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50%

Advanced Energy Design Guide for Medium to Big Box Retail Buildings

Achieving 50% Energy Savings Toward a Net Zero Energy Building

Developed by:
American Society of Heating, Refrigerating and Air-Conditioning Engineers
The American Institute of Architects
Illuminating Engineering Society of North America
U.S. Green Building Council
U.S. Department of Energy

Advanced Energy Design Guide for Medium to Big Box Retail Buildings

This is an ASHRAE Design Guide. Design Guides are developed under ASHRAE's Special Publication procedures and are not consensus documents. This document is an application manual that provides voluntary recommendations for consideration in achieving greater levels of energy savings relative to minimum standards.

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Acknowledgments

The *Advanced Energy Design Guide for Medium to Big Box Retail Buildings* is the third in a series of Advanced Energy Design Guide (AEDG) publications designed to provide design strategies and recommendations to achieve 50% energy savings over the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. The 50% AEDG series addresses building types that represent major energy users in the commercial building stock. This Guide is the result of the dedicated, collective efforts of many professionals who devoted countless hours to help retail stores use less energy.

The primary authors were the six members of the ASHRAE Special Project Committee (SP-135) who represented the participating organizations, primarily the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), the American Institute of Architects (AIA), the U.S. Green Building Council (USGBC), the Illuminating Engineering Society of North America (IES), and the U.S. Department of Energy (DOE). Thanks also to members of the Standing Standards Project Committee 90.1.

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The chair also would like to personally thank all the members of the project committee for their diligence, creativity, persistence, and willingness to take the time to support this Guide. They worked extremely hard to pull together practical, technically sound information covering all aspects of low-energy-use retail store design. They provided guidance in the lighting area, including daylighting recommendations, many types of HVAC systems, and envelope considerations. Their expertise and differing views greatly enriched this Guide. The authors brought many years of experience and good practices in design, construction, commissioning, and operation of retail buildings to achieve significant energy savings.

The project committee met four times and held eight conference calls in six months. Each face-to-face meeting required two nights in a hotel; thus, the chair would like to express his appreciation to the authors' families for their patience. The chair also would like to acknowledge the support of the project committee members' employers, including Owens Corning, WSP Flack + Kurtz, Carol Marriott Consulting, Puget Sound Energy, Integrated Lighting

Concepts, Target Corporation, the University of Kentucky, and the National Renewable Energy Laboratory.

The project committee's efforts were guided by the AEDG Steering Committee, composed of members from the partner organizations: ASHRAE, AIA, USGBC, IES, and DOE. Its members provided direction and guidance to complete the Guide within nine months. The Steering Committee assembled an expert team of authors and defined a scope that kept the project committee's task manageable and focused. The representatives from these organizations brought a collegial and constructive spirit to the task of setting policy.

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Shanti Pless
Chair, Special Project 135

December 2011

Abbreviations and Acronyms

100% OAS	100% outdoor air system (also *dedicated outdoor air system* [*DOAS*])
AEDG	Advanced Energy Design Guide
AFF	above finished floor
AHRI	Air-Conditioning, Heating, and Refrigeration Institute
AIA	American Institute of Architects
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	ASTM International
BAS	building automation system
BAU	business as usual
BF	ballast factor
BoD	Basis of Design
Btu	British thermal unit
C	thermal conductance, $Btu/h \cdot ft^2 \cdot °F$
CAV	constant air volume
CBECS	Commercial Buildings Energy Consumption Survey
CBP	Commercial Building Partnerships
CD	construction document
CDD	cooling degree-days
CFL	compact fluorescent
cfm	cubic feet per minute
c.i.	continuous insulation
CMH	ceramic metal halide
CO_2	carbon dioxide
COP	coefficient of performance, dimensionless
CRI	Color Rendering Index
CRRC	Cool Roof Rating Council
Cx	commissioning
CxA	commissioning authority
DCV	demand-controlled ventilation
DL	Advanced Energy Design Guide code for "daylighting"

DOAS	dedicated outdoor air system (also *100% outdoor air system* [*100% OAS*])
DOE	U.S. Department of Energy
DX	direct expansion
EA	effective aperture
ECM	energy conservation measure
EER	energy efficiency ratio, Btu/W·h
EERE	Energy Efficiency and Renewable Energy, a division of the U.S. DOE
EF	energy factor
EL	Advanced Energy Design Guide code for "electric lighting"
EN	Advanced Energy Design Guide code for "envelope"
ERV	energy recovery ventilator
ESP	external static pressure
E_t	thermal efficiency, dimensionless
EUI	energy use intensity
EWT	entering water temperature
F	slab edge heat loss coefficient per foot of perimeter, Btu/h•ft•°F
fc	footcandle
FC	filled cavity
FEG	Fan Efficiency Grade
GSHP	ground-source heat pump
Guide	*Advanced Energy Design Guide for Medium to Big Box Retail Buildings*
HC	heat capacity, Btu/(ft^2•°F)
HDD	heating degree-days
HID	high-intensity discharge
HPS	high-pressure sodium
HSPF	heating seasonal performance factor, Btu/W•h
HV	Advanced Energy Design Guide code for "HVAC systems and equipment"
HVAC	heating, ventilating, and air-conditioning
IAQ	indoor air quality
ICC	International Code Council
IECC	International Energy Conservation Code
IEER	integrated energy efficiency ratio, Btu/W·h
IES/IESNA	Illuminating Engineering Society of North America
in.	inch
in. w.c.	inches of water column
kW	kilowatt
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LCCA	life-cycle cost analysis
LCD	liquid crystal display
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
lf	linear foot
LPD	lighting power density, W/ft^2
LPW	lumens per watt
Ls	liner system
LZ	lighting zone
M&V	measurement and verification
MERV	Minimum Efficiency Reporting Value
MH	metal halide
N/A	not applicable
NAAQS	National Ambient Air Quality Standards

NEMA	National Electrical Manufacturers Association
NFRC	National Fenestration Rating Council
NREL	National Renewable Energy Laboratory
OA	outdoor air
O&M	operation and maintenance
OPR	Owner's Project Requirements
PF	projection factor, dimensionless
PL	Advanced Energy Design Guide code for "plug loads"
PNNL	Pacific Northwest National Laboratory
POE	post-occupancy evaluation
ppm	parts per million
PV	photovoltaic
QA	quality assurance; Advanced Energy Design Guide code for "quality assurance"
R	thermal resistance, h•ft^2•°F/Btu
RFP	request for proposal
RFQ	request for qualifications
ROI	return on investment
RTU	rooftop unit
SAT	supply air temperature
SEER	seasonal energy efficiency ratio, Btu/W·h
SFR	skylight-to-floor-area ratio
SHGC	solar heat gain coefficient, dimensionless
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SRI	Solar Reflectance Index, dimensionless
SSL	solid-state lighting
SWH	service water heating
U	thermal transmittance, Btu/h•ft^2•°F
USGBC	U.S. Green Building Council
VAV	variable air volume
VFD	variable-frequency drive
VLT	visible light transmittance
VOC	volatile organic compound
VSD	variable-speed drive
VT	visible transmittance
W	watt
WH	Advanced Energy Design Guide code for "service water heating"
WSHP	water-source heat pump
WWR	window-to-wall ratio

Foreword:
A Message for Building Owners and Developers

The *Advanced Energy Design Guide for Medium to Big Box Retail Buildings* (the Guide) is a continuation of the series of Advanced Energy Design Guide (AEDG) publications designed to provide recommendations to achieve 50% energy savings when compared with the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004 (ASHRAE 2004). This Guide applies to medium to big box retail buildings with gross floor areas between 40,000 and 100,000 ft^2; however, many of the recommendations also can be applied to smaller or larger retail buildings.

Incorporating energy-efficient building techniques into retail buildings is nothing new to many retailers. Often, retailers design, construct, own, and operate their facilities, and good design that provides energy-efficient and long-term, low-cost operations is part of a successful business. Energy costs are typically the second highest operating expense for a retailer, so implementing cost-effective energy saving strategies will have a direct and significant impact on profitability.

Use of this Guide can help in creating a cost-effective design for new retail buildings and major renovations that consume substantially less energy compared to the minimum code-compliant design and that result in lower operating costs. Also important, through use of an integrated design process, an energy-efficient building offers a great possibility to enhance the shopping and working environment with respect to indoor air quality (IAQ), thermal comfort, and visual comfort.

For successful designs of brand-appropriate energy-efficient buildings, owners and designers must consider the following criteria as they collaborate on the design for their buildings:

- Meets all brand requirements of the retailer
- Creates a healthy and inviting indoor environment
- Understands where energy is used in the building
- Minimizes oversizing and unnecessary redundancy to reduce capital cost
- Follows construction practices, such as the use of low-emitting materials and oversight, to avoid moisture intrusion
- Maintains clean, dry buildings with reduced sources of contaminants to help ensure good IAQ
- Optimizes ventilation requirements through a performance-based approach such as demand control or the IAQ Procedure in ANSI/ASHRAE Standard 62.1 (ASHRAE 2010)
- Allows for downsized HVAC systems due to better envelope, optimized ventilation, more efficient lighting, and reduced and better managed miscellaneous electric loads

- Provides ongoing monitoring and oversight to ensure operational efficiency is maintained
- Leverages successful efficiency measures into a chain-wide rollout to drive down existing building energy use

Many retailers are in the unique position of having a portfolio of buildings of similar design across many climate zones. This portfolio of existing buildings can provide the basis to understand where energy is used and where opportunities exist for high-performance improvements. Focusing on the design of a prototypical retail building will allow best practices to be applied to site-specific building locations across the chain.

The ability for a prototypical design to achieve and maintain 50% energy use reduction in any climate and on any site requires more than just project design team agreement on any specific set of building energy systems. Maintaining brand is critical for retailers, as is the need for flexibility in merchandizing. It is more difficult to significantly vary the shape or orientation of site-specific buildings to account for location-specific parameters, such as a site location's impact on solar energy usage. To meet highest performance levels in all locations, retailers will need to accept more flexibility in design features to take advantage of climate-specific measures that make economic sense in some areas but not in others. For example, indirect evaporative cooling may make sense in hot, dry climates but may not in colder climates. When designs do vary from prototype, close attention must be carried through implementation and operations to ensure long-term success and true high-performing operations.

Strong owner's advocates that understand the risks and rewards of design decisions are crucial in achieving high performance. This could be owners with internal design expertise or a consultant with long-term detailed knowledge of the owner's needs. In any case, a partnership must be established to encourage calculated design risk (such as not oversizing HVAC equipment). Owners will benefit from reduced capital cost and improved energy efficiency if systems are optimally designed without excessive safety factors. Designers should communicate opportunities along with the risk/rewards to owners in high-performance design. When using new technology, consider options for modifications that could be made if performance isn't as intended, particularly in the technology's early stages.

It is also worth noting that whatever time and effort is spent by the project's design team to achieve this level of efficiency has a high risk of being negated or lost if the building's operations and maintenance (O&M) staff is not provided with the tools, education, information, and decisions made during the initial design process, including the assumptions made concerning equipment, maintenance, calibration, and replacement of critical building systems. Ultimately, the design team should take into consideration the O&M procedures used by the building owner and ensure system design can be effectively incorporated into standard processes or inform the owner of special training and procedures that must be used for the high-performance building. Measurement and verification (M&V) of system performance after construction and at ongoing intervals is critical to sustained high performance of the building.

This Guide presents a broad range of subject matter, including broad concepts such as the integrated design process, multidisciplinary design strategies, and design tips and good practices on specific energy systems. The focus of this Guide, especially the later chapters, is on building and system details that can help achieve the desired results.

ENHANCED SHOPPING AND WORKING ENVIRONMENTS

In addition to high energy efficiency, good design practice focuses on creating healthier building environments including visual comfort, acceptable acoustic comfort, thermal comfort, and good IAQ for shoppers and employees. The goal of retailers is to create an inviting environment for customers visiting for a quick "grab and go" shopping experience as well as those shopping for an extended period of time. The focus within a retail store is on the products being sold and avoiding conditions within the store that negatively impact the customer or employee experience. Energy-saving designs and products that interfere with the occupant experience or store brand will likely negatively impact future implementation of energy savings measures. Buildings are for people, and energy-efficient design must consider long-term impact on occupants to ensure long-term success.

In the past, general merchandise retailers rarely considered active humidity control. Humidity control for thermal comfort in buildings becomes increasingly important for high-performance buildings in many climate zones. Most retailers only control space temperature, while humidity is controlled as a byproduct of the cooling process. As internal space loads such as lighting are reduced and buildings are better insulated, the sensible cooling load is reduced and cooling systems operate less. With a requirement for continuous outdoor air (OA) supplied for ventilation and when cooling systems are off and outdoor dew points are high, space dew-point conditions (humidity) will rise and can lead to uncomfortable conditions indoors. System designs that address humidity by first ensuring ventilation rates are adequate for good IAQ and then adding systems that monitor and control dew-point levels will help maintain good environmental conditions for store occupants.

LOWER LIFE-CYCLE COSTS

Often the higher capital cost of energy-efficient building system technology cannot be justified by the energy cost savings alone. Through use of an integrated design process and project delivery, energy-efficient retail buildings can cost less to build than traditional retail buildings. For example, optimizing the building envelope for the climate can substantially reduce the required size of the mechanical systems as well as ongoing maintenance and energy costs. Retailers also have the opportunity to directly purchase much of the energy-using components of a building. Direct procurement not only can lower purchase cost but also allows direct owner decision on the level of energy efficiency and other features for the equipment.

Retailers have the opportunity to drive down the costs of energy-efficient technologies through purchasing power. Market supply and demand can result in high costs for new technology. Retailers with the ability to purchase large quantities of product for rollout in similar buildings often can help accelerate cost savings driven from quantity production. This is particularly true if technology rollout ideas are shared with other owners to expand the market. Local utility and federal tax incentives also provide possible ways to reduce capital costs of energy-efficient technology.

Driving down capital costs through good design practices and procurement efforts on top of energy cost savings and maximizing incentives will help meet energy savings goals while maintaining fiscal responsibility required for a successful commercial building owner.

REDUCED OPERATING COSTS

It is likely that when a retailer better understands where the energy is being consumed within their stores they will find opportunities to reduce operating costs through modification of operations and controls. Existing practices that should be challenged include those such as how much lighting is needed to stock and clean a store after hours or whether lighting is even needed in a store that is closed. Other operational enhancements such as variable-air-volume HVAC systems not only save energy but also extend filter life and reduce wear on fans, motors, and drives. Solid-state lighting (SSL) has the potential to save energy and can greatly extend lamp life, resulting in reduced long-term maintenance costs. Accounting for reduced operations costs can help provide economic justification for many high-performance measures.

Designing a high-performance building isn't enough to ensure it actually will save energy. Ensuring that systems are installed and operating as intended is critical. Retailers can take advantage of prototypical processes to incorporate commissioning-related activities into design and through building construction and then monitor operations through centralized monitoring and control systems. M&V processes will help achieve and maintain the high-performance goals of the building. Findings from ongoing monitoring also will provide information valuable to continuous improvement in the design and operation of high-performance buildings. Participation in an ongoing performance rating system such as the U.S. Environmental Protection Agency's ENERGY STAR® rating system for buildings or ASHRAE's Building Energy Quotient (bEQ) program provides an opportunity for retailers to benchmark their building's energy use against that of other buildings in their own portfolio and against other retail buildings.

WATER AS A RESOURCE

Water is a rapidly depleting natural resource. Though this Guide deals only with direct building-related energy conservation measures, including service water heating, all water savings result in related energy savings. Water savings from low-flow fixtures and reduced water use from efficient landscaping result in indirect energy savings from pumping and waste disposal. Potable water savings also result in water supply and processing energy savings of 10–25 Btu per gallon of water saved (Carlson and Walburger 2007). Water is also used to produce electricity and to extract and process fossil fuels. Saving energy saves water and saving water saves energy. Water savings should be integrated into high-performance retail building design.

REDUCED GREENHOUSE GAS EMISSIONS

According to some estimates, buildings are responsible for nearly 40% of all carbon dioxide (CO_2) emissions annually in the United States (DOE 2007). CO_2, which is produced when fossil fuel is burned, is the primary contributor to greenhouse gas emissions. Retailers can be a part of the solution when they reduce their consumption of fossil fuels for heating, cooling, and electricity. Carbon offsets also can be considered for retail buildings by minimizing the carbon footprint of building and parking areas while maximizing low-maintenance native vegetation. Customers, employees, and communities where stores reside will appreciate this forward-thinking leadership.

PARTNERS IN THE COMMUNITY

Retailers are an integral part of the communities in which they reside. Customers and employees typically live near the retail building, and the operations of that building can directly impact the surrounding community. Energy-efficient buildings draw fewer resources from the community and can assist the power grid in a community through programs such as electrical demand control. Measures such as reduced building lighting during peak power demand reduces risk that homes in the community will experience power interruption. Energy efficiency measures also can help a retailer be a better neighbor. For example, reduced operation of building and parking lot lighting and equipment when not needed reduces light and noise pollution to the surrounding neighborhood. Similar benefits can be obtained with exterior night lighting that is designed to minimize light trespass and light pollution to enhance the neighborhood image.

The products promoted and sold by retailers directly impact the energy use of customers. Promotions of products with ENERGY STAR ratings educate consumers on how they can make purchase decisions with energy efficiency as a key component. Retail buildings are very public facing, and customers and store employees who see products such as SSL, often referred to as light-emitting diodes, being used successfully in their local store will more likely be comfortable using those products in their homes.

Retailers compete for product sales, but when it comes to sustainable design and energy efficiency, there is a strong common partnership among retailers to share information that will drive down the energy footprint of the retail sector. The DOE-sponsored Retailer Energy Alliance (REA) includes over 50 major retailers coming together to share best practices and partners with U.S. National Labs and organizations such as ASHRAE to promote research on products to drive energy efficiency into the market. REA members participated in creating and reviewing this Guide to share best practices with other retailers. The common voice of the REA is also helping equipment manufacturers better understand needs to economically incorporate high-efficiency products into the market.

CLOSING

Energy-efficient retail building design can add value in addition to direct expense reduction, including the ability to publicize a corporate commitment for sustainability, linking to a corporate sustainable mission, higher employee morale, and maintenance cost savings when properly implemented.

Hopefully, the contents of this Guide will allow retailers to incorporate energy-efficient design practices into their buildings. It should also challenge owners and designers to look beyond its recommendations to find additional efficiency and cost-saving measures that are unique to their specific building designs and operations.

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Introduction

1

The *50% Advanced Energy Design Guide for Medium to Big Box Retail Buildings* (the Guide) provides user-friendly, how-to design guidance and efficiency recommendations for medium to big box retail buildings. The intended audience of this Guide includes but is not limited to building owners, architects, design engineers, energy modelers, general contractors, facility managers, and building operations staff. The specific target audience for Chapter 2 is the members of the design team, whether they are design professionals, construction experts, owner representatives, or other stakeholders. Chapters 3 through 5 orient more toward design professionals to pursue sound design advice and identify interdisciplinary opportunities for significant energy reduction. Application of the recommendations in the Guide can be expected to result in medium to big box retail buildings with at least 50% site energy reductions when compared to those same facilities designed to meet the minimum code requirements of ANSI/ASRAE/IESNA Standard 90.1-2004, *Energy Standard for Buildings Except Low-Rise Residential Buildings* (ASHRAE 2004a).

This Guide contains recommendations to design a low-energy-use building and is *not* a minimum code or standard. A voluntary guidance document, this Guide is intended to supplement existing codes and standards and is not intended to replace, supersede, or circumvent them. The Guide provides both multidisciplinary design strategies and prescriptive design packages to significantly reduce energy consumption in medium to big box retail buildings. Even though several design packages are provided in the document, this Guide represents *a way* but *not the only way* to build energy-efficient box retail buildings with 50% energy savings.

The mission of a retail building is to facilitate the delivery of goods and services to the public. The performance requirements of a building intended for that purpose should be the driving force behind most design decisions for the building, and it should be noted that the benefits of some energy-saving measures could compromise that fundamental goal. The energy-saving measures in this Guide are intended to complement, or at least to avoid compromising, the main goal of these buildings.

The focus of this Guide is to identify proven concepts that are feasible to implement and benchmark necessary energy performance criteria for achieving 50% energy savings. The Guide will require retail leaders and design professionals to be very intentional about a project's goals and possibly to think differently about their processes and operations.

The energy savings projections of this Guide are based on site energy consumption rather than source energy. *Site energy* refers to the number of units of energy consumed on the site and typically metered at the property line. *Source energy* takes into account the efficiency with which raw materials are converted into energy and transmitted to the site and refers to the total amount of energy originally embodied in the raw materials. For example, it is generally accepted that site electrical energy is 100% efficient, but in fact it takes approximately 3 kWh of total energy to produce and deliver 1 kWh to the customer because the production and distribution of electrical energy is roughly 33% efficient.

This Guide was developed by a project committee that represents a diverse group of professionals and practitioners. Guidance and support was provided through a collaboration of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IES), the U.S. Green Building Council (USGBC), and the U.S. Department of Energy (DOE). Members of the project committee also are affiliated with the ASHRAE Standing Standards Project Committee 90.1 (SSPC 90.1) and the ASHRAE Standing Standards Project Committee 62.1 (SSPC 62.1).

In essence, this Guide provides design teams a methodology for achieving energy savings goals that are financially feasible, operationally workable, and otherwise readily achievable. Because technology to conserve and generate energy is growing rapidly, it is clear that innovation is an important ingredient to the success of reducing energy consumption in retail facilities, and it is the hope of the authors that this publication will expose other existing best practices and lead to the development of new concepts.

GOAL OF THIS GUIDE

This Guide strives to provide guidance and recommendations to reduce the total energy use in medium to big box retail buildings by 50% or more, on a site-energy basis, using a building that complies with ASHRAE/IESNA Standard 90.1-2004 as the minimum code-compliant baseline. The energy savings goal is to be achieved in each climate location rather than at an aggregated national average. The 50% savings is determined based on whole-building site energy savings, which includes process and plug loads.

SCOPE

This Guide is intended for box retail stores ranging in size from 20,000 to 100,000 ft^2 but also applies to smaller or larger retail stores with similar space types. The Guide is applicable to general merchandise stores, specialty retailers, department stores, and other types of standalone retail buildings. Space types covered by the Guide include vestibules, administrative and office areas, general merchandise sales floors, fitting/dressing rooms, specialty sales areas, corridors and transition areas, restrooms, mechanical rooms, break rooms, conference rooms, and stocking areas. This Guide will not cover atypical specialty spaces with extraordinary heat or pollution generation, such as commercial kitchens or restaurants. This Guide also does not cover large, centralized refrigeration systems commonly found in grocery stores.

The primary focus of this Guide is new construction, but recommendations may be equally applicable to stores undergoing complete renovation and in part to many other retail renovation, addition, remodeling, and modernization projects (including changes to one or more systems in existing buildings).

Included in the Guide are recommendations for the design of the building opaque envelope; fenestration; lighting systems (including electrical interior and exterior lights and daylighting); heating, ventilation, and air-conditioning (HVAC) systems; building automation and controls; outdoor air (OA) requirements; service water heating (SWH); and plug and process loads. Additional savings recommendations not necessary for 50% savings are discussed in the "Additional Bonus Savings" section of Chapter 5.

Chapter 4 contains prescriptive recommendations contained in a single table for each climate zone. These tables do not include all the components listed in ASHRAE/IESNA Standard 90.1. Though this Guide focuses only on the primary energy systems within a building, the underlying energy analysis assumes that all the other components and systems comply with the minimum design criteria in ASHRAE/IESNA Standard 90.1 and ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 2004b).

The recommendations in this Guide are based on typical prototype operational schedules and industry best practices as well as typical costs and utility rates. The operational schedule, actual costs, and utility rates of any one project may vary, and it is encouraged that each specific project have life-cycle cost analysis performed for key design considerations to properly capture the unique project cost and operational considerations.

In addition, the Guide is not intended to substitute for rating systems or references that address the full range of sustainability issues in retail design, such as acoustics, productivity, sales rates, indoor air quality (IAQ), water efficiency, landscaping, and transportation, except as they relate to energy use. Nor is it a comprehensive design text. The Guide assumes good design skills and expertise in retail building design.

ENERGY MODELING ANALYSIS

To provide a baseline and quantify the energy savings for this Guide, three prototypical retail stores were developed and analyzed using hourly building simulations. These building models include both high- and low-plug-load versions of a 40,000 ft^2 medium box store and a low-plug-load 100,000 ft^2 big box store, each of which was carefully assembled to be representative of construction for retail buildings of that class. Information was drawn from a number of sources, including Commercial Buildings Energy Consumption Survey (EIA 2003), Dodge Construction Data, and various retail store templates from around the country. The space types included in each prototype design are as follows:

- Sales areas
- Entrance/exit vestibule
- Stocking room
- Mechanical room
- Corridor/transition spaces
- Restrooms
- Enclosed offices
- Break rooms
- Conference rooms

Two sets of hour-by-hour simulations were run for each prototype. The first set meets the minimum requirements of ASHRAE/IESNA Standard 90.1-2004, and the second uses the recommendations in this Guide. Each prototype setup was simulated in the eight climate zones adopted by the International Energy Code Council (IECC) and ASHRAE in development of the prevailing energy codes and standards. The climate zones were further divided into moist and dry regions, represented by 16 climate locations. All materials and equipment modeled in the simulations are commercially available from two or more manufacturers.

Energy savings for the recommendations vary depending on climate zone, HVAC system type, and store type, but in all cases are at least 50% when compared to ASHRAE/IESNA Standard 90.1-2004, ranging from 50% to 60%. Analysis also determined savings ranging from approximately 45% to 56% when compared to ASHRAE/IESNA Standard 90.1-2007 and from approximately 26% to 41% when compared to ASHRAE/IES Standard 90.1-2010 (ASHRAE 2007, 2010). A savings range of approximately 57% to 66% is estimated when compared to ASHRAE/IESNA Standard 90.1-1999 (ASHRAE 1999), the baseline standard of the 30% Advanced Energy Design Guide (AEDG) series. The energy saving analysis approach, methodologies, and complete results of the prototype building simulations are documented in a technical report that was published by the National Renewable Energy Laboratory (Hale et al. 2009).

ACHIEVING 50% ENERGY SAVINGS

Meeting the 50% energy savings goal is challenging and requires more than following business as usual. Here are the essentials.

1. *Obtain building owner buy-in*. There must be strong buy-in from the owner/operator's leadership and staff. The more they know about and participate in the planning and design process, the better they will be able to help achieve 50% energy savings after the store becomes operational. The building owner must decide on the goals and provide the leadership to make those goals a reality.
2. *Assemble an experienced, innovative design team*. Interest and experience in designing energy-efficient buildings, innovative thinking, and the ability to work together as a team are all critical to meeting 50% energy savings. The team achieves this goal by creating a building that maximizes daylighting; minimizes process, heating, and cooling loads; and has highly efficient lighting and HVAC systems. Energy goals should be communicated in the request for proposal (RFP). Design team selection should be based in part on the team's ability to meet the goals, as it is responsible for their implementation.
3. *Adopt an integrated design process*. Cost-effective, energy-efficient design requires trade-offs among potential energy-saving features; thus, an integrated approach is necessary for retail store design. A highly efficient lighting system, for instance, may cost more than a conventional one, but because it produces less heat, the building's cooling system often can be downsized. The greater the energy savings, the more complicated the trade-offs become and the more design team members must work together to determine the optimal mix of energy-saving features. Because many options are available, the design team will need wide latitude when making energy-saving trade-offs.
4. *Understand the performance of the current prototype*. For retailers that already utilize an existing, predetermined prototype, understanding energy performance and actual operational trends in their existing portfolios will provide a valuable starting point for applying the Guide's recommendations. Benchmarking actual energy use by climate, understanding actual occupancy density and OA requirements, and measuring unoccupied load profiles can provide valuable insight into the most effective strategies to meet 50% savings.
5. *Consider energy modeling*. This Guide provides a few design packages to help achieve energy savings of 50% without having to invest in early design energy modeling, but whole-building energy modeling programs can provide additional flexibility and optimization to evaluate energy efficiency measures on an individual project. These simulation programs have learning curves of varying difficulty, but energy modeling for retail store design is highly encouraged and is considered necessary for achieving energy savings of 50%. See DOE's Building Energy Software Tools Directory (DOE 2011) for links to energy modeling programs. Part of the key to energy savings is using the simulations to make envelope decisions first and then to evaluate heating, cooling, and lighting systems. Developing HVAC load calculations is not energy modeling and is not a substitute for energy modeling.
6. *Use building commissioning.* Building systems, no matter how carefully designed, are often improperly installed or set up and do not operate as efficiently as expected. The 50% goal can best be achieved through building commissioning (Cx), a systematic process of ensuring that all building systems—including envelope, lighting, and HVAC—perform as intended. The Cx process works because it integrates the traditionally separate functions of building design; system selection; equipment start-up; system control calibration; testing, adjusting, and balancing; documentation; and staff training. The more comprehensive the Cx process, the greater the likelihood of energy savings. A commissioning authority (CxA) should be appointed at the beginning of the project and work with the design team throughout. Solving problems in the design phase is more effective and less expensive than making changes or fixes during construction. See the "Using Integrated Design to Maximize Energy Efficiency" section of Chapter 2, the "Quality Assurance" sections of Chapters 3 and 5, and Appendix C of this Guide for more information.

7. *Train building users and operations staff*. Staff training can be part of the building Cx process, but a plan must be in place to train staff for the life of the building to meet energy savings goals. The building's designers and contractors normally are not responsible for the store after it becomes operational, so the building owner must establish a continuous training program that helps occupants and operations and maintenance (O&M) staff maintain and operate the building for maximum energy efficiency. This training should include information about the impact of plug loads on energy use and the importance of using energy-efficient equipment and appliances.
8. *Monitor the building*. A monitoring plan is necessary to ensure that energy goals are met over the life of the building. Even simple plans, such as recording and plotting monthly utility bills, can help ensure that the energy goals are met. Buildings that do not meet design goals often have operational issues that should be corrected.

CONDITIONS TO PROMOTE HEALTH AND COMFORT

Throughout the project, the design team should routinely discuss how energy-saving measures will impact comfort, IAQ, and acoustics. The design and construction of a high-performance retail building requires an integrated approach where these factors remain a priority and are not adversely affected when striving for energy reduction.

For specific guidance regarding the interaction of thermal comfort, IAQ, sound and vibration, and other factors, refer to ASHRAE Guideline 10-2011, *Interactions Affecting the Achievement of Acceptable Indoor Environments* (ASHRAE 2011).

INDOOR AIR QUALITY (IAQ)

ASHRAE Standard 62.1 (ASHRAE 2010b) defines minimum requirements for the design, installation, operation, and maintenance of ventilation systems, but IAQ encompasses more than just ventilation. For more information, refer to *The Indoor Air Quality Guide: Best Practices for Design, Construction, and Commissioning* (ASHRAE 2009a), which provides specific guidance for achieving the following key objectives:

- Manage the design and construction process to achieve good IAQ
- Control moisture in building assemblies
- Limit entry of outdoor contaminants
- Control moisture and contaminants related to mechanical systems
- Limit contaminants from indoor sources
- Capture and exhaust contaminants from building equipment and activities
- Reduce contaminant concentrations through ventilation, filtration, and air cleaning
- Apply more advanced ventilation approaches

THERMAL COMFORT

ANSI/ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy* (ASHRAE 2010), defines the combinations of indoor thermal environmental factors and personal factors that will produce conditions acceptable to a majority of occupants.

According to ASHRAE Standard 55, six primary factors must be addressed when defining conditions for thermal comfort: metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity. Appropriate levels of clothing, the cooling effect of air motion, radiant cooling or heating systems, and personal environmental control, for example, can increase occupant comfort efficiently.

Lastly, all parties should consider allowing a wide dead band for occupied mode setpoints to help reduce energy use (as compared to the minimum dead band range stated in energy codes). However, these expanded temperature ranges should not be so extreme as to compromise occupant comfort.

VISUAL COMFORT

Lighting, both daylighting and electric lighting, will minimize visual comfort issues if properly designed and integrated. Electric lighting levels should be designed to meet IES recommended light levels (IES 2011). Providing light levels that are too high or too low will cause eye strain. For example, direct sun penetration should be minimized because the resulting high contrast ratio will cause discomfort issues.

Occupant orientation to windows is also very important in minimizing discomfort. Computer screens, such as those found at point-of-sale terminals, should be faced perpendicular to the window wall to minimize visual discomfort. They should never be orientated facing the window (operator's back to the window) or facing directly away from the window (operator facing out the window). Both of these situations produce very high contrast ratios, which can cause eye strain.

Steps for the Building Owner to Follow when Using the Advanced Energy Design Guide

Project Phase	Actions	Outcomes
Project Conception	☐ Select the AEDG(s) for your building type from *www.ashrae.org/aedg.* ☐ Learn about the business case for advanced energy design in the Foreword. ☐ Review similar projects in the case studies.	➢ Appropriate AEDG ➢ Project-specific energy performance goals
Team Selection	☐ Incorporate AEDG recommendations in the RFP. ☐ Ask proposers how they used AEDG recommendations and made the business case for energy savings in past projects.	➢ Team with AEDG experience ➢ Team committed to using AEDG recommendations
Conceptual Design	☐ Require design teams to implement AEDG recommendations. ☐ Learn about integrated design in Chapter 2. ☐ Review site-specific costs and benefits of the AEDG recommendations.	➢ Understanding and application of the AEDG recommendations ➢ Awareness of cost impacts of the AEDG recommendations
Design Development	☐ Include AEDG recommendations in the Owner's Project Requirements (OPR). ☐ Integrate AEDG recommendations into project tracking and status meetings.	➢ Design that incorporates AEDG recommendations
Construction	☐ Request regular updates on progress toward AEDG goals. ☐ Ensure that late project modifications to not compromise AEDG goals.	➢ Verification that AEDG recommendations are installed as designed (through commissioning process)
Operation	☐ Verify that AEDG recommended systems function as intended (through commissioning). ☐ Leverage the one-year warranty period to address outstanding issues.	➢ High-performance building incorporating AEDG recommendations ➢ Achievement of design energy goals

Further recommendations on visual comfort can be found in the *The IES Lighting Handbook*, specifically the “Vision: Eye and Brain” section in Chapter 2 and the “Perception and Performance” section in Chapter 4 (IES 2011).

ACOUSTIC COMFORT

Proper acoustics must be a priority when considering design decisions and must not be adversely affected when striving for energy reduction. Addressing acoustics during the design phase of a project, rather than attempting to fix problems after construction, will likely minimize the financial impact.

Further recommendations on acoustic comfort can be found in the *ASHRAE Handbook—Fundamentals* “Sound and Vibration” chapter (ASHRAE 2009b).

HOW TO USE THIS GUIDE

- Review Chapter 2 to understand how an integrated design process is used to maximize energy efficiency. Integrated design strategies for design professionals, including information on architectural design features, are provided. Checklists also are included to help establish and maintain the energy savings target throughout the project.
- Review Chapter 3 for information on applying energy modeling, benchmarking, and goal setting to your specific project. This is especially important when designers have to design a unique project on a specific site whose characteristics do not match the analyzed baseline building in the Guide in regards to shape, orientation, and/or glazing.
- Use Chapter 4 to review climate-specific design strategies and select specific energy-saving measures by climate zone. This chapter provides prescriptive packages that do not require modeling for energy savings. These measures also can be used to earn credits for Leadership in Energy and Environmental Design (LEED) Green Building Rating System and other building rating systems.
- Use Chapter 5 to apply the energy-saving measures found in Chapter 4. This chapter has suggestions about best design practices, how to avoid problems, and how to achieve additional savings with energy-efficient appliances, plug-in equipment, and other energy-saving measures.
- Refer to the Appendices for additional information:
  - Appendix A—Envelope Thermal Performance Factors
  - Appendix B—International Climatic Zone Definitions
  - Appendix C—Commissioning Information and Examples
- Refer to case studies and technology examples throughout the Guide for examples of energy-efficient technologies in retail buildings.
- Note that this Guide is presented in Inch-Pound (I-P) units only; it is up to the individual user to convert values to International System (SI) units as required.

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Integrated Design Process

2

This chapter discusses the principles of integrated design and demonstrates how they can be used to implement energy efficiency strategies. For the most part, these strategies will apply to initial prototype development and "one-off" stores. The final section in this chapter discusses how the integrated design process can be modified for the future refinement of existing prototype designs.

Some retail stores are one-off (unique buildings), while others are built from prototype designs. The integrated design process applies to both types of retail stores in different ways. A one-off retail building uses a more traditional integrated design process, much like the process used for an office building or school. The traditional integrated design process also applies to the initial development of a prototype design. Once the prototype has been established, a less extensive version of the integrated design process may be followed, as only changes for site-specific building designs need to be considered. Both traditional and prototypical integrated design processes are further described in this chapter.

Applying the integrated design process to retail includes reducing internal loads, sizing equipment for optimal performance at part load through demand-based controls and strategies such as demand-controlled ventilation, evaluating life-cycle cost savings, coordinating implementation of design features, and benchmarking/verifying energy savings. Additionally, understanding the building owner's needs is a critical part of integrated design. Owner's Project Requirements (OPR) should be part of early design discussions to allow for optimal system design that meets the current and future needs of the building owner without unnecessary assumptions leading to system and equipment oversizing that can reduce operational efficiency.

PRINCIPLES OF INTEGRATED DESIGN

Integrated design is a method for design and construction that considers whole-building system interactions and uses an interactive team approach to all phases of a project's management. Integrated design is necessary (in some form) to achieve 50% or better energy savings. In this process, all parties work together through all phases of a project to maximize the efficiency and result in a coordinated, constructible, and cost-effective design. Integrated design increases the productivity of the project process, provides higher-performing buildings, and protects the construction budget by reducing unnecessary construction change orders.

Integrated design in a retail project fosters unique opportunities to build connections between the energy savings strategies in the retail facility and the retailer's corporate sustainability mission. Saving energy not only results in bottom-line profit but also can become a visible symbol of a retailer's commitment to sustainability and community well-being.

One of the most important concepts of integrated design is that some of the simplest, up-front architectural decisions about a building's form, orientation, window placement, and even architectural style can have the greatest, long-term impact on HVAC or lighting efficiency strategies. Integrated design encourages the team to take these issues into account from their earliest design decisions through active project team discussion and collaborative dialog between all parties on a project team. The efficiency and quality of the project's design and construction are obtained through the following team interaction and process recommendations:

- Issue a request for proposal (RFP) or request for qualifications (RFQ) to define energy design and performance goals and expectations and identify the project team and stakeholders. Preferably, the building's owner will set annual energy performance goals for the building, providing direction for the design team.
- Establish early involvement of all design and construction team members.
- Establish initially-agreed-upon and documented common goals, including operational baseline performance benchmarks.
- Consider new and different methodologies.
- Establish open communication with early input from all parties on project strategies.
- Provide life-cycle costing and factor in value-added benefits to determine the feasibility of project systems.

A key difference between integrated design and conventional design is the consideration of life-cycle costs in making project decisions. This requires a holistic approach at the beginning of the project to input relevant programming, design, construction, and operations information to the greatest extent possible. This means that corporate representatives, architects, engineers, contractors, commissioning authorities, building operators, and other integrated design team members must work together from the outset of a project to accumulate the necessary information to make data-driven decisions. In design-bid-build project deliveries, contractor input is needed to ensure that needed construction information is available in a design-build, or construction management, delivery.

