			U-Factor ($Btu/h \cdot ft^2 \cdot °F$)	0.137

Category	Subcategory	EDM Type	EDM Instance	5B
			Materials Cost ($/ft^2)	$3.99
			Installation Cost ($/ft^2)	$1.72
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft^2·°F)	0.0507
			Materials Cost ($/ft^2)	$3.43
			Installation Cost ($/ft^2)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	53.8
			Fan Static Pressure (in. w.c.)	1.62
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	None
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35

Category	Subcategory	EDM Type	EDM Instance	5B
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	#3: #1 plus sliding doors
			Length (ft)	10.0
			Materials Cost ($/ft)	$789.15
			Installation Cost ($/ft)	$31.01
		Med. Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	2.80
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00

Table B-24 5B Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			3,010	1,430	265	133	N/A
Low-Energy			1,470	1,380	130	129	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	Lighting Power Density	1,590	1,390	140	129	–3.8%
	Form	Effective Aperture	1,470	1,390	130	129	0.1%
		Glazing Quantity	1,470	1,390	130	129	0.1%
	Fabric	Opaque Envelope Constructions	1,500	1,380	132	129	–0.8%
		Fenestration Constructions	1,490	1,390	131	129	–0.5%
	Equipment	Entire HVAC System	1,740	1,390	153	129	–8.9%
		Energy Recovery	1,730	1,390	152	129	–8.4%
		Rooftop Unit	1,600	1,390	141	129	–4.2%
	Refrigeration	Dairy and Deli Cases	2,050	1,400	180	130	–19.1%
		Frozen Food Cases	1,750	1,380	154	128	–9.1%
		Ice Cream Cases	1,650	1,400	145	130	–5.8%
		Meat Cases	1,540	1,380	136	128	–2.2%
		Refrigeration Compressors	1,500	1,380	132	128	–0.9%

B.13 Climate Zone 6A: Minneapolis, Minnesota

Table B-25 6A Selected Results

Category	Subcategory	EDM Type	EDM Instance	6A
Program	Daylighting	Daylighting Controls	EDM Key	None
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.490
			VLT (Ratio)	0.622
			U-Factor ($Btu/h{\cdot}ft^2{\cdot}°F$)	0.690
			Materials Cost ($\$/ft^2$)	$20.06
			Installation Cost ($\$/ft^2$)	$27.17
			Fixed O&M Cost ($\$/ft^2{\cdot}yr$)	$0.22
		Windows	EDM Key	Double pane with low-e and argon
			SHGC (Ratio)	0.564
			VLT (Ratio)	0.745
			U-Factor ($Btu/h{\cdot}ft^2{\cdot}°F$)	0.264
			Materials Cost ($\$/ft^2$)	$19.63
			Installation Cost ($\$/ft^2$)	$27.17
			Fixed O&M Cost ($\$/ft^2{\cdot}yr$)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.
			U-Factor ($Btu/h{\cdot}ft^2{\cdot}°F$)	0.0859

Category	Subcategory	EDM Type	EDM Instance	6A
			Materials Cost ($/ft²)	$4.41
			Installation Cost ($/ft²)	$1.90
		Roof	EDM Key	R-20 c.i.
			U-Factor (Btu/h·ft²·°F)	0.0507
			Materials Cost ($/ft²)	$3.43
			Installation Cost ($/ft²)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	50.8
			Fan Static Pressure (in. w.c.)	1.53
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35
			Materials Cost ($/ft)	$688.12

Category	Subcategory	EDM Type	EDM Instance	6A
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Baseline
			COP (Ratio)	1.50
			Materials Cost ($/each)	$50,000.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$10,500.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	Baseline
			Length (ft)	10.0
			Materials Cost ($/ft)	$656.23
			Installation Cost ($/ft)	$22.40
		Med. Temp. Rack	EDM Key	Baseline
			COP (Ratio)	2.80
			Materials Cost ($/each)	$50,000.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$10,500.00