Consider a design team that contains a strong corporate/owner's advocate who understands the risks and rewards of design decisions when building energy-efficient retail buildings. This could be an internal person with design expertise or a consultant with long-term, detailed knowledge of the corporation's/owner's needs. In any case, a partnership must be established to encourage calculated design risk (such as not oversizing HVAC equipment). The corporation/owner will benefit from reduced capital cost and improved energy efficiency if systems are optimally designed without excessive safety factors.

It follows that the integrated design process requires the formation of the project team as early in the process as possible. Early collaborative goals and metrics of performance and open inclusive participation contribute to trust among team members and to the overall success of the project. The inclusion of all the project team members benefits the project by allowing all the participants to provide their expertise throughout the process.

USING INTEGRATED DESIGN TO MAXIMIZE ENERGY EFFICIENCY

Integrated design establishes key collaboration agreements to remove barriers between parties and to encourage early contributions of wisdom and experience. This section provides best practice guidance to achieve 50% or better energy efficiency than ANSI/ASHRAE/IESNA Standard 90.1-2004, *Energy Standard for Buildings Except Low-Rise Residential Buildings* (ASHRAE 2004) in the building design.

PROJECT KICK-OFF

This is the most important meeting of the entire project in establishing the OPR. This exercise may be led by the commissioning authority (CxA), and it allows the corporate personnel and stakeholders to define what a successful project means for them. Well-defined OPRs at the beginning of the project will help ensure that the energy goals are integrated into the design and considered throughout the project. Inclusion of the stakeholders (corporate representatives, store managers, maintenance staff, store employees, customers, etc.) will produce more creative and integrated solutions, which are key to the project's success. The requirements can cover construction costs, serviceability, operating costs, required spaces and adjacencies, functional aspects, specific maintenance or system preferences, frequency of use, and other corporation priorities. It is strongly recommended that the traditional OPR from the commissioning process are augmented to include the following information:

- Corporate brand requirements that might restrict some design measures
- Energy rating systems (Leadership in Energy and Environmental Design (LEED) Green Building Rating System, Green Globes, ENERGY STAR®, etc.)
- Life-cycle cost of systems and cost transfer
- Quantification of value-added benefits of efficiency measures
- Ownership/leasing arrangements, including renewable energy credits and utility back-charging or metering
- Prioritization of requirements
- The corporation's chain of command (decision making) and communication, including change requests and expenditure approvals
- Constraints imposed by the site, code, or planning agreements with the city, preexisting standards (if any), corporate sustainability policy statements, etc.
- Site-based measurements of existing equipment or similar equipment at another store to determine actual plug-load usage

The OPR is necessary to ensure that all parties on the design and construction team are equally aware of the corporation's priorities. While there may be multiple systems that can meet the criteria, systems that meet the criteria can be narrowed or identified early in the project. This lowers risk for all parties and provides a reference document to guide future decisions when budget pressures challenge system selections. It is acknowledged that the OPR may grow (or change) during the course of the project to accommodate corporate preferences and take advantage of new technology or opportunities. Nevertheless, it is good practice to keep a comprehensive list of all OPR.

PROGRAMMING AND PROJECT DESIGN

The use of programming and concept design compiles and organizes the project's inputs. It also incorporates a series of brainstorming sessions that assist the integrated design team in evaluating the OPR for opportunities and risks in context of the site. A key conceptual exercise usually covers a series of holistic site investigation and building massing studies to see which strategy best addresses the following issues:

- Site conditions (e.g., existing shading from adjacent buildings or landscaping, outdoor air quality, outdoor ambient noise environment, site surface material)
- Orientation and availability of natural resources (e.g., sun, wind, geothermal, climate, bodies of water)
- Local material availability or reuse
- Storm water runoff scheme, wetlands impact, available utilities
- Status of surrounding buildings and review of code/planning regulations that may create obstructions to natural resources in the future or otherwise limit the design

- Hardscaping or landscaping potential to reduce heat island effect or provide natural shading
- Security concerns
- Accessibility to transportation
- Sustainability opportunities
- Environmental risks or challenges

The goal of the programming and concept meetings is to review a number of schemes and identify appropriate strategies and resources. It may be difficult to correctly estimate final costs for each model or to determine the final systems, but past experience should provide the integrated design team the ability to rank schemes qualitatively against the OPR. The exercise should result in the integrated design team coming to consensus on the major site parameters and identifying the major design strategies to meet the OPR.

Proper building orientation and envelope are critical to achieving 50% energy savings or better. Most program information will be in verbal or diagrammatic form, but building orientation and envelope strategies should emerge early in the process. If the program concept meetings reveal possible building massing and orientation strategies, the integrated design team should review them to see if low-energy solutions are possible and what building strategies might be necessary to ensure comfort and performance.

Space adjacency inside the building is critical for retailers, so early discussion in the programming phase of the impact of space location relative to energy efficiency is important. Space programming inside the building might change the building shell or orientation requirements. Adjacency can reduce the cost of implementing energy efficiency measures and improve their effectiveness. For example, high-plug-load electronics areas may help offset heating system needs due to infiltration at the main building entrance or loading docks.

At the end of programming and project design, a consensus should be reached among the integrated design team regarding program design concepts or parameters including (but not limited to) the OPR, site, building envelope, orientation, possible systems, and so on. However, the corporation must confirm the basic strategies for a positive and productive workplace environment, including the extent of visual connection with the outdoors. A retail building may have limited options for site orientation and placement due to standardized design or coordination with surrounding buildings, but considerations should be discussed when possible.

SCHEMATIC DESIGN

The schematic design phase is for developing programming ideas and concepts into diagrammatic plans. At this phase, the architectural team members identify where the various program occupancies are projected to be in the building as a test exercise. The schematic design plan and proposed building massing provide opportunities to study and identify envelope strategies for fenestration and opaque surfaces to carry out program parameters and enhance the indoor environment for the occupants.

A more detailed weather/climate/natural resource analysis usually quantifies true "frequency of occurrence" potential for the following (among others):

- Free cooling through HVAC systems
- Nighttime heat purge of thermal mass
- Heat recovery
- Use of radiant surfaces

All of this additional analysis informs the design team as to which mechanical and electrical systems should be considered in order to provide a comfortable indoor environment. As a start, typical mechanical and electrical plant room sizes, riser locations, and ceiling cross-sectional depths should be generated for the most traditional services approach and to serve as a baseline for initial and life-cycle cost comparisons in subsequent phases.

Once a baseline building is created, its costs are estimated and compared to the OPR to ensure that even the most "standard" of the available designs meets the first-cost and program requirements. It is often useful to perform a preliminary energy analysis by zone to determine approximate annual operating costs. During schematic design, this level of calculation is usually adequate to confirm trends in energy savings associated with design decisions.

The last necessary work for the schematic design phase is to identify energy conservation measures (ECMs) that might be applied to the baseline case or an alternate scheme that gives an identical performance to the baseline case. This is the point at which a thorough discussion of trade-offs and cost transfers should be documented. Typical exploratory interdisciplinary discussions during this phase include the following:

- Selection of structural material and its relative use as thermal mass or thermal insulation
- Selection of internal wall finish type and its potential obstruction of thermal mass heat transfer performance
- Selection of floor material type and finish and its potential use as an air-distribution, heating, or cooling device
- Selection of façade type and orientation and each face's relative proportion and performance (properties of glazing and opaque wall insulation)
- Configuration of roofing shape/slope/direction and applicability of cool-roofing materials, clerestories, and skylights and/or installation of photovoltaic (PV) panels
- Selection of daylighting/electric lighting systems and zoning compatibility to accommodate ambient versus task lighting, occupancy sensors, and time-of-day controls
- Commitment to ENERGY STAR equipment for plug load usage reduction
- Review of plug load use intensity
- Review of alternate HVAC and comfort cooling systems

As a conclusion to the discussions, the design team usually identifies a certain number of optimal ECMs that they wish to append to the baseline. Through a LCCA, a more complete energy model is created to evaluate ECM payback. A matrix of options is developed to assess each ECM against a common set of criteria, including but not limited to the following:

- Additional first-cost investment
- Anticipated annual energy cost savings
- Anticipated annual maintenance costs savings or additions
- Simple payback period
- Return on investment
- Energy reduction
- Carbon emissions savings
- Potential additional LEED points for Energy and Atmosphere Credit 1
- Range of indoor temperatures achieved throughout the year
- Range of lighting levels achieved throughout the year
- Value-added benefits not related to energy use

There may be other project-specific OPR that should be incorporated into the matrix. The key point is that it is important for all parties to understand the whole view of any ECM application so that a balanced decision can be made inclusive of all impacts on the desired goals of the project, including operations. The goal is to pick a selection of ECMs to pursue during the design development phase. These decisions are quite crucial before design work and calculations are begun in design development. In many cases, energy savings may not be enough to justify the cost of a more efficient strategy; that strategy may still be justifiable, however, based on other value-added benefits. For example, a measure that improves occupant comfort may increase employee productivity and improve the overall shopping experience, resulting in reduced costs and increased sales.

Canadian Tire Corporation—A Case Study

Canadian Tire Corporation opened their most energy-efficient store to date in Kemptville, Ontario, in May 2011. The 40,000 ft^2 of general retail space includes areas for automotive, sporting goods, and tools, along with household essentials, storage and organization, hardware, and an expanded garden center. A new 6000 ft^2 Mark's (clothing) store is also located within the space.

The company's approach to sustainability is evidenced by a number of initiatives undertaken throughout the chain. The design for this store was targeted to be 75% more efficient than other model designs and is a candidate for both LEED Silver certification and a Green Globes award. The store is forecasted to have an electrical energy use intensity (EUI) of 9.7 kWh/ft^2 (33.1 $kBtu/ft^2$) as compared to 17.8 kWh/ft^2 (60.7 $kBtu/ft^2$) for a similarly sized store under previous design models—a roughly 45% reduction in energy use.

Lighting and Daylighting

In the retail area, six-lamp T8, 28 W fixtures with electronic ballast replaced eight-lamp fluorescent fixtures. Efficiency was increased by rotating the fixtures 45° to the long axis of the building and by dropping the height by 18 in. The result was fewer fixtures and lamps without sacrificing the lighting levels in the store. In office/administrative areas, light-emitting diode (LED) fixtures connected to occupancy sensors replaced traditional fluorescent lighting.

Clerestory windows along the front and side of the building allow daylight into the store. Daylight sensor controls on the window perimeter zone monitor the amount of natural light available and automatically turn lights on and off as needed.

All exterior lighting (parking lot and building signage) is LED, which has a longer life expectancy than fluorescent and metal halide (MH) fixtures, thereby reducing maintenance costs.

Canadian Tire Store
Photography courtesy of Canadian Tire Corporation; Credit: Kendall Townend

HVAC Systems

Because the store is located near Ottawa, the HVAC system is dominated by its heating load. Decoupling the heating and air-conditioning system allows each system to be at its most efficient while minimizing capital cost for the smaller air-conditioning system. The primary source of heating for the store is high-efficiency boilers that distribute the heat through a combination of in-floor systems and overhead unit heaters. Additional benefits include the following:

- Reduction in the number of traditional rooftop units
- Fewer roof penetrations
- Reduction in fan power, as the hydronic systems provide heat via radiant heat transfer and natural convection rather than requiring fans to move warm air

Three systems work together to reduce the energy needed to efficiently heat and cool the outdoor air (OA) required for the space. These systems are as follows:

- In winter, energy recovery ventilators (ERVs) capture energy from the building's exhaust air and use that energy to preheat the OA supply, decreasing heating requirements. In warmer months, heat from the OA supply is transferred to waste exhaust, precooling incoming OA and decreasing air-conditioning demand.
- Demand-controlled ventilation (DCV) brings OA into the store as required, thus reducing OA and energy requirements for both heating and cooling.
- All ventilation air is introduced near the ceiling and has low-level returns located near the floor. This increases the ventilation effectiveness of the system and thus lowers the OA requirements of the store, which in turn reduces the energy associated with heating/cooling.

The combination of energy recovery ventilation and fluorescent light fixtures reduces the cooling load requirements for the building, resulting in fewer, smaller, and more efficient rooftop units dedicated to cooling on demand.

Other Features

- A white roofing membrane reduces heat transfer through the roofing assembly.
- The number of overhead doors in the automotive service center was reduced from five to three. To prevent heat from escaping out open doors, unit heaters associated with the overhead doors automatically shut off when the doors open and restart when the doors close.
- Automated low-flow plumbing fixtures were installed in all staff and public restrooms.
- High-pressure washers in the service bays use cold water only.
- Warm-mix asphalt, prepared at temperatures cooler than traditional asphalt, reduced fuel consumption and greenhouse gases.
- Locally produced building construction materials/products and those with recycled content were used where possible. Approximately 90% of construction-generated waste (117,000 lb) was diverted from landfills.
- The use of low-volatile organic compound (VOC) paints, coatings, and sealants improves air quality.

Additional information on Canadian Tire's Kemptville store and other sustainable initiatives throughout the chain can be found on Canadian Tire Company's informational Web site (Canadian Tire 2011).

DESIGN DEVELOPMENT

The design development phase establishes the final scope of ECMs into the architectural scheme for the project. The final energy models are usually used for submission to code authorities to show compliance with ASHRAE/IESNA Standard 90.1 and may be used for submissions for LEED. The development of the scheme includes further design, calculation, and documentation of the building envelope, lighting, and mechanical/plumbing systems that are regulated by code, as well as corporate-set limits on plug load densities. Additionally, there is often a financial investment/LCCA of the ECM components. These cost estimates are more detailed at this phase. The cost analysis justifies the ECMs to be maintained as goals in the next phase of design. During design development, the focus is on documentation of the design intent, and most energy-related disciplines will write a Basis of Design (BoD) report explaining the design intent. This BoD is then compared to the OPR by the CxA during a peer review process to ensure that the corporation's goals are met by the design development model.

Design development is the phase of the project where the original OPR are confirmed through the project scope. The cost analysis provides the basis for value engineering and decisions regarding first costs and operations. If prototypical design is used by the retailer, the prototype documents may be carried through design development with many of the typical design decisions addressed.

CONSTRUCTION DOCUMENTS

The construction documents (CDs) phase is the final detailing of all systems, inclusive of sustainability features and ECMs. The mechanical, electrical, and plumbing systems incorporate system drawings, specifications, BoD reports, controls drawings, controls points lists, and sequences of operation. The CxA reviews all of the documents and the updated BoD for compliance with the OPR.

At this point, it is important for the team to review and confirm project constructability, cost-optimization and waste-reduction techniques, necessary documentation, and acquisition of materials to meet the performance requirements for each of the ECMs, control strategies, and the design intent of the specifications. Since many retailers purchase components of their buildings directly, any modifications to typical materials should be coordinated with the retailer's procurement group to ensure appropriate materials will be procured.

BID PHASE

Most retail projects will use a design-bid-build delivery. Projects using other deliveries may bypass the bid phase. For projects that include a bid phase, the following measures by the design team are essential to achieve 50% savings or better:

- Acquire timely and appropriate construction information and expertise over the early phases of the project to ensure constructability, availability of equipment, materials, necessary skilled labor, and quality, accurate estimating and cost control.
- Provide a thorough and interactive prebid conference to discuss the desired corporate goals, including ECMs, the Cx process, and contract documents.
- Consider adding general performance specification requirements to ensure that corporate goals are achieved, including contractor experience on high-performance buildings.

CONSTRUCTION ADMINISTRATION

During the construction administration phase, the CxA and the design professionals on the integrated design team will review submittals and construction performance to ensure compliance with the contract (construction) documents. In accordance with the contract documents, the integrated design team will ensure that construction meets all regulatory requirements and is in compliance with manufacturer performance and warranty standards. Design professionals on the integrated design team are responsible for reviewing the construction, reporting any deficiencies of installed work, and requiring remedial efforts to correct the work if necessary. Any deviation from the CDs must be approved by the integrated design team, and the documentation must prove that the substitution will not adversely affect energy efficiency (among other things).

After all the equipment is installed and the building is enclosed, equipment manufacturers perform testing procedures during start-up and confirm that the equipment is operating correctly. A testing and balancing contractor adjusts the settings on the equipment to achieve the water flow and airflow as required in the contract CDs.

The contracting team and manufacturer representatives are responsible for producing a set of operations and maintenance (O&M) manuals and performing the specified hours of training for the building's personnel. It is recommended that the training sessions be recorded and kept on file for future operators. It is further recommended that key technical facility operators of the building overlap contractor operations at least a month before the final inspection and checklists are started to familiarize them with the equipment and design intent. When final inspection begins, building operators should accompany the contractor and design team during testing of the equipment.

COMMISSIONING

The commissioning process is the last performance testing applied to most projects. The CxA will have written checklists based on the equipment submittals reviewed during the construction administration phase. The CxA will turn over the checklists to the construction team to complete based on manufacturer start-up reports and other collected information (including warranty and wiring information). Once the checklists are complete, the CxA will do an on-site random sampling to check results and confirm that the reported findings are true and repeatable. Once this is confirmed, the CxA will release the functional test procedures, written in response to the contractor's detailed sequence of operations. The CxA will supervise the controls contractor running the equipment through its operations to prove adequate automatic reaction of the system to artificially applied inputs. The inputs simulate a variety of extreme, transition, emergency, and normal conditions. When this testing is complete to the satisfaction of the CxA, a report is written for the owner, confirming that the performance goals of the project have been met. At that time, the owner can take over the building operations from the contractor with confidence that the design and construction are operating as intended, meeting the 50% energy savings goal.

The CxA assists with the supervision of the formal training of the owner's operations personnel. The training ensures operators can operate the systems properly and can make corrective actions should the system operations deviate from their commissioned state. It is useful to run and monitor key aspects of the building for a one-month period just before contractor transfer to verify energy-related performance and the final setpoint configurations in the O&M documents. This will allow the building operator to return the systems to the original commissioned state (assuming good maintenance) at a future point, with comparative results.

Additionally, prior to transfer of the building to the owner, it is recommended for the integrated design team to provide a seminar to the store managers and employees, building staff, and other stakeholders on the building. As recommended with the training for building operators, it is recommended that this seminar be recorded for future occupants. The integrated design process began with these same stakeholders. Now it is best practice to review the goals of the project, including energy conservation and occupant behavior.

OPERATIONS AND MAINTENANCE

Operations and maintenance (O&M) of the equipment after the contractor's transfer of the building to the owner are essential to achieving and maintaining 50% energy savings. It is recommended that building operators secure certification as certified energy managers. It is often the case that the first year of occupancy will reveal a truer nature of how the building will actually

JCPenney—A Case Study

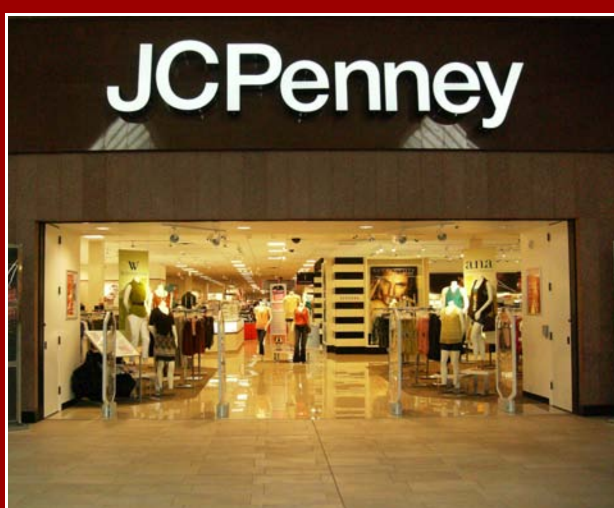
As a participant in DOE's Commercial Building Partnerships, JCPenney worked with Pacific Northwest National Laboratory (PNNL) to identify energy efficiency design measures that can be applied to store locations across the country. The one-story, 107,000 ft^2 Colonial Heights, VA, store was one of the first stores selected to receive the energy upgrades, in large part because it already was due for some major renovations. While the work at this store was applied to an existing facility, the measures implemented provide valuable insight for new construction projects as well.

Integrated Design Approach

By looking at the whole building as an integrated system as well as the interactions of all the components, the design team was able to maximize the energy savings potential at the store. The team included experts in lighting design, mechanical engineering, and systems controls who worked together on all aspects of the design. Extensive energy modeling was conducted to analyze the performance of design choices. This approach helps lower costs by identifying energy-saving measures that complement and build on each other. One result of this project was the use of smaller and more-efficient HVAC systems with no sacrifice in performance. Energy savings from the total package are expected to be 45% as compared to the store's historic energy usage.

Building Envelope

Two inches of R-12 polyisocyanurate insulation was added during roof replacement. The benefits from this improvement were significant enough that JCPenney will now consider adding additional insulation to future reroofing projects at all locations.



JCPenney Retail Store Entrance
Photography courtesy of PNNL

Cosmetic Counter Case Lighting
Photography courtesy of PNNL

Lighting

Lighting accounted for about one-third of the total building energy use at the store, so lighting improvements were a major consideration in the project. The estimated annual cost savings for the full package of lighting improvements is over $47,000, providing a payback of 2.8 years. Some of the specific measures employed are as follows:

- 50 W incandescent display lighting was replaced with 16 W LED lighting. LEDs provide better color rendition and their reduced temperatures improve product shelf life.
- Fluorescent lighting in the cosmetic counter cases was upgraded to LEDs, which had the added benefit of increasing product longevity.
- Lighting circuits and switching were synchronized to turn off retail display lighting after hours during housekeeping or stocking activities.
- Existing 1000 W metal halide (MH) parking lot lamps were upgraded to 320 W pulse start ceramic MH lamps, saving 78,020 kWh per year. While the store's security policy requires that some parking lot lighting remain on from dusk to dawn, exterior lighting not designated for security purposes turns off when the building is unoccupied.

HVAC Systems

Two packaged rooftop unit (RTU) air conditioners were replaced with high-efficiency units that included economizers. Outdoor air ventilation was reduced during low-occupancy periods through the addition of demand-controlled ventilation to the main air-handing unit. An ERV recovers exhaust air energy from the sales area, restrooms, and salon and preconditions sales area ventilation air. Two high-efficiency air-cooled chillers were installed along with high-efficiency pumps and motors, which were sized to match the flow rate of the chilled water.

The HVAC controls system was optimized, and the following measures were taken:

- Run times and schedules were matched to store operating hours.
- The sales floor was zoned to allow the systems to meet each zone-specific requirement.
- Heating setpoints were lowered in vestibules and stockrooms.

Additional information on JCPenney's collaboration with PNNL on the Colonial Heights store renovation can be found on DOE's Web site for The Office of Energy Efficiency and Renewable Energy (EERE) (PNNL 2011).

High-Efficiency Packaged RTU
Photography courtesy of PNNL

Air-Cooled Chillers
Photography courtesy of PNNL

perform. The actual occupancy patterns may be different from the original design assumptions in the energy model. Often, the CxA will have a service extension 11 to 18 months after the building has been transferred to review the status of operations. The CxA may recommend adjustments to system setpoints to optimize operations. Occasionally, a second measurement and verification (M&V) exercise is performed at this time to benchmark the energy use of each piece of equipment. If there are extreme seasonal differences in the particular climate, a second set of benchmarks may be established in an alternate season.

Many multisite retailers provide remote monitoring and oversight of building operations. In this case, it is important that the remote operators of building systems are aware of any unique aspects of the energy efficiency measures of a specific building so they can help ensure appropriate operations. This remote monitoring also provides a means of ongoing verification of operations and can alert staff to faults that may impact performance.

Maintenance is another corporate-controlled aspect of operational efficiency. The O&M manuals will contain information regarding preventative and periodic maintenance activities that should be performed to keep the equipment running to achieve 50% energy savings. Some examples of necessary preventative maintenance activities are as follows:

- Keep HVAC filters clean to minimize pressure drops.
- Inspect and replace broken sensors to maintain proper feedback from the control system to the HVAC equipment.
- Inspect and repair broken actuators to maintain proper DCV and/or air-side economizer cycles.
- Inspect and maintain water quality to ensure proper performance of heat exchangers and clean inner surfaces of piping.
- Inspect and maintain condensate pans to reduce microbial growth and ensure air quality.
- Inspect, clean, repair, and possibly replace fixtures and lamps that are not maintaining proper light levels.
- If using daylighting controls, ensure that the setpoints are correct and the system is performing as commissioned.
- Inspect and calibrate supply air HVAC sensors to ensure comfort and air quality.

In retail buildings designed for low-energy use, it is important to remember that occupant behavior and building operation are crucial to achieving 50% or better energy savings. When people understand the goals of the building and the impact of occupant behavior on energy conservation, they can substantially reduce energy use. Store leaders, especially the corporate staff and store managers, must build support for the energy efficiency initiatives at the corporate level. With that foundation, employees can change the culture at the store level.

It can be beneficial for the design and construction team to host a seminar for the initial occupants (taped if possible for future occupants) to describe the building's design intent and sustainability features. This is an ideal way to introduce the occupants to the building and to allow the store leadership to state their support for the energy efficiency initiatives in the building. It is important to caution occupants that a low-energy building sometimes takes a period of operation to reach its optimized control strategy. All occupants are invited to submit and share energy performance comments as additional inputs for improving the operations. This type of personal engagement will encourage positive-impact behaviors with the occupants. These first adopters can act as efficiency coaches for future occupants.

For retailers using a prototypical design for building construction, a similar procedure can be used to provide a consistent approach to operating the building. Standardized training manuals, videos, and classes can be provided for on-site building operators and outside service vendors that work on building systems. Very specific operational materials focused on the systems found in the store without extraneous information will help maintain high-performance operations.

PROTOTYPE DEVELOPMENT—CONTINUOUS IMPROVEMENT

Retail stores differ from many other building types in that they often have a prototype design that is constructed at many different locations across the country. The integrated design process above should be followed for initial prototype development. It is encouraged that if a prototype design already exists it be reevaluated using the full integrated design process. However, this exercise may not be feasible considering how much time, effort, and money has already been invested in the existing prototype design. Some other methods to incorporate energy efficiency into a building portfolio include:

- Take advantage of the portfolio of buildings to continually optimize design based on an understanding of how existing similar buildings operate.
- Be prepared to vary the prototype by climate to achieve 50% energy savings.
- Design in possible future retrofit opportunities by allowing for future flexibility and upgrade potential, such as increased structural capacity for heavier HVAC equipment.

Even though complete overhaul of the prototype design may not be feasible for marketing or cost reasons, there are some advantages that a prototype design has over a typical one-off retail store. The prototype often has been constructed in many different locations and been in operation for many years, which means that there are hard data (utility bills) that can be used to benchmark its energy performance. Many portfolios have detailed submetered data as well, providing even more information for benchmarking. Using these data can help immensely in evaluating current prototypes and existing stock for energy improvement opportunities, both as retrofits to existing stores and improvements to the existing prototype design.

CONTROLLING COSTS

In the retail sector, energy is typically the second highest cost of operation (depending on the operating hours), so cost is very important. Some of the strategies that can be used to control costs in energy-efficient retail design include the following:

- Costs of added insulation can be offset by reducing the HVAC loads and the number or size of rooftops.
- The additional investment in a high-performance lighting system can be offset with reduced cooling capacity.
- Consider fewer, larger rooftop units (RTUs) that can more cost-effectively incorporate advanced HVAC recommendations such as energy recovery and economizers. Overall HVAC system costs may drop even if additional ductwork is required to maintain good air distribution.
- The owner/corporation sets the expectation for peak sizing and occupancy loading based on an understanding of peak loading in previous prototypes; therefore, design team sizing risk can be mitigated by considering realistic peak occupancy and internal demands. Often, sizing HVAC systems based on actual loading seen in previously built prototypes can result in both significant first-cost savings and energy savings.
- Highly visible "green" measures such as daylighting can provide added benefit as symbols of a retailer's commitment to sustainability and community well-being.
- Lower lighting power densities (LPDs) can be achieved through careful integration with interior design while maintaining desired illuminance levels—white or brightly colored ceilings, walls, and floors result in better distribution of electrical lighting in the space, which can allow for less overall installed electrical lighting.

Strategies for Reducing Energy Use across a Portfolio

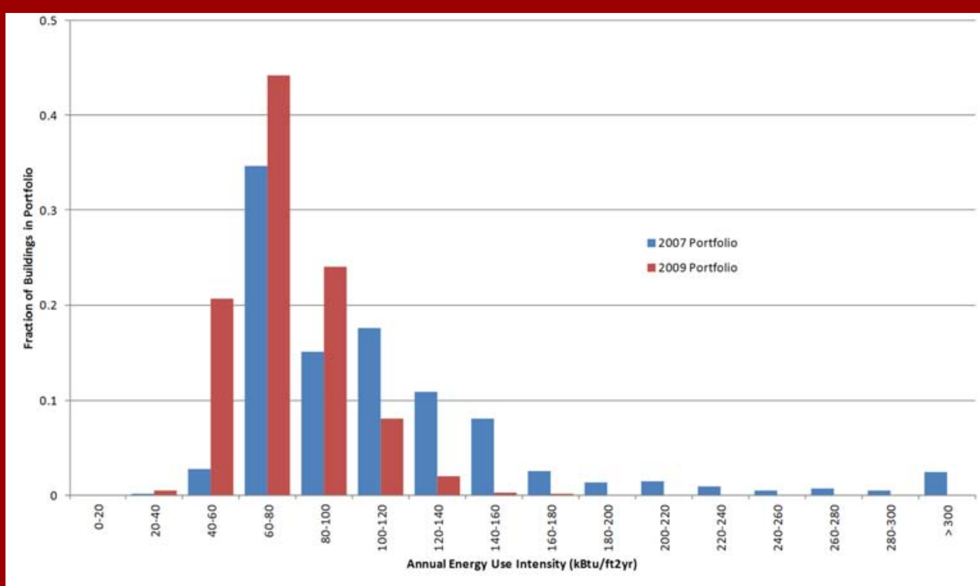
Many retailers have a portfolio of buildings that share a common, prototypical design. This approach allows retailers to invest in demonstration projects to validate efficiency strategies, both for new construction and retrofit projects. Then, these proven strategies can be rolled out across a portfolio of buildings to maximize overall efficiency impact. Through a portfolio-wide rollout of proven, cost-effective energy efficiency strategies, Target, the second-largest big box retailer in the United States, has seen a significant shift toward lower EUI across their portfolio since 2007. This is especially true for stores that were particularly high energy users prior to efficiency rollouts. With over 1750 stores covering 234 million ft^2 of total area, the overall cost savings has been substantial.

Prototype Design and Portfolio Management

Target's approach to building design centers on the continuous development of a prototype design, characterized by three steps:

1. Use new construction projects to push the prototype design to the forefront of retail best practice (e.g., AEDG recommendations).
2. During renovation cycles, take the opportunity to implement significant energy efficiency retrofits (based on lessons learned from new construction projects).
3. Identify quick payback, minimally invasive energy efficiency measures that can be rolled out portfolio-wide without requiring extensive renovation.

A key capability that allows Target to implement portfolio-wide strategies cost-effectively is central control and monitoring via energy management systems. From its headquarters in Minneapolis, MN, Target can monitor system operation and update algorithms across its portfolio. Central control and monitoring provides flexibility for future improvements and is an important advantage in maintaining efficiency performance between renovation projects.



Shift in Target Portfolio Energy Use from 2007 to 2009

Prototype Design Development through New Construction

A new construction project in Brookfield, WI (to be completed in October 2012), was designed to achieve 50% energy savings beyond minimal compliance with ASHRAE/IESNA Standard 90.1-2004 and demonstrates many of Target's key efficiency strategies. Lighting strategies such as 90% efficient, 59 W lighting fixtures (with no accent lighting) for the sales floor and 25 W T8 lamps for office and storage areas will result in a whole-building lighting power density of 0.76 W/ft^2.

HVAC efficiency measures include the following:

- Implementing a performance-based, continuous (24 hours per day) ventilation flow rate of 0.08 cfm/ft^2 (proven through experiment to meet the air quality requirements of ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality* [ASHRAE 2010] at significantly less flow than the prescribed rates)
- Decoupling ventilation and conditioning requirements through dedication of certain RTUs to OA intake
- Specifying RTUs with variable-frequency drives to facilitate variable-air-volume operation
- Adding energy recovery ventilators to the dedicated outdoor air systems (DOASs).

Plug loads will be reduced through careful specification of installed equipment and careful scheduling via the energy management system.

Energy efficiency measures will be prominently featured in the design of the store entrance. Floor-to-ceiling interior vestibule walls will reduce infiltration and the combination of vestibule clerestory glass, and daylight sensors will facilitate daylighting of the entrance space. Additional efficiency measures will aim to reduce loads associated with kitchen and refrigeration equipment, including the specification of high-efficiency equipment wherever possible.

Prototype Design Trickle Down through Renovation

An energy upgrade project in Thornton, CO (completed October 2011), designed to achieve 30% energy savings beyond minimal compliance with ASHRAE/IESNA Standard 90.1-2004, provides an

Target Vestibule Design with Clerestory Glass
Photography courtesy of NREL; Credit: Dennis Schroeder

example of how Target is able to roll out key efficiency strategies in coordination with renovation projects. Lighting will be upgraded to current prototype specifications, including:

- 114 W sales floor fixtures will be replaced with the same 90% efficient, 59 W lighting fixtures
- 32 W T8 lamps will be replaced with 25 W T8 lamps in office and storage areas
- Valance accent lighting will be upgraded to lower-wattage, higher-efficacy linear fluorescent lamps

The net effect will be a whole-building reduction in installed lighting power density from 1.3 to about 0.8 W/ft^2. The HVAC system will be upgraded as well; certain RTUs will be replaced with variable-speed fans and dedicated outdoor air units equipped with energy recovery ventilation.

Continuous Portfolio-Wide Performance Improvement

Target's central control and monitoring capabilities provide significant opportunity for implementation of minimally invasive efficiency measures that require little or no capital investment and can result in significant overall energy savings when implemented portfolio-wide. Details of control strategies can have significant effects on overall energy performance and are often overlooked. Target invests time to explore the energy implications of setpoints, schedules, and sequences of operations and maximizes the energy-saving impact of the resulting refinements through portfolio-wide updates. Examples include the following:

- Raising store dew-point temperature from 53°F to between 55°F and 57°F for nongrocery sections while maintaining a dew point of 53°F in grocery sections
- Widening temperature dead bands, occupied and unoccupied, 2°F or more
- Turning off sales floor plug equipment, including televisions and other electronic displays, during unoccupied hours
- Changing computer power settings to default to standby mode when not in use
- Updating operations (stocking, janitorial, maintenance, etc.) schedules to minimize off-hour lighting and plug loads

Results from the Brookfield and Thornton projects will be documented as part of DOE's Commercial Building Partnerships (CBP), through which Target is working with National Renewable Energy Laboratory (NREL) to identify and share energy-saving opportunities and best practices with the commercial buildings sector. Additional information is available on the EERE Building Technologies CBP Web site (DOE 2011).

Sales Floor Lighting Fixtures

Photos Courtesy NREL; Credit: Dennis Schroeder

- LED lights have benefits beyond energy savings that can offset additional capital investment required; benefits include increased comfort through reduction of "hot spots" near lights, flexibility of application according to display needs, increased focus of light for improved contrast in merchandise display, and reduced maintenance costs.
- Streamline the envelope construction process through use of modular wall sections constructed off site; additional costs of modular constructions can be offset by construction cost savings.
- Shaded overhangs for fully glazed entrance façades can be cost justified by added value created by a shaded, sheltered entryway that protects customers from the elements.
- Properly designed vestibules can provide a covered placed to store shopping carts, increase employee comfort in point-of-sale areas, and create opportunities for targeted merchandising and advertizing.
- Balance and understand actual maintenance costs with energy costs.
- Leverage purchasing power and direct purchase of specific cost-effective equipment that meets the efficiency requirements in this Guide.
- Utilize tax and utility incentives and rebates.

DESIGN CONSIDERATIONS

HVAC Design

Some items to consider when incorporating energy efficiency into HVAC design include the following:

- Understand loads
  - Avoid oversizing
  - Don't use rules of thumb
  - Measure actual quantity of people, plug loads, etc.
  - Consider if peak cooling loads coincide (i.e., the peak number of people may not occur on the peak outdoor design day)
  - Consider changing the sensible heat ratio due to lower internal gains, which likely will be required to maintain a comfortable environment dew point
- Address ventilation
  - Understand requirements through the use of the performance-based IAQ Procedure of ASHRAE Standard 62.1 to determine contaminants of concern and the appropriate amount of ventilation required to provide good IAQ
  - Maintain net positive pressure, keep buildings clean and dry, and use low-emitting materials for good IAQ and to allow for reduced ventilation using a performance-based approach, which includes understanding contaminant concentrations through testing
- For any area with primarily heating requirements, consider vertical throw grilles (and avoid heating air temperatures over 100°F) to get warm air to the floor (an example is the front of the store near registers)
- In vestibules, use high-velocity vertical airflow to temper infiltration air
- Employ centralized monitoring and control, as remote monitoring and control allows store personnel to deal with customer service and sales, not temperature adjustment
- Understand the needs of the space (i.e., a pharmacy may need 24-hour conditioning)
- Fan power for air movement is a major energy use due to continuous operation during occupied times, so consider the following:
  - Variable-speed fan control
  - Dedicated outdoor air HVAC units with energy recovery ventilation
  - Primary outdoor air HVAC units with other HVAC units cycling for temperature control

  - Lower fan cfm/ton to the lowest acceptable by equipment supplier. The fan energy savings will likely outweigh any efficiency lost in cooling mode; this also improves dehumidification performance
  - Make sure any fan speed reduction accounts for the need to maintain appropriate ventilation levels, high ventilation effectiveness, and good IAQ

Operations and Maintenance

Some items to consider when incorporating energy efficiency into O&M include the following:

- Higher-efficiency equipment may require more maintenance, particularly with added components such as ERVs and evaporative cooling.
- Simple measures, such as passive strategies that integrate efficiency with the building envelope and structure, have low O&M costs and lower life-cycle costs, in general, than comparable, tech-heavy measures.
- Efficiency is improved by tighter fin spacing on coils, but a tighter fin spacing also collects more dirt and efficiency may be quickly lost.
- Provide detailed design application and installation instructions, start-up procedures, and operational guidelines. A high-efficiency system can easily become a poor performer if any of these steps is not followed.
- Understand building management system control sequences.
  - Manufacturer-provided operational sequences may not be optimal for the operation of the building.
  - Simple control algorithm changes, such as coil staging sequence, can often improve performance and efficiency.

INTEGRATED DESIGN BEST PRACTICES

BUILDING SITE AND DESIGN INFLUENCES

Climate Characterizations

Understanding the efficiency opportunities and challenges by climate zone is necessary for a retailer to reach advanced levels of energy savings. Retailers will have to be prepared to apply the most effective efficiency strategies by climate zone to the base prototype designs. There are several major climatic variables that impact the energy performance of buildings, including temperature, wind, solar, and moisture. These variables continuously change and can be characterized by annual or seasonal metrics:

- An indicator of the intensity and length of the heating season is represented by heating degree days (HDDs) as shown in Figure 2-1.
- An indicator of the intensity and length of the cooling season is represented by cooling degree days (CDDs) as shown in Figure 2-2.
- An indicator of the consistent intensity of the sun's energy is represented by the annual solar radiation as shown in Figure 2-3.
- An indicator of the worst case for removal of airborne moisture (i.e., dehumidification) is represented by the design dew point as shown in Figure 2-4.
- An indicator of the ability of the air to engage in evaporative cooling is represented by the design wet-bulb temperature as shown in Figure 2-5.

In combination, these variables show that distinct patterns emerge with regard to climate types, each of which has particular energy impacts on building design and operation. The U.S. has been divided into eight primary climate zones for the specification of design criteria in major energy codes such as ASHRAE/IES Standard 90.1 and ANSI/ASHRAE/USGBC/IES Standard 189.1,

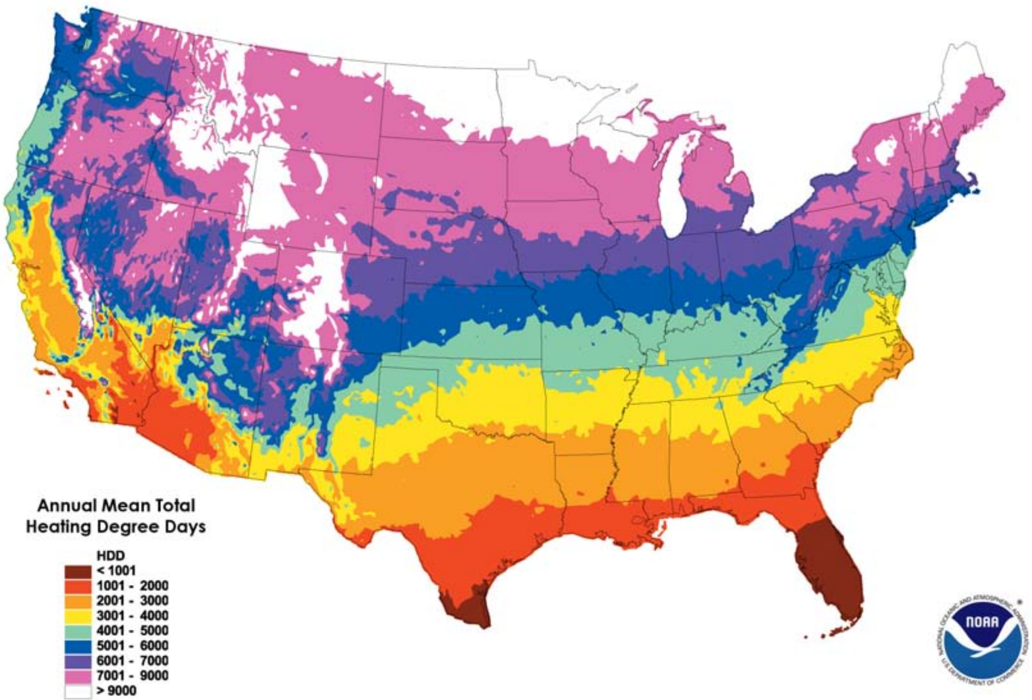


Figure 2-1 Heating-Degree Days
Source: http://cdo.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl

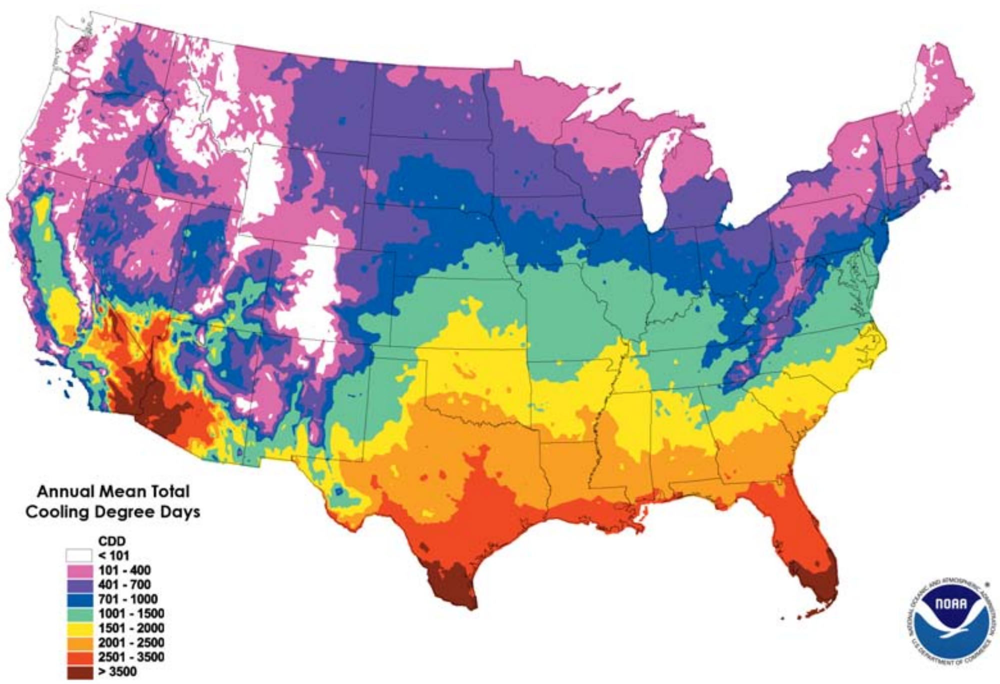


Figure 2-2 Cooling-Degree Days
Source: http://cdo.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl

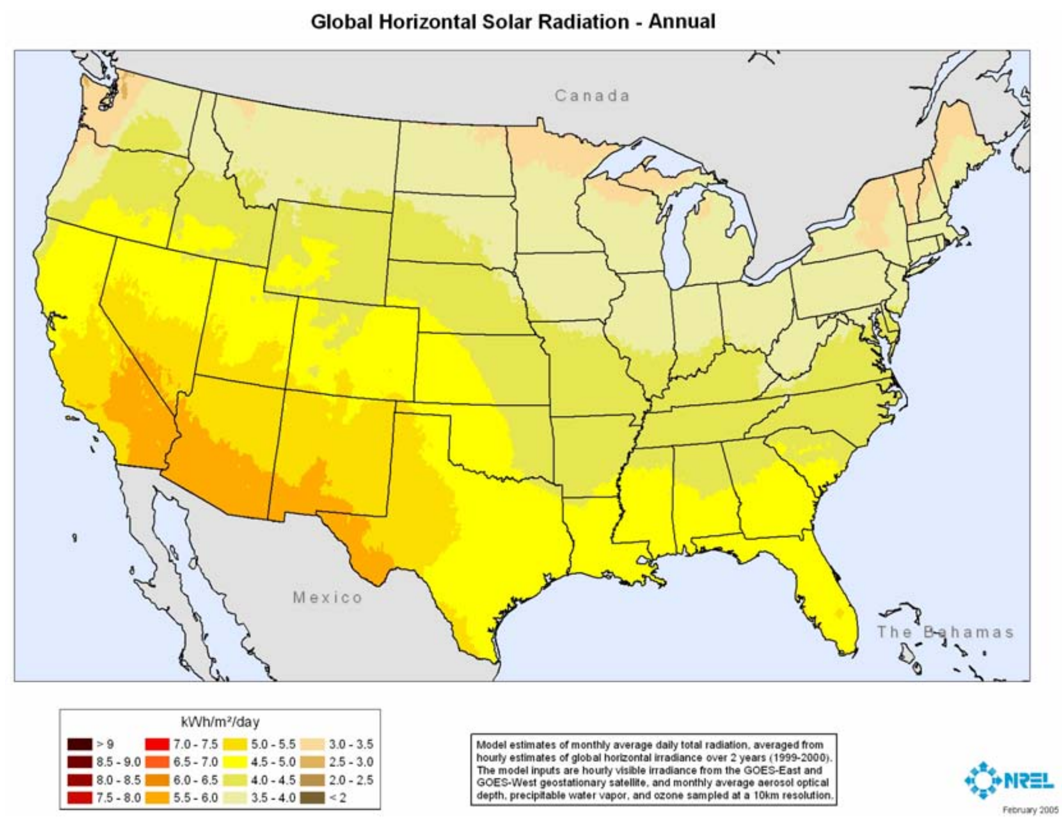


Figure 2-3 Annual Solar Radiation
Source: http://www.nrel.gov/gis/images/solar_glo.jpg

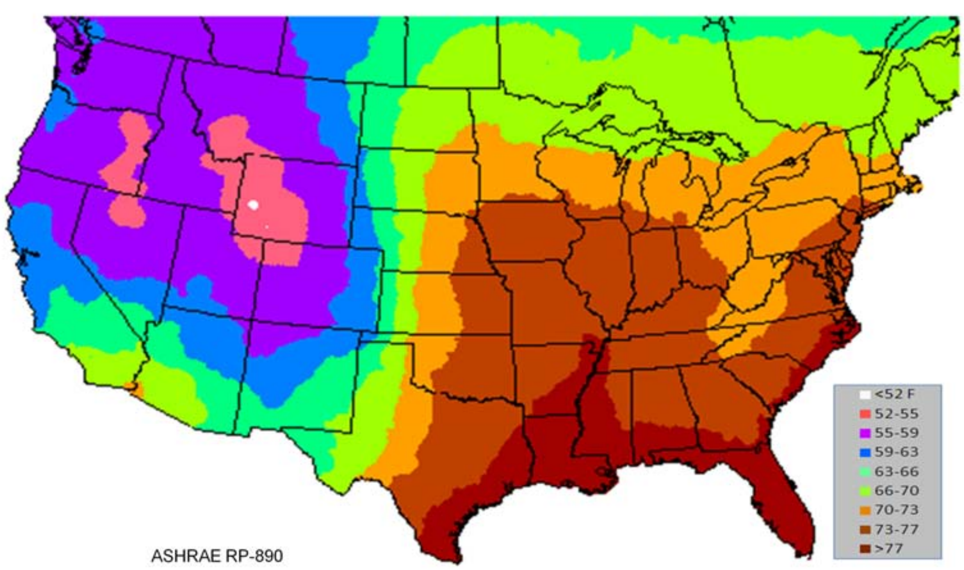


Figure 2-4 Design Dew Point
Source: ASHRAE RP-890

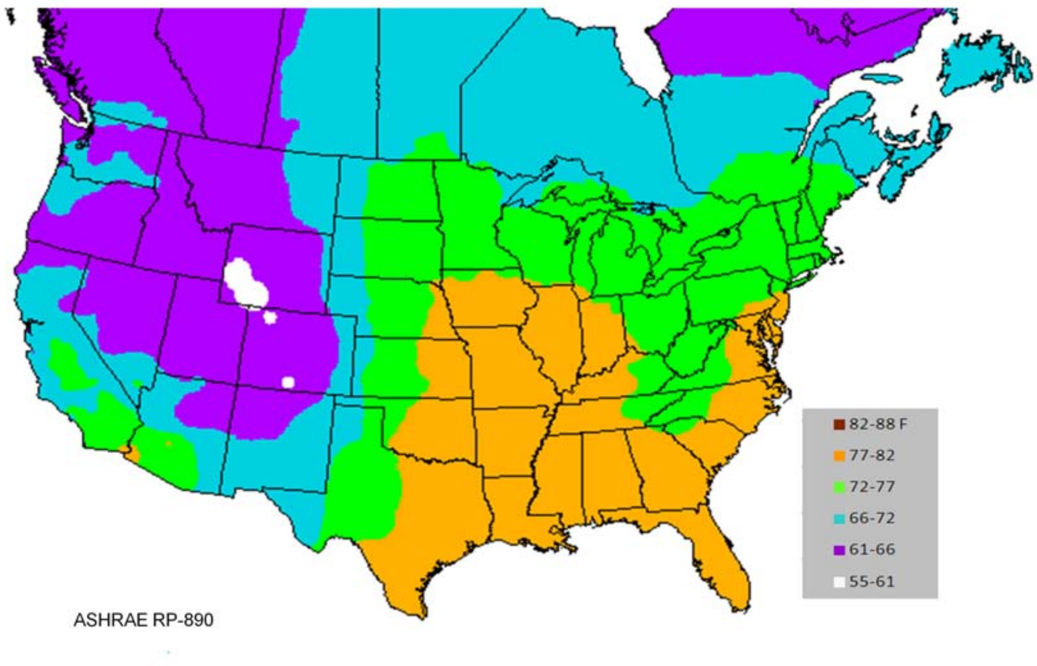


Figure 2-5 Design Wet-Bulb Temperatures
Source: ASHRAE RP-890

Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings (ASHRAE 2009). Figure 2-6 shows these climate zones as compared to CDD and HDD.

The characterization of these climate zones is based on seasonal performance metrics, not on peak or design values. Each climate zone is clustered by HDD65 for the heating and CDD50 for the cooling, and these climate zones are further subdivided by moisture levels into humid (A), dry (B), and marine (C) to characterize their seasonal weather values (see Figure 2-6). Sixteen cities have been identified as sufficient to represent the total variation in climate, as shown in Table 2-1.

It is important for the design team to determine the unique characteristics of the climate closest to the site. Annual hourly climate data is usually used for energy modeling and is available from federal government sources (see the "Weather Data" heading at energyplus.gov for a complete list). In addition to the acquisition of local data, it is necessary to assess any local topography or adjacent properties that may cause reduction in access to sunlight for daylighting and passive solar heating.

Climate Dependence

Multiple combinations of climate conditions influence the energy performance of a building. Comparisons of the energies needed for heating, cooling, interior and exterior lights and equipment, fans, and service water heating (SWH) in a retail store with water-source heat pump heating and cooling systems are shown in Figure 2-7.

A review of the graph shows that there are distinct trends. In climates below 3000 HDD65, the cooling energy is greater than the heating energy. In climates above 5000 HDD65, heating energy use dominates cooling energy use. In all climates, the energy use is essentially constant for interior and exterior lights and equipment, fans, pumps, and SWH. These relationships are similar for a retail store with a variable-speed fan RTU heating and cooling system, as shown in Figure 2-8.

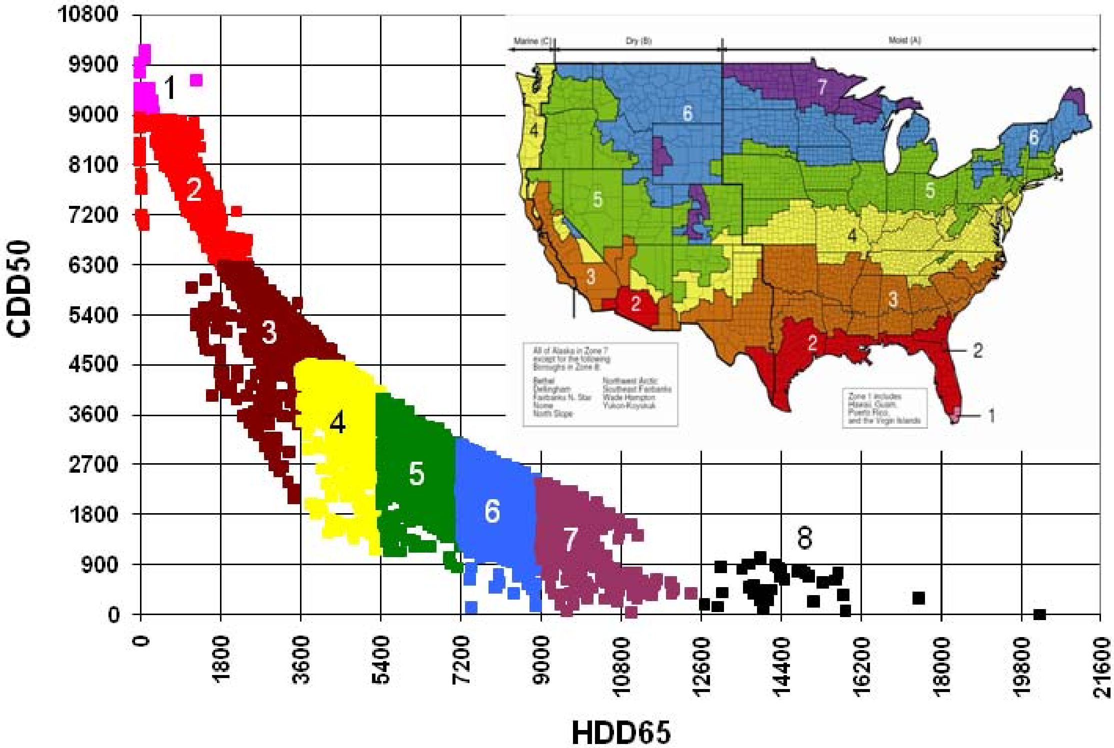


Figure 2-6 U.S. Climate Zone Map

Table 2-1 Cities Characterized by Climate Combinations

Climate	Hot	Mild	Cold	Very Cold	Extremely Cold
Marine		San Francisco-3C Seattle-4C			
Humid	Miami-1A Houston-2A Atlanta-3A	Baltimore-4A	Chicago-5A Minneapolis-6A		
Dry	Phoenix-2B Los Angeles-3B (coastal) Las Vegas-3B (others)	Albuquerque-4B	Denver-5B Helena-6B	Duluth-7	Fairbanks-8

The heat released by the interior lights, plug loads, and fans adds to the cooling load and diminishes the heating load, which highlights the importance in addressing these loads in conjunction with the envelope constructions.

Fundamentally, what can be seen in Figures 2-7 and 2-8 is as follows:

- Lighting, plug, and fan loads are constant inputs and therefore are very consistent in the EUI budget. Indeed, the only fluctuation most likely occurs from fan energy responding to on/off controls in response to climate.
- Heating energy contribution increases with HDDs, as expected, but the variation in the plot has to do with passive heating arising from solar contributions depending on the sun profile of the particular city. This becomes particularly obvious when looking at the pairs of heating and cooling contributions for a given HDD value—high heating goes with low cooling, which means that there is limited solar-free heating. Similarly, high cooling goes

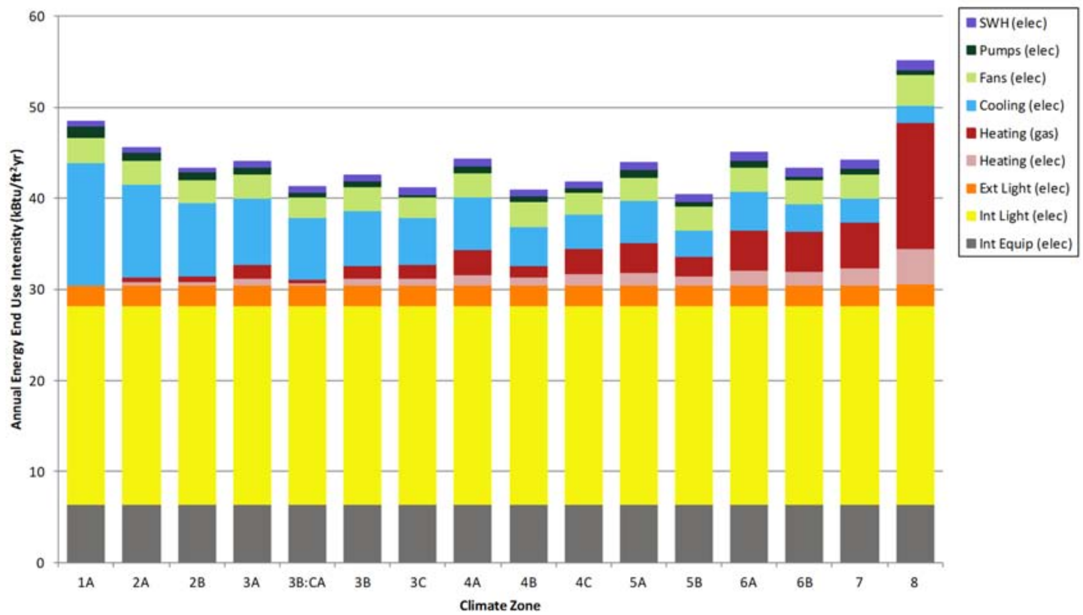


Figure 2-7 Retail Store with Water-Source Heat Pumps

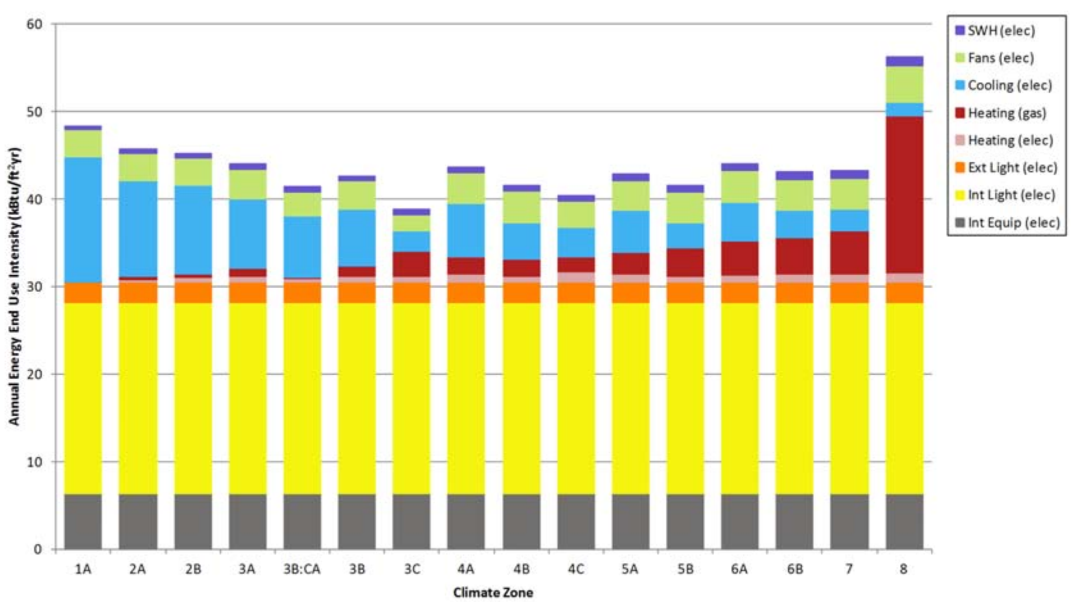


Figure 2-8 Retail Store with Variable-Speed Fan RTUs

with low heating, meaning there is a lot of solar heat to manage and the design team has to note whether the savings in heating sufficiently offset the penalties in cooling energy.

The basic shape of the building has a fundamental impact on the daylighting potential, energy transfer characteristics, and overall energy usage of the building. Daylighting is not required to achieve energy performance goals, but accessing its potential is part of good design practice.

Building plans that are circular, square, or rectangular result in more compact building forms, and these buildings tend to have deep floor plates that enhance the potential of toplighting a significant percentage of the sales space. Building plans that resemble letters of the alphabet, such as H, L, and U, or that have protruding sections and surfaces at angles other than 90° relative to adjacent building surfaces, tend to have shallow floor plates where sidelighting strategies result in a higher percentage of daylighted floor area. (Atriums and other core lighting strategies also may be introduced into more compact building forms to achieve a similar effect.)

Less-compact forms increase a building's daylighting potential from sidelighting, but they also may magnify the influence of outdoor climate fluctuations. Greater surface-to-volume ratios increase conductive and convective heat transfer through the building envelope. Therefore, it is critical to assess the daylighting characteristics of the building form in combination with the heat transfer characteristics of the building envelope in order to optimize overall building energy performance. See Sections DL1–DL3.

The shape of the building also defines the window area and orientations that are available. Windows allow solar gains to enter the building, which are typically beneficial during the heating season but not during the cooling season. The building shape needs to be designed so that the solar loading is properly managed. The solar management strategy changes with local climate characteristics, as solar intensity and cloud cover differ. In addition, attention must be paid to the effect of wind passing through openings in the façade (e.g., windows, louvers, trickle vents, cracks), as this can drive unforeseen and/or uncontrollable infiltration.

Building Orientation

When building orientation is a possible variable for a retailer, consider an orientation that will maximize beneficial solar energy for daylighting and PV while minimizing additional HVAC loads from solar energy gains. Energy modeling will help with balancing the design options.

MULTIDISCIPLINARY COORDINATION FOR ENERGY EFFICIENCY

Integrated design strategies require significant multilateral agreement on design intent from a variety of stakeholders. The following tips are provided to identify a series of items for which a direction and agreement must be achieved. Truly holistic low-energy design solutions are not achieved solely through the optimization of each component but rather by exploiting the mutually beneficial synergies between design strategies.

Define Business as Usual and Baseline Buildings

One of the very first things that the design team must define is what the business-as-usual (BAU) design solution would be. The BAU case is typically defined as a simple, box-shaped building that fills the site and is minimally compliant with ASHRAE/IES Standard 90.1. The energy use of this building typically defines the upper bound for allowable energy use and sets the comparative standard against which absolute savings are measured on the road toward net zero energy use. As each ECM is applied, the design team should track incremental victories. Because comparison to the BAU case truly reflects all design decisions, including those related to building form and orientation, this comparison is the real measure of project success; this is especially true with respect to cost justification.

The second key item that the design team must define is what the baseline design solution would be once the preferred building configuration's design is completed. The baseline, which defines the energy use goal that 50% savings represents, is very different from the BAU case. ASHRAE/IES Standard 90.1 requires that all proposed and baseline energy models have identical shapes, footprints, and occupancies. Thus, the baseline does not reward fundamental building configuration decisions for their positive effect on energy use. Again, while such decisions do not contribute to energy savings as defined with respect to an ASHRAE/IES Standard 90.1 baseline, it is important to remember that they do contribute to overall project success and can be quantified using the BAU case.

It is important for the design team to agree to move away from both the BAU case and the baseline in making proactive design decisions. It is also important that there be no shifting benchmark of success.

Benchmarking

While the BAU case represents the highest allowable EUI on site by calculation methods, there are a series of other energy use benchmarks that represent the existing building stock in the United States:

- Environmental Protection Agency's (EPA) ENERGY STAR Portfolio Manager
- The retailer's existing portfolio
- Commercial Buildings Energy Consumption Survey (CBECS)
- California End Use Survey (CEUS)
- Energy targets described in Chapter 3

It is possible to benchmark the proposed design against the BAU case and against its preexisting peers to demonstrate that substantial steps have been taken toward energy use reduction. Designers often successfully compare their designs to the "typical" equivalent building in the preexisting stock or to the number of houses that could be powered on the energy savings to make it easier for laypeople to understand the magnitude of energy savings.

Historic data, however, are not the inspiration for good design in the future. This is where more aspirational benchmarking can benefit the team. The most frequently used benchmarks are as follows:

- Energy savings as designated by percentage annual cost savings as compared to ASHRAE/IES Standard 90.1 Appendix G (typically used by codes and policies, but also used by LEED)
- Absolute EUI definitions (occasionally used by campuses, regularly used by the General Services Administration; easiest to measure and verify after construction)
- Net zero energy definitions

As noted above, it is important for the design team to agree to move away from the design practices that have led to poor performance in the past and toward a quantifiable target that is consistent with the available funding.

BUDGET SHARING

One oft-heard but fundamentally unnecessary question is "Whose budget pays for improved energy efficiency?" The answer should always be, "The owner's budget!" When a team commits itself to delivering low-energy, holistic solutions, it is virtually impossible to distinguish for the accountants how much energy efficiency each trade or discipline "purchased" on behalf of the project through its respective design decisions. A classic example is the cost of building shading: there are increased structural and façade costs, but these may be offset by reduced capital cost for window glazing and air conditioning. These trade-offs are absolutely necessary to explore in consideration of the particular goals and context of the building. So

Mountain Equipment Co-op Retail Store—A Case Study

Design work for the Mountain Equipment Co-op retail store in Montreal, Canada, began in May 2002. In addition to an open-air retail space, the 45,000 ft^2 building also includes storage areas, office spaces, and a small coffee shop. Because an integrated design approach was used, all the stakeholders were brought together at the beginning of the design process. The team targeted at least 50% energy savings compared to the *Model National Energy Code for Buildings* (MNECB) 1997 reference building while maintaining reasonable cost and technical expectations (NRC 1997).

Envelope and Daylighting

After evaluating the energy savings potential for various levels of insulation, the design team specified values of R-35 for the walls and R-40 for the roof. This is twice what is required by local code. An installed window U-factor of 0.3 was used for the windows, and various shading coefficients were adapted to each facing.

A roof monitor and two sets of clerestory windows provide daylight to the second floor with minimal glare. Sensors automatically turn off the general electric lighting when total lighting exceeds a set minimum. Daylighting provides the lighting for about half of the yearly operating hours.

HVAC Systems

With heating as the main energy use for the building, a ground-coupled heat pump radiant flooring system was selected for the building design. Twelve bore holes (575 ft deep) are combined with eight liquid-to-liquid 10 ton heat pumps. The floor slab operates as a low-temperature radiant and thermal storage system; heating and cooling is facilitated via fluid flow through crosslinked polyethyline (PEX) tubing embedded in the slab.

The heat pumps are bypassed when the geoexchange loop can provide water cold enough to cool the space. This is free geothermal cooling and is another benefit of the central liquid-to-liquid heat pump system.

To supply ventilation to the building, a hybrid (mechanical-natural) ventilation system was selected over a typical natural ventilation system in order to save energy while minimizing dust, noise, and

Mountain Equipment Co-op Retail Store
Photography courtesy of Pageau Morel

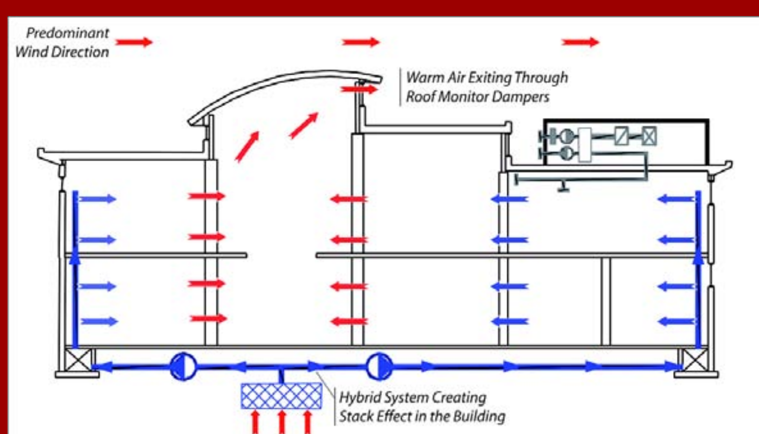
security issues. The hybrid system operates during free cooling hours and can be used during roughly half of the yearly operating hours. Using underground tunnels and vertical shafts, air circulates in a displacement ventilation mode. Sixteen exhaust dampers installed in the roof monitor help control the air. When conditions require, outdoor air is supplied by a 6000 cfm DOAS unit, and the hybrid system acts a recirculating system.

Other sustainable features include the use of an hydrofluorocarbon (HFC) refrigerant (no ozone-depleting potential), a rainwater collection system, and a solar domestic water heating system. Located in a regular commercial neighborhood, this store provides an example to the community of a retail store constructed using sustainable design principles.

Additional information on the systems utilized in this Mountain Equipment Co-op retail store building, along with additional sustainable building strategies, can be found in the Winter 2008 issue of *High Performing Buildings* (Genest and Charneux 2008).

Open-Air Retail Space with Roof Monitor
Photography courtesy of Pageau Morel

Bare Concrete Floors with Protective Coating
Photography courtesy of Pageau Morel



Hybrid Ventilation Free Cooling Mode
Figure courtesy of Pageau Morel

long as the overall building construction budget remains consistent with the OPR, it doesn't matter where the money was spent as far as energy efficiency measures are concerned. Early understanding of additional capital cost (if any) required for energy measures will allow the owner to consider increases to the building capital budget that will reduce long-term energy use and the life-cycle cost of the building.

Therefore, discipline-based construction budget allocations might be inappropriate for the integrated design paradigm and should be reviewed early in the project. Similarly, it might be argued that traditional fee percentages may also be unintentionally preventing the disciplines most capable of proposing and proving energy reduction techniques from applying their analytical technologies and abilities to the solutions.

Lastly, the EUI budget itself must also be equitably shared. The building envelope does not consume energy but significantly affects energy use of mechanical and lighting systems (when daylighting is used). Legislation and ingenuity have brought us to the point at which most electrical, mechanical, and lighting equipment have been optimized for the current state of technology. Therefore, it is important for design teams to carefully review the relative proportion of energy use by discretionary design choice and collectively attack those portions of the pie chart that represent the greediest users. A classic example is the use of all-glass façades with the expectation that highly efficient HVAC systems will somehow accommodate the egregious gesture; thankfully, energy codes are now biased to avoid this practice. Another, more subtle, example is the issue of plug loads in highly efficient buildings. As ECMs are applied to reduce lighting and mechanical energy use, the plug loads grow in a relative manner to upwards of 50% of electrical use. This should immediately tell all parties that plug loads need to be addressed, either with automatic shutdown controls or with substantial reduction in required, desired, or assumed load on the part of the owner and design team. If the team knows that it is accountable to share the responsibility for the end-use energy budget, it sets the tone for sharing the energy savings as well.

INVESTMENT FINANCIAL ANALYSIS

Many of the examples so far have discussed trade-offs made by the design team to reduce total building energy use. In order to confirm that each decision contributes to affordable energy savings, energy modeling can be coupled with a series of financial analyses to show which ECM gives the "biggest bang for the buck." The three most typical tools include the following:

- LCCA is a calculation method that adds first cost to a selected number of years of annual energy and maintenance costs, inclusive of equipment replacement costs and an estimate on inflation. The option that has the lowest life-cycle cost is usually chosen if the capital budget allows. LCCA is the financial tool most often used by institutional owners planning to hold and operate the building through a few generations of equipment technology.
- Simple Payback Period is a calculation method that divides the incremental first cost by the net annual operational savings (energy savings and maintenance impact) to determine how long it will take to break even on the investment. Simple payback method is most often used by developers looking to recoup costs before divesting of a property or long-term building owners with limited funding for retrofits.
- Return on Investment (ROI) is a calculation that takes the ratio of the energy savings over a predefined number of years minus the capital costs divided by the capital costs:

$$\frac{\text{Energy savings over } X \text{ years} - \text{Capital Cost}}{\text{Capital Costs}}$$

where X = predefined number of years

It essentially asks "What is my rate of return on the investment?" and it allows a somewhat parallel comparison to the rate of return used in the financial markets. The ROI method is usually used by wealth-holding clients comparing relative opportunity costs when looking to invest in stable profit growth. In downturn economies burdened with the ever-rising cost of energy, some financial institutions have begun to provide financing for energy efficiency upgrades based on projected ROI.

It is important in all of these financial comparisons that the team agrees on what inflation and depreciation rates are appropriate to be used. It is also important to consider the financial implications of potential value-added benefits unrelated to energy use.

BUILDING CONFIGURATION AND FLOOR AREA MINIMIZATION

For first-cost reasons, there is obviously a drive toward the minimization of built square footage, and the entire team should review the requested occupancies to determine if space can be shared as flexible space between uses otherwise listed separately. For instance, shared conference spaces or lounge spaces can reduce the redundancy of built space while also encouraging interdepartmental synergy. Another area often under scrutiny for cost savings (both first cost and operating costs) is the transient gross square footage associated with circulation spaces and lobbies. It is recommended that space planning exercises include a review of ways for these types of spaces to be reduced in size by merging functions or to be limited in scope to reduce the expenditure of energy under low-occupancy conditions.

The second major item for the team to address is the architectural configuration of the building. Façade square footage represents a source of conductive heat loss or heat gain as the outdoor air temperatures fluctuate; the larger the amount of façade area, the greater this impact. Additionally, some façades for retail buildings contain windows for the benefit of the occupants. Glazing is a poorer insulator than most opaque constructions and should be reviewed with regards to its placement and size. Generally speaking, daylighting is possible up to about 25 ft from a façade, a value that may govern the depth of footprints aspiring to greater connectivity to the outdoors. Beyond the impact on the interior floorplate, the shape of the building also informs where and how the building self-shades and begins to inform where glazing can be most effectively placed. Generally speaking, in the northern hemisphere, glazing that points toward the north captures atmospherically scattered (diffused) sunlight with minimal solar heat content, making it the ideal source of even light. Eastern and western glazing is impacted by low-angle sun throughout the year, which can cause glare and thermal discomfort if not mitigated properly. Lastly, in the northern hemisphere, southern façades with glazing benefit from overhangs to reduce solar load during the summer season.

SAFETY FACTORS AND DIVERSITY FACTORS

It is quite important for all members of the design team to openly reveal their safety factors so that systems are not oversized. The judicious application of diversity factors based on how normal buildings operate is important to the tight control of "rightsizing" the equipment for optimum efficiency. A classic example is the plug load allowance requested by the owner. The owner knows what the nameplates are—these can be up to four times higher than normal actual operating levels. The HVAC designer accepts that load and then applies a factor of +20% to account for "future expansion" and then, as per code, is allowed to size equipment for an additional 20%–30% for morning warm-up and boost. Then the fans are all sized for an extra 10% for air leakage, and the electrical engineer takes the mechanical loads and adds an extra 15% for unforeseen additional load or for effectively following the *National Electrical Code* by taking everything at face value simultaneously (NFPA 2011). All told, one can find transformers sized over three times larger than the largest load ever likely to be experienced. The result of this drastic oversizing is that some equipment may be operating in inefficient ranges, distribution flows may become unstable at low turndown rates, and excessive material has been installed as compared to what was actually needed. It is strongly recommended that a map of all safety factors and diversity assumptions is clearly laid out in a transparent way so that the whole team can make judgments together with regard to the assumptions. Measuring actual use of plug loads in the existing stock of a retailer's portfolio should also be used to inform actual diversity factors.

Diversity factors are very different from safety factors. The latter are meant to deal with unknown uncertainty in the operations in the future, while the former are meant to deal with known uncertainties or fluctuations based on professional judgment and industry practice. For instance, in HVAC and electrical design, it is quite common to find the following diversity factors applied:

- Solar diversity is embedded in most computer modeling software in calculating energy use and total peak load
- Diversity assumptions about occupancy
- Diversity assumptions about computer use with links to occupancy diversity
- Diversity assumptions with regards to likely simultaneity of peak airflows or peak water flows occurring on a single system (often used to downsize system capacity)

It is important to note that diversity factors are independent of schedules and as such must be reviewed with the schedules to ensure that the appropriate level of fluctuation is accounted for only once (especially when the schedule is a percent of load type of schedule). It is crucial for the entire team to agree on the diversity factors, as using them to downsize HVAC equipment for energy efficiency might run the risk of reduced capacity on peak days. It is necessary to project the extreme internal conditions arising with these peak conditions and get buy-in from the owner for exceeding internal temperatures or dew-point setpoints over a known number of hours in a typical meteorological year. Evaluation of actual occupancy diversity and outdoor air needs in a retailer's existing portfolio also can be used to understand which systems are oversized. HVAC systems are good examples of systems that are often oversized. Oversizing of the HVAC system not only leads to inefficient equipment, but it also can result in poor dehumidification, increased maintenance costs, and early failure of the system. Rightsizing the HVAC system can reduce fan power energy by almost 30% for a retail building.