Table B-26 6A Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			3,380	1,490	298	138	N/A
Low-Energy			1,680	1,410	148	131	50.3%
	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	Lighting Power Density	1,780	1,420	157	132	–2.9%
	Form	Effective Aperture	1,680	1,420	148	132	0.1%
		Glazing Quantity	1,680	1,420	148	132	0.1%
	Fabric	Opaque Envelope Constructions	1,740	1,410	154	131	–1.8%
		Fenestration Constructions	1,700	1,420	150	132	–0.6%
	Equipment	Entire HVAC System	2,190	1,440	193	134	–15.0%
		Energy Recovery	1,990	1,420	176	132	–9.2%
		Demand Control Ventilation	1,780	1,430	157	133	–2.9%
		Rooftop Unit	1,730	1,420	152	131	–1.3%
	Refrigeration	Dairy and Deli Cases	2,280	1,440	201	134	–17.8%
		Frozen Food Cases	1,960	1,420	173	132	–8.2%
		Ice Cream Cases	1,870	1,430	165	133	–5.5%
		Refrigeration Compressors	1,680	1,410	148	131	0.0%
		Meat Cases	1,680	1,410	148	131	0.0%

B.14 Climate Zone 6B: Helena, Montana

Table B-27 6B Selected Results

Category	Subcategory	EDM Type	EDM Instance	6B
Program	Daylighting	Daylighting Controls	EDM Key	None
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.490
			VLT (Ratio)	0.622
			U-Factor (Btu/h·ft^2·°F)	0.690
			Materials Cost ($/ft^2)	$20.06
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.22
		Windows	EDM Key	Double pane with low-e and argon
			SHGC (Ratio)	0.564
			VLT (Ratio)	0.745
			U-Factor (Btu/h·ft^2·°F)	0.264
			Materials Cost ($/ft^2)	$19.63
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0859

Category	Subcategory	EDM Type	EDM Instance	6B
			Materials Cost ($/ft²)	$4.41
			Installation Cost ($/ft²)	$1.90
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft²·°F)	0.0507
			Materials Cost ($/ft²)	$3.43
			Installation Cost ($/ft²)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	53.8
			Fan Static Pressure (in. w.c.)	1.62
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35

Category	Subcategory	EDM Type	EDM Instance	6B
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Evaporative condenser
			COP (Ratio)	1.50
			Materials Cost ($/each)	$47,800.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$11,616.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	Baseline
			Length (ft)	10.0
			Materials Cost ($/ft)	$656.23
			Installation Cost ($/ft)	$22.40
		Med. Temp. Rack	EDM Key	Baseline
			COP (Ratio)	2.80
			Materials Cost ($/each)	$50,000.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$10,500.00

Table B-28 6B Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			3,230	1,530	285	142	N/A
Low-Energy			1,600	1,440	141	134	50.4%
	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	1,690	1,450	149	135	–2.7%
	Form	Effective Aperture	1,600	1,440	141	134	0.1%
		Glazing Quantity	1,600	1,440	141	134	0.1%
	Fabric	Opaque Envelope Constructions	1,660	1,440	146	134	–1.6%
		Fenestration Constructions	1,620	1,440	143	134	–0.7%
	Equipment	Entire HVAC System	2,030	1,450	179	135	–13.1%
		Energy Recovery	1,880	1,440	166	134	–8.6%
		Rooftop Unit	1,720	1,440	151	134	–3.6%
		Demand Control Ventilation	1,660	1,440	147	134	–1.9%
	Refrigeration	Dairy and Deli Cases	2,240	1,470	197	137	–19.8%
		Frozen Food Cases	1,880	1,450	166	134	–8.6%
		Ice Cream Cases	1,790	1,460	158	136	–5.8%
		Refrigeration Compressors	1,610	1,440	142	134	–0.3%
		Meat Cases	1,600	1,440	141	134	0.0%

B.15 Climate Zone 7: Duluth, Minnesota

Table B-29 7 Selected Results

Category	Subcategory	EDM Type	EDM Instance	7
Program	Daylighting	Daylighting Controls	EDM Key	None
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.490
			VLT (Ratio)	0.490
			U-Factor (Btu/h·ft^2·°F)	0.690
			Materials Cost ($/ft^2)	$20.05
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.22
		Windows	EDM Key	Double pane with low-e and argon
			SHGC (Ratio)	0.564
			VLT (Ratio)	0.745
			U-Factor (Btu/h·ft^2·°F)	0.264
			Materials Cost ($/ft^2)	$19.63
			Installation Cost ($/ft^2)	$27.17
			Fixed O&M Cost ($/ft^2·yr)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque Constructions	Walls	EDM Key	Baseline Wall Construction, R-11.4 c.i.