SCHEDULES OF OCCUPANCY, USE, AND UTILITY RATES

It is essential that the team understand the schedules related to utility rates, especially any embedded demand charges and on/off/high/low/seasonal peak-period definitions local to the site and its service utility. This is because the prevailing benchmarks for energy savings in ASHRAE/IES Standard 90.1 and most energy codes are based on annual cost, not absolute energy savings. Most importantly, the owner pays for the demand and consumption charges. This means that discretionary decisions by the team to avoid onerous demand charges through load shifting may be appropriate when looking to reduce annual operating expenditures.

It is important for the team to map out the anticipated schedules of use and occupancy for each area of the building. This information is crucial to the energy modeling and can greatly affect the outcomes with regard to estimated energy savings over a known benchmark or through LCCA. It is important to note that most energy models run the same schedule week after week, so schedules not only should be configured to cover typical weeks but also should be changed to account for any known periods of building closure or times of higher than normal building occupancy, such as the holiday shopping season.

The last item to bear in mind regarding scheduling is whether a standardized schedule will be imposed on the energy model through regulatory requirements. For compliance modeling, in particular, some codes such as the *California Energy Code* require that prescribed schedules are used instead of a schedule grounded in a realistic review of actual prototype use (California Energy Commission 2008). It is important for the entire team to be aware of any such constraints ahead of time.

REDUNDANT AND STANDBY CAPACITY SIZING PROTOCOLS

It is recommended that a thorough discussion of redundancy be conducted early in the design with the owner. In particular, how redundancy is determined and if it is necessary should be discussed. Redundancy is the creation of spare capacity such that a single piece of equipment can be down for maintenance and the rest of the system can operate at some level. It is usually the case that percentage of capacity is used to define redundancy.

For instance, in a system in which two pumps are each sized at 60% of total load, the facility can lose one pump and still have at least 60% capacity. In a real-life installation, it would be necessary to ensure that the pump is selected to maximize efficiency during normal flow instead of an artificially high peak design flow.

If 100% capacity is desired at all times, some engineers prefer to use standby equipment—a whole spare unit capable of running when any of the normal "run" equipment is not functional. In this case, it might be appropriate to have three pumps, each sized for 50% capacity, available in the system—this would be a two run/one standby approach, and the pumps would generally be rotated in their operation in order to equalize runtime.

It is important in the energy modeling context that the appropriate horsepower associated with the actual 100% of capacity be used, lest the project be overburdened with a model of energy use that would not occur in real life, even when the model includes a variable flow control.

CHARETTES AND DESIGN REVIEWS

It is very desirable that design teams pursuing significant energy savings engage in the habit of early-phase design charettes involving all team members, followed by periodic design reviews. This process of holding one another accountable throughout the design process helps ensure that unintentionally myopic thinking on the part of any one team member doesn't accidentally propagate into a vulnerability not identified until commissioning. The entire team must understand the multidisciplinary multilateral agreements as noted herein, must acknowledge and support the achievement of stated energy-use goals, and must comb through the documents as they grow to ensure that the holistic system survives through detailing and value engineering processes.

Typically, kick-off charettes are convened by a named facilitator who sets the ground rules of the brainstorming session to encourage people to contribute and, most importantly, to listen. There should be agreed-upon time limits to each person's speaking length during the brainstorming time and time limits on the brainstorming period. All ideas are welcome and can be raised without judgment during the brainstorming period. It is often useful to start with a brainstorming period related to project and team goals, followed by a discernment session that allows the "brain-dump" list to be ordered with prioritization for time and cost investment. This can then be followed by a "blue-sky" type of brainstorming related to energy-efficiency measures. During this brainstorming session, it is necessary to refrain from actually starting to design or the value of the limited-time creative output from all team members may be diminished. There will be months to design using the great ideas thereafter.

Design reviews can benefit from reviewers that are both internal and external to the team. Internal reviewers are intimately aware of all of the step-by-step decisions that led to the current state. External reviewers provide a level of objectivity and can offer advice from past experience on similar challenges. The CxA's job is to review the content for commissionability and impact on energy use. Again, a facilitator may be necessary to ensure that all reviewers have time to speak without his suggestions being immediately contested by those parties with an investment in the status quo of the current design or who are biased for whatever reason. It is often beneficial to capture in writing all of the comments in an objective manner so that they can be respectfully addressed in sequence and a resolution on change of or continuance of design direction can be achieved and shared by the entire team.

USE OF ENERGY MODELING AS DESIGN GUIDANCE

Energy modeling is a powerful design tool to review relative energy savings of various ECMs. It can be further exploited when coupled with thorough financial analysis to ensure that the investment in initial cost will pay for itself in annual energy savings. The whole design team should understand that it is difficult for the current state of energy modeling software to predict actual energy use of a building; it is best suited to compare options to each other. It should be noted that there is no federal standard verifying the absolute accuracy of an energy modeling engine as compared to real life in uncontrolled circumstances. As a rule of thumb, results of at least a 5% relative energy savings arising from comparative energy models with ECMs applied to the same source file are probably a true indicator of measurable savings in real life. Anything less should be reviewed in the design team in a careful risk management process.

The energy modeling process involves a very large amount of data input, and in some software programs it is extremely difficult to change geometry after the fact without rebuilding the entire model. As such, the design team should understand how it will choose to spend its limited energy modeling fee from the start and ensure that each model run is absolutely necessary to confirm beneficial direction. There are many aspects of this Guide that have proven energy reduction benefits and are now considered best practice that do not need to be analyzed individually for cost-effectiveness. For instance, any nontechnical person would acknowledge that reductions in plug and lighting loads will reduce ultimate energy use, given equivalent schedule of usage. In order to achieve 50% reduction in building energy use as compared to ASHRAE/IESNA Standard 90.1-2004, energy modeling should be confirming the relative size of an already known benefit, not proving a bad position to resistant team members.

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Applying Energy Modeling and Benchmarking Strategies

3

INTRODUCTION

Integrated design strategies are necessary to achieve an energy efficiency level of 50% or greater. As noted in Chapter 2, no single discipline can apply sufficient measures to achieve this level of energy efficiency. The burden must be shared, and a holistic approach must be understood. Therefore, the recommendations provided in Chapter 4 provide a set of preevaluated and integrated solutions for reaching 50% savings for typical medium to big box retail buildings. Even though several design packages are provided in Chapter 4, the recommendations represent a few ways but not the only ways to build energy-efficient box retail buildings that use significantly less energy than those built to minimum code requirements. This chapter helps return control back to an integrated team of design professionals to make good decisions for a unique project on a specific site, especially one whose characteristics do not match the prototype buildings in space types, operations, or HVAC system types. Nevertheless, the analyses clearly show that systematically applied multidisciplinary approaches are essential to achieving 50% energy savings.

The recommendations in Chapter 4 of this Guide are based on typical prototype medium to big box retail buildings with industry standard operational schedules and typical costs and utility rates. As shown in Table 3-1 and Figure 3-1, the recommendations were developed based on stand-alone 40,000 and 100,000 ft^2 single-story medium and big box retail models, with the following common space types:

- Sales areas
- Administrative and office areas
- Meeting and break areas
- Hallways and restrooms
- Storage spaces and mechanical/electrical rooms

Typical ranges of internal gains, plug loads, and accent lighting up to 1.3 W/ft^2 are included in the development of the recommendations, as well as typical opaque envelope and glazing constructions. Higher internal gains, such as significant refrigeration or unique retail plug loads, were not included in the scope of the recommendations. Typical operation hours were included in the prototype models, with employees arriving to open the building at 7:00 a.m., full store operation starting at 9:00 a.m., operations shutting down at 9:00 p.m., and staff staying until

Whole Foods Market—A Case Study

This single-story, 40,000 ft^2 Whole Foods Market store in Raleigh, NC, opened in March 2011. Whole Foods Market worked closely with National Renewable Energy Laboratory (NREL), which employed extensive energy modeling to examine the building systems and interactions in order to design a store that would be 50% more efficient than ANSI/ASRAE/IESNA Standard 90.1-2004, *Energy Standard for Buildings Except Low-Rise Residential Buildings* (ASHRAE 2004).

Energy Modeling

Taking a new approach to the design, the team looked at the systems as an integrated whole rather than evaluating individual systems' energy use and then combining the systems together. In order to effectively analyze the proposed systems, the model was calibrated with utility bills, submetered data, and other energy use information from other, similar, recently built Whole Foods Market stores. The modeling also provided the team with a better understanding of how the various energy-consuming systems in the store affect one another as well as the overall energy use of the building.

Energy efficiency measures can work together or against each other. One example of this is the use of skylights. Skylights save electricity by reducing lighting, but they also affect heating/cooling loads by allowing in sunlight that heats up the space as well as allowing loss of heat through the skylight itself. Analysis of these interactions across all four seasons determined that skylights would indeed save energy as compared to an all-electric lighting scenario.

Lessons Learned

Collecting the information needed for modeling can be a challenge. The approach used in this project was to push the responsibility back to the manufacturers through requirements in the request for proposal (RFP) and participation in design conference calls. This approach provided critical details not readily available in product descriptions.

Whole Foods Market
Photography reprinted with permission from Whole Foods Market (NREL/PIX 18608, 18607)

The adoption of new or different equipment and technologies in order to meet design goals can also pose an issue. Verifying performance claims with unbiased information and measured data is a key component to accepting new energy efficiency measures in a design.

Whole Foods Market leases its buildings, so the developer is responsible for the structure, the envelope, and the building-level HVAC systems. A regional construction team oversees the interior construction details for the store. Writing specifications for the building's performance into the lease is critical to reaching desired energy savings goals.

Energy Efficiency Measures

Vestibules with offset doors were installed at both store exits and entrances; offset doors reduce airflow into the building when doors on both ends of the vestibule are open. Glazing area was reduced and more efficient glazing was specified, including the following:

- Skylights specified at 0.50 U-factor, 0.60 solar heat gain coefficient (SHGC), and 50% visible transmittance (VT)
- Vertical glazing specified at 0.25 U-factor, 0.27 SHGC, and 64% VT

The store was able to reduce the total installed lighting from 2.4 W/ft^2 (code maximum) to roughly 1.0 W/ft^2. Ambient lighting is provided with a combination of linear fluorescent, metal halide, and light-emitting diode (LED) fixtures. Other lighting measures include the following:

- Skylights installed with 40 in. light wells to provide diffuse light
- Occupancy sensors in frequently unoccupied spaces
- Bilevel control of fluorescent fixtures to allow for OFF, 50% ON, and 100% ON lighting

The total airflow rate on the sales floor was reduced from 1.0 cfm/ft^2 (standard) to 0.6 cfm/ft^2, which reduced fan power consumption. The main air-handling unit includes a desiccant wheel to dehumidify outdoor ventilation air. Instead of using natural gas, the wheel is reactivated with waste heat from the condenser coil.

Other Features

The Raleigh store is the most environmentally friendly Whole Foods Market store in the southern region, incorporating additional measures, including:

- A rainwater harvesting system for water reuse in store toilets and coolers
- Store furnishings made with reclaimed wood from a nearby barn and use of low-volatile organic compound (VOC) paints and finishes
- Bicycle racks and charging stations for electric vehicles

Additional information on Whole Foods Market's collaboration with NREL on the construction of their Raleigh, NC, store and the measures employed in the refrigeration and kitchen areas can be found on the Energy Efficiency and Renewable Energy (EERE) Building Technologies Web site within the Commercial Building Initiative Resource Database (Deru et al. 2010).

11:00 p.m. to close the building. December occupancy profiles were modeled to be 40% higher than January–November profiles to account for holiday shopping patterns. Whole-building models adapted from the prototype designs were equipped with HVAC systems designed to meet minimum ventilation requirements and maintain ASHRAE comfort standards (ASHRAE 2004) yearround. High-efficiency HVAC recommendations for rooftop units (RTUs), variable-air-volume (VAV) air systems, and all-electric heat pump systems are provided in Chapter 4. Additional detail about the assumptions in generating the recommendations and prototype models is available in the technical support document "Development of the Advanced Energy Design Guide for Medium to Big Box Retail Buildings—50% Energy Savings" (Hale et al. 2009).

In general, the Chapter 4 recommendations apply to typical medium and big box retail buildings with a range of internal loads and accent lighting. If a specific retail project includes atypical characteristics (such as a two-story building), unique operation patterns (such as 24/7 operating hours), or specialty space types or plug loads (such as a significant grocery store refrigeration load), 50% savings is still possible using the Guide's recommendations. However, additional custom energy modeling and life-cycle costing evaluations may be needed to ensure the Chapter 4 recommendations are applicable in these situations. In addition, whole-building energy modeling pro-

Table 3-1 Prototype Model Space Types and Sizes

Space Type	Medium Box Area (ft^2)	Big Box Area (ft^2)
Main sales	31,500	78,750
Perimeter sales	3076	4050
Enclosed office	300	664
Meeting room	500	1106
Break room	500	1106
Restroom	625	1382
Mechanical room	200	442
Corridor	450	450
Vestibule	300	675
Active storage	3050	10,600
Total	**40,500**	**99,225**

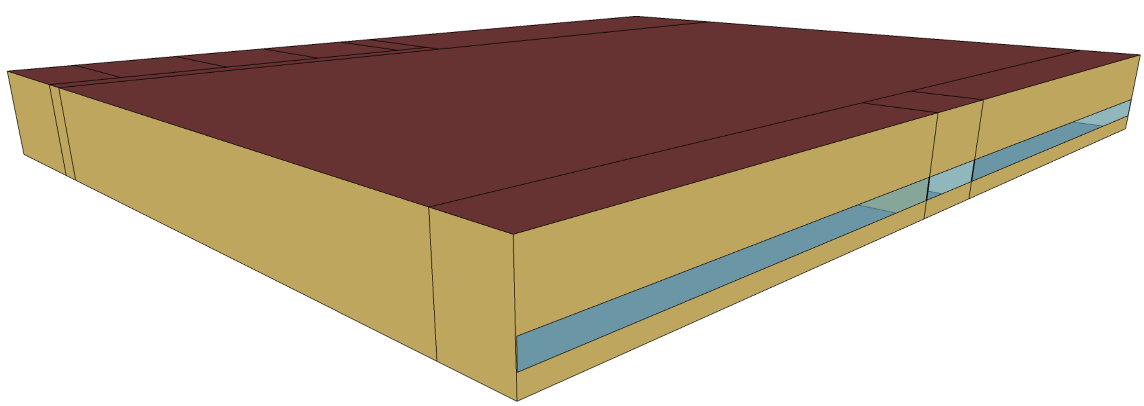

Figure 3-1 Rendering of a Medium Box Retail Model

grams can provide more design flexibility to evaluate the energy-efficient measures on an individual project. Ultimate flexibility is provided to a project team by allowing a project to meet the whole-building 50% savings targets without consideration to subsystems or prescriptive recommendations through the modeling approach outlined in this chapter. Similarly, if one of the three recommended HVAC system types is not feasible, then an energy modeling approach to evaluate a specialty system should be pursued. Local site constraints, actual project costs, and available utility rebates can also vary by project. Therefore, performing life-cycle cost analysis (LCCA) for key unique design considerations is encouraged to properly capture project-specific local cost and operational considerations.

ENERGY MODELING TASKS

The following key energy modeling tasks should be pursued by design teams looking to reach 50% savings for unique projects whose characteristics have significant variations in space types, operations, rebates, economics, or HVAC system types.

BENCHMARKING

For most national retailers, a prototype model that represents past store design and operations will be the business-as-usual (BAU) case. There are also a series of other energy use benchmarks, such as EPA's ENERGY STAR Portfolio Manager, that can be used by retailers without prototype designs and that represent the existing retail building stock in the United States.

For retailers with a portfolio of operating stores, there is a unique opportunity to define a realistic BAU reference point that all efficiency strategies can be evaluated against. Before a modeling analysis or design process starts, the team should spend time early in the process to understand the performance of the current prototype and to develop a realistic BAU case. For retailers that already utilize a predetermined prototype that has previously been built, understanding energy performance and actual operational trends in the existing portfolio will provide a valuable starting point for developing a realistic and calibrated baseline for evaluating the Guide's recommendations. Benchmarking actual energy use by climate, understanding actual occupancy density and outdoor air requirements, and measuring unoccupied load profiles can provide valuable insight into the most effective strategies to meet 50% savings. Applying this understanding to the modeling process removes many of the uncertainties present in a typical modeling exercise, allowing for a more precise analysis of the applicable recommendations.

For retailers without an existing portfolio available for benchmarking, it is still possible to benchmark the proposed design against a BAU case and against its preexisting peers to demonstrate that substantial steps have been taken toward energy use reduction. Designers often successfully compare their designs to a typical equivalent preexisting building. Access to benchmarks is available through the Retailer Energy Alliance (DOE 2011). More information on the BAU case and baseline energy model is provided in Chapter 2 of this Guide.

GOAL SETTING

To achieve a retail building that uses 50% less energy than the industry standard takes careful goal setting. Setting a target of 50% less than a baseline fictitious building built to a standard is a recognized goal. To better define the goal, an absolute whole-building energy use intensity (EUI) should be defined as a best practice. Designers and owners should strive to set their own whole-building EUI targets to provide focused and measurable 50% savings goals. These EUI targets can be used to select design teams as part of a procurement strategy to set early design goals, to

BTI Greensburg, John Deere Dealership—A Case Study

In 2007, a tornado destroyed most of Greensburg, KS. When the town decided to rebuild a greener, more sustainable community, the local John Deere dealership set the goal for their new 28,000 ft^2 facility to use as little energy as possible and attain a LEED Platinum rating. The design was so successful that the John Deere Company has made it the new model design for dealers across the country. Completed in March 2009, the facility operates as half retail and half service center for John Deere equipment.

Building Envelope

The metal building construction used insulation levels well beyond standard practice, including the following:

- R-16 insulated metal wall panels, such as those typically used in refrigerated warehouses, which eliminate thermal breaks typically seen in metal building construction
- R-14 insulated panels in overhead dock doors
- R-38 insulated ceilings with thermal blocks to minimize thermal breaks at the roof structure

Daylighting/Lighting

In order to take full advantage of daylighting throughout the building, the design included 24 skylights in the service area and 12 tubular daylighting devices in the retail area. The tubular daylighting devices provide diffused light with minimal glare and unwanted heat transfer. Daylighting controls adjust electric lighting in response to daylight levels in order to maximize energy savings. Occupancy sensors are installed to turn off electric lighting when not needed.

HVAC Systems

Heating and cooling are provided by a high-efficiency (16 SEER) VAV system. Combined with CO_2 demand-controlled ventilation, the system also provides outdoor air to the retail area. Motion detectors provide additional controls for the heating and cooling systems.

John Deere Dealership

Photography courtesy of NREL; Credit: Rachel Sullivan
Used with permission of BTI-Greensburg John Deere

The concrete slab floor incorporates radiant slab heating, which minimizes heating requirements to maintain thermal comfort during the frequent opening of the overhead dock doors. The hot water for the system is provided by both a natural gas boiler and a boiler that burns recycled waste oil collected from the service center.

Other Features

A number of sustainable practices were included in the design and construction, including the following:

- Two wind turbines sized at 5 and 1.8 kW offset roughly 8% of the electricity at the facility.
- Waterless urinals and low-flow fixtures are installed in the restrooms.
- Runoff and rainwater are collected and used to irrigate the site.
- Recycled materials were used in the construction of the building and the facility instituted an on-site recycling plan.

Additional information on the BTI-Greensburg John Deere Dealership and the collaboration with NREL can be found on the EERE Commercialization and Deployment Web site (NREL 2011).

Tubular Daylighting (top) and Insulated Garage Door and Skylights (bottom)

Photography courtesy of NREL; Credit: Lynn Billman
Used with permission from BTI-Greensburg John Deere

track design development progress, and to verify performance during operations. These EUI targets can be generated from multiple data sources, including the following:

- ENERGY STAR Target Finder (DOE and EPA 2009)
- Other retail buildings in the applicable, or similar, climate zone, especially those in the portfolio
- Other retail buildings within the portfolio but outside of the applicable climate zones
- Case studies of high-performance retail buildings with a similar scope of application and within similar climate zones (see case studies in this chapter)
- The recommended EUIs in the tables that follow are based on a typical configuration for general merchandise retail, with variations in installed plug loads and accent lighting to account for variation in application. These are good targets but may not apply if the retail building has atypical high-use energy loads or other special circumstances.

In general, the energy targets in this Guide are applicable to most retail buildings, with programs and use profiles typical to general merchandise retail. The Guide provides energy targets for medium box (represented by the 40,000 ft^2 prototype) and big box (represented by the 100,000 ft^2 prototype) retail application. The prototypes presented here are representative of typical general merchandise retail, with space type distributions and internal gains as previously defined in this chapter. To account for wide variation across the retail industry in installed plug loads and accent lighting by space type and retail application, the Guide provides energy use targets for a range of installed plug loads and lighting levels. Energy targets are provided for two levels of baseline plug loads, dubbed “low” and “high,” defined by whole-building average installed plug load densities of 0.5 and 0.7 W/ft^2, respectively. A general merchandise store would be a typical low-plug-load case, whereas a dedicated electronics store would be a typical high-plug-load case. Within each category of installed plug loads, energy targets are provided for three levels of baseline accent lighting: (1) little or no accent lighting (“min”), with a value of 0 W/ft^2 for simplicity; (2) a typical level of accent lighting (“med”), calculated as 1.6 W/ft^2 for sales areas by applying the accent lighting allowance of ASHRAE/IES Standard 90.1-2004 to the sales area application distribution that attributed to general merchandise; and (3) a high level of accent lighting (“high”), representative of retail applications with specialty accent lighting requirements, such as jewelry sales, with a value of 3.9 W/ft^2, according to the allowance of ASHRAE/IES Standard 90.1-2004.

These energy targets assume a baseline HVAC configuration of discrete, constant-volume, packaged RTUs with direct-expansion (DX) cooling, gas heating, and electric reheat, which is typical for retail applications. These targets assume a typical weather year for a typical climate zone. These targets also reflect control assumptions and assume properly operating, well-maintained equipment. Caution should be used when applying these targets, especially if the retail building under consideration has atypical spaces, high-use energy loads, etc. For additional detail about the assumptions in generating these energy targets, see the technical support document for this Guide (Hale et al. 2009).

These energy targets can be used to give designers flexibility while still reaching the 50% energy savings goal. The numbers given in the tables below are annual whole-building energy consumption targets for achieving 50% energy savings when measured against a baseline that is minimally compliant with respect to ASHRAE/IES Standard 90.1-2004 and otherwise typical for general merchandise retail. Following the recommendations in Chapter 4 has been shown though whole-building energy modeling to result in at least 50% energy savings for any combination of building size, recommended HVAC type, plug load and accent lighting categories, and climate zone. However, if there is a specific prescriptive recommendation that is not feasible in a specific project, this Guide can still be used to achieve 50% savings, as long as the project team ensures that the appropriate whole-building energy consumption target is met, likely through exceeding one or more prescriptive recommendations elsewhere. Tables 3-2 and 3-3 present annual whole-building energy consumption targets for medium box and big box retail buildings, respectively.

All tables provide energy targets for the 16 defined climate zones as shown in Figure 3-2 (climate zones 1–8 with subcategories A, B, and C, as applicable) (Leach et al. 2011).

Table 3-2 Medium Box Retail Energy Use Targets for 50% Savings

Climate Zone	Energy Use Intensity (kBtu/ft²yr)					
	Low Plug			High Plug		
	Min Accent	Med Accent	High Accent	Min Accent	Med Accent	High Accent
1A	42	58	81	45	61	85
2A	41	56	77	44	59	80
2B	37	53	75	40	56	79
3A	38	51	70	40	53	73
3B-CA	31	46	67	34	49	69
3B	36	50	72	38	53	75
3C	29	43	61	32	45	64
4A	39	51	68	41	53	70
4B	36	50	70	39	53	72
4C	33	44	61	35	47	63
5A	40	50	65	42	52	67
5B	36	49	67	39	51	69
6A	43	53	66	45	54	68
6B	39	50	65	41	52	67
7	44	52	63	46	54	65
8	56	61	69	57	62	71

Table 3-3 Big Box Retail Energy Use Targets for 50% Savings

Climate Zone	Energy Use Intensity (kBtu/ft²yr)					
	Low Plug			High Plug		
	Min Accent	Med Accent	High Accent	Min Accent	Med Accent	High Accent
1A	42	58	82	45	62	85
2A	41	56	77	44	58	80
2B	38	54	77	41	57	80
3A	35	49	69	38	52	72
3B-CA	30	45	66	33	48	69
3B	34	49	71	37	52	74
3C	28	41	61	30	44	63
4A	37	49	66	39	51	68
4B	34	48	68	37	51	71
4C	31	43	60	33	45	62
5A	38	49	64	40	51	66
5B	35	47	66	37	50	68
6A	41	51	64	43	52	66
6B	37	48	63	39	50	65
7	42	50	62	44	52	63
8	53	58	67	54	60	68

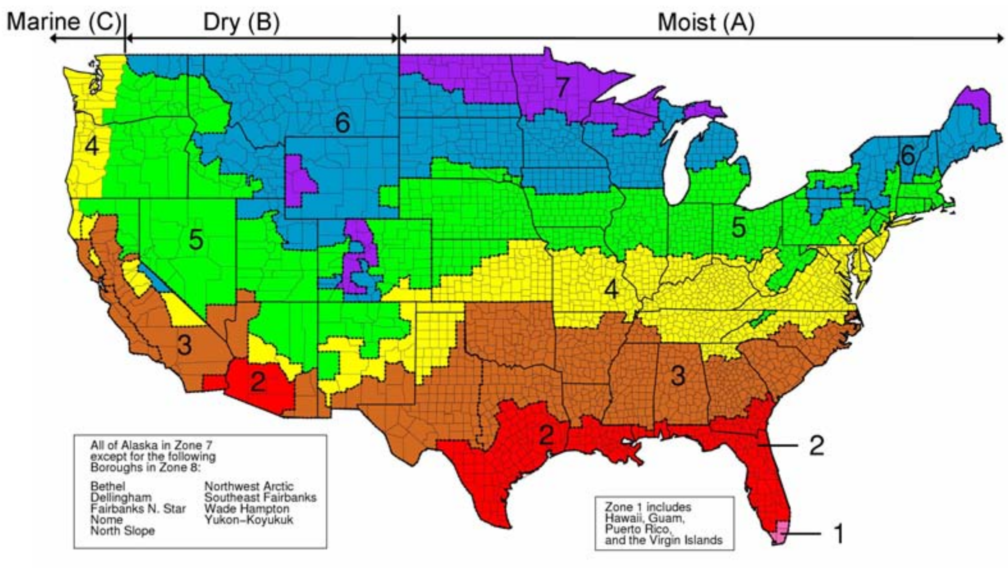

Figure 3-2 U.S. Map Showing the DOE Climate Zones (Briggs et al. 2003)

Table 3-4 Using Energy Modeling to Achieve 50% Energy Savings

Modeling Stage	Key Tasks	Key Outcomes
Benchmarking	Define a BAU case according to past design or other energy use benchmark	Determination of cost justification reference using BAU model
	Use BAU case to create a baseline model	Quantification of energy goal using baseline model
Goal Setting	Select an energy metric, such as whole-building EUI, and define a measurable energy performance goal	Definition of the energy goal by which project success will be evaluated
Prototype Design	Evaluate of applicable AEDG recommendations	Definition of prototype model
		Identification of climate-specific issues
Climate-Specific Design Optimization	Additional evaluation of applicable AEDG recommendations, accounting for project-specific rebate programs, utility rates, and life-cycle costs	Selection of general design strategies to incorporate into design development; determination of approach to daylighting, ventilation controls, envelope strategies, and HVAC system selection
	Apply climate-specific recommendations to prototype model	
Final Design	Update model to reflect key design changes that impact energy performance	Final analysis of life-cycle cost savings
		Initial verification of energy goal achievement
As-Built	Update model to reflect key construction changes that impact energy performance	Refinement of energy goal verification
As-Operated	Update model to reflect key operational changes that impact energy performance	Final verification of energy goal achievement
		Lessons learned inform goal setting for future projects

USING ENERGY MODELING THROUGHOUT THE DESIGN PROCESS

It is important for the design team to agree to move away from both the BAU case and the baseline by establishing a clear and measurable energy goal and making proactive design decisions to achieve that goal. Energy modeling is integral throughout this process. Best practice for the use of energy modeling by a design team is summarized for each stage in the design process in Table 3-4.

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Design Strategies and Recommendations by Climate Zone

4

INTRODUCTION

Users should determine the recommendations for their design and construction projects by first locating the correct climate zone. The U.S. Department of Energy (DOE) has identified eight climate zones for the United States, with each defined by county borders, as shown in Figure 4-1. This Guide uses these climate zones in defining energy recommendations that vary by climate. The definitions for the climate zones are provided in Appendix B so that the information can be applied outside the United States.

This chapter contains a unique set of energy-efficient recommendations for each climate zone. The recommendation tables represent *a way* but *not the only way* to reach the 50% energy savings target over ASHRAE/IESNA Standard 90.1–2004 (ASHRAE 2004). Other approaches may also achieve the 50% savings target, and Chapter 3 provides energy target, benchmarking, and modeling recommendations for those who wish to generate other viable design options; confirmation of energy savings for those uniquely designed systems is left to the user. The user should note that the recommendation tables do not include all of the components listed in Standard 90.1 because the Guide focuses only on the primary energy systems within a building.

When a recommendation is provided, the recommended value differs from the requirements in Standard 90.1–2004. When “No recommendation” is indicated, the user must meet the more stringent of either the applicable version of Standard 90.1 or the local code requirements.

Each of the climate zone recommendation tables includes a set of common items arranged by building subsystem: envelope, daylighting/lighting, plug loads, service water heating (SWH), HVAC, and quality assurance (QA). Recommendations are included for each item, or subsystem, by component within that item or subsystem. For some subsystems, recommendations depend on the construction type. For example, insulation values are given for mass, steel-framed, and wood-framed wall types. For other subsystems, recommendations are given for each subsystem attribute. For example, vertical fenestration recommendations are given for thermal transmittance and solar heat gain coefficient (SHGC).

The fourth column in each table references the locations of how-to tips for implementing the recommended criteria. The tips are found in Chapter 5 under separate sections coded for envelope (EN), daylighting (DL), electric lighting (EL), plug loads (PL), service water heating systems and equipment (WH), HVAC systems and equipment (HV), and quality assurance

(QA). In addition to representing good practice for design and maintenance suggestions, these how-to tips include cautions for what to avoid. Important QA considerations and recommendations are also given for the building design, construction, and post-occupancy phases. Note that each tip is tied to the applicable climate zone in Chapter 4. The final column is provided as a simple checklist to identify the recommendations being used for a specific building design and construction.

CLIMATE ZONE RECOMMENDATIONS

The recommendations presented are minimum, maximum, or specific values (which are both the minimum and maximum values). Appendix A provides U-factors and F-factors for the prescriptive construction R-value options provided in the climate zone recommendation tables for opaque envelope measures.

Minimum values include the following:

- R-values
- Solar Reflectance Index (SRI)
- visible transmittance (VT)
- vertical fenestration effective aperture
- interior surface average reflectance
- mean lumens per watt (LPW)
- gas water heater or boiler efficiency
- thermal efficiency (E_t)
- energy factor (EF)
- energy efficiency ratio (EER)
- integrated energy efficiency ratio (IEER)
- integrated part-load value (IPLV)
- coefficient of performance (COP)
- energy recovery effectiveness
- fan or motor efficiency
- duct or pipe insulation thickness

Maximum values include the following:

- fenestration and door U-factors
- fenestration SHGC
- lighting power density (LPD)
- fan input power per cubic feet per minute of supply airflow (W/cfm)
- window-to-wall ratio (WWR)
- external static pressure

BONUS SAVINGS

Chapter 5 provides additional recommendations and strategies for energy savings over and above the 50% savings recommendations contained in the eight climate zone recommendation tables.

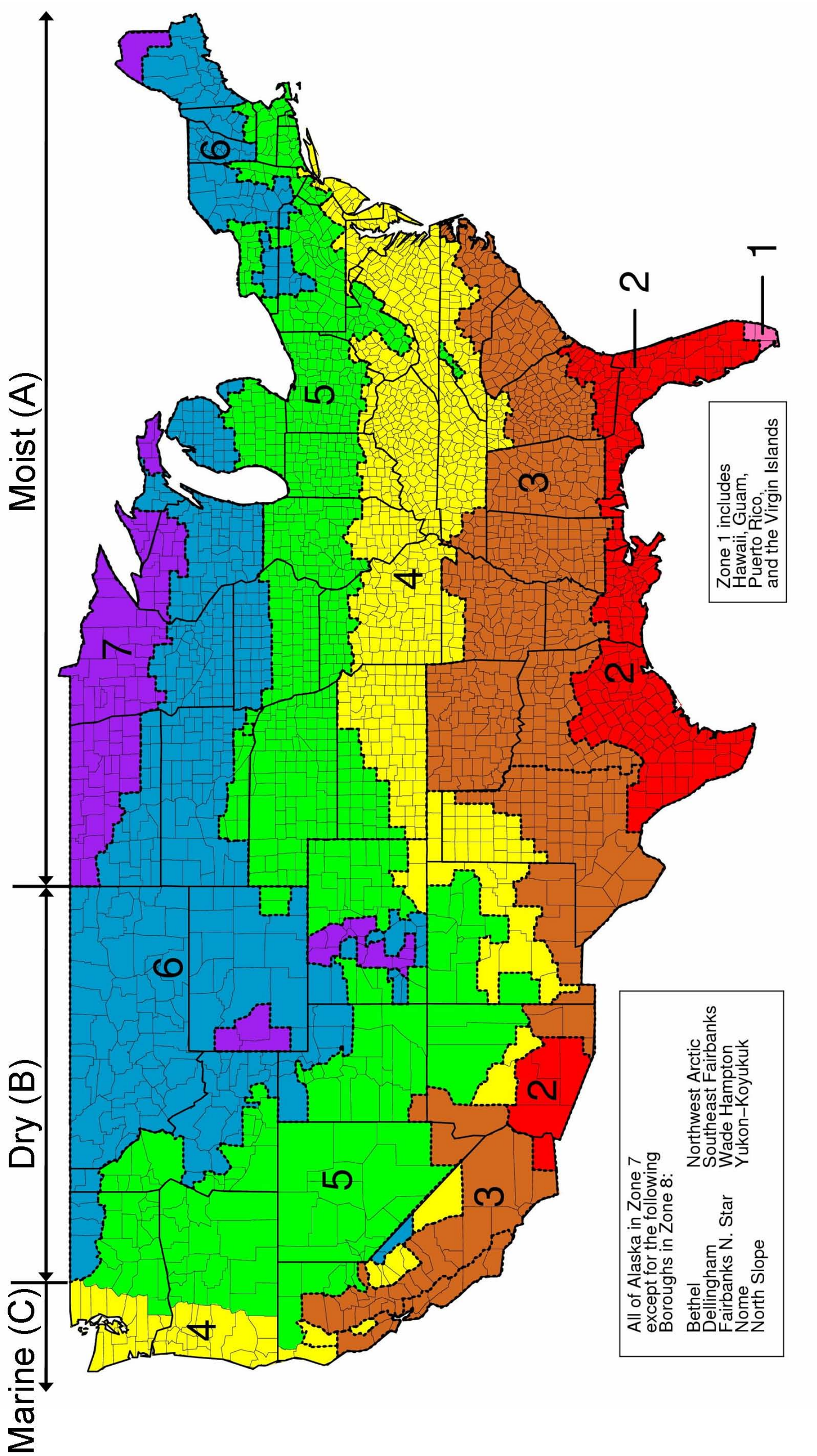
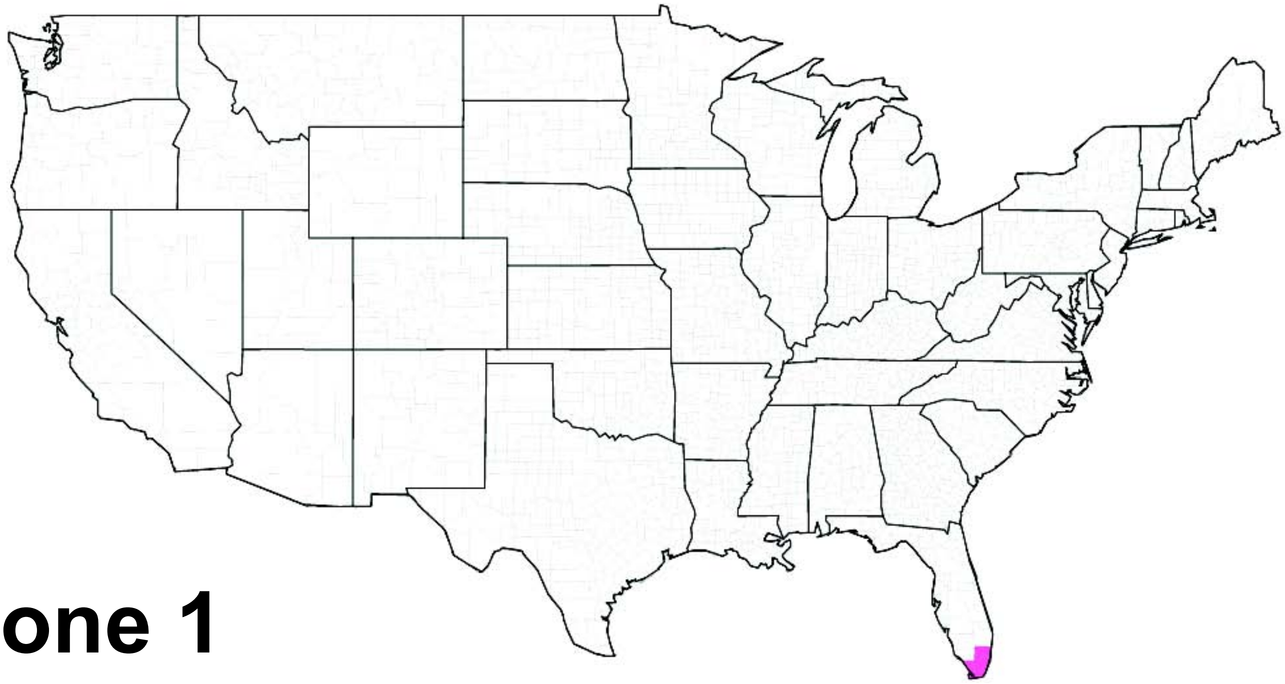


Figure 4-1 U.S. Map Showing the DOE Climate Zones (Briggs et al. 2003)



Zone 1

Florida

Broward
Miami-Dade
Monroe

Guam

Hawaii

Puerto Rico

U.S. Virgin Islands

Climate Zone 1 Recommendation Table for Medium to Big Box Retail Buildings

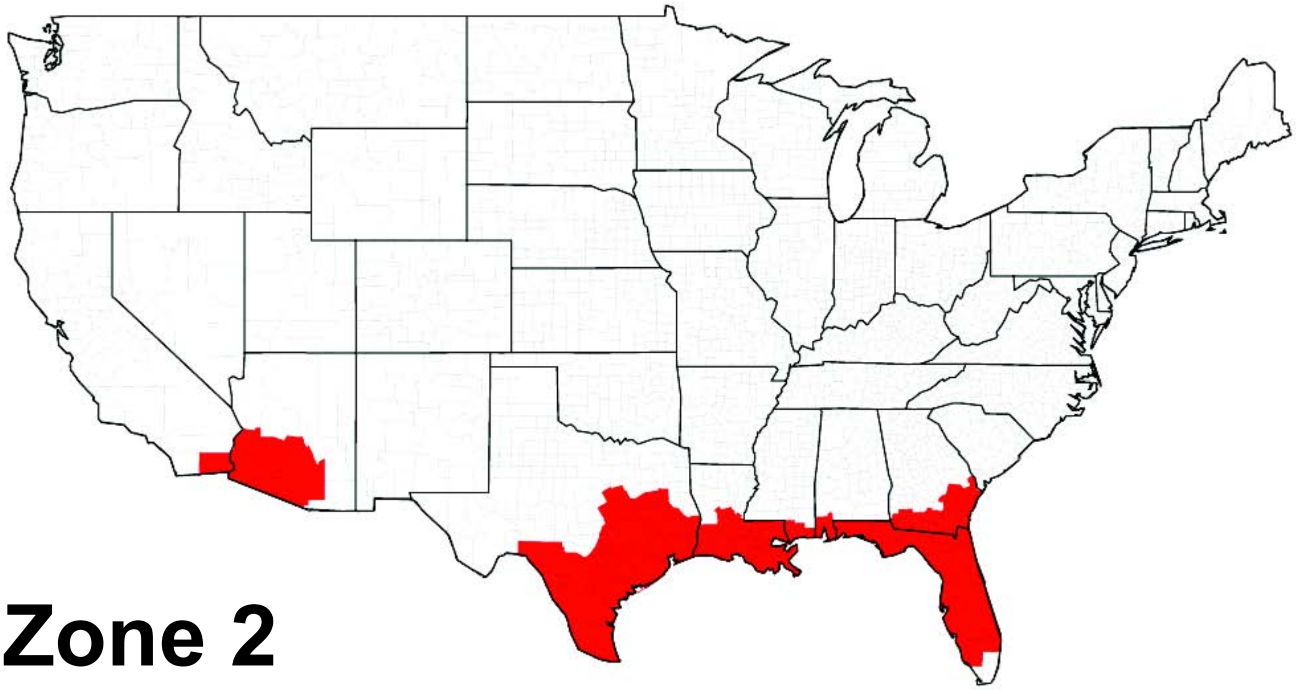
	Item	Component	Recommendation	How-to Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-20.0 c.i.	EN1–2, 18–21	
		Metal building	R-19.0 + R-10.0 FC	EN1, 3, 18–21	
		SRI	78	EN1	
	Walls	Mass (HC > 7 Btu/ft^2)	No recommendation	EN4, 18–20	
		Metal building	R-0.0 + R-9.8 c.i.	EN5, 18–20	
		Steel framed	R-13.0 + R-7.5 c.i.	EN6, 18–20	
	Floors	Mass	No recommendation	EN7, 18–20	
		Steel framed	No recommendation	EN8, 18–20	
	Slabs	Unheated	No recommendation	EN11	
		Heated	R-7.5 for 12 in.	EN10–11, 18–21	
	Doors	Swinging	U-0.70	EN12, 18–20	
		Nonswinging	Roll-up = U-0.25 All other = U-0.07	EN13–14, 18–20	
		Vehicular/dock infiltration—door closed	0.28 cfm/ft^2 of door area	EN15, 18–20	
		Vehicular/dock infiltration—door open, truck in place	Weather seals for dock, levelers, trailer hinges	EN16, 18–20	
	Vestibules	At building entrance	Yes	EN17–20	
	View Fenestration—All Orientations	Thermal transmittance	U-1.20	EN22–23	
		SHGC	0.25	EN23–26	
		VT	0.25	EN23, 26	
Daylighting / Lighting	Interior Lighting	LPD—Ambient Lighting	Sales floor = 1.15 W/ft^2	EL1, 3–7, 9–11, 17–23, 28	
			Stock room = 0.6 W/ft^2	EL1, 4, 9–11, 17–19, 26, 28	
			Average of all other = 0.9 W/ft^2	EL1–2, 4, 8–11, 17–19, 24–28	
		LPD—Additional specialty sales floor lighting	Sporting goods, small electronics = 0.6 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Furniture, clothing, cosmetics, art = 0.95 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Jewelry, crystal, china = 1.5 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			All other = 0.4 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
		Light source efficacy (mean LPW)	T8 and T5 lamps > 2 ft = 92 T8 and T5 lamps ≤ 2 ft = 85 All other > 50	EL12, 14	
		T8 ballasts	Nondimming = NEMA Premium Instant Start Dimming = NEMA Premium Programmed Start	EL12	
		All T5/T5HO ballasts	Electronic programmed start	EL12	
		All CFL and HID ballasts	Electronic	EL13	
		Lighting controls	Sales floor = Time switch—auto to 25% 3 h before and after store open hours; auto to 2% or less after hours	EL16	
			Additional specialty lighting = auto ON only during store open hours	EL16	
			Stock room, restrooms = auto ON/OFF occupancy sensors	EL15	
			All other = manual ON, auto OFF occupancy sensors	EL15	
			After hours = max 2% of total building LPD	EL16	
	Exterior Lighting	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ3 and LZ4, 0.05 W/ft^2 in LZ2 Controls = auto OFF between 12 a.m. and 6 a.m.	EL31–33	
		Parking lots and drives	LPD = 0.1 W/ft^2 in LZ3 and LZ4, 0.06 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL29, 32–33	
		Walkways, plaza, and special feature areas	LPD = 0.16 W/ft^2 LZ3 and LZ4, 0.14 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL30, 32–33	
		All other exterior lighting	LPD = follow Standard 90.1-2010 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL32–33	
Plug Loads	Equipment Choices	ENERGY STAR® equipment	All illuminated signage, security monitors, computers, equipment, and appliances (where available)	PL1–5	
		Vending machines	Delamp in break rooms and specify best-in-class efficiency; Specify load managing systems for refrigerated vending	PL6	
		Procurement	Incorporate control and efficiency options in negotiations for all third-party owned plug loads; Consolidate equipment where possible	PL2, 8	
		Computers	Specify laptops, tablets, or mini-desktops where feasible	PL3	
		Signage	Use LED internally illuminated where applicable; Consolidate/replace static media with dynamic	PL5	

*Note: Where the table says “No recommendation,” the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Climate Zone 1 Recommendation Table for Medium to Big Box Retail Buildings *(Continued)*

	Item	Component	Recommendation	How-to Tips	✓
Plug Loads, cont.	Controls	Sales floor plug control	Auto control all display outlets that can be turned off during nonbusiness hours and all other sales outlets that can be turned off during unoccupied hours; Specify auto standby modes for third-party owned/supplied plug loads	PL2, 6	
		Computer power control	Network control with power-saving modes and control during unoccupied hours	PL6	
		Occupancy sensors	Office/break/security room plug strip occupancy sensors; Other equipment as applicable	PL4, 6	
		Timer switches	Water coolers, coffee makers, other small appliances auto shut-off during unoccupied hours	PL6	
		Policies	Store policy on allowed equipment	PL6	
SWH	SWH	Gas water heater efficiency	Condensing water heaters = 95% efficiency	WH4	
		Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 – 0.0012 × volume	WH4	
		Point-of-use heater selection	0.81 EF or 81% E_t	WH4	
		Electric heat pump water heater	COP 3.0 (interior heat source)	WH2	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in. / 1.5 in.	WH6	
HVAC	Packaged Variable-Volume DX Air Conditioners with DOAS	Heating efficiency	80%	HV3	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV3	
		Maximum external static pressure	Single zone = 0.7 in. w.c. Multizone = 1.8 in. w.c.	HV3,22	
	Packaged Constant-Volume DX Air Conditioners with DOAS	Heating efficiency	80%	HV4	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV4	
		Maximum external static pressure	0.7 in. w.c.	HV4	
	Packaged Single-Zone Air-Source Heat Pumps with DOAS	Heating efficiency	< 65 kBtu/h = 9.0 HSPF 65–135 kBtu/h = 3.4 COP at 47°F; 2.4 COP at 17°F 135–240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F ≥ 240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F	HV5	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER, 12.0 EER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER ≥ 240 kBtu/h = 10.5 EER, 11.3 IEER	HV5	
		Maximum external static pressure	0.7 in. w.c.	HV5	
		Maximum fan power	0.4 W/cfm	HV5	
	Packaged Single-Zone Water-Source Heat Pumps with DOAS	Heating efficiency	Full load =15.0 EER; Part load= 17.6 EER	HV6	
		Cooling efficiency	Full load = 5.0 COP; Part load = 5.7 COP	HV6	
		Maximum external static pressure	0.7 in. w.c.	HV6	
		Maximum fan power	0.4 W/cfm	HV6	
		Water circulation pumps	VFD and NEMA premium efficiency	HV6	
		Cooling tower/fluid cooler	VFD on fans	HV6, 12	
		Boiler efficiency	90% E_c	HV6,12, 27	
	Dedicated Outdoor Air System (DOAS)	Heating efficiency	See Table 5-10 in HV7	HV7	
		Cooling efficiency	See Table 5-10 in HV7	HV7	
		Fan external static pressure	Constant volume = 1.0 in. w.c. Variable volume (DCV) = 1.8 in. w.c.	HV7	
		Fan and motor	65% mechanical/motor efficiency in absence of whole unit EER rating; Motor efficiency as per Standard 90.1-2010 Table 10.8B	HV7	
	Ventilation/Exhaust	Cooling capacity for which an economizer is required	No economizer		
		DCV/performance-based ventilation	Control ventilation air based on pollutant concentrations in space (CO_2, VOCs, etc.)	HV15–16	
		Exhaust air recovery	A (humid) zones= 75% total effectiveness; B (dry) zones = 75% sensible effectiveness; Capture min. 80% available exhaust air, including general and bathroom, for energy recovery	HV10	
		Exhaust airflow control	Control based on occupancy using time clock or occupancy sensor	HV17	
	Ducts and Dampers	Outdoor air damper	Motorized damper	HV14	
		Duct seal class	Seal Class A	HV18, 20	
		Insulation level	R-6	HV19	
QA	M&V/Benchmarking	Electrical submeters	Design and circuit for separate submeters for lighting, HVAC, general 120V, service water heater, renewables, and whole building	QA15–16	
		Benchmarks	Benchmark monthly energy use	QA17	
		Training	Facility operator on continuous benchmarking	QA13–14	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.



Zone 2

Alabama

Baldwin
Mobile

Arizona

La Paz
Maricopa
Pima
Pinal
Yuma

California

Imperial

Florida

Alachua
Baker
Bay
Bradford
Brevard
Calhoun
Charlotte
Citrus
Clay
Collier
Columbia
DeSoto
Dixie
Duval
Escambia
Flagler
Franklin
Gadsden
Gilchrist
Glades
Gulf
Hamilton
Hardee
Hendry
Hernando
Highlands
Hillsborough
Holmes
Indian River
Jackson
Jefferson
Lafayette
Lake
Lee
Leon
Levy
Liberty
Madison
Manatee
Marion
Martin
Nassau
Okaloosa
Okeechobee
Orange
Osceola
Palm Beach
Pasco
Pinellas
Polk
Putnam
Santa Rosa
Sarasota
Seminole
St. Johns
St. Lucie
Sumter
Suwannee
Taylor
Union
Volusia
Wakulla
Walton
Washington

Georgia

Appling
Atkinson
Bacon
Baker
Berrien
Brantley
Brooks
Bryan
Camden
Charlton
Chatham
Clinch
Colquitt
Cook
Decatur
Echols
Effingham
Evans
Glynn
Grady
Jeff Davis
Lanier
Liberty
Long
Lowndes
McIntosh
Miller
Mitchell
Pierce
Seminole
Tattnall
Thomas
Toombs
Ware
Wayne

Louisiana

Acadia
Allen
Ascension
Assumption
Avoyelles
Beauregard
Calcasieu
Cameron
East Baton Rouge
East Feliciana
Evangeline
Iberia
Iberville
Jefferson
Jefferson Davis
Lafayette
Lafourche
Livingston
Orleans
Plaquemines
Pointe Coupee
Rapides
St. Bernard
St. Charles
St. Helena
St. James
St. John the Baptist
St. Landry
St. Martin
St. Mary
St. Tammany
Tangipahoa
Terrebonne
Vermilion
Washington
West Baton Rouge
West Feliciana

Mississippi

Hancock
Harrison
Jackson
Pearl River
Stone

Texas

Anderson
Angelina
Aransas
Atascosa
Austin
Bandera
Bastrop
Bee
Bell
Bexar
Bosque
Brazoria
Brazos
Brooks
Burleson
Caldwell
Calhoun
Cameron
Chambers
Cherokee
Colorado
Comal
Coryell
DeWitt
Dimmit
Duval
Edwards
Falls
Fayette
Fort Bend
Freestone
Frio
Galveston
Goliad
Gonzales
Grimes
Guadalupe
Hardin
Harris
Hays
Hidalgo
Hill
Houston
Jackson
Jasper
Jefferson
Jim Hogg
Jim Wells
Karnes
Kenedy
Kinney
Kleberg
La Salle
Lavaca
Lee
Leon
Liberty
Limestone
Live Oak
Madison
Matagorda
Maverick
McLennan
McMullen
Medina
Milam
Montgomery
Newton
Nueces
Orange
Polk
Real
Refugio
Robertson
San Jacinto
San Patricio
Starr
Travis
Trinity
Tyler
Uvalde
Val Verde
Victoria
Walker
Waller
Washington
Webb
Wharton
Willacy
Williamson
Wilson
Zapata
Zavala

Climate Zone 2 Recommendation Table for Medium to Big Box Retail Buildings

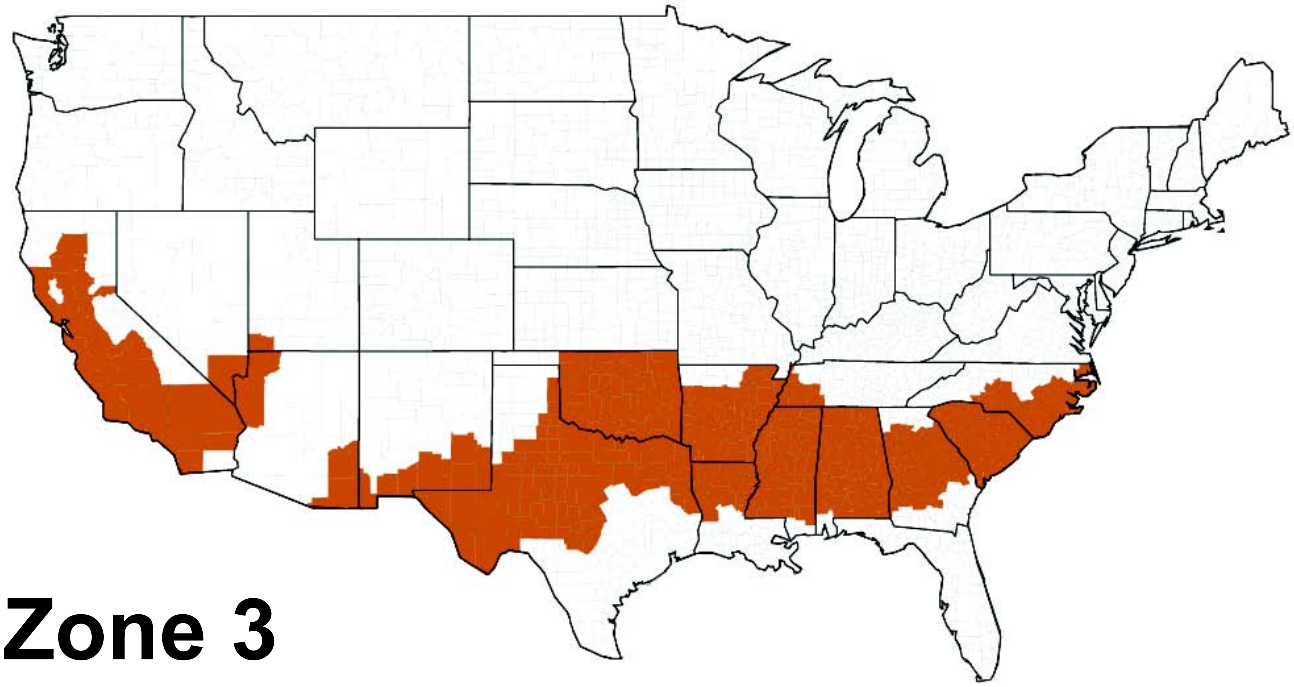
	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-25.0 c.i.	EN1–2, 18–21	
		Metal building	R-19.0 + R-10.0 FC	EN1, 3, 18–21	
		SRI	78	EN1	
	Walls	Mass (HC > 7 Btu/ft^2)	R-5.7 c.i.	EN4, 18–20	
		Metal building	R-0.0 + R-9.8 c.i.	EN5, 18–20	
		Steel framed	R-13.0 + R-7.5 c.i.	EN6, 18–20	
	Floors	Mass	R-10.4 c.i.	EN7, 18–20	
		Steel framed	R-30.0	EN8, 18–20	
	Slabs	Unheated	No recommendation	EN11	
		Heated	R-10 for 24 in.	EN10–11, 18–21	
	Doors	Swinging	0-0.70	EN12, 18–20	
		Nonswinging	Roll-up = U-0.25 All other = U-0.07	EN13–14, 18–20	
		Vehicular/dock infiltration—door closed	0.28 cfm/ft^2 of door area	EN15, 18–20	
		Vehicular/dock infiltration—door open, truck in place	Weather seals for dock, levelers, trailer hinges	EN16, 18–20	
	Vestibules	All building entrances	Yes	EN17–20	
	View Fenestration—All Orientations	Thermal transmittance	U-0.70	EN22–23	
		SHGC	0.25	EN23–26	
		VT	0.25	EN23, 26	
Daylighting/Lighting	Interior Lighting	LPD—Ambient Lighting	Sales floor = 1.15 W/ft^2	EL1, 3–7, 9–11, 17–23, 28	
			Stock room = 0.6 W/ft^2	EL1, 4, 9–11, 17–19, 26, 28	
			Average of all other = 0.9 W/ft^2	EL1–2, 4, 8–11, 17–19, 24–28	
		LPD—Additional specialty sales floor lighting	Sporting goods, small electronics = 0.6 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Furniture, clothing cosmetics, art = 0.95 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Jewelry, crystal, china = 1.5 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			All other = 0.4 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
		Light source efficacy (mean LPW)	T8 and T5 lamps > 2 ft = 92; T8 and T5 lamps ≤ 2 ft = 85; All other > 50	EL12, 14	
		T8 ballasts	Nondimming = NEMA Premium Instant Start Dimming = NEMA Premium Programmed Start	EL12	
		All T5/T5HO ballasts	Electronic programmed start	EL12	
		All CFL and HID ballasts	Electronic	EL13	
		Lighting controls	Sales floor = Time switch—auto to 25% 3 h before and after store open hours; auto to 2% or less after hours	EL16	
			Additional specialty lighting = auto ON only during store open hours	EL16	
			Stock room, restrooms = auto ON/OFF occupancy sensors	EL15	
			All other = manual ON, auto OFF occupancy sensors	EL15	
			After hours = max 2% of total building LPD	EL16	
	Exterior Lighting	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ3 and LZ4, 0.05 W/ft^2 in LZ2 Controls = auto OFF between 12 a.m. and 6 a.m.	EL31–33	
		Parking lots and drives	LPD = 0.1 W/ft^2 in LZ3 and LZ4, 0.06 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL29, 32–33	
		Walkways, plaza, and special feature areas	LPD = 0.16 W/ft^2 LZ3 and LZ4, 0.14 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL30, 32–33	
		All other exterior lighting	LPD = follow Standard 90.1-2010 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL32–33	
Plug Loads	Equipment Choices	ENERGY STAR® equipment	All illuminated signage, security monitors, computers, equipment, and appliances (where available)	PL1–5	
		Vending machines	Delamp in break rooms and specify best-in-class efficiency; Specify load managing systems for refrigerated vending	PL6	
		Procurement	Incorporate control and efficiency options in negotiations for all third-party owned plug loads; Consolidate equipment where possible	PL2, 8	
		Computers	Specify laptops, tablets, or mini-desktops where feasible	PL3	
		Signage	Use LED internally illuminated where applicable; Consolidate/replace static media with dynamic	PL5	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Climate Zone 2 Recommendation Table for Medium to Big Box Retail Buildings *(Continued)*

	Item	Component	Recommendation	How-To Tips	✓
Plug Loads, cont.	Controls	Sales floor plug control	Auto control all display outlets that can be turned off during nonbusiness hours and all other sales outlets that can be turned off during unoccupied hours; Specify auto standby modes for third-party owned/ supplied plug loads	PL2, 6	
		Computer power control	Network control with power-saving modes and control during unoccupied hours	PL6	
		Occupancy sensors	Office/break/security room plug strip occupancy sensors; Other equipment as applicable	PL4, 6	
		Timer switches	Water coolers, coffee makers, other small appliances auto shut-off during unoccupied hours	PL6	
		Policies	Store policy on allowed equipment	PL6	
SHW	SWH	Gas water heater efficiency	Condensing water heaters = 95% efficiency	WH4	
		Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 – 0.0012 × volume	WH4	
		Point-of-use heater selection	0.81 EF or 81% E_t	WH4	
		Electric heat pump water heater	COP 3.0 (interior heat source)	WH2	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in. / 1.5 in.	WH6	
HVAC	Packaged Variable-Volume DX Air Conditioners with DOAS	Heating efficiency	80%	HV3	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV3	
		Maximum external static pressure	Single zone = 0.7 in. w.c. Multizone = 1.8 in. w.c.	HV3,22	
	Packaged Constant-Volume DX Air Conditioners with DOAS	Heating efficiency	80%	HV4	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV4	
		Maximum external static pressure	0.7 in. w.c.	HV4	
	Packaged Single-Zone Air-Source Heat Pumps with DOAS	Heating efficiency	< 65 kBtu/h = 9.0 HSPF 65–135 kBtu/h = 3.4 COP at 47°F; 2.4 COP at 17°F 135–240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F ≥ 240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F	HV5	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER, 12.0 EER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER ≥ 240 kBtu/h = 10.5 EER, 11.3 IEER	HV5	
		Maximum external static pressure	0.7 in. w.c.	HV5	
		Maximum fan power	0.4 W/cfm	HV5	
	Packaged Single-Zone Water-Source Heat Pumps with DOAS	Heating efficiency	Full load =15.0 EER; Part load= 17.6 EER	HV6	
		Cooling efficiency	Full load = 5.0 COP; Part load = 5.7 COP	HV6	
		Maximum external static pressure	0.7 in. w.c.	HV6	
		Maximum fan power	0.4 W/cfm	HV6	
		Water circulation pumps	VFD and NEMA premium efficiency	HV6	
		Cooling tower/fluid cooler	VFD on fans	HV6, 12	
		Boiler efficiency	90% E_c	HV6,12, 27	
	Dedicated Outdoor Air System (DOAS)	Heating efficiency	See Table 5-10 in HV7	HV7	
		Cooling efficiency	See Table 5-10 in HV7	HV7	
		Fan external static pressure	Constant volume = 1.0 in. w.c. Variable volume (DCV) = 1.8 in. w.c.	HV7	
		Fan and motor	65% mechanical/motor efficiency in absence of whole unit EER rating; Motor efficiency as per Standard 90.1-2010 Table 10.8B	HV7	
	Ventilation/ Exhaust	Cooling capacity for which an economizer is required	≥ 54,000 Btu/h	HV14	
		DCV/performance-based ventilation	Control ventilation air based on pollutant concentrations in space (CO_2, VOCs, etc.)	HV15–16	
		Exhaust air recovery	A (humid) zones= 75% total effectiveness; B (dry) zones = 75% sensible effectiveness; Capture min. 80% available exhaust air, including general and bathroom, for energy recovery	HV10	
		Exhaust airflow control	Control based on occupancy using time clock or occupancy sensor	HV17	
	Ducts and Dampers	Outdoor air damper	Motorized damper	HV14	
		Duct seal class	Seal Class A	HV18, 20	
		Insulation level	R-6	HV19	
QA	M&V/ Benchmarking	Electrical submeters	Design and circuit for separate submeters for lighting, HVAC, general 120V, service water heater, renewables, and whole building	QA15–16	
		Benchmarks	Benchmark monthly energy use	QA17	
		Training	Facility operator on continuous benchmarking	QA13–14	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.



Zone 3

Alabama

All counties except:
- Baldwin
- Mobile

Arizona

- Cochise
- Graham
- Greenlee
- Mohave
- Santa Cruz

Arkansas

All counties except:
- Baxter
- Benton
- Boone
- Carroll
- Fulton
- Izard
- Madison
- Marion
- Newton
- Searcy
- Stone
- Washington

California

All counties except:
- Alpine
- Amador
- Calaveras
- Del Norte
- El Dorado
- Humboldt
- Imperial
- Inyo
- Lake
- Lassen
- Mariposa
- Modoc
- Mono
- Nevada
- Plumas
- Sierra
- Siskiyou
- Trinity
- Tuolumne

Georgia

All counties except:
- Appling
- Atkinson
- Bacon
- Baker
- Banks
- Berrien
- Brantley
- Brooks
- Bryan
- Catoosa
- Camden
- Charlton
- Chatham
- Chattooga
- Clinch
- Colquitt
- Cook
- Dade
- Dawson
- Decatur
- Echols
- Effingham
- Evans
- Fannin
- Floyd
- Franklin
- Gilmer
- Glynn
- Gordon
- Grady
- Habersham
- Hall
- Jeff Davis
- Lanier
- Liberty
- Long
- Lowndes
- Lumpkin
- McIntosh
- Miller
- Mitchell
- Murray
- Pickens
- Pierce
- Rabun
- Seminole
- Stephens
- Tattnall
- Thomas
- Toombs
- Towns
- Union
- Walker
- Ware
- Wayne
- White
- Whitfield

Louisiana

- Bienville
- Bossier
- Caddo
- Caldwell
- Catahoula
- Claiborne
- Concordia
- De Soto
- East Carroll
- Franklin
- Grant
- Jackson
- La Salle
- Lincoln
- Madison
- Morehouse
- Natchitoches
- Ouachita
- Red River
- Richland
- Sabine
- Tensas
- Union
- Vernon
- Webster
- West Carroll
- Winn

Mississippi

All counties except:
- Hancock
- Harrison
- Jackson
- Pearl River
- Stone

New Mexico

- Chaves
- Dona Ana
- Eddy
- Hidalgo
- Lea
- Luna
- Otero

Nevada

- Clark

Texas

- Andrews
- Archer
- Baylor
- Blanco
- Borden
- Bowie
- Brewster
- Brown
- Burnet
- Callahan
- Camp
- Cass
- Childress
- Clay
- Coke
- Coleman
- Collingsworth
- Collin
- Comanche
- Concho
- Cottle
- Cooke
- Crane
- Crockett
- Crosby
- Culberson
- Dallas
- Dawson
- Delta
- Denton
- Dickens
- Eastland
- Ector
- El Paso
- Ellis
- Erath
- Fannin
- Fisher
- Foard
- Franklin
- Gaines
- Garza
- Gillespie
- Glasscock
- Grayson
- Gregg
- Hall
- Hamilton
- Hardeman
- Harrison
- Haskell
- Hemphill
- Henderson
- Hood
- Hopkins
- Howard
- Hudspeth
- Hunt
- Irion
- Jack
- Jeff Davis
- Johnson
- Jones
- Kaufman
- Kendall
- Kent
- Kerr
- Kimble
- King
- Knox
- Lamar
- Lampasas
- Llano
- Loving
- Lubbock
- Lynn
- Marion
- Martin
- Mason
- McCulloch
- Menard
- Midland
- Mills
- Mitchell
- Montague
- Morris
- Motley
- Nacogdoches
- Navarro
- Nolan
- Palo Pinto
- Panola
- Parker
- Pecos
- Presidio
- Rains
- Reagan
- Reeves
- Red River
- Rockwall
- Runnels
- Rusk
- Sabine
- San Augustine
- San Saba
- Schleicher
- Scurry
- Shackelford
- Shelby
- Smith
- Somervell
- Stephens
- Sterling
- Stonewall
- Sutton
- Tarrant
- Taylor
- Terrell
- Terry
- Throckmorton
- Titus
- Tom Green
- Upshur
- Upton
- Van Zandt
- Ward
- Wheeler
- Wichita
- Wilbarger
- Winkler
- Wise
- Wood
- Young

Utah

- Washington

North Carolina

- Anson
- Beaufort
- Bladen
- Brunswick
- Cabarrus
- Camden
- Carteret
- Chowan
- Columbus
- Craven
- Cumberland
- Currituck
- Dare
- Davidson
- Duplin
- Edgecombe
- Gaston
- Greene
- Hoke
- Hyde
- Johnston
- Jones
- Lenoir
- Martin
- Mecklenburg
- Montgomery
- Moore
- New Hanover
- Onslow
- Pamlico
- Pasquotank
- Pender
- Perquimans
- Pitt
- Randolph
- Richmond
- Robeson
- Rowan
- Sampson
- Scotland
- Stanly
- Tyrrell
- Union
- Washington
- Wayne
- Wilson

Oklahoma

All counties except:
- Beaver
- Cimarron
- Texas

South Carolina

- All counties

Tennessee

- Chester
- Crockett
- Dyer
- Fayette
- Hardeman
- Hardin
- Haywood
- Henderson
- Lake
- Lauderdale
- Madison
- McNairy
- Shelby
- Tipton

Climate Zone 3 Recommendation Table for Medium to Big Box Retail Buildings

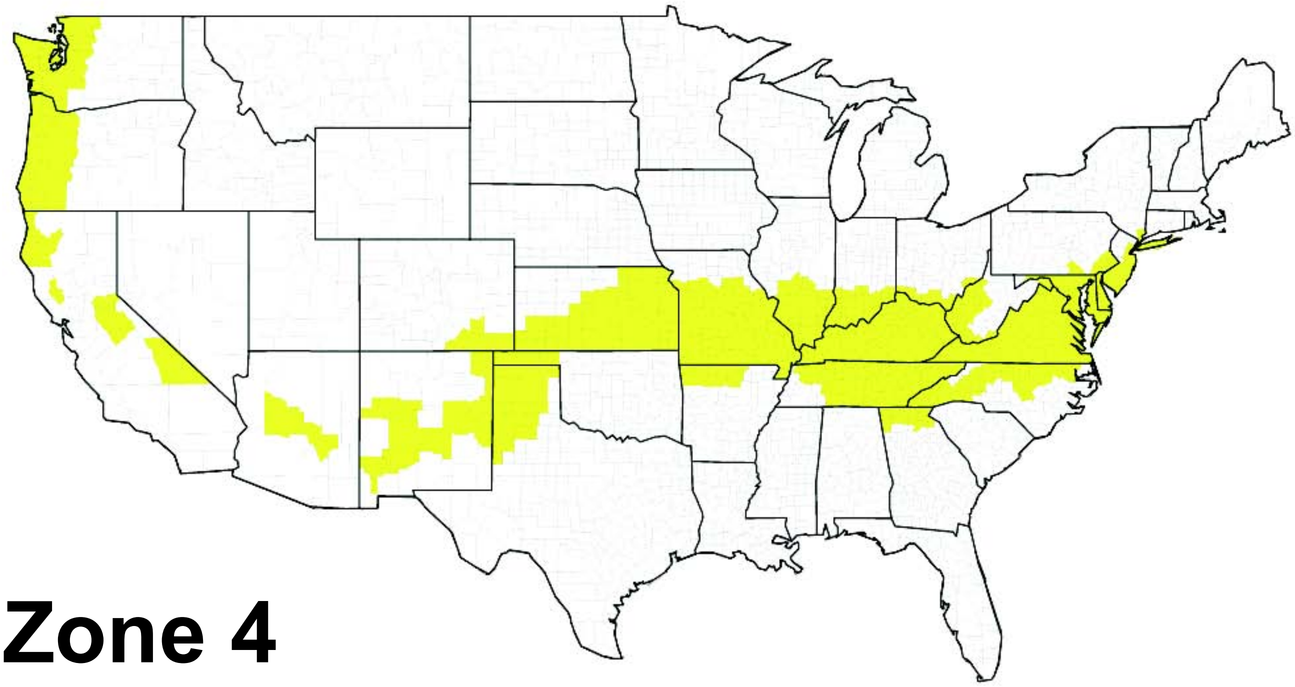
	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-25.0 c.i.	EN1–2, 18–21	
		Metal building	R-19.0 + R-10.0 FC	EN1, 3, 18–21	
		SRI	78	EN1	
	Walls	Mass (HC > 7 Btu/ft^2)	R-7.6 c.i.	EN4, 18–20	
		Metal building	R-0.0 + R-13.0 c.i.	EN5, 18–20	
		Steel framed	R-13.0 + R-7.5 c.i.	EN6, 18–20	
	Floors	Mass	R-12.5 c.i.	EN7, 18–20	
		Steel framed	R-30.0	EN8, 18–20	
	Slabs	Unheated	No recommendation	EN11	
		Heated	R-15.0 for 24 in.	EN10–11, 18–21	
	Doors	Swinging	U-0.70	EN12, 18–20	
		Nonswinging	Roll-up = U-0.25 All other = U-0.07	EN13–14, 18–20	
		Vehicular/dock infiltration—door closed	0.28 cfm/ft^2 of door area	EN15, 18–20	
		Vehicular/dock infiltration—door open, truck in place	Weather seals for dock, levelers, trailer hinges	EN16, 18–20	
	Vestibules	All building entrances	Yes	EN17–20	
	View Fenestration—All Orientations	Thermal transmittance	U-0.60	EN22–23	
		SHGC	0.25	EN23–26	
		VT	0.32	EN23, 26	
Daylighting / Lighting	Interior Lighting	LPD—Ambient Lighting	Sales floor = 1.15 W/ft^2	EL1, 3–7, 9–11, 17–23, 28	
			Stock room = 0.6 W/ft^2	EL1, 4, 9–11, 17–19, 26, 28	
			Average of all other = 0.9 W/ft^2	EL1–2, 4, 8–11, 17–19, 24–28	
		LPD—Additional specialty sales floor lighting	Sporting goods, small electronics = 0.6 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Furniture, clothing cosmetics, art = 0.95 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Jewelry, crystal, china = 1.5 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			All other = 0.4 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
		Light source efficacy (mean LPW)	T8 and T5 lamps > 2 ft = 92; T8 and T5 lamps ≤ 2 ft = 85; All other > 50	EL12, 14	
		T8 ballasts	Nondimming = NEMA Premium Instant Start Dimming = NEMA Premium Programmed Start	EL12	
		All T5/T5HO ballasts	Electronic programmed start	EL12	
		All CFL and HID ballasts	Electronic	EL13	
		Lighting controls	Sales floor = Time switch—auto to 25% 3 h before and after store open hours; auto to 2% or less after hours	EL16	
			Additional specialty lighting = auto ON only during store open hours	EL16	
			Stock room, restrooms = auto ON/OFF occupancy sensors	EL15	
			All other = manual ON, auto OFF occupancy sensors	EL15	
			After hours = max 2% of total building LPD	EL16	
	Exterior Lighting	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ3 and LZ4, 0.05 W/ft^2 in LZ2 Controls = auto OFF between 12 a.m. and 6 a.m.	EL31–33	
		Parking lots and drives	LPD = 0.1 W/ft^2 in LZ3 and LZ4, 0.06 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL29, 32–33	
		Walkways, plaza, and special feature areas	LPD = 0.16 W/ft^2 LZ3 and LZ4, 0.14 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL30, 32–33	
		All other exterior lighting	LPD = follow Standard 90.1-2010 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL32–33	
Plug Loads	Equipment Choices	ENERGY STAR® equipment	All illuminated signage, security monitors, computers, equipment, and appliances (where available)	PL1–5	
		Vending machines	Delamp in break rooms and specify best-in-class efficiency; Specify load managing systems for refrigerated vending	PL6	
		Procurement	Incorporate control and efficiency options in negotiations for all third-party owned plug loads; Consolidate equipment where possible	PL2, 8	
		Computers	Specify laptops, tablets, or mini-desktops where feasible	PL3	
		Signage	Use LED internally illuminated where applicable; Consolidate/replace static media with dynamic	PL5	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Climate Zone 3 Recommendation Table for Medium to Big Box Retail Buildings *(Continued)*

	Item	Component	Recommendation	How-To Tips	✓
Plug Loads, cont.	Controls	Sales floor plug control	Auto control all display outlets that can be turned off during nonbusiness hours and all other sales outlets that can be turned off during unoccupied hours; Specify auto standby modes for third-party owned/supplied plug loads	PL2, 6	
		Computer power control	Network control with power-saving modes and control during unoccupied hours	PL6	
		Occupancy sensors	Office/break/security room plug strip occupancy sensors; Other equipment as applicable	PL4, 6	
		Timer switches	Water coolers, coffee makers, other small appliances auto shut-off during unoccupied hours	PL6	
		Policies	Store policy on allowed equipment	PL6	
SWH	SWH	Gas water heater efficiency	Condensing water heaters = 95% efficiency	WH4	
		Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 – 0.0012 × volume	WH4	
		Point-of-use heater selection	0.81 EF or 81% E_t	WH4	
		Electric heat pump water heater	COP 3.0 (interior heat source)	WH2	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in. / 1.5 in.	WH6	
HVAC	Packaged Variable-Volume DX Air Conditioners	Heating efficiency	80%	HV3	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV3	
		Maximum external static pressure	Single zone = 0.7 in. w.c. Multizone = 1.8 in. w.c.	HV3,22	
	Packaged Constant-Volume DX Air Conditioners with DOAS	Heating efficiency	80%	HV4	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV4	
		Maximum external static pressure	0.7 in. w.c.	HV4	
	Packaged Single-Zone Air-Source Heat Pumps with DOAS	Heating efficiency	< 65 kBtu/h = 9.0 HSPF 65–135 kBtu/h = 3.4 COP at 47°F; 2.4 COP at 17°F 135–240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F ≥ 240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F	HV5	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER, 12.0 EER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER ≥ 240 kBtu/h = 10.5 EER, 11.3 IEER	HV5	
		Maximum external static pressure	0.7 in. w.c.	HV5	
		Maximum fan power	0.4 W/cfm	HV5	
	Packaged Single-Zone Water-Source Heat Pumps with DOAS	Heating efficiency	Full load =15.0 EER; Part load= 17.6 EER	HV6	
		Cooling efficiency	Full load = 5.0 COP; Part load = 5.7 COP	HV6	
		Maximum external static pressure	0.7 in. w.c.	HV6	
		Maximum fan power	0.4 W/cfm	HV6	
		Water circulation pumps	VFD and NEMA premium efficiency	HV6	
		Cooling tower/fluid cooler	VFD on fans	HV6, 12	
		Boiler efficiency	90% E_c	HV6,12, 27	
	Dedicated Outdoor Air System (DOAS)	Heating efficiency	See Table 5-10 in HV7	HV7	
		Cooling efficiency	See Table 5-10 in HV7	HV7	
		Fan external static pressure	Constant volume = 1.0 in. w.c. Variable volume (DCV) = 1.8 in. w.c.	HV7	
		Fan and motor	65% mechanical/motor efficiency in absence of whole unit EER rating; Motor efficiency as per Standard 90.1-2010 Table 10.8B	HV7	
	Ventilation/ Exhaust	Cooling capacity for which an economizer is required	≥ 54,000 Btu/h	HV14	
		DCV/performance-based ventilation	Control ventilation air based on pollutant concentrations in space (CO_2, VOCs, etc.)	HV15–16	
		Exhaust air recovery	A (humid) zones= 75% total effectiveness; B (dry) zones = 75% sensible effectiveness; Capture min. 80% available exhaust air, including general and bathroom, for energy recovery	HV10	
		Exhaust airflow control	Control based on occupancy using time clock or occupancy sensor	HV17	
	Ducts and Dampers	Outdoor air damper	Motorized damper	HV14	
		Duct seal class	Seal Class A	HV18, 20	
		Insulation level	R-6	HV19	
QA	M&V/ Benchmarking	Electrical submeters	Design and circuit for separate submeters for lighting, HVAC, general 120V, service water heater, renewables, and whole building	QA15–16	
		Benchmarks	Benchmark monthly energy use	QA17	
		Training	Facility operator on continuous benchmarking	QA13–14	

*Note: Where the table says “No recommendation,” the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.