Category	Subcategory	EDM Type	EDM Instance	7
			U-Factor (Btu/h·ft^2·°F)	0.0975
			Materials Cost ($/ft^2)	$4.27
			Installation Cost ($/ft^2)	$1.84
		Roof	EDM Key	R-20 c.i.
			U-Factor (Btu/h·ft^2·°F)	0.0507
			Materials Cost ($/ft^2)	$3.43
			Installation Cost ($/ft^2)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	50.8
			Fan Static Pressure (in. w.c.)	1.53
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35

Category	Subcategory	EDM Type	EDM Instance	7
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Baseline
			COP (Ratio)	1.50
			Materials Cost ($/each)	$50,000.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$10,500.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	Baseline
			Length (ft)	10.0
			Materials Cost ($/ft)	$656.23
			Installation Cost ($/ft)	$22.40
		Med. Temp. Rack	EDM Key	Baseline
			COP (Ratio)	2.80
			Materials Cost ($/each)	$50,000.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$10,500.00

Table B-30 7 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			3,580	1,490	315	139	N/A
Low-Energy			1,750	1,420	154	132	51.3%
	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	Lighting Power Density	1,820	1,420	161	132	–2.2%
	Form	Effective Aperture	1,740	1,420	153	132	0.1%
		Glazing Quantity	1,740	1,420	153	132	0.1%
	Fabric	Opaque Envelope Constructions	1,800	1,420	158	132	–1.4%
		Fenestration Constructions	1,770	1,420	155	132	–0.5%
	Equipment	Entire HVAC System	2,370	1,440	209	134	–17.5%
		Energy Recovery	2,140	1,430	188	133	–11.0%
		Demand Control Ventilation	1,870	1,430	165	133	–3.5%
		Rooftop Unit	1,780	1,420	157	132	–0.9%
	Refrigeration	Dairy and Deli Cases	2,390	1,440	210	134	–17.9%
		Frozen Food Cases	2,020	1,420	178	132	–7.8%
		Ice Cream Cases	1,930	1,440	170	133	–5.3%
		Refrigeration Compressors	1,750	1,420	154	132	0.0%
		Meat Cases	1,750	1,420	154	132	0.0%

B.16 Climate Zone 8: Fairbanks, Alaska

Table B-31 8 Selected Results

Category	Subcategory	EDM Type	EDM Instance	8
Program	Daylighting	Daylighting Controls	EDM Key	None
	Generation	PV	EDM Key	None
	Lighting Power	LPD	EDM Key	40% LPD reduction and occupancy sensors
			Power Density (W/ft^2)	0.885
	Plug Loads	Plug Loads	EDM Key	Baseline
			Power Density (W/ft^2)	0.884
Form	Shading	Shading Depth	EDM Key	None
	Skylights	Skylight Fraction	EDM Key	None
	Vertical Glazing	South Window Fraction	EDM Key	80% of baseline glazing
			South Window-to-Wall Ratio (%)	21.6
Fabric	Fenestration	Skylights	EDM Key	Baseline Skylight Construction
			SHGC (Ratio)	0.490
			VLT (Ratio)	0.490
			U-Factor ($Btu/h{\cdot}ft^2{\cdot}°F$)	0.580
			Materials Cost ($\$/ft^2$)	$23.87
			Installation Cost ($\$/ft^2$)	$27.17
			Fixed O&M Cost ($\$/ft^2{\cdot}yr$)	$0.22
		Windows	EDM Key	Baseline Window Construction
			SHGC (Ratio)	0.491
			VLT (Ratio)	0.626
			U-Factor ($Btu/h{\cdot}ft^2{\cdot}°F$)	0.573
			Materials Cost ($\$/ft^2$)	$16.65
			Installation Cost ($\$/ft^2$)	$23.23
			Fixed O&M Cost ($\$/ft^2{\cdot}yr$)	$0.19
	Infiltration	Infiltration	EDM Key	Baseline
			Rate (ACH)	0.322
	Opaque Constructions	Walls	EDM Key	R-13.3 c.i.
			U-Factor ($Btu/h{\cdot}ft^2{\cdot}°F$)	0.0859