Zone 4

Arizona
Gila
Yavapai

Arkansas
Baxter
Benton
Boone
Carroll
Fulton
Izard
Madison
Marion
Newton
Searcy
Stone
Washington

California
Amador
Calaveras
Del Norte
El Dorado
Humboldt
Inyo
Lake
Mariposa
Trinity
Tuolumne

Colorado
Baca
Las Animas
Otero

Delaware
All counties

District of Columbia

Georgia
Banks
Catoosa
Chattooga
Dade
Dawson
Fannin
Floyd
Franklin
Gilmer
Gordon
Habersham
Hall
Lumpkin
Murray
Pickens
Rabun
Stephens
Towns
Union
Walker
White
Whitfield

Illinois
Alexander
Bond
Brown
Christian
Clay
Clinton
Crawford
Edwards
Effingham
Fayette
Franklin
Gallatin
Hamilton
Hardin
Jackson
Jasper
Jefferson
Johnson
Lawrence
Macoupin
Madison
Marion
Massac
Monroe
Montgomery
Perry
Pope
Pulaski
Randolph
Richland
Saline
Shelby
St. Clair
Union
Wabash
Washington
Wayne
White
Williamson

Indiana
Clark
Crawford
Daviess
Dearborn
Dubois
Floyd
Gibson
Greene
Harrison
Jackson
Jefferson
Jennings
Knox
Lawrence
Martin
Monroe
Ohio
Orange
Perry
Pike
Posey
Ripley
Scott
Spencer
Sullivan
Switzerland
Vanderburgh
Warrick
Washington

Kansas
All counties except:
Cheyenne
Cloud
Decatur
Ellis
Gove
Graham
Greeley
Hamilton
Jewell
Lane
Logan
Mitchell
Ness
Norton
Osborne
Phillips
Rawlins
Republic
Rooks
Scott
Sheridan
Sherman
Smith
Thomas
Trego
Wallace
Wichita

Kentucky
All counties

Maryland
All counties except:
Garrett

Missouri
All counties except:
Adair
Andrew
Atchison
Buchanan
Caldwell
Chariton
Clark
Clinton
Daviess
DeKalb
Gentry
Grundy
Harrison
Holt
Knox
Lewis
Linn
Livingston
Macon
Marion
Mercer
Nodaway
Pike
Putnam
Ralls
Schuyler
Scotland
Shelby
Sullivan
Worth

New Jersey
All counties except:
Bergen
Hunterdon
Mercer
Morris
Passaic
Somerset
Sussex
Warren

New Mexico
Bernalillo
Cibola
Curry
DeBaca
Grant
Guadalupe
Lincoln
Quay
Roosevelt
Sierra
Socorro
Union
Valencia

New York
Bronx
Kings
Nassau
New York
Queens
Richmond
Suffolk
Westchester

North Carolina
Alamance
Alexander
Bertie
Buncombe
Burke
Caldwell
Caswell
Catawba
Chatham
Cherokee
Clay
Cleveland
Davie
Durham
Forsyth
Franklin
Gates
Graham
Granville
Guilford
Halifax
Harnett
Haywood
Henderson
Hertford
Iredell
Jackson
Lee
Lincoln
Macon
Madison
McDowell
Nash
Northampton
Orange
Person
Polk
Rockingham
Rutherford
Stokes
Surry
Swain
Transylvania
Vance
Wake
Warren
Wilkes
Yadkin

Ohio
Adams
Brown
Clermont
Gallia
Hamilton
Lawrence
Pike
Scioto
Washington

Oklahoma
Beaver
Cimarron
Texas

Oregon
Benton
Clackamas
Clatsop
Columbia
Coos
Curry
Douglas
Jackson
Josephine
Lane
Lincoln
Linn
Marion
Multnomah
Polk
Tillamook
Washington
Yamhill

Pennsylvania
Bucks
Chester
Delaware
Montgomery
Philadelphia
York

Tennessee
All counties except:
Chester
Crockett
Dyer
Fayette
Hardeman
Hardin
Haywood
Henderson
Lake
Lauderdale
Madison
McNairy
Shelby
Tipton

Texas
Armstrong
Bailey
Briscoe
Carson
Castro
Cochran
Dallam
Deaf Smith
Donley
Floyd
Gray
Hale
Hansford
Hartley
Hockley
Hutchinson
Lamb
Lipscomb
Moore
Ochiltree
Oldham
Parmer
Potter
Randall
Roberts
Sherman
Swisher
Yoakum

Virginia
All counties

Washington
Clallam
Clark
Cowlitz
Grays Harbor
Island
Jefferson
King
Kitsap
Lewis
Mason
Pacific
Pierce
San Juan
Skagit
Snohomish
Thurston
Wahkiakum
Whatcom

West Virginia
Berkeley
Boone
Braxton
Cabell
Calhoun
Clay
Gilmer
Jackson
Jefferson
Kanawha
Lincoln
Logan
Mason
McDowell
Mercer
Mingo
Monroe
Morgan
Pleasants
Putnam
Ritchie
Roane
Tyler
Wayne
Wirt
Wood
Wyoming

Climate Zone 4 Recommendation Table for Medium to Big Box Retail Buildings

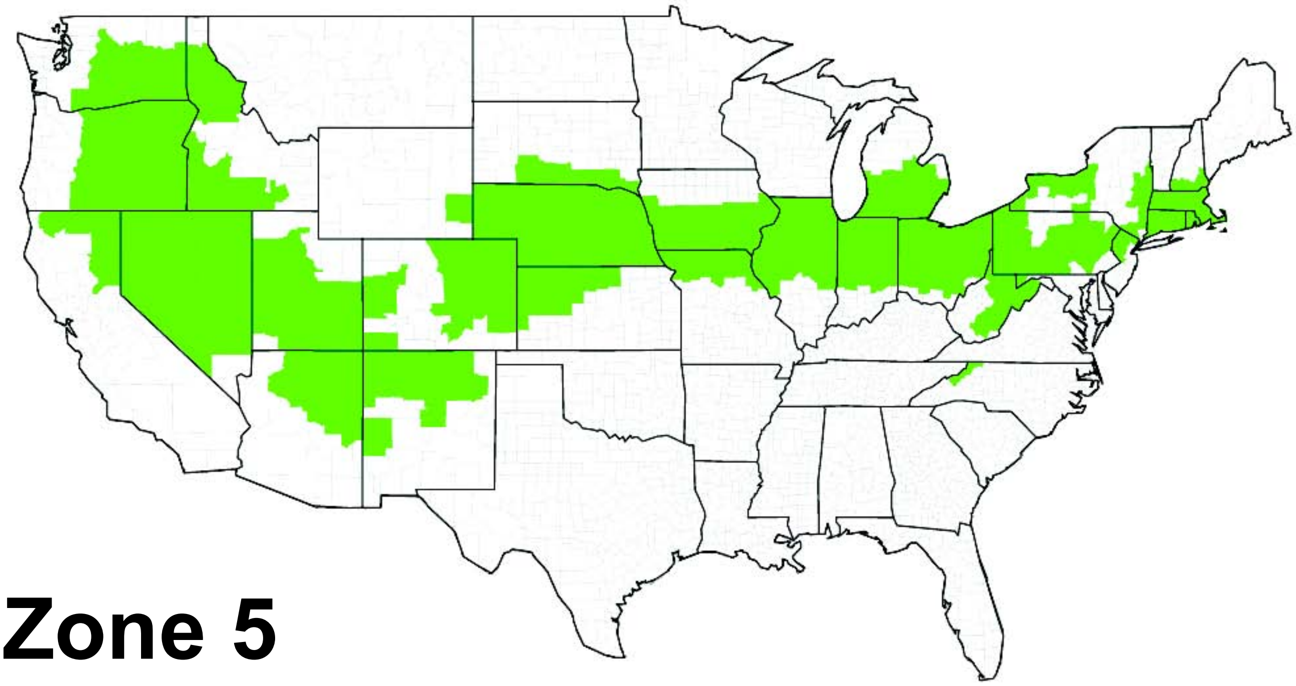
	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-25.0 c.i.	EN1–2, 18–21	
		Metal building	R-19.0 + R-11.0 Ls	EN1, 3, 18–21	
		SRI	No recommendation	None	
	Walls	Mass (HC > 7 Btu/ft^2)	R-9.5 c.i.	EN4, 18–20	
		Metal building	R-0.0 + R-15.8 c.i.	EN5, 18–20	
		Steel framed	R-13.0 + R-10.0 c.i.	EN6, 18–20	
	Floors	Mass	R-14.6 c.i.	EN7, 18–20	
		Steel framed	R-38.0	EN8, 18–20	
	Slabs	Unheated	R-15 for 24 in.	EN9, 18–21	
		Heated	R-20 for 24 in.	EN10, 18–21	
	Doors	Swinging	U-0.50	EN12, 18–20	
		Nonswinging	Roll-up = U-0.25 All other = U-0.07	EN13–14, 18–20	
		Vehicular/dock infiltration—door closed	0.28 cfm/ft^2 of door area	EN15, 18–20	
		Vehicular/dock infiltration—door open, truck in place	Weather seals for dock, levelers, trailer hinges	EN16, 18–20	
	Vestibules	All building entrances	Yes	EN17–20	
	View Fenestration—All Orientations	Thermal transmittance	U-0.50	EN22–23	
		SHGC	0.40	EN23–24, 27	
		VT	0.51	EN23	
Daylighting / Lighting	Interior Lighting	LPD—Ambient Lighting	Sales floor = 1.15 W/ft^2	EL1, 3–7, 9–11, 17–23, 28	
			Stock room = 0.6 W/ft^2	EL1, 4, 9–11, 17–19, 26, 28	
			Average of all other = 0.9 W/ft^2	EL1–2, 4, 8–11, 17–19, 24–28	
		LPD—Additional specialty sales floor lighting	Sporting goods, small electronics = 0.6 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Furniture, clothing, cosmetics, art = 0.95 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Jewelry, crystal, china = 1.5 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			All other = 0.4 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
		Light source efficacy (mean LPW)	T8 and T5 lamps > 2 ft = 92; T8 and T5 lamps ≤ 2 ft = 85; All other > 50	EL12, 14	
		T8 ballasts	Nondimming = NEMA Premium Instant Start Dimming = NEMA Premium Programmed Start	EL12	
		All T5/T5HO ballasts	Electronic programmed start	EL12	
		All CFL and HID ballasts	Electronic	EL13	
		Lighting controls	Sales floor = Time switch—auto to 25% 3 h before and after store open hours; auto to 2% or less after hours	EL16	
			Additional specialty lighting = auto ON only during store open hours	EL16	
			Stock room, restrooms = auto ON/OFF occupancy sensors	EL15	
			All other = manual ON, auto OFF occupancy sensors	EL15	
			After hours = max 2% of total building LPD	EL16	
	Exterior Lighting	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ3 and LZ4, 0.05 W/ft^2 in LZ2 Controls = auto OFF between 12 a.m. and 6 a.m.	EL31–33	
		Parking lots and drives	LPD = 0.1 W/ft^2 in LZ3 and LZ4, 0.06 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL29, 32–33	
		Walkways, plaza, and special feature areas	LPD = 0.16 W/ft^2 LZ3 and LZ4, 0.14 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL30, 32–33	
		All other exterior lighting	LPD = follow Standard 90.1-2010 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL32–33	
Plug Loads	Equipment Choices	ENERGY STAR® equipment	All illuminated signage, security monitors, computers, equipment, and appliances (where available)	PL1–5	
		Vending machines	Delamp in break rooms and specify best-in-class efficiency; Specify load managing systems for refrigerated vending	PL6	
		Procurement	Incorporate control and efficiency options in negotiations for all third-party owned plug loads; Consolidate equipment where possible	PL2, 8	
		Computers	Specify laptops, tablets, or mini-desktops where feasible	PL3	
		Signage	Use LED internally illuminated where applicable; Consolidate/replace static media with dynamic	PL5	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Climate Zone 4 Recommendation Table for Medium to Big Box Retail Buildings *(Continued)*

	Item	Component	Recommendation	How-To Tips	✓
Plug Loads, cont.	Controls	Sales floor plug control	Auto control all display outlets that can be turned off during nonbusiness hours and all other sales outlets that can be turned off during unoccupied hours; Specify auto standby modes for third-party owned/ supplied plug loads	PL2, 6	
		Computer power control	Network control with power-saving modes and control during unoccupied hours	PL6	
		Occupancy sensors	Office/break/security room plug strip occupancy sensors; Other equipment as applicable	PL4, 6	
		Timer switches	Water coolers, coffee makers, other small appliances auto shut-off during unoccupied hours	PL6	
		Policies	Store policy on allowed equipment	PL6	
SWH	SWH	Gas water heater efficiency	Condensing water heaters = 95% efficiency	WH4	
		Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 – 0.0012 × volume	WH4	
		Point-of-use heater selection	0.81 EF or 81% E_t	WH4	
		Electric heat pump water heater	COP 3.0 (interior heat source)	WH2	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in. / 1.5 in.	WH6	
HVAC	Packaged Variable-Volume DX Air Conditioners	Heating efficiency	80%	HV3	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV3	
		Maximum external static pressure	Single zone = 0.7 in. w.c. Multizone = 1.8 in. w.c.	HV3,22	
	Packaged Constant-Volume DX Air Conditioners with DOAS	Heating efficiency	80%	HV4	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV4	
		Maximum external static pressure	0.7 in. w.c.	HV4	
	Packaged Single-Zone Air-Source Heat Pumps with DOAS	Heating efficiency	< 65 kBtu/h = 9.0 HSPF 65–135 kBtu/h = 3.4 COP at 47°F; 2.4 COP at 17°F 135–240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F ≥ 240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F	HV5	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER, 12.0 EER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER ≥ 240 kBtu/h = 10.5 EER, 11.3 IEER	HV5	
		Maximum external static pressure	0.7 in. w.c.	HV5	
		Maximum fan power	0.4 W/cfm	HV5	
	Packaged Single-Zone Water-Source Heat Pumps with DOAS	Heating efficiency	Full load =15.0 EER; Part load= 17.6 EER	HV6	
		Cooling efficiency	Full load = 5.0 COP; Part load = 5.7 COP	HV6	
		Maximum external static pressure	0.7 in. w.c.	HV6	
		Maximum fan power	0.4 W/cfm	HV6	
		Water circulation pumps	VFD and NEMA premium efficiency	HV6	
		Cooling tower/fluid cooler	VFD on fans	HV6, 12	
		Boiler efficiency	90% E_c	HV6,12, 27	
	Dedicated Outdoor Air System (DOAS)	Heating efficiency	See Table 5-10 in HV7	HV7	
		Cooling efficiency	See Table 5-10 in HV7	HV7	
		Fan external static pressure	Constant volume = 1.0 in. w.c. Variable volume (DCV) = 1.8 in. w.c.	HV7	
		Fan and motor	65% mechanical/motor efficiency in absence of whole unit EER rating; Motor efficiency as per Standard 90.1-2010 Table 10.8B	HV7	
	Ventilation/ Exhaust	Cooling capacity for which an economizer is required	≥ 54,000 Btu/h	HV14	
		DCV/performance-based ventilation	Control ventilation air based on pollutant concentrations in space (CO_2, VOCs, etc.)	HV15–16	
		Exhaust air recovery	A (humid) zones= 75% total effectiveness; B (dry) zones = 75% sensible effectiveness; Capture min. 80% available exhaust air, including general and bathroom, for energy recovery	HV10	
		Exhaust airflow control	Control based on occupancy using time clock or occupancy sensor	HV17	
	Ducts and Dampers	Outdoor air damper	Motorized damper	HV14	
		Duct seal class	Seal Class A	HV18, 20	
		Insulation level	R-6	HV19	
QA	M&V/ Benchmarking	Electrical submeters	Design and circuit for separate submeters for lighting, HVAC, general 120V, service water heater, renewables, and whole building	QA15–16	
		Benchmarks	Benchmark monthly energy use	QA17	
		Training	Facility operator on continuous benchmarking	QA13–14	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.



Zone 5

Arizona
Apache
Coconino
Navajo

California
Lassen
Modoc
Nevada
Plumas
Sierra
Siskiyou

Colorado
Adams
Arapahoe
Bent
Boulder
Cheyenne
Crowley
Delta
Denver
Douglas
Elbert
El Paso
Fremont
Garfield
Gilpin
Huerfano
Jefferson
Kiowa
Kit Carson
La Plata
Larimer
Lincoln
Logan
Mesa
Montezuma
Montrose
Morgan
Phillips
Prowers
Pueblo
Sedgwick
Teller
Washington
Weld
Yuma

Connecticut
All counties

Idaho
Ada
Benewah
Canyon
Cassia
Clearwater
Elmore
Gem
Gooding
Idaho
Jerome
Kootenai
Latah
Lewis
Lincoln
Minidoka
Nez Perce
Owyhee
Payette
Power
Shoshone
Twin Falls
Washington

Illinois
All counties except:
Alexander
Bond
Christian
Clay
Clinton
Crawford
Edwards
Effingham
Fayette
Franklin
Gallatin
Hamilton
Hardin
Jackson
Jasper
Jefferson
Johnson
Lawrence
Macoupin
Madison
Marion
Massac
Monroe
Montgomery
Perry
Pope
Pulaski
Randolph
Richland
Saline
Shelby
St. Clair
Union
Wabash
Washington
Wayne
White
Williamson
Brown

Indiana
All counties except:
Clark
Crawford
Daviess
Dearborn
Dubois
Floyd
Gibson
Greene
Harrison
Jackson
Jefferson
Jennings
Knox
Lawrence
Martin
Monroe
Ohio
Orange
Perry
Pike
Posey
Ripley
Scott
Spencer
Sullivan
Switzerland
Vanderburgh
Warrick
Washington

Iowa
All counties except:
Allamakee
Black Hawk
Bremer
Buchanan
Buena Vista
Butler
Calhoun
Cerro Gordo
Cherokee
Chickasaw
Clay
Clayton
Delaware
Dickinson
Emmet
Fayette
Floyd
Franklin
Grundy
Hamilton
Hancock
Hardin
Howard
Humboldt
Ida
Kossuth
Lyon
Mitchell
O'Brien
Osceola
Palo Alto
Plymouth
Pocahontas
Sac
Sioux
Webster
Winnebago
Winneshiek
Worth
Wright

Kansas
Cheyenne
Cloud
Decatur
Ellis
Gove
Graham
Greeley
Hamilton
Jewell
Lane
Logan
Mitchell
Ness
Norton
Osborne
Phillips
Rawlins
Republic
Rooks
Scott
Sheridan
Sherman
Smith
Thomas
Trego
Wallace
Wichita

Maryland
Garrett

Massachusetts
All counties

Michigan
Allegan
Barry
Bay
Berrien
Branch
Calhoun
Cass
Clinton
Eaton
Genesee
Gratiot
Hillsdale
Ingham
Ionia
Jackson
Kalamazoo
Kent
Lapeer
Lenawee
Livingston
Macomb
Midland
Monroe
Montcalm
Muskegon
Oakland
Ottawa
Saginaw
Shiawassee
St. Clair
St. Joseph
Tuscola
Van Buren
Washtenaw
Wayne

Missouri
Adair
Andrew
Atchison
Buchanan
Caldwell
Chariton
Clark
Clinton
Daviess
DeKalb
Gentry
Grundy
Harrison
Holt
Knox
Lewis
Linn
Livingston
Macon
Marion
Mercer
Nodaway
Pike
Putnam
Ralls
Schuyler
Scotland
Shelby
Sullivan
Worth

Nebraska
All counties

Nevada
All counties except:
Clark

New Hampshire
Cheshire
Hillsborough
Rockingham
Strafford

New Jersey
Bergen
Hunterdon
Mercer
Morris
Passaic
Somerset
Sussex
Warren

New Mexico
Catron
Colfax
Harding
Los Alamos
McKinley
Mora
Rio Arriba
Sandoval
San Juan
San Miguel
Santa Fe
Taos
Torrance

New York
Albany
Cayuga
Chautauqua
Chemung
Columbia
Cortland
Dutchess
Erie
Genesee
Greene
Livingston
Monroe
Niagara
Onondaga
Ontario
Orange
Orleans
Oswego
Putnam
Rensselaer
Rockland
Saratoga
Schenectady
Seneca
Tioga
Washington
Wayne
Yates

North Carolina
Alleghany
Ashe
Avery
Mitchell
Watauga
Yancey

Ohio
All counties except:
Adams
Brown
Clermont
Gallia
Hamilton
Lawrence
Pike
Scioto
Washington

Oregon
Baker
Crook
Deschutes
Gilliam
Grant
Harney
Hood River
Jefferson
Klamath
Lake
Malheur
Morrow
Sherman
Umatilla
Union
Wallowa
Wasco
Wheeler

Pennsylvania
All counties except:
Bucks
Cameron
Chester
Clearfield
Delaware
Elk
McKean
Montgomery
Philadelphia
Potter
Susquehanna
Tioga
Wayne
York

Rhode Island
All counties

South Dakota
Bennett
Bon Homme
Charles Mix
Clay
Douglas
Gregory
Hutchinson
Jackson
Mellette
Todd
Tripp
Union
Yankton

Utah
All counties except:
Box Elder
Cache
Carbon
Daggett
Duchesne
Morgan
Rich
Summit
Uintah
Wasatch
Washington

Washington
Adams
Asotin
Benton
Chelan
Columbia
Douglas
Franklin
Garfield
Grant
Kittitas
Klickitat
Lincoln
Skamania
Spokane
Walla Walla
Whitman
Yakima

Wyoming
Goshen
Platte

West Virginia
Barbour
Brooke
Doddridge
Fayette
Grant
Greenbrier
Hampshire
Hancock
Hardy
Harrison
Lewis
Marion
Marshall
Mineral
Monongalia
Nicholas
Ohio
Pendleton
Pocahontas
Preston
Raleigh
Randolph
Summers
Taylor
Tucker
Upshur
Webster
Wetzel

Climate Zone 5 Recommendation Table for Medium to Big Box Retail Buildings

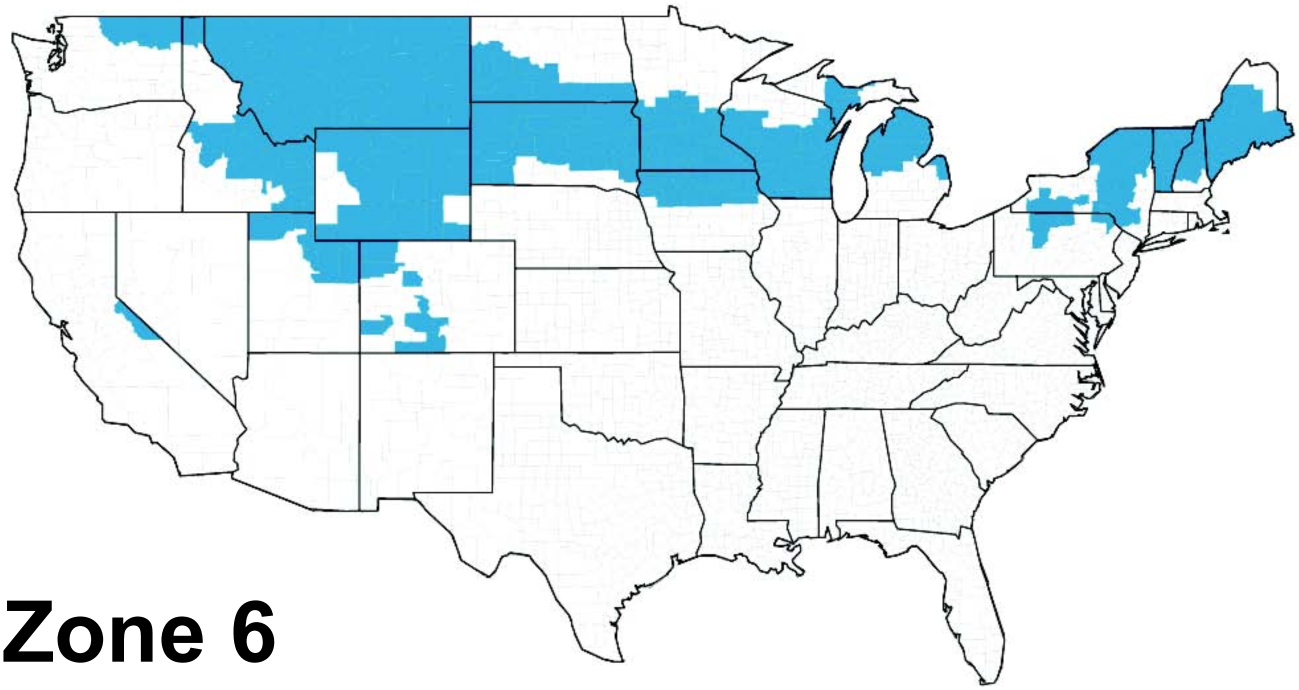
	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-30.0 c.i.	EN1–2, 18–21	
		Metal building	R-19.0 + R-11.0 Ls	EN1, 3, 18–21	
		SRI	No recommendation	None	
	Walls	Mass (HC > 7 Btu/ft^2)	R-11.4 c.i.	EN4, 18–20	
		Metal building	R-0.0 + R-19 c.i.	EN5, 18–20	
		Steel framed	R-13.0 + R-12.5 c.i.	EN6, 18–20	
	Floors	Mass	R-14.6 c.i.	EN7, 18–20	
		Steel framed	R-38.0	EN8, 18–20	
	Slabs	Unheated	R-15 for 24 in.	EN9, 18–21	
		Heated	R-20 for 48 in.	EN10, 18–21	
	Doors	Swinging	U-0.50	EN12, 18–20	
		Nonswinging	Roll-up = U-0.25 All other = U-0.07	EN13–14, 18–20	
		Vehicular/dock infiltration—door closed	0.28 cfm/ft^2 of door area	EN15, 18–20	
		Vehicular/dock infiltration—door open, truck in place	Weather seals for dock, levelers, trailer hinges	EN16, 18–20	
	Vestibules	All building entrances	Yes	EN17–20	
	View Fenestration—All Orientations	Thermal transmittance	U-0.45	EN22–23	
		SHGC	0.40	EN23–24, 27	
		VT	0.51	EN23	
Daylighting / Lighting	Interior Lighting	LPD—Ambient Lighting	Sales floor = 1.15 W/ft^2	EL1, 3–7, 9–11, 17–23, 28	
			Stock room = 0.6 W/ft^2	EL1, 4, 9–11, 17–19, 26, 28	
			Average of all other = 0.9 W/ft^2	EL1–2, 4, 8–11, 17–19, 24–28	
		LPD—Additional specialty sales floor lighting	Sporting goods, small electronics = 0.6 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Furniture, clothing, cosmetics, art = 0.95 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Jewelry, crystal, china = 1.5 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			All other = 0.4 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
		Light source efficacy (mean LPW)	T8 and T5 lamps > 2 ft = 92; T8 and T5 lamps ≤ 2 ft = 85; All other > 50	EL12, 14	
		T8 ballasts	Nondimming = NEMA Premium Instant Start Dimming = NEMA Premium Programmed Start	EL12	
		All T5/T5HO ballasts	Electronic programmed start	EL12	
		All CFL and HID ballasts	Electronic	EL13	
		Lighting controls	Sales floor = Time switch—auto to 25% 3 h before and after store open hours; auto to 2% or less after hours	EL16	
			Additional specialty lighting = auto ON only during store open hours	EL16	
			Stock room, restrooms = auto ON/OFF occupancy sensors	EL15	
			All other = manual ON, auto OFF occupancy sensors	EL15	
			After hours = max 2% of total building LPD	EL16	
	Exterior Lighting	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ3 and LZ4, 0.05 W/ft^2 in LZ2 Controls = auto OFF between 12 a.m. and 6 a.m.	EL31–33	
		Parking lots and drives	LPD = 0.1 W/ft^2 in LZ3 and LZ4, 0.06 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL29, 32–33	
		Walkways, plaza, and special feature areas	LPD = 0.16 W/ft^2 LZ3 and LZ4, 0.14 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL30, 32–33	
		All other exterior lighting	LPD = follow Standard 90.1-2010 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL32–33	
Plug Loads	Equipment Choices	ENERGY STAR® equipment	All illuminated signage, security monitors, computers, equipment, and appliances (where available)	PL1–5	
		Vending machines	Delamp in break rooms and specify best-in-class efficiency; Specify load managing systems for refrigerated vending	PL6	
		Procurement	Incorporate control and efficiency options in negotiations for all third-party owned plug loads; Consolidate equipment where possible	PL2, 8	
		Computers	Specify laptops, tablets, or mini-desktops where feasible	PL3	
		Signage	Use LED internally illuminated where applicable; Consolidate/replace static media with dynamic	PL5	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Climate Zone 5 Recommendation Table for Medium to Big Box Retail Buildings *(Continued)*

	Item	Component	Recommendation	How-To Tips	✓
Plug Loads, cont.	Controls	Sales floor plug control	Auto control all display outlets that can be turned off during nonbusiness hours and all other sales outlets that can be turned off during unoccupied hours; Specify auto standby modes for third-party owned/supplied plug loads	PL2, 6	
		Computer power control	Network control with power-saving modes and control during unoccupied hours	PL6	
		Occupancy sensors	Office/break/security room plug strip occupancy sensors; Other equipment as applicable	PL4, 6	
		Timer switches	Water coolers, coffee makers, other small appliances auto shut-off during unoccupied hours	PL6	
		Policies	Store policy on allowed equipment	PL6	
SWH	SWH	Gas water heater efficiency	Condensing water heaters = 95% efficiency	WH4	
		Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 – 0.0012 × volume	WH4	
		Point-of-use heater selection	0.81 EF or 81% E_t	WH4	
		Electric heat pump water heater	COP 3.0 (interior heat source)	WH2	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in. / 1.5 in.	WH6	
HVAC	Packaged Variable-Volume DX Air Conditioners	Heating efficiency	80%	HV3	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV3	
		Maximum external static pressure	Single zone = 0.7 in. w.c. Multizone = 1.8 in. w.c.	HV3,22	
	Packaged Constant-Volume DX Air Conditioners with DOAS	Heating efficiency	80%	HV4	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV4	
		Maximum external static pressure	0.7 in. w.c.	HV4	
	Packaged Single-Zone Air-Source Heat Pumps with DOAS	Heating efficiency	< 65 kBtu/h = 9.0 HSPF 65–135 kBtu/h = 3.4 COP at 47°F; 2.4 COP at 17°F 135–240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F ≥ 240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F	HV5	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER, 12.0 EER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER ≥ 240 kBtu/h = 10.5 EER, 11.3 IEER	HV5	
		Maximum external static pressure	0.7 in. w.c.	HV5	
		Maximum fan power	0.4 W/cfm	HV5	
	Packaged Single-Zone Water-Source Heat Pumps with DOAS	Heating efficiency	Full load =15.0 EER; Part load= 17.6 EER	HV6	
		Cooling efficiency	Full load = 5.0 COP; Part load = 5.7 COP	HV6	
		Maximum external static pressure	0.7 in. w.c.	HV6	
		Maximum fan power	0.4 W/cfm	HV6	
		Water circulation pumps	VFD and NEMA premium efficiency	HV6	
		Cooling tower/fluid cooler	VFD on fans	HV6, 12	
		Boiler efficiency	90% E_c	HV6,12, 27	
	Dedicated Outdoor Air System (DOAS)	Heating efficiency	See Table 5-10 in HV7	HV7	
		Cooling efficiency	See Table 5-10 in HV7	HV7	
		Fan external static pressure	Constant volume = 1.0 in. w.c. Variable volume (DCV) = 1.8 in. w.c.	HV7	
		Fan and motor	65% mechanical/motor efficiency in absence of whole unit EER rating; Motor efficiency as per Standard 90.1-2010 Table 10.8B	HV7	
	Ventilation/ Exhaust	Cooling capacity for which an economizer is required	≥ 54,000 Btu/h	HV14	
		DCV/performance-based ventilation	Control ventilation air based on pollutant concentrations in space (CO_2, VOCs, etc.)	HV15–16	
		Exhaust air recovery	A (humid) zones= 75% total effectiveness; B (dry) zones = 75% sensible effectiveness; Capture min. 80% available exhaust air, including general and bathroom, for energy recovery	HV10	
		Exhaust airflow control	Control based on occupancy using time clock or occupancy sensor	HV17	
	Ducts and Dampers	Outdoor air damper	Motorized damper	HV14	
		Duct seal class	Seal Class A	HV18, 20	
		Insulation level	R-6	HV19	
QA	M&V/ Benchmarking	Electrical submeters	Design and circuit for separate submeters for lighting, HVAC, general 120V, service water heater, renewables, and whole building	QA15–16	
		Benchmarks	Benchmark monthly energy use	QA17	
		Training	Facility operator on continuous benchmarking	QA13–14	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.



Zone 6

California

Alpine
Mono

Colorado

Alamosa
Archuleta
Chaffee
Conejos
Costilla
Custer
Dolores
Eagle
Moffat
Ouray
Rio Blanco
Saguache
San Miguel

Idaho

Adams
Bannock
Bear Lake
Bingham
Blaine
Boise
Bonner
Bonneville
Boundary
Butte
Camas
Caribou
Clark
Custer
Franklin
Fremont
Jefferson
Lemhi
Madison
Oneida
Teton
Valley

Iowa

Allamakee
Black Hawk
Bremer
Buchanan
Buena Vista
Butler
Calhoun
Cerro Gordo
Cherokee
Chickasaw
Clay
Clayton
Delaware
Dickinson
Emmet
Fayette
Floyd
Franklin
Grundy
Hamilton
Hancock
Hardin
Howard
Humboldt
Ida
Kossuth
Lyon
Mitchell
O'Brien
Osceola
Palo Alto
Plymouth
Pocahontas
Sac
Sioux
Webster
Winnebago
Winneshiek
Worth
Wright

Maine

All counties except:
Aroostook

Michigan

Alcona
Alger
Alpena
Antrim
Arenac
Benzie
Charlevoix
Cheboygan
Clare
Crawford
Delta
Dickinson
Emmet
Gladwin
Grand Traverse
Huron
Iosco
Isabella
Kalkaska
Lake
Leelanau
Manistee
Marquette
Mason
Mecosta
Menominee
Missaukee
Montmorency
Newaygo
Oceana
Ogemaw
Osceola
Oscoda
Otsego
Presque Isle
Roscommon
Sanilac
Wexford

Minnesota

Anoka
Benton
Big Stone
Blue Earth
Brown
Carver
Chippewa
Chisago
Cottonwood
Dakota
Dodge
Douglas
Faribault
Fillmore
Freeborn
Goodhue
Hennepin
Houston
Isanti
Jackson
Kandiyohi
Lac qui Parle
Le Sueur
Lincoln
Lyon
Martin
McLeod
Meeker
Morrison
Mower
Murray
Nicollet
Nobles
Olmsted
Pipestone
Pope
Ramsey
Redwood
Renville
Rice
Rock
Scott
Sherburne
Sibley
Stearns
Steele
Stevens
Swift
Todd
Traverse
Wabasha
Waseca
Washington
Watonwan
Winona
Wright
Yellow Medicine

Montana

All counties

New Hampshire

Belknap
Carroll
Coos
Grafton
Merrimack
Sullivan

New York

Allegany
Broome
Cattaraugus
Chenango
Clinton
Delaware
Essex
Franklin
Fulton
Hamilton
Herkimer
Jefferson
Lewis
Madison
Montgomery
Oneida
Otsego
Schoharie
Schuyler
Steuben
St. Lawrence
Sullivan
Tompkins
Ulster
Warren
Wyoming

North Dakota

Adams
Billings
Bowman
Burleigh
Dickey
Dunn
Emmons
Golden Valley
Grant
Hettinger
LaMoure
Logan
McIntosh
McKenzie
Mercer
Morton
Oliver
Ransom
Richland
Sargent
Sioux
Slope
Stark

Pennsylvania

Cameron
Clearfield
Elk
McKean
Potter
Susquehanna
Tioga
Wayne

South Dakota

All counties except:
Bennett
Bon Homme
Charles Mix
Clay
Douglas
Gregory
Hutchinson
Jackson
Mellette
Todd
Tripp
Union
Yankton

Utah

Box Elder
Cache
Carbon
Daggett
Duchesne
Morgan
Rich
Summit
Uintah
Wasatch

Vermont

All counties

Washington

Ferry
Okanogan
Pend Oreille
Stevens

Wisconsin

All counties except:
Ashland
Bayfield
Burnett
Douglas
Florence
Forest
Iron
Langlade
Lincoln
Oneida
Price
Sawyer
Taylor
Vilas
Washburn

Wyoming

All counties except:
Goshen
Platte
Lincoln
Sublette
Teton

Climate Zone 6 Recommendation Table for Medium to Big Box Retail Buildings

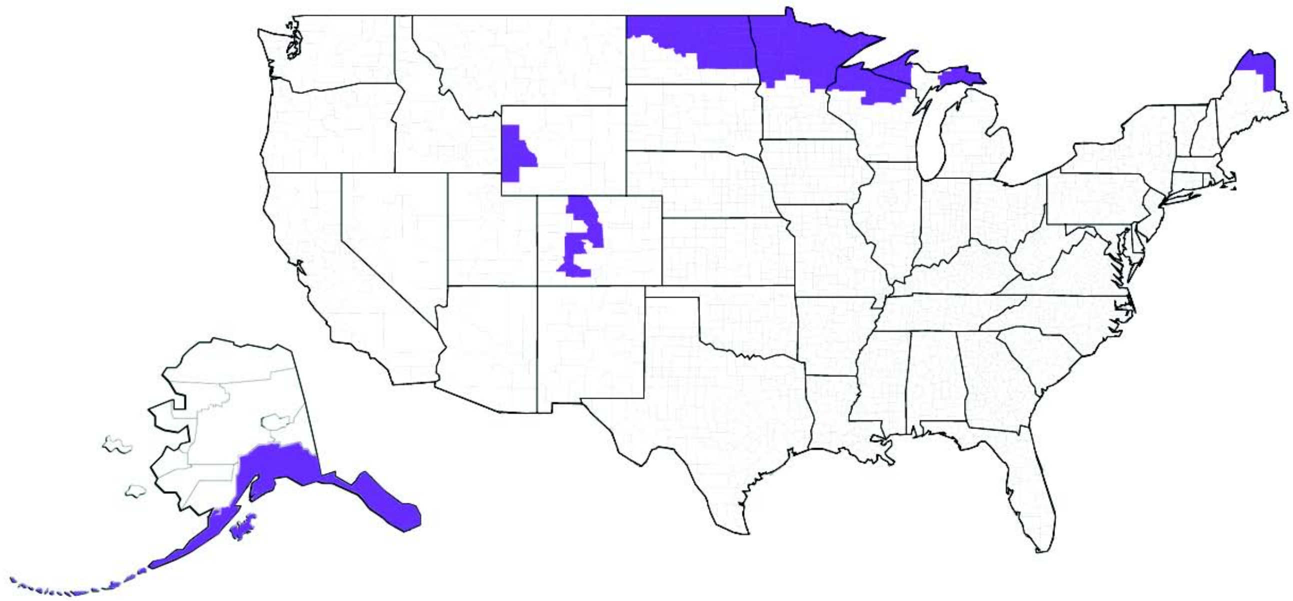
	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-30.0 c.i.	EN1–2, 18–21	
		Metal building	R-25.0 + R-11.0 Ls	EN1, 3, 18–21	
		SRI	No recommendation	None	
	Walls	Mass (HC > 7 Btu/ft^2)	R-15.4 c.i.	EN4, 18–20	
		Metal building	R-0.0 + R-19 c.i.	EN5, 18–20	
		Steel framed	R-13.0 + R-15.0 c.i.	EN6, 18–20	
	Floors	Mass	R-16.7 c.i.	EN7, 18–20	
		Steel framed	R-38.0	EN8, 18–20	
	Slabs	Unheated	R-20 for 24 in.	EN9, 18–21	
		Heated	R-20 for 48 in.	EN10, 18–21	
	Doors	Swinging	U-0.50	EN12, 18–20	
		Nonswinging	Roll-up = U-0.25 All other = U-0.07	EN13–14, 18–20	
		Vehicular/dock infiltration—door closed	0.28 cfm/ft^2 of door area	EN15, 18–20	
		Vehicular/dock infiltration—door open, truck in place	Weather seals for dock, levelers, trailer hinges	EN16, 18–20	
	Vestibules	All building entrances	Yes	EN17–20	
	View Fenestration—All Orientations	Thermal transmittance	U-0.45	EN22–23	
		SHGC	0.40	EN23–24, 27	
		VT	0.51	EN23	
Daylighting / Lighting	Interior Lighting	LPD—Ambient Lighting	Sales floor = 1.15 W/ft^2	EL1, 3–7, 9–11, 17–23, 28	
			Stock room = 0.6 W/ft^2	EL1, 4, 9–11, 17–19, 26, 28	
			Average of all other = 0.9 W/ft^2	EL1–2, 4, 8–11, 17–19, 24–28	
		LPD—Additional specialty sales floor lighting	Sporting goods, small electronics = 0.6 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Furniture, clothing, cosmetics, art = 0.95 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Jewelry, crystal, china = 1.5 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			All other = 0.4 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
		Light source efficacy (mean LPW)	T8 and T5 lamps > 2 ft = 92; T8 and T5 lamps ≤ 2 ft = 85; All other > 50	EL12, 14	
		T8 ballasts	Nondimming = NEMA Premium Instant Start Dimming = NEMA Premium Programmed Start	EL12	
		All T5/T5HO ballasts	Electronic programmed start	EL12	
		All CFL and HID ballasts	Electronic	EL13	
		Lighting controls	Sales floor = Time switch—auto to 25% 3 h before and after store open hours; auto to 2% or less after hours	EL16	
			Additional specialty lighting = auto ON only during store open hours	EL16	
			Stock room, restrooms = auto ON/OFF occupancy sensors	EL15	
			All other = manual ON, auto OFF occupancy sensors	EL15	
			After hours = max 2% of total building LPD	EL16	
	Exterior Lighting	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ3 and LZ4, 0.05 W/ft^2 in LZ2 Controls = auto OFF between 12 a.m. and 6 a.m.	EL31–33	
		Parking lots and drives	LPD = 0.1 W/ft^2 in LZ3 and LZ4, 0.06 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL29, 32–33	
		Walkways, plaza, and special feature areas	LPD = 0.16 W/ft^2 LZ3 and LZ4, 0.14 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL30, 32–33	
		All other exterior lighting	LPD = follow Standard 90.1-2010 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL32–33	
Plug Loads	Equipment Choices	ENERGY STAR® equipment	All illuminated signage, security monitors, computers, equipment, and appliances (where available)	PL1–5	
		Vending machines	Delamp in break rooms and specify best-in-class efficiency; Specify load managing systems for refrigerated vending	PL6	
		Procurement	Incorporate control and efficiency options in negotiations for all third-party owned plug loads; Consolidate equipment where possible	PL2, 8	
		Computers	Specify laptops, tablets, or mini-desktops where feasible	PL3	
		Signage	Use LED internally illuminated where applicable; Consolidate/replace static media with dynamic	PL5	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Climate Zone 6 Recommendation Table for Medium to Big Box Retail Buildings *(Continued)*

	Item	Component	Recommendation	How-To Tips	✓
Plug Loads, cont.	Controls	Sales floor plug control	Auto control all display outlets that can be turned off during nonbusiness hours and all other sales outlets that can be turned off during unoccupied hours; Specify auto standby modes for third-party owned/ supplied plug loads	PL2, 6	
		Computer power control	Network control with power-saving modes and control during unoccupied hours	PL6	
		Occupancy sensors	Office/break/security room plug strip occupancy sensors; Other equipment as applicable	PL4, 6	
		Timer switches	Water coolers, coffee makers, other small appliances auto shut-off during unoccupied hours	PL6	
		Policies	Store policy on allowed equipment	PL6	
SWH	SWH	Gas water heater efficiency	Condensing water heaters = 95% efficiency	WH4	
		Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 – 0.0012 × volume	WH4	
		Point-of-use heater selection	0.81 EF or 81% E_t	WH4	
		Electric heat pump water heater	COP 3.0 (interior heat source)	WH2	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in. / 1.5 in.	WH6	
HVAC	Packaged Variable-Volume DX Air Conditioners	Heating efficiency	80%	HV3	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV3	
		Maximum external static pressure	Single zone = 0.7 in. w.c. Multizone = 1.8 in. w.c.	HV3,22	
	Packaged Constant-Volume DX Air Conditioners with DOAS	Heating efficiency	80%	HV4	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV4	
		Maximum external static pressure	0.7 in. w.c.	HV4	
	Packaged Single-Zone Air-Source Heat Pumps with DOAS	Heating efficiency	< 65 kBtu/h = 9.0 HSPF 65–135 kBtu/h = 3.4 COP at 47°F; 2.4 COP at 17°F 135–240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F ≥ 240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F	HV5	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER, 12.0 EER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER ≥ 240 kBtu/h = 10.5 EER, 11.3 IEER	HV5	
		Maximum external static pressure	0.7 in. w.c.	HV5	
		Maximum fan power	0.4 W/cfm	HV5	
	Packaged Single-Zone Water-Source Heat Pumps with DOAS	Heating efficiency	Full load =15.0 EER; Part load= 17.6 EER	HV6	
		Cooling efficiency	Full load = 5.0 COP; Part load = 5.7 COP	HV6	
		Maximum external static pressure	0.7 in. w.c.	HV6	
		Maximum fan power	0.4 W/cfm	HV6	
		Water circulation pumps	VFD and NEMA premium efficiency	HV6	
		Cooling tower/fluid cooler	VFD on fans	HV6, 12	
		Boiler efficiency	90% E_c	HV6,12, 27	
	Dedicated Outdoor Air System (DOAS)	Heating efficiency	See Table 5-10 in HV7	HV7	
		Cooling efficiency	See Table 5-10 in HV7	HV7	
		Fan external static pressure	Constant volume = 1.0 in. w.c. Variable volume (DCV) = 1.8 in. w.c.	HV7	
		Fan and motor	65% mechanical/motor efficiency in absence of whole unit EER rating; Motor efficiency as per Standard 90.1-2010 Table 10.8B	HV7	
	Ventilation/ Exhaust	Cooling capacity for which an economizer is required	≥ 54,000 Btu/h	HV14	
		DCV/performance-based ventilation	Control ventilation air based on pollutant concentrations in space (CO_2, VOCs, etc.)	HV15–16	
		Exhaust air recovery	A (humid) zones= 75% total effectiveness; B (dry) zones = 75% sensible effectiveness; Capture min. 80% available exhaust air, including general and bathroom, for energy recovery	HV10	
		Exhaust airflow control	Control based on occupancy using time clock or occupancy sensor	HV17	
	Ducts and Dampers	Outdoor air damper	Motorized damper	HV14	
		Duct seal class	Seal Class A	HV18, 20	
		Insulation level	R-6	HV19	
QA	M&V/ Benchmarking	Electrical submeters	Design and circuit for separate submeters for lighting, HVAC, general 120V, service water heater, renewables, and whole building	QA15–16	
		Benchmarks	Benchmark monthly energy use	QA17	
		Training	Facility operator on continuous benchmarking	QA13–14	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.



Zone 7

Alaska

Aleutians East
Aleutians West (CA)
Anchorage
Angoon (CA)
Bristol Bay
Denali
Haines
Juneau
Kenai Peninsula
Ketchikan (CA)
Ketchikan Gateway
Kodiak Island
Lake and Peninsula
Matanuska-Susitna
Prince of Wales-Outer
Sitka
Skagway-Hoonah-
Valdez-Cordova (CA)
Wrangell-Petersburg (CA)
Yakutat

Colorado

Clear Creek
Grand
Gunnison
Hinsdale
Jackson
Lake
Mineral
Park
Pitkin
Rio Grande
Routt
San Juan
Summit

Maine

Aroostook

Michigan

Baraga
Chippewa
Gogebic
Houghton
Iron
Keweenaw
Luce
Mackinac
Ontonagon
Schoolcraft

Minnesota

Aitkin
Becker
Beltrami
Carlton
Cass
Clay
Clearwater
Cook
Crow Wing
Grant
Hubbard
Itasca
Kanabec
Kittson
Koochiching
Lake
Lake of the Woods
Mahnomen
Marshall
Mille Lacs
Norman
Otter Tail
Pennington
Pine
Polk
Red Lake
Roseau
St. Louis
Wadena
Wilkin

North Dakota

Barnes
Benson
Bottineau
Burke
Cass
Cavalier
Divide
Eddy
Foster
Grand Forks
Griggs
Kidder
McHenry
McLean
Mountrail
Nelson
Pembina
Pierce
Ramsey
Renville
Rolette
Sheridan
Steele
Stutsman
Towner
Traill
Walsh
Ward
Wells
Williams

Wisconsin

Ashland
Bayfield
Burnett
Douglas
Florence
Forest
Iron
Langlade
Lincoln
Oneida
Price
Sawyer
Taylor
Vilas
Washburn

Wyoming

Lincoln
Sublette
Teton

Climate Zone 7 Recommendation Table for Medium to Big Box Retail Buildings

	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-35.0 c.i.	EN1–2, 18–21	
		Metal building	R-30.0 + R-11.0 Ls	EN1, 3, 18–21	
		SRI	No recommendation	None	
	Walls	Mass (HC > 7 Btu/ft^2)	R-17.0 c.i.	EN4, 18–20	
		Metal building	R-0.0 + R-22.1 c.i.	EN5, 18–20	
		Steel framed	R-13.0 + R-18.8 c.i.	EN6, 18–20	
	Floors	Mass	R-20.9 c.i.	EN7, 18–20	
		Steel framed	R-49.0	EN8, 18–20	
	Slabs	Unheated	R-20 for 24 in.	EN9, 18–21	
		Heated	R-25 for 48 in.	EN10, 18–21	
	Doors	Swinging	U-0.50	EN12, 18–20	
		Nonswinging	Roll-up = U-0.25 All other = U-0.07	EN13–14, 18–20	
		Vehicular/dock infiltration—door closed	0.28 cfm/ft^2 of door area	EN15, 18–20	
		Vehicular/dock infiltration—door open, truck in place	Weather seals for dock, levelers, trailer hinges	EN16, 18–20	
	Vestibules	All building entrances	Yes	EN17–20	
	View Fenestration—All Orientations	Thermal transmittance	U-0.40	EN22–23	
		SHGC	0.45	EN23–24, 27	
		VT	0.45	EN23	
Daylighting / Lighting	Interior Lighting	LPD—Ambient Lighting	Sales floor = 1.15 W/ft^2	EL1, 3–7, 9–11, 17–23, 28	
			Stock room = 0.6 W/ft^2	EL1, 4, 9–11, 17–19, 26, 28	
			Average of all other = 0.9 W/ft^2	EL1–2, 4, 8–11, 17–19, 24–28	
		LPD—Additional specialty sales floor lighting	Sporting goods, small electronics = 0.6 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Furniture, clothing, cosmetics, art = 0.95 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Jewelry, crystal, china = 1.5 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			All other = 0.4 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
		Light source efficacy (mean LPW)	T8 and T5 lamps > 2 ft = 92; T8 and T5 lamps ≤ 2 ft = 85; All other > 50	EL12, 14	
		T8 ballasts	Nondimming = NEMA Premium Instant Start Dimming = NEMA Premium Programmed Start	EL12	
		All T5/T5HO ballasts	Electronic programmed start	EL12	
		All CFL and HID ballasts	Electronic	EL13	
		Lighting controls	Sales floor = Time switch—auto to 25% 3 h before and after store open hours; auto to 2% or less after hours	EL16	
			Additional specialty lighting = auto ON only during store open hours	EL16	
			Stock room, restrooms = auto ON/OFF occupancy sensors	EL15	
			All other = manual ON, auto OFF occupancy sensors	EL15	
			After hours = max 2% of total building LPD	EL16	
	Exterior Lighting	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ3 and LZ4, 0.05 W/ft^2 in LZ2 Controls = auto OFF between 12 a.m. and 6 a.m.	EL31–33	
		Parking lots and drives	LPD = 0.1 W/ft^2 in LZ3 and LZ4, 0.06 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL29, 32–33	
		Walkways, plaza, and special feature areas	LPD = 0.16 W/ft^2 LZ3 and LZ4, 0.14 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL30, 32–33	
		All other exterior lighting	LPD = follow Standard 90.1-2010 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL32–33	
Plug Loads	Equipment Choices	ENERGY STAR® equipment	All illuminated signage, security monitors, computers, equipment, and appliances (where available)	PL1–5	
		Vending machines	Delamp in break rooms and specify best-in-class efficiency; Specify load managing systems for refrigerated vending	PL6	
		Procurement	Incorporate control and efficiency options in negotiations for all third-party owned plug loads; Consolidate equipment where possible	PL2, 8	
		Computers	Specify laptops, tablets, or mini-desktops where feasible	PL3	
		Signage	Use LED internally illuminated where applicable; Consolidate/replace static media with dynamic	PL5	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Climate Zone 7 Recommendation Table for Medium to Big Box Retail Buildings *(Continued)*

	Item	Component	Recommendation	How-To Tips	✓
Plug Loads, cont.	Controls	Sales floor plug control	Auto control all display outlets that can be turned off during nonbusiness hours and all other sales outlets that can be turned off during unoccupied hours; Specify auto standby modes for third-party owned/supplied plug loads	PL2, 6	
		Computer power control	Network control with power-saving modes and control during unoccupied hours	PL6	
		Occupancy sensors	Office/break/security room plug strip occupancy sensors; Other equipment as applicable	PL4, 6	
		Timer switches	Water coolers, coffee makers, other small appliances auto shut-off during unoccupied hours	PL6	
		Policies	Store policy on allowed equipment	PL6	
SWH	SWH	Gas water heater efficiency	Condensing water heaters = 95% efficiency	WH4	
		Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 – 0.0012 × volume	WH4	
		Point-of-use heater selection	0.81 EF or 81% E_t	WH4	
		Electric heat pump water heater	COP 3.0 (interior heat source)	WH2	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in. / 1.5 in.	WH6	
HVAC	Packaged Variable-Volume DX Air Conditioners	Heating efficiency	80%	HV3	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV3	
		Maximum external static pressure	Single zone = 0.7 in. w.c. Multizone = 1.8 in. w.c.	HV3,22	
	Packaged Constant-Volume DX Air Conditioners with DOAS	Heating efficiency	80%	HV4	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV4	
		Maximum external static pressure	0.7 in. w.c.	HV4	
	Packaged Single-Zone Air-Source Heat Pumps with DOAS	Heating efficiency	< 65 kBtu/h = 9.0 HSPF 65–135 kBtu/h = 3.4 COP at 47°F; 2.4 COP at 17°F 135–240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F ≥ 240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F	HV5	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER, 12.0 EER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER ≥ 240 kBtu/h = 10.5 EER, 11.3 IEER	HV5	
		Maximum external static pressure	0.7 in. w.c.	HV5	
		Maximum fan power	0.4 W/cfm	HV5	
	Packaged Single-Zone Water-Source Heat Pumps with DOAS	Heating efficiency	Full load =15.0 EER; Part load= 17.6 EER	HV6	
		Cooling efficiency	Full load = 5.0 COP; Part load = 5.7 COP	HV6	
		Maximum external static pressure	0.7 in. w.c.	HV6	
		Maximum fan power	0.4 W/cfm	HV6	
		Water circulation pumps	VFD and NEMA premium efficiency	HV6	
		Cooling tower/fluid cooler	VFD on fans	HV6, 12	
		Boiler efficiency	90% E_c	HV6,12, 27	
	Dedicated Outdoor Air System (DOAS)	Heating efficiency	See Table 5-10 in HV7	HV7	
		Cooling efficiency	See Table 5-10 in HV7	HV7	
		Fan external static pressure	Constant volume = 1.0 in. w.c. Variable volume (DCV) = 1.8 in. w.c.	HV7	
		Fan and motor	65% mechanical/motor efficiency in absence of whole unit EER rating; Motor efficiency as per Standard 90.1-2010 Table 10.8B	HV7	
	Ventilation/Exhaust	Cooling capacity for which an economizer is required	≥ 54,000 Btu/h	HV14	
		DCV/performance-based ventilation	Control ventilation air based on pollutant concentrations in space (CO_2, VOCs, etc.)	HV15–16	
		Exhaust air recovery	A (humid) zones= 75% total effectiveness; B (dry) zones = 75% sensible effectiveness; Capture min. 80% available exhaust air, including general and bathroom, for energy recovery	HV10	
		Exhaust airflow control	Control based on occupancy using time clock or occupancy sensor	HV17	
	Ducts and Dampers	Outdoor air damper	Motorized damper	HV14	
		Duct seal class	Seal Class A	HV18, 20	
		Insulation level	R-6	HV19	
QA	M&V/Benchmarking	Electrical submeters	Design and circuit for separate submeters for lighting, HVAC, general 120V, service water heater, renewables, and whole building	QA15–16	
		Benchmarks	Benchmark monthly energy use	QA17	
		Training	Facility operator on continuous benchmarking	QA13–14	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Zone 8

Alaska

Bethel (CA)
Dillingham (CA)
Fairbanks North Star
Nome (CA)
North Slope
Northwest Arctic
Southeast Fairbanks (CA)
Wade Hampton (CA)
Yukon-Koyukuk (CA)

Climate Zone 8 Recommendation Table for Medium to Big Box Retail Buildings

	Item	Component	Recommendation	How-To Tips	✓
Envelope	Roofs	Insulation entirely above deck	R-35.0 c.i.	EN1–2, 18–21	
		Metal building	R-25.0 + R-11.0 + R-11.0 Ls	EN1, 3, 18–21	
		SRI	No recommendation	None	
	Walls	Mass (HC > 7 Btu/ft^2)	R-19.0 c.i.	EN4, 18–20	
		Metal building	R-0.0 + R-25 c.i.	EN5, 18–20	
		Steel framed	R-13.0 + R-18.8 c.i.	EN6, 18–20	
	Floors	Mass	R-23.0 c.i.	EN7, 18–20	
		Steel framed	R-60.0	EN8, 18–20	
	Slabs	Unheated	R-20 for 24 in.	EN9, 18–21	
		Heated	R-25 for 48 in.	EN10, 18–21	
	Doors	Swinging	U-0.50	EN12, 18–20	
		Nonswinging	Roll-up = U-0.25 All other = U-0.07	EN13–14, 18–20	
		Vehicular/dock infiltration—door closed	0.28 cfm/ft^2 of door area	EN15, 18–20	
		Vehicular/dock infiltration—door open, truck in place	Weather seals for dock, levelers, trailer hinges	EN16, 18–20	
	Vestibules	All building entrances	Yes	EN17–20	
	View Fenestration—All Orientations	Thermal transmittance	U-0.40	EN22–23	
		SHGC	0.45	EN23–24, 27	
		VT	0.45	EN23	
Daylighting / Lighting	Interior Lighting	LPD—Ambient Lighting	Sales floor = 1.15 W/ft^2	EL1, 3–7, 9–11, 17–23, 28	
			Stock room = 0.6 W/ft^2	EL1, 4, 9–11, 17–19, 26, 28	
			Average of all other = 0.9 W/ft^2	EL1–2, 4, 8–11, 17–19, 24–28	
		LPD—Additional specialty sales floor lighting	Sporting goods, small electronics = 0.6 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Furniture, clothing, cosmetics, art = 0.95 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			Jewelry, crystal, china = 1.5 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
			All other = 0.4 W/ft^2	EL1, 4–5, 7, 10–11, 21–23	
		Light source efficacy (mean LPW)	T8 and T5 lamps > 2 ft = 92; T8 and T5 lamps ≤ 2 ft = 85; All other > 50	EL12, 14	
		T8 ballasts	Nondimming = NEMA Premium Instant Start Dimming = NEMA Premium Programmed Start	EL12	
		All T5/T5HO ballasts	Electronic programmed start	EL12	
		All CFL and HID ballasts	Electronic	EL13	
		Lighting controls	Sales floor = Time switch—auto to 25% 3 h before and after store open hours; auto to 2% or less after hours	EL16	
			Additional specialty lighting = auto ON only during store open hours	EL16	
			Stock room, restrooms = auto ON/OFF occupancy sensors	EL15	
			All other = manual ON, auto OFF occupancy sensors	EL15	
			After hours = max 2% of total building LPD	EL16	
	Exterior Lighting	Façade and landscape lighting	LPD = 0.075 W/ft^2 in LZ3 and LZ4, 0.05 W/ft^2 in LZ2 Controls = auto OFF between 12 a.m. and 6 a.m.	EL31–33	
		Parking lots and drives	LPD = 0.1 W/ft^2 in LZ3 and LZ4, 0.06 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL29, 32–33	
		Walkways, plaza, and special feature areas	LPD = 0.16 W/ft^2 LZ3 and LZ4, 0.14 W/ft^2 in LZ2 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL30, 32–33	
		All other exterior lighting	LPD = follow Standard 90.1-2010 Controls = auto reduce to 25% (12 a.m. to 6 a.m.)	EL32–33	
Plug Loads	Equipment Choices	ENERGY STAR® equipment	All illuminated signage, security monitors, computers, equipment, and appliances (where available)	PL1–5	
		Vending machines	Delamp in break rooms and specify best-in-class efficiency; Specify load managing systems for refrigerated vending	PL6	
		Procurement	Incorporate control and efficiency options in negotiations for all third-party owned plug loads; Consolidate equipment where possible	PL2, 8	
		Computers	Specify laptops, tablets, or mini-desktops where feasible	PL3	
		Signage	Use LED internally illuminated where applicable; Consolidate/replace static media with dynamic	PL5	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

Climate Zone 8 Recommendation Table for Medium to Big Box Retail Buildings *(Continued)*

	Item	Component	Recommendation	How-To Tips	✓
Plug Loads, cont.	Controls	Sales floor plug control	Auto control all display outlets that can be turned off during nonbusiness hours and all other sales outlets that can be turned off during unoccupied hours; Specify auto standby modes for third-party owned/ supplied plug loads	PL2, 6	
		Computer power control	Network control with power-saving modes and control during unoccupied hours	PL6	
		Occupancy sensors	Office/break/security room plug strip occupancy sensors; Other equipment as applicable	PL4, 6	
		Timer switches	Water coolers, coffee makers, other small appliances auto shut-off during unoccupied hours	PL6	
		Policies	Store policy on allowed equipment	PL6	
SWH	SWH	Gas water heater efficiency	Condensing water heaters = 95% efficiency	WH4	
		Electric storage EF (≤12 kW, ≥20 gal)	EF > 0.99 – 0.0012 × volume	WH4	
		Point-of-use heater selection	0.81 EF or 81% E_t	WH4	
		Electric heat pump water heater	COP 3.0 (interior heat source)	WH2	
		Pipe insulation (d < 1.5 in. / d ≥ 1.5 in.)	1 in. / 1.5 in.	WH6	
HVAC	Packaged Variable-Volume DX Air Conditioners	Heating efficiency	80%	HV3	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV3	
		Maximum external static pressure	Single zone = 0.7 in. w.c. Multizone = 1.8 in. w.c.	HV3,22	
	Packaged Constant-Volume DX Air Conditioners with DOAS	Heating efficiency	80%	HV4	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER 240–760 kBtu/h = 10.5 EER, 11.3 IEER ≥ 760 kBtu/h = 9.7 EER, 10.9 IEER	HV4	
		Maximum external static pressure	0.7 in. w.c.	HV4	
	Packaged Single-Zone Air-Source Heat Pumps with DOAS	Heating efficiency	< 65 kBtu/h = 9.0 HSPF 65–135 kBtu/h = 3.4 COP at 47°F; 2.4 COP at 17°F 135–240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F ≥ 240 kBtu/h = 3.2 COP at 47°F; 2.1 COP at 17°F	HV5	
		Cooling efficiency	< 65 kBtu/h = 15.0 SEER, 12.0 EER 65–135 kBtu/h = 11.5 EER, 12.8 IEER 135–240 kBtu/h = 11.5 EER, 12.3 IEER ≥ 240 kBtu/h = 10.5 EER, 11.3 IEER	HV5	
		Maximum external static pressure	0.7 in. w.c.	HV5	
		Maximum fan power	0.4 W/cfm	HV5	
	Packaged Single-Zone Water-Source Heat Pumps with DOAS	Heating efficiency	Full load =15.0 EER; Part load= 17.6 EER	HV6	
		Cooling efficiency	Full load = 5.0 COP; Part load = 5.7 COP	HV6	
		Maximum external static pressure	0.7 in. w.c.	HV6	
		Maximum fan power	0.4 W/cfm	HV6	
		Water circulation pumps	VFD and NEMA premium efficiency	HV6	
		Cooling tower/fluid cooler	VFD on fans	HV6, 12	
		Boiler efficiency	90% E_c	HV6,12, 27	
	Dedicated Outdoor Air System (DOAS)	Heating efficiency	See Table 5-10 in HV7	HV7	
		Cooling efficiency	See Table 5-10 in HV7	HV7	
		Fan external static pressure	Constant volume = 1.0 in. w.c. Variable volume (DCV) = 1.8 in. w.c.	HV7	
		Fan and motor	65% mechanical/motor efficiency in absence of whole unit EER rating; Motor efficiency as per Standard 90.1-2010 Table 10.8B	HV7	
	Ventilation/ Exhaust	Cooling capacity for which an economizer is required	≥ 54,000 Btu/h	HV14	
		DCV/performance-based ventilation	Control ventilation air based on pollutant concentrations in space (CO_2, VOCs, etc.)	HV15–16	
		Exhaust air recovery	A (humid) zones= 75% total effectiveness; B (dry) zones = 75% sensible effectiveness; Capture min. 80% available exhaust air, including general and bathroom, for energy recovery	HV10	
		Exhaust airflow control	Control based on occupancy using time clock or occupancy sensor	HV17	
	Ducts and Dampers	Outdoor air damper	Motorized damper	HV14	
		Duct seal class	Seal Class A	HV18, 20	
		Insulation level	R-6	HV19	
QA	M&V/ Benchmarking	Electrical submeters	Design and circuit for separate submeters for lighting, HVAC, general 120V, service water heater, renewables, and whole building	QA15–16	
		Benchmarks	Benchmark monthly energy use	QA17	
		Training	Facility operator on continuous benchmarking	QA13–14	

*Note: Where the table says "No recommendation," the user must meet the more stringent of either the applicable version of ASHRAE/IES Standard 90.1 or the local code requirements.

REFERENCES

ASHRAE. 2004. ANSI/ASHRAE/IESNA Standard 90.1-2004, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning.

Briggs, R.S., R.G. Lucas, and Z.T. Taylor. 2003. Climate classification for building energy codes and standards: Part 1—Development process. *ASHRAE Transactions* 109(1):109–121.

How to Implement Recommendations

5

Recommendations for energy-saving measures for each climate zone are contained in the individual tables in Chapter 4, "Design Strategies and Recommendations by Climate Zone." The following how-to tips are intended to provide guidance on good practices for implementing the recommendations as well as cautions to avoid known problems and obstacles to energy-efficient construction.

ENVELOPE

OPAQUE ENVELOPE COMPONENTS

Good Design Practice

EN1 ***Cool Roofs*** **(Climate Zones: ❶ ❷ ❸)**

For a roof to be considered a cool roof, a Solar Reflectance Index (SRI) of 78 or higher is recommended. A high reflectance keeps much of the sun's energy from being absorbed while a high thermal emissivity surface radiates away any solar energy that is absorbed, allowing the roof to cool more rapidly. Cool roofs are typically white and have a smooth surface. Commercial roof products that qualify as cool roofs fall into three categories: single ply, liquid applied, and metal panels. Examples are presented in Table 5-1.

Table 5-1 Examples of Cool Roofs

Category	Product	Reflectance	Emissivity	SRI
Single ply	White polyvinyl chloride (PVC)	0.86	0.86	107
	White chlorinated polyethylene (CPE)	0.86	0.88	108
	White chlorosulfonated polyethylene (CPSE)	0.85	0.87	106
	White thermoplastic polyolefin (TSO)	0.77	0.87	95
Liquid applied	White elastomeric, polyurethane, acrylic coating	0.71	0.86	86
	White paint (on metal or concrete)	0.71	0.85	86
Metal panels	Factory-coated white finish	0.90	0.87	113

The solar reflectance and thermal emissivity property values represent initial conditions as determined by a laboratory accredited by the Cool Roof Rating Council (CRRC). An SRI can be determined by the following equation:

$$SRI = 123.97 - 141.35(\chi) + 9.655(\chi^2)$$

where

$$\chi = \frac{20.797 \times \alpha - 0.603 \times \varepsilon}{9.5205 \times \varepsilon + 12.0}$$

and

α = solar absorptance = 1 – solar reflectance

ε = thermal emissivity

These equations were derived from ASTM E1980 (ASTM 2011) assuming a medium wind speed. Note that cool roofs are not a substitute for the appropriate amount of insulation.

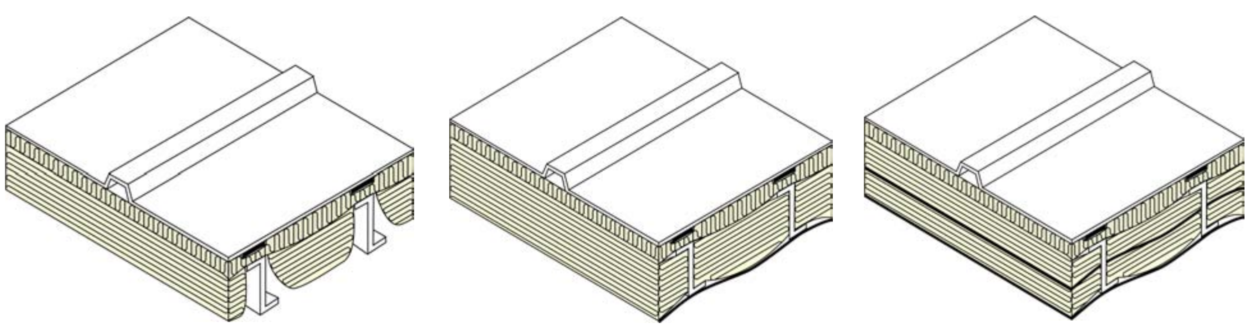
EN2 *Roofs—Insulation Entirely above Deck* (Climate Zones: all)

The insulation entirely above deck should be continuous insulation (c.i.) rigid boards. Continuous insulation is important because no framing members are present that would introduce thermal bridges or short circuits to bypass the insulation. When two layers of c.i. are used in this construction, the board edges should be staggered to reduce the potential for convection losses or thermal bridging. If an inverted or protected membrane roof system is used, at least one layer of insulation is placed above the membrane and a maximum of one layer is placed beneath the membrane.

EN3 *Roofs—Metal Buildings* (Climate Zones: all)

Metal buildings pose particular challenges in the pursuit of designing and constructing advanced buildings. The metal skin and purlin/girt connection, even with compressed fiberglass between them, is highly conductive, which limits the effectiveness of the insulation. A purlin is a horizontal structural member that supports the roof covering. In metal building construction, this is typically a z-shaped, cold-formed steel member; a steel bar or open web joists can be used for longer spans.

The thermal performance of metal building roofs with fiberglass batts is improved by treating the thermal bridging associated with fasteners. Use of foam blocks is a proven technique to reduce the thermal bridging. Thermal blocks, with minimum dimensions of 1 × 3 in., should be R-5 rigid insulation installed parallel to the purlins. (See Figure 5-1.)



(a) (b) (c)

Figure 5-1 (EN3) Prefabricated Metal Roofs Showing Thermal Blocking of Purlins—(a) Filled Cavity; (b) Liner System, One Layer; and (c) Liner System, Two Layers

Thermal blocks can be used successfully with standing seam roofs that utilize concealed clips of varying heights to accommodate the block. However, a thermal block cannot be used with a through-fastened roof that is screwed directly to the purlins because it diminishes the structural load carrying capacity by "softening" the connection and restraint provided to the purlin by the roof.

In climate zones 1 through 3, the recommended construction is a filled cavity that has the first layer of insulation, R-19, parallel to and between the purlins and the second layer of insulation, R-10, perpendicular to and over the top of the purlins (see Figure 5-1a).

In climate zones 4 through 7, the recommended construction is a liner system that has the first layer of insulation parallel to and between the purlins and the second layer of insulation perpendicular to and over the top of the purlins (see Figure 5-1b).

In climate zone 8, the recommended construction is a liner system with the first and second layers of insulation, R-25 and R-11 respectively, parallel to and between the purlins and the third layer of insulation, R-11, perpendicular to and over the top of the purlins (see Figure 5-1c).

Rigid c.i. can be added to provide additional insulation if required to meet the U-factors listed in Appendix A. In any case, rigid c.i. or other high-performance insulation systems may be used provided the total roof assembly has a U-factor that is less than or equal to the U-factor found in the appropriate climate zone construction listed in Appendix A.

EN4 *Walls—Mass* (Climate Zones: all)

Mass walls are defined as those with a heat capacity (HC) exceeding 7 Btu/ft^2·°F. Insulation may be placed on either the inside or the outside of the mass wall. When insulation is placed on the exterior, rigid c.i. is recommended. When insulation is placed on the interior, a furring or framing system may be used, provided the total wall assembly has a U-factor that is less than or equal to the appropriate climate zone construction listed in Appendix A.

The greatest advantages of mass can be obtained when insulation is placed on its exterior. In this case, the mass absorbs heat from the interior spaces that is later released in the evenings when the buildings are not occupied. The thermal mass of a building (typically contained in the building envelope) absorbs heat during the day and reduces the magnitude of indoor air temperature swings, reduces peak cooling loads, and transfers some of the absorbed heat into the night hours. The cooling load can then be covered by passive cooling techniques (natural ventilation) when the outdoor conditions are more favorable. An unoccupied building can also be precooled during the night by natural or mechanical ventilation to reduce the cooling energy use. This same effect reduces heating load as well.

Thermal mass also has a positive effect on thermal comfort. High-mass buildings attenuate interior air and wall temperature variations and sustain a stable overall thermal environment. This increases thermal comfort, particularly during mild seasons (spring and fall), during large air temperature changes (high solar gain), and in areas with large day-night temperature swings.

Designers should keep in mind that the occupants will be the final determinants on the extent of the usability of any building system, including thermal mass. Changing the use of internal spaces and surfaces can drastically reduce the effectiveness of thermal storage. The final use of the space must be considered when making the heating and cooling load calculations and incorporating possible energy savings from thermal mass effects.

EN5 *Walls—Metal Building* (Climate Zones: all)

In all climate zones, rigid c.i. on the exterior of the girts is recommended. Alternate constructions are allowed provided the total wall assembly has a U-factor that is less than or equal to the U-factor found in the appropriate climate zone construction listed in Appendix A.

If a single layer of faced fiberglass batt insulation is proposed, the insulation is installed continuously perpendicular to the exterior of the girts and is compressed as the metal panel is attached to the girts. If a layer of faced fiberglass batt insulation and a layer of rigid board insulation are proposed, the layer of faced fiberglass is installed continuously perpendicular to

Benefits and Applicability of Cool Roofs

Cool roof surfaces help reduce the net gain of solar energy within a building by limiting the amount of energy that is absorbed through the roof. Accordingly, cool roof surfaces decrease cooling loads, which can result in measurable energy savings in warm climates.

The effect of a cool roof surface on building energy use intensity (EUI) was quantified through a simulation of annual energy use. The starting point was a set of models—one for each of the 16 climate zones—of a 40,500 ft^2 single-story building. Models were defined according to the prescriptive path in this Guide for achieving 50% savings with a dedicated outdoor air system (DOAS) and a zone-level water-source heat pump (WSHP) HVAC system. For each climate zone, models were simulated with and without the application of a cool roof surface. For the standard roof surface, a thermal emissivity of 0.9 and a solar reflectance of 0.3 were assumed, resulting in an SRI of 32. For the cool roof surface, a thermal emissivity of 0.9 and a solar reflectance of 0.7 were assumed, resulting in an SRI of 86, roughly equivalent to that of white paint on metal or concrete or of a white elastomeric acrylic coating.

Application of cool roof surfaces resulted in significant cooling savings except in very cold climates (climate zones 6, 7, and 8). On average, cool roof surfaces reduced cooling energy by

- 5.1% in arid climates (2B, 3B–CA, 3B, 4B, and 5B),
- 3.1% in humid climates (1A, 2A, 3A, 4A, and 5A),
- 1.9% in marine climates (3C and 4C), and
- 0.9% in very cold climates (6A, 6B, 7, and 8).

Application of a Cool Roof Surface
Photography courtesy of NREL; Credit: Craig Miller Productions

the exterior of the girts and is compressed as the rigid board insulation is installed continuously and perpendicular then attached to the girts from the exterior (on top of the fiberglass). The metal panels are then attached over the rigid board insulation using screws that penetrate through the insulation assembly into the girts.

In addition to reducing cooling loads, cool roofs can also increase heating loads, especially in cold climates. Accordingly, applicability of cool roofs is typically limited to warm climates where the increase in heating energy cost is offset by the decrease in cooling energy cost. The analysis indicated that application of cool roof surfaces should result in a net energy cost savings (assuming national average utility rates) in most warm and mild climates. The cool roof analysis results are included in the table below.