Category	Subcategory	EDM Type	EDM Instance	8
			Materials Cost ($/ft²)	$4.41
			Installation Cost ($/ft²)	$1.90
		Roof	EDM Key	R-20 c.i. with cool roof
			U-Factor (Btu/h·ft²·°F)	0.0507
			Materials Cost ($/ft²)	$3.43
			Installation Cost ($/ft²)	$1.48
Equipment	HVAC System	System	EDM Key	Baseline COP with efficient fan
			Cooling COP (Ratio)	3.69
			Heating Efficiency (%)	80.0
			Economizer	False
			Motorized Damper	False
			Fan Efficiency (%)	50.8
			Fan Static Pressure (in. w.c.)	1.53
			Materials Cost ($/ton)	$1,487.27
			Installation Cost ($/ton)	$157.98
			Fixed O&M Cost ($/ton·yr)	$131.99
	Outdoor Air	DCV	EDM Key	Installed
		ERV	EDM Key	High effectiveness
			Sensible Effectiveness (%)	80.0
			Latent Effectiveness (%)	70.0
			Pressure Drop (in. w.c.)	1.00
			Materials Cost ($/ton)	$103.43
			Installation Cost ($/ton)	$8.19
Refrigeration	Low Temp	Ice Cream	EDM Key	Replace with efficient vertical door model, hot gas defrost
			Length (ft)	7.35

Category	Subcategory	EDM Type	EDM Instance	8
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Frozen Food	EDM Key	#2 with hot gas defrost
			Length (ft)	25.4
			Materials Cost ($/ft)	$688.12
			Installation Cost ($/ft)	$43.72
		Low Temp. Rack	EDM Key	Baseline
			COP (Ratio)	1.50
			Materials Cost ($/each)	$50,000.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$10,500.00
	Med Temp	Dairy/Deli	EDM Key	Replace with efficient vertical door model
			Length (ft)	14.5
			Materials Cost ($/ft)	$636.23
			Installation Cost ($/ft)	$39.15
		Meat Display	EDM Key	Baseline
			Length (ft)	10.0
			Materials Cost ($/ft)	$656.23
			Installation Cost ($/ft)	$22.40
		Med. Temp. Rack	EDM Key	Baseline
			COP (Ratio)	2.80
			Materials Cost ($/each)	$50,000.00
			Installation Cost ($/each)	$57,500.00
			Fixed O&M Cost ($/each/yr)	$10,500.00

Table B-32 8 Perturbation Results

Building Name			EUI (MJ/m²·yr)	5-TLCC Intensity ($/m²)	EUI (kBtu/ft²yr)	5-TLCC Intensity ($/ft²)	Percent Savings
Baseline			4,140	1,560	364	145	N/A
Low-Energy			2,020	1,460	177	136	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	Lighting Power Density	2,070	1,480	183	137	–1.4%
	Form	Effective Aperture	2,020	1,470	178	136	–0.1%
		Glazing Quantity	2,020	1,470	178	136	–0.1%
	Fabric	Opaque Envelope Constructions	2,010	1,460	177	136	0.2%
	Equipment	Entire HVAC System	2,990	1,470	263	137	–23.5%
		Energy Recovery	2,580	1,470	227	136	–13.7%
		Demand Control Ventilation	2,270	1,470	200	136	–6.3%
		Rooftop Unit	2,040	1,470	179	136	–0.5%
	Refrigeration	Dairy and Deli Cases	2,680	1,490	236	139	–16.1%
		Frozen Food Cases	2,300	1,480	203	137	–6.9%
		Ice Cream Cases	2,210	1,490	194	138	–4.7%
		Refrigeration Compressors	2,020	1,460	177	136	0.0%
		Meat Cases	2,020	1,460	177	136	0.0%

Appendix C. Detailed End Use Data

Table C-1 Detailed End Uses, Absolute EUIs

	kBtu/ft²	PV Power: Electricity	Cooling: Electricity	Int. Lighting: Electricity	Ext. Lighting: Electricity	Int. Equip.: Electricity	Fans: Electricity	Refrigeration: Electricity	Heating: Gas	Int. Equip.: Gas	Water Systems: Gas
1A	Baseline	0.0	14.2	32.6	0.3	14.1	16.8	133	6.3	6.1	1.9
	Low-Energy	-3.6	8.2	13.0	0.3	12.7	6.1	67.2	1.3	5.5	1.9
2A	Baseline	0.0	9.4	32.6	0.3	14.1	16.6	126	33.7	6.1	2.4
	Low-Energy	0.0	5.9	15.8	0.3	12.7	9.3	61.8	6.5	5.5	2.4
3A	Baseline	0.0	4.6	32.6	0.3	14.1	14.6	119	53.9	6.1	2.9
	Low-Energy	0.0	4.4	15.7	0.3	14.1	10.4	55.6	14.0	6.1	2.9
4A	Baseline	0.0	3.6	32.6	0.3	14.1	14.7	116	77.0	6.1	3.2
	Low-Energy	0.0	4.1	15.9	0.3	14.1	10.8	53.0	24.2	6.1	3.2
5A	Baseline	0.0	2.7	32.6	0.3	14.1	15.7	113	93.7	6.1	3.6
	Low-Energy	0.0	3.0	19.2	0.3	14.1	11.1	50.1	32.5	6.1	3.6
6A	Baseline	0.0	2.3	32.6	0.3	14.1	16.3	112	110	6.1	3.8
	Low-Energy	0.0	3.1	19.2	0.3	14.1	12.0	51.4	38.0	6.1	3.8
2B	Baseline	0.0	11.7	32.6	0.3	14.1	19.4	123	27.2	6.1	2.1
	Low-Energy	0.0	7.3	15.3	0.3	14.1	9.9	51.7	10.0	6.1	2.1
3B-CA	Baseline	0.0	2.1	32.6	0.3	14.1	12.5	117	39.8	6.1	2.8
	Low-Energy	0.0	2.8	15.5	0.3	14.1	7.9	55.9	8.4	6.1	2.8
3B-NV	Baseline	0.0	6.5	32.6	0.3	14.1	16.0	118	40.1	6.1	2.5
	Low-Energy	0.0	6.2	15.3	0.3	14.1	10.4	47.1	15.8	6.1	2.5
4B	Baseline	0.0	2.9	32.6	0.3	14.1	16.3	113	60.6	6.1	3.2
	Low-Energy	0.0	3.9	15.4	0.3	14.1	12.2	46.5	18.5	6.1	3.2
5B	Baseline	0.0	1.9	32.6	0.3	14.1	17.5	111	78.3	6.1	3.5
	Low-Energy	0.0	3.1	19.2	0.3	14.1	13.0	45.4	24.9	6.1	3.5
6B	Baseline	0.0	1.2	32.6	0.3	14.1	17.6	109	99.8	6.1	3.9
	Low-Energy	0.0	2.1	19.2	0.3	14.1	12.7	46.8	35.8	6.1	3.9
3C	Baseline	0.0	0.9	32.6	0.3	14.1	12.5	112	64.5	6.1	3.2
	Low-Energy	0.0	1.8	15.6	0.3	14.1	8.8	50.7	20.9	6.1	3.2
4C	Baseline	0.0	0.9	32.6	0.3	14.1	13.4	110	82.4	6.1	3.4
	Low-Energy	0.0	1.9	16.4	0.3	14.1	9.4	50.6	24.8	6.1	3.4
7	Baseline	0.0	1.1	32.6	0.3	14.1	16.7	108	132	6.1	4.3
	Low-Energy	0.0	1.9	19.2	0.3	14.1	12.7	48.0	47.1	6.1	4.3
8	Baseline	0.0	0.5	32.6	0.3	14.1	17.6	106	182	6.1	4.8
	Low-Energy	0.0	1.1	19.2	0.3	14.1	14.3	45.3	72.1	6.1	4.8

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

	Percentages	PV Power: Electricity	Cooling: Electricity	Int. Lighting: Electricity	Ext. Lighting: Electricity	Int. Equip.: Electricity	Fans: Electricity	Refrigeration: Electricity	Heating: Gas	Int. Equip.: Gas	Water Systems: Gas
1A	Baseline	0.0	6.3	14.5	0.1	6.3	7.5	59.0	2.8	2.7	0.9
	Low-Energy	-3.2	7.3	11.5	0.3	11.3	5.4	59.6	1.1	4.9	1.7
2A	Baseline	0.0	3.9	13.5	0.1	5.8	6.9	52.2	14.0	2.5	1.0
	Low-Energy	0.0	4.9	13.1	0.2	10.6	7.8	51.4	5.4	4.6	2.0
3A	Baseline	0.0	1.8	13.1	0.1	5.7	5.9	48.0	21.7	2.5	1.2
	Low-Energy	0.0	3.6	12.7	0.2	11.4	8.4	45.0	11.3	5.0	2.3
4A	Baseline	0.0	1.3	12.2	0.1	5.3	5.5	43.3	28.8	2.3	1.2
	Low-Energy	0.0	3.1	12.1	0.2	10.7	8.2	40.2	18.4	4.7	2.5
5A	Baseline	0.0	0.9	11.6	0.1	5.0	5.6	40.1	33.3	2.2	1.3
	Low-Energy	0.0	2.1	13.7	0.2	10.1	7.9	35.8	23.2	4.4	2.5
6A	Baseline	0.0	0.8	11.0	0.1	4.7	5.5	37.6	37.0	2.1	1.3
	Low-Energy	0.0	2.1	13.0	0.2	9.5	8.1	34.7	25.7	4.1	2.6
2B	Baseline	0.0	4.9	13.8	0.1	6.0	8.2	52.0	11.5	2.6	0.9
	Low-Energy	0.0	6.3	13.1	0.2	12.1	8.5	44.2	8.5	5.3	1.8
3B-CA	Baseline	0.0	0.9	14.3	0.1	6.2	5.5	51.5	17.5	2.7	1.2
	Low-Energy	0.0	2.5	13.6	0.3	12.4	7.0	49.1	7.3	5.4	2.4
3B-NV	Baseline	0.0	2.7	13.8	0.1	6.0	6.8	50.0	17.0	2.6	1.0
	Low-Energy	0.0	5.2	13.0	0.2	12.0	8.8	40.0	13.4	5.2	2.1
4B	Baseline	0.0	1.2	13.1	0.1	5.7	6.5	45.4	24.3	2.5	1.3
	Low-Energy	0.0	3.3	12.8	0.2	11.7	10.1	38.7	15.4	5.1	2.6
5B	Baseline	0.0	0.7	12.3	0.1	5.3	6.6	41.8	29.5	2.3	1.3
	Low-Energy	0.0	2.4	14.8	0.2	10.9	10.0	35.0	19.2	4.7	2.7
6B	Baseline	0.0	0.4	11.5	0.1	5.0	6.2	38.3	35.1	2.2	1.4
	Low-Energy	0.0	1.5	13.6	0.2	10.0	9.0	33.2	25.4	4.4	2.8
3C	Baseline	0.0	0.4	13.2	0.1	5.7	5.1	45.5	26.2	2.5	1.3
	Low-Energy	0.0	1.5	12.8	0.2	11.6	7.2	41.7	17.2	5.1	2.6
4C	Baseline	0.0	0.3	12.4	0.1	5.4	5.1	41.8	31.3	2.3	1.3
	Low-Energy	0.0	1.5	12.9	0.2	11.1	7.4	39.8	19.5	4.8	2.7
7	Baseline	0.0	0.3	10.3	0.1	4.5	5.3	34.3	41.9	1.9	1.4
	Low-Energy	0.0	1.2	12.5	0.2	9.2	8.3	31.2	30.6	4.0	2.8
8	Baseline	0.0	0.1	9.0	0.1	3.9	4.8	29.1	50.0	1.7	1.3
	Low-Energy	0.0	0.6	10.8	0.2	7.9	8.1	25.5	40.7	3.5	2.7

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This report provides recommendations that architects, designers, contractors, developers, owners, and lessees of grocery store 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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