Note that a net energy cost savings indicates that application of a cool roof surface is cost-effective when there is no first cost associated with the application, such as for a single-ply membrane top layer application. For cool roof surfaces that require first-cost investment, cost-effectiveness will depend on many factors, including climate, architectural characteristics, cost of cool roof application, R-value of roof insulation, and payback requirements. If cool roof technology is evaluated early in the design process, first costs may be partially or fully offset with the costs saved from the downsizing in HVAC capacity that a reduction in cooling load allows.

Not all physical processes that effect or are affected by roof surface properties were captured by the analysis. First, the analysis did not take into account the amount of time that a roof may be covered in snow during the winter months. Nonreflective roofs can absorb more heat than cool roofs can during winter months, but not when covered by snow. Second, the analysis did not account for the reduction in air temperature above the roof surface that a cool roof can provide during summer months. By reducing the temperature of the air above the roof surface, a cool roof reduces the condenser inlet temperature of rooftop HVAC units, increasing cooling efficiency.

Cool Roof Analysis Results

Savings Metric	Climate Zone							
	1A	2A	2B	3A	3B–CA	3B	3C	4A
Cooling Savings	3.8%	2.7%	5.5%	3.7%	3.3%	5.9%	1.8%	2.5%
Net Energy Cost Savings	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Savings Metric	**Climate Zone**							
	4B	**4C**	**5A**	**5B**	**6A**	**6B**	**7**	**8**
Cooling Savings	5.6%	2.0%	2.9%	5.0%	3.0%	–0.5%	–0.4%	1.6%
Net Energy Cost Savings	Yes	No	No	No	No	No	No	No

EN6 *Walls—Steel Framed* (Climate Zones: all)

Cold-formed steel framing members are thermal bridges to the cavity insulation. Adding exterior foam sheathing as c.i. is the preferred method to upgrade the wall's thermal performance because it will increase the wall's overall thermal performance and tends to minimize the impact of the thermal bridging.

Alternative combinations of cavity insulation and sheathing in thicker steel-framed walls can be used provided that the proposed total wall assembly has a U-factor that is less than or equal to the

U-factor for the appropriate climate zone construction listed in Appendix A. Batt insulation installed in cold-formed steel-framed wall assemblies is to be ordered as "full width batts" and installation is normally by friction fit. Batt insulation should fill the entire cavity and not be cut short.

EN7 *Floors—Mass* (Climate Zones: all)

Insulation should be continuous and either integral to or above the slab. This can be achieved by placing high-density extruded polystyrene above the slab with either plywood or a thin layer of concrete on top. Placing insulation below the deck is not recommended due to losses through any concrete support columns or through the slab perimeter.

Exception: Buildings or zones within buildings that have durable floors for heavy machinery or equipment could place insulation below the deck.

EN8 *Floors—Metal Joist or Steel Framed* (Climate Zones: all)

Insulation should be installed parallel to the framing members and in intimate contact with the flooring system supported by the framing member in order to avoid the potential thermal short-circuiting associated with open or exposed air spaces. Nonrigid insulation should be supported from below, no less frequently than 24 in. on center.

EN9 *Slab-on-Grade Floors, Unheated* (Climate Zones: 4 5 6 7 8)

Rigid c.i. should be used around the perimeter of the slab and should reach the depth listed in the recommendation tables in Chapter 4 of the Guide or to the bottom of the footing, whichever is less.

EN10 *Slab-on-Grade Floors, Heated* (Climate Zones: all)

Rigid c.i. should be used around the perimeter of the slab and should reach to the depth listed or to the frost line, whichever is deeper. Additionally, in climate zone 8, continuous insulation should be placed below the slab as well.

Note: In areas where termites are a concern and rigid insulation is not recommended for use under the slab, a different heating system should be used.

EN11 *Slab Edge Insulation* (Climate Zones: all)

Use of slab edge insulation improves thermal performance, but problems can occur in regions that have termites.

EN12 *Doors—Opaque, Swinging* (Climate Zones: all)

A U-factor of 0.7 corresponds to a double-panel metal door. A U-factor of 0.5 corresponds to an insulated double-panel metal door. If at all possible, single swinging doors should be used. Double swinging doors are difficult to seal at the center of the doors unless there is a center post. Double swinging doors without a center post should be minimized and limited to areas where width is important. Vestibules or revolving doors can be added to further improve energy efficiency. See Figure 5-2.

EN13 *Doors—Opaque, Roll-up* (Climate Zones: all)

Roll-up doors are recommended to have R-4.75 rigid insulation or meet the recommended U-factor. When meeting the recommended U-factor, the thermal bridging at the door and section edges is to be included in the analysis. Roll-up doors that have solar exposure should be painted with a reflective (or high emissivity) paint and/or should be shaded. The issue with metal doors is that they typically have poor emissivity and collect heat, which is transmitted through even the best insulated door and causes cooling loads and thermal comfort issues in the space.

EN14 *Doors—Opaque, Sectional or Sliding* (Climate Zones: all)

Sectional or sliding doors are recommended to have R-14 rigid insulation or meet the recommended U-factor. When meeting the recommended U-factor, the thermal bridging at the

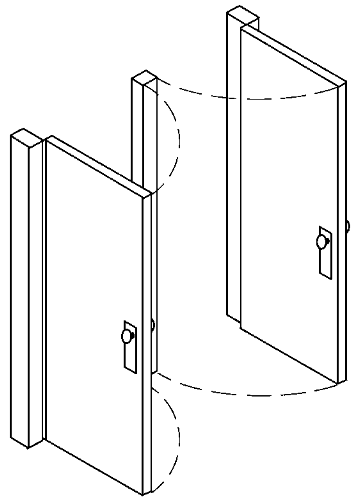


Figure 5-2 (EN12) Swinging Opaque Doors with Hinges on One Side, Closing to a Center Post

door and section edges is to be included in the analysis. Insulated panel doors can provide a tighter seal to minimize infiltration.

EN15 *Vehicular/Dock Infiltration—Door Closed* (Climate Zones: all)

Vehicular/dock doors that have air leakage in the closed position need to have weather seals that minimize air infiltration to less than 0.28 cfm/ft^2 of door area. Dock seals should conform closely to the sides, top, and bottom of the door to minimize area of opening for infiltration.

EN16 *Vehicular/Dock Infiltration—Door Open, Truck in Place* (Climate Zones: all)

Infiltration through loading dock doors when open for truck loading or unloading can result in significant energy consumption. ANSI/ASRAE/IESNA Standard 90.1-2004 (ASHRAE 2004) requires that loading dock doors be equipped with weather seals to restrict infiltration when the doors are open and the trailers are in place. Dock seals or shelters should conform closely to the sides and top of the trailer to minimize the opening area for infiltration. Two additional apertures, the dock leveler operating clearance and the hinge gap of the trailer doors, are not covered by ASHRAE/IES Standard 90.1-2004. Dock levelers should be furnished with brush-type seals to reduce the effective leakage crack width of the operating clearance from approximately 1.125 in. to less than 0.25 in. Inflatable or foam type hinge seals should be utilized to minimize infiltration through this gap.

EN17 *Vestibules* (Climate Zones: all)

Vestibules are recommended for building entrances routinely used by occupants, not for emergency exits, maintenance doors, loading docks, or any other specialty entrances. Vestibules are to be designed so that in passing through the vestibule it is not necessary for the interior and exterior doors to open at the same time.

Interior and exterior doors should have a minimum distance between them of not less than 16 ft when the doors opening into and out of the vestibule are equipped with automatic, electrically driven, self-closing devices. Interior and exterior doors should have a minimum distance between them of not less than 7 ft when the doors opening into and out of the vestibule are equipped with automatic, mechanically driven, self-closing devices.

Vestibules should be designed only as areas to traverse between the exterior and the interior. The exterior envelope of conditioned vestibules should comply with the requirements for a conditioned space. Either the interior or exterior envelope of unconditioned vestibules should comply with the requirements for a conditioned space.

Pedestrian traffic flows have a direct influence on the airflow patterns that impact the building energy use. A study exploring air leakage through high-use automatic doors indicates that adding a vestibule can reduce unwanted air leakage by up to 38%. For vestibules designed such that the inner doors are directly across from the outer doors, the study estimates that adding a vestibule reduces infiltration by 31% for sliding door configurations and by 35% for swinging door configurations. The study also indicates that vestibules designed such that inner and outer doors face perpendicular to each other can further reduce infiltration (from 31% to 38% for sliding doors) by eliminating direct leakage paths (Yuill et al. 2000). Walkways that have 90° turns are the preferred geometry (Figure 5-3a). Straight through entrance and 90° exit walkways are the next best geometry (Figure 5-3b). Offset walkways (Figure 5-3c) are better than straight though walkways (Figure 5-3d), which are the least efficient.

EN18 *Air Infiltration Control* (Climate Zones: all)

The building envelope should be designed and constructed with a continuous air barrier system to control air leakage into or out of the conditioned space and should extend over all surfaces of the building envelope (at the lowest floor, exterior walls, and ceiling or roof). An air barrier system should also be provided for interior separations between conditioned space and space designed to maintain temperature or humidity levels that differ from those in the conditioned space by more than 50% of the difference between the conditioned space and design ambient conditions. If possible, a blower door should be used to depressurize the building to find leaks in the infiltration barrier. At a minimum, the air barrier system should have the following characteristics.

- It should be continuous, with all joints made airtight.
- Air barrier materials used in frame walls should have an air permeability not to exceed 0.004 cfm/ft^2 under a pressure differential of 0.3 in. w.c. (1.57 lb/ft^2) when tested in accordance with ASTM E2178 (ASTM 2003).
- The system should be able to withstand positive and negative combined design wind, fan, and stack pressures on the envelope without damage or displacement and should transfer the load to the structure. It should not displace adjacent materials under full load.
- It should be durable or maintainable.
- The air barrier material of an envelope assembly should be joined in an airtight and flexible manner to the air barrier material of adjacent assemblies, allowing for the relative movement of these assemblies and components due to thermal and moisture variations, creep, and structural deflection.
- Connections should be made between:
  a. Foundation and walls
  b. Walls and windows or doors
  c. Different wall systems
  d. Wall and roof
  e. Wall and roof over unconditioned space
  f. Walls, floors, and roof across construction, control, and expansion joints
  g. Walls, floors, and roof to utility, pipe, and duct penetrations
- All penetrations of the air barrier system and paths of air infiltration/exfiltration should be made airtight.

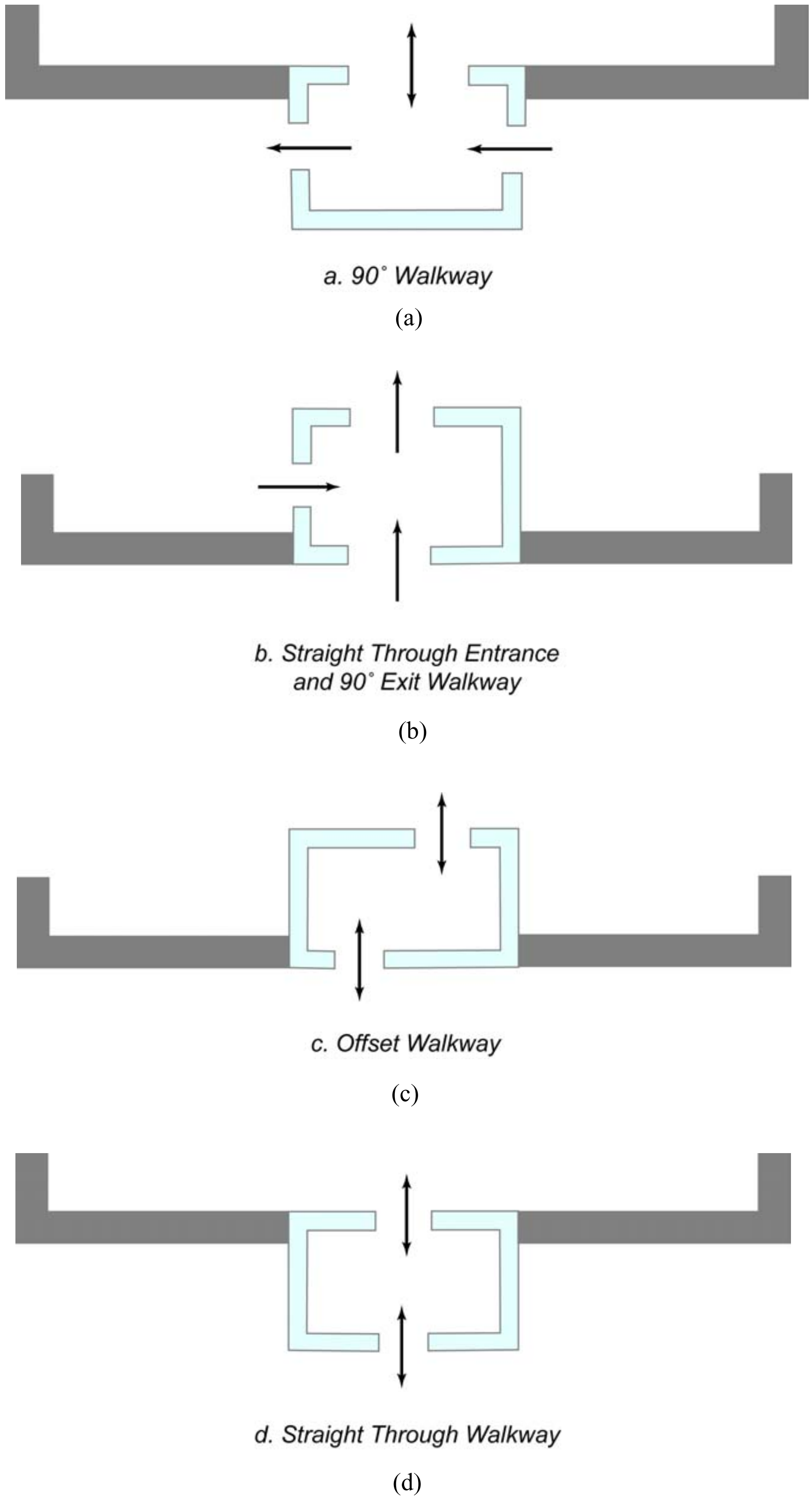


Figure 5-3 (a) 90° Walkway Vestibule Configuration; (b) Straight Through Entrance and 90° Exit Walkway Vestibule Configuration; (c) Offset Walkway; and (d) Straight Through Walkway Vestibule Configuration

Options

EN19 *Alternative Constructions* (Climate Zones: all)

The climate zone recommendations in Chapter 4 provide only one solution for upgrading the thermal performance of the envelope. Other constructions can be equally effective, but they are not included in this Guide. Any alternative construction that is less than or equal to the U-factor or F-factor presented in Appendix A for the appropriate climate zone construction is equally acceptable. U-factors and F-factors that correspond to all the recommendations are presented in Appendix A.

Procedures to calculate U-factors are presented in *ASHRAE Handbook—Fundamentals* (ASHRAE 2009), and expanded U-factor and F-factor tables are presented in ANSI/ASHRAE/IES Standard 90.1-2010, Appendix A (ASHRAE 2010c).

Cautions

The design of building envelopes for durability, indoor environmental quality, and energy conservation should not create conditions of accelerated deterioration or reduced thermal performance or problems associated with moisture, air infiltration, or termites.

The following cautions should be incorporated into the design and construction of the building.

EN20 *Moisture Control* (Climate Zones: all)

Building envelope assemblies (see Figures 5-4a and 5-4b) should be designed to prevent wetting, high moisture content, liquid water intrusion, and condensation caused by diffusion of water vapor. See *ASHRAE Handbook—Fundamentals*, Chapter 24, for additional information.

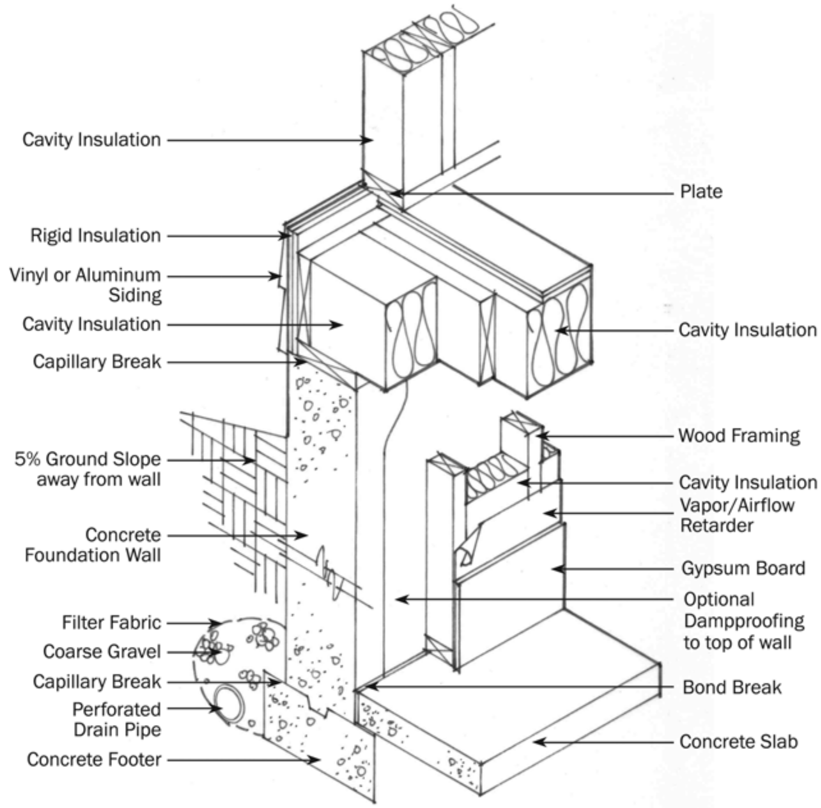
EN21 *Thermal Bridging—Opaque Components* (Climate Zones: all)

Thermal bridging in opaque components occurs when continuous conductive elements connect internal and external surfaces. The adverse effects of thermal bridging are most notable in cold climates where frost can develop on internal surfaces and lead to water droplets when the indoor temperature increases. The solution to thermal bridging is to provide thermal breaks or continuous insulation. Common problem areas are parapets, foundations, and penetrations of insulation.

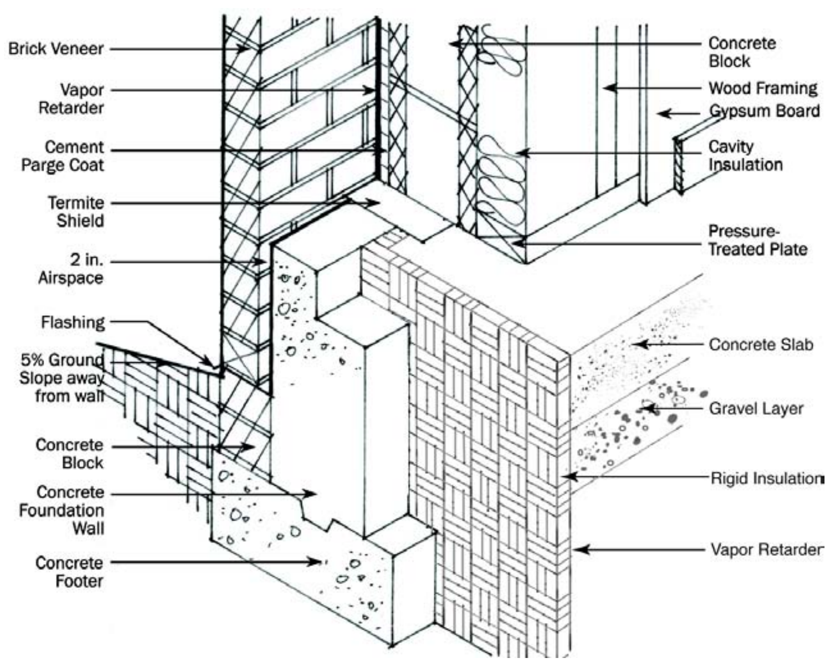
The thermal bridge at parapets is shown in Figure 5-5a. The problem is that a portion of the wall construction is extended to create a parapet that extends above the roof to ensure worker safety per local code requirements. Since the wall insulation is on the outer face of the structure, it does not naturally connect to the insulation at the roof structure. One solution is to wrap the parapet with continuous insulation in the appropriate locations as shown in Figure 5-5b. Alternatively, a structural solution would be an independent parapet structure in which the roof insulation line is periodically penetrated to limit the thermal bridging effects

Thermal bridges in foundations are shown in Figure 5-6a. This detail usually occurs because of construction sequences for the installation of the below-grade insulation. It is often an oversight to complete the connection between the below-grade and above-grade thermal protections because the installations of these elements are separate both in discipline and in time period on site. Design and construction teams must make it clear that action to establish thermal continuity of the insulation line is a performance requirement of both parties in order to achieve a typical solution as shown in Figure 5-6b. The insulation above grade needs to be protected with a surface or coating that is weather resistant and abuse tolerant.

Penetrations of insulation in which metal structural members must protrude from the building in order to support an external shade or construction (balcony, signage, etc.) need to be insulated. In these cases, the insulation should wrap the protruding metal piece when it is within the indoor cavity, and an additional length of insulation should be provided on its connection in each direction in order to prevent excessive heat transfer from the metal into the internal wall cavity. It should be noted that a façade consultant can model these types of situations to advise on the various lengths and thicknesses of insulation that would be needed to limit adverse impacts from condensation within the wall cavity.

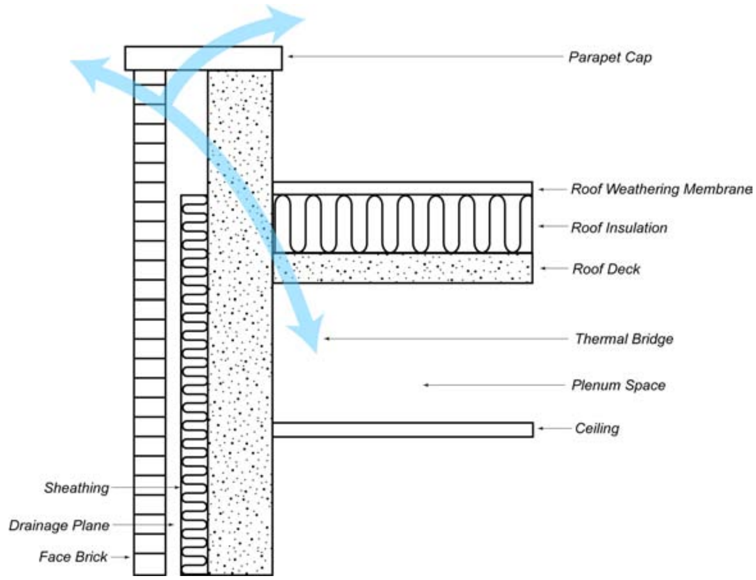


(a)

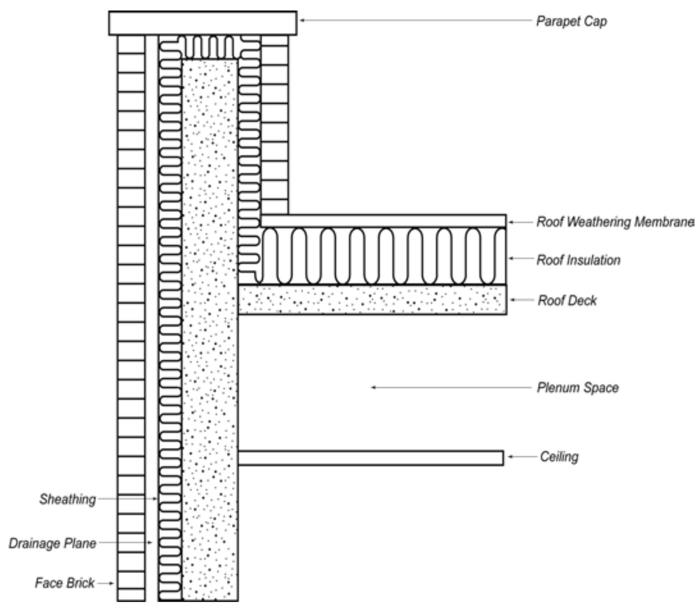


(b)

Figure 5-4 (EN20) (a) Moisture Control for Mixed Climates and (b) Moisture Control for Warm, Humid Climates



(a) Problem



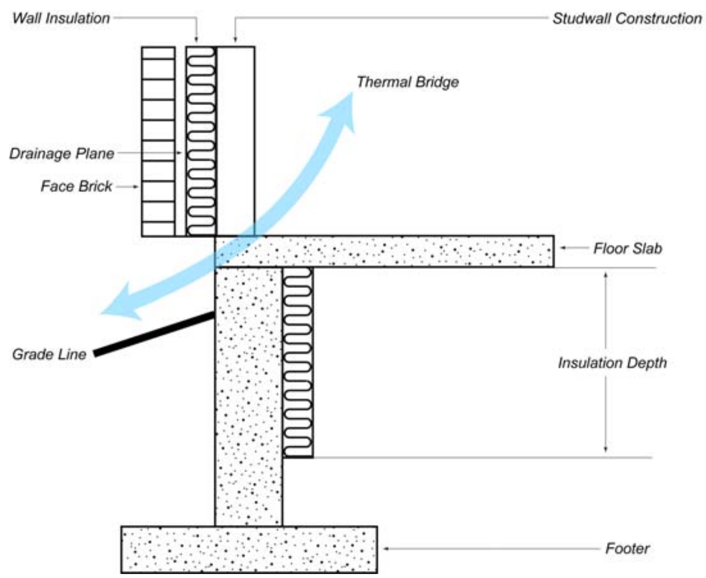
(b) Solution

Figure 5-5 (EN21) Thermal Bridges—Parapets

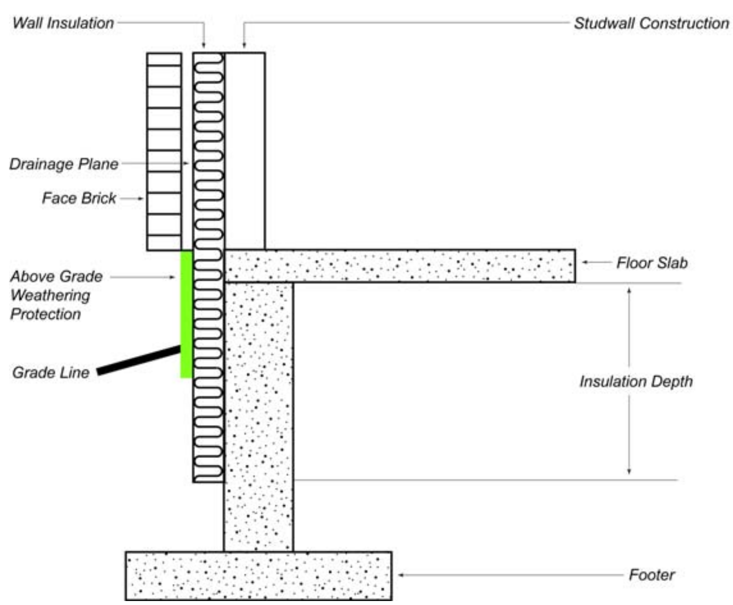
EN22 Thermal Bridging—Fenestration (Climate Zones: all)

In colder climates, it is essential to select a glazing unit to avoid large amounts of condensation. This requires an analysis to determine internal surface temperatures, since glass is a higher thermal conductor as compared to the wall in which it is mounted. There is a risk of condensation occurring on the inner face of the glass whenever the inner surface temperature approaches the room dew-point temperature.

Careful specification is also necessary to ensure that the framing of the glazed units also incorporates a thermal break.



(a) Problem



(b) Solution

Figure 5-6 (EN21) Thermal Bridges—Foundations

A typical fenestration situation where thermal bridging arises is at the detailing of how a piece of well-insulated glazing abuts the opaque façade, whether it be through a metal mullion system or whether it just frames into the wall. Windows that are installed out of the plane of the wall insulation are an example of this construction, as shown in Figure 5-7a. Installing the fenestration outside of the plane of the wall insulation defeats the thermal break in the window frame. In cold climates this causes condensation and frosting. The normal solution is not to rebuild the wall but to blow hot air against the window to increase the interior surface temperature of the frame and glazing, which increases the temperature difference across the glazing and reduces the interior film coefficient thermal resistance from 0.68 to 0.25 h·ft^2·F°/Btu.

Fenestration should be installed to align the frame thermal break with the wall thermal barrier (see Figure 5-7b). This will minimize the thermal bridging of the frame due to fenestration projecting beyond the insulating layers in the wall.

VERTICAL FENESTRATION

Good Design Practice

EN23 *Vertical Fenestration Descriptions* (Climate Zones: all)

Fenestration refers to the light-transmitting areas of a wall or roof, mainly windows and skylights but also including glass doors, glass block walls, and translucent plastic panels. Vertical fenestration includes sloped glazing if it has a slope equal to or more than 60° from the horizontal. If it slopes less than 60° from the horizontal, the fenestration falls in the skylight category. This means clerestories, roof monitors, and other such fenestration fall in the vertical category.

The recommendations for vertical fenestration are listed in Chapter 4 by climate zone. To be useful and consistent, the U-factors for windows should be measured over the entire window assembly, not just the center of glass. Look for a label that denotes the window rating is certified by the National Fenestration Rating Council (NFRC). The selection of high-performance window products should be considered separately for each orientation of the building and for daylighting and viewing functions.

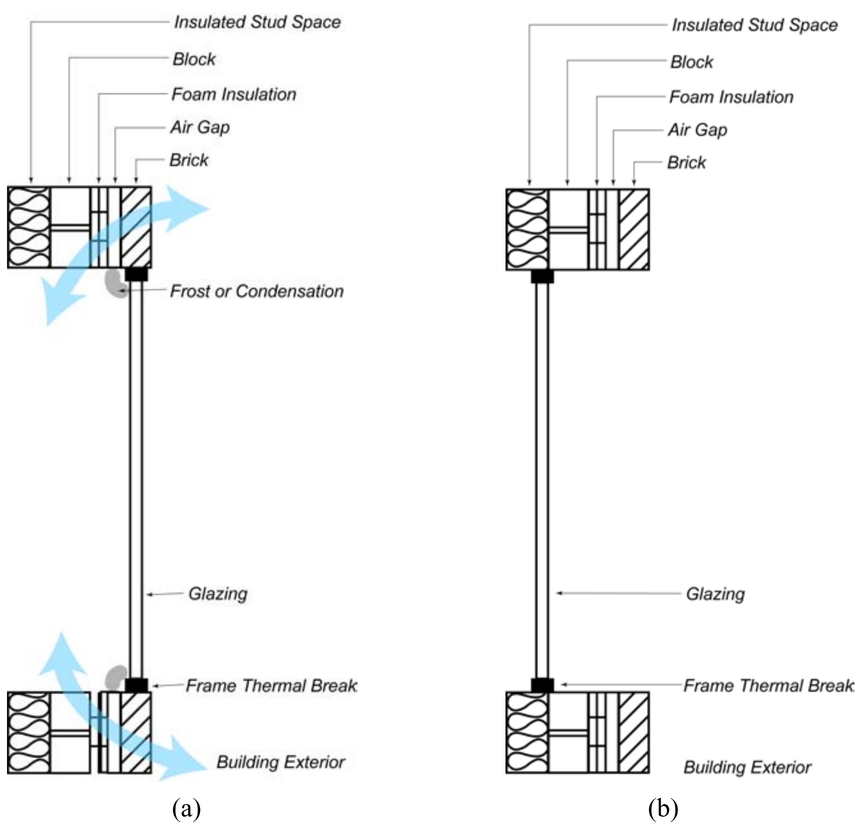


Figure 5-7 (EN22) Thermal Break at (a) Window Frame and (b) in Window Frame Aligned with Wall Insulation

Table 5-2 shows the type of vertical glazing construction that generally corresponds to the U-factors and solar heat gain coefficient (SHGC) values in the Chapter 4 recommendation tables.

To meet the SHGC recommendations for vertical fenestration in Chapter 4, use the SHGC multipliers for permanent projections as provided in Table 5.5.4.4.1 in ASHRAE/IES 90.1-2010 (ASHRAE 2010). These multipliers allow for a higher SHGC for vertical fenestration with overhangs.

WINDOW DESIGN GUIDELINES FOR THERMAL CONDITIONS

Uncontrolled solar heat gain is a major cause of energy use for cooling in warmer climates and thermal discomfort for occupants. Appropriate configuration of windows according to the orientation of the wall on which they are placed can significantly reduce these problems.

EN24 *Outdoor Control of Unwanted Solar Heat Gain* (Climate Zones: all)

Significantly greater energy savings are realized when sun penetration is blocked before it enters the windows. Horizontal overhangs at the tops of the windows are most effective for south-facing façades and must continue beyond the width of the windows to adequately shade them (see Figure 5-8). Vertical fins oriented slightly north are most effective for east- and west-facing façades. Consider louvered or perforated sun control devices, especially in primarily overcast and colder climates, to prevent a totally dark appearance in those environments.

Warm Climates

EN25 *Building Form and Window Orientation* (Climate Zones: ❶ ❷ ❸)

In warm climates, south-facing glass can be more easily shielded and can result in less solar heat gain and glare than can east- and west-facing glass. During early building configuration studies and pre-design, preference should be given to site layouts that permit elongating the building in the east-west direction and that permit orienting more windows to the north and south. A good design strategy avoids areas of glass that do not contribute to the view from the building or to the daylighting of the space. If possible, configure the building to maximize north- and south-facing walls and glass by elongating the floor plan. Since sun control devices are less effective on the east and west façades, the solar penetration through the east- and west-facing

Table 5-2 Vertical Fenestration Descriptions

Climate Zone		U-Factor	SHGC	VT	Glass and Coating	Gas	Spacer	Frame
1	Table	1.20	0.25	0.25	Low-e semi-reflective	Air	Metal	Thermally improved
	Actual	0.50	0.26	0.40				
2	Table	0.70	0.25	0.25	Low-e semi-reflective	Air	Metal	Thermally improved
	Actual	0.50	0.26	0.40				
3	Table	0.60	0.25	0.32	Low-e semi-reflective	Air	Metal	Thermally improved
	Actual	0.50	0.26	0.40				
4	Table	0.50	0.4	0.51	Selective low-e double	Air	Metal	Thermally improved
	Actual	0.50	0.37	0.59				
5-6	Table	0.45	0.4	0.51	Selective low-e double	Air	Insul.	Break
	Actual	0.41	0.36	0.59				
7-8	Table	0.40	0.45	0.45	Selective low-e double	Argon	Insul.	Break
	Actual	0.37	0.35	0.59				

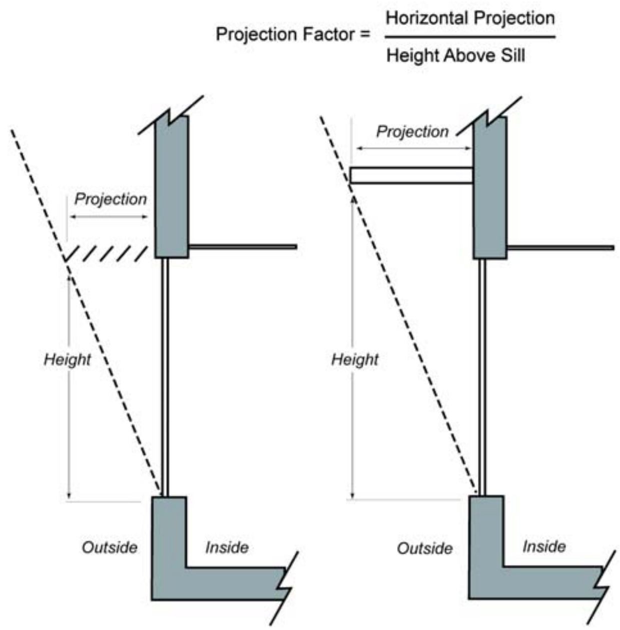


Figure 5-8 (EN24) Windows with Overhang

glazing should be minimized. This can be done by reducing the area of glazing or, if the glass is needed for view or egress, by reducing the SHGC, or by utilizing automated operable shading systems. For buildings where a predominantly east-west exposure is unavoidable, more aggressive energy conservation measures will be required in other building components to achieve an overall 50% energy savings. See DL1 and DL8 for more information on building orientation and shape as they relate to daylighting strategies.

EN26 *Glazing* (Climate Zones: ❶ ❷ ❸)

For north- and south-facing windows, select windows with a low SHGC and an appropriate visible transmittance (VT). Certain window coatings, called *selective low-e*, transmit the visible portions of the solar spectrum selectively, rejecting the nonvisible infrared sections. These glass and coating selections can provide a balance between VT and solar heat gain. Window manufacturers market special "solar low-e" windows for warm climates. All values are for the entire fenestration assembly, in compliance with NFRC procedures, and are not simply center-of-glass values. For warm climates, a low SHGC is much more important for low-energy use than the window assembly U-factor. Windows with low SHGC values will tend to have a low center-of-glass U-factor because they are designed to reduce the conduction of the solar heat gain absorbed on the outer layer of glass through to the inside of the window.

Cold Climates

EN27 *Window Orientation* (Climate Zones: ❹ ❺ ❻ ❼ ❽)

Only the south glass receives much sunlight during the cold winter months. If possible, maximize south-facing windows by elongating the floor plan in the east-west direction and relocating windows to the south face. Careful configuration of overhangs or other simple solar control devices will allow for passive heating when desired but prevent unwanted glare and solar overheating in the warmer months. To improve performance, operable shading systems should be employed that achieve superior daylight harvesting and passive solar gains and also operate more effectively when facing east and west directions. Unless such operable shading systems are used, glass facing east and west should be significantly limited. Areas of glazing facing north should be optimized for daylighting and view and focus on low U-factors to minimize heat loss and maintain thermal comfort by considering triple glazing to eliminate drafts and discomfort. During early building configuration studies and pre-design, preference should be given to sites that permit elongating the building in the east-west direction and that permit orienting more windows to the south. See DL1 and DL8 for more information on building orientation and shape as they relate to daylighting strategies.

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DAYLIGHTING

While not used for energy savings in the recommendation tables of Chapter 4, daylighting can be considered for brand image and additional energy savings.

From an energy standpoint, the energy savings from reduced loads as the electric lights are dimmed in response to daylight must be greater than any increase in heating/cooling loads from using skylights or rooftop monitors to bring the daylight into the space. The following recommendations for skylights and rooftop monitors are for spaces of at least 2500 ft^2 in area.

Daylighting should be thought of in two components: direct sun, which should be avoided in general retail spaces due to the high light levels and the high contrasts created by direct sunlight, and diffuse daylight, which can be very beneficial in brightening the sales area, allowing a reduction in the energy used by the electric lighting system.

GENERAL RECOMMENDATIONS

When considering daylighting in your design, please consider the following actions:

- Use rooftop monitors instead of skylights to light the general sales floor area for better control of heat gain/loss.
- Windows should be included in office/conference rooms and break rooms to promote a connection to the outdoors.
- Use light-colored matte finishes on ceiling and walls to promote inter-reflections and better utilization of electric light and daylight.
- Controls should include daylight dimming on the sales floor, time switches (time clocks) in corridors, and vacancy sensing with daylight override in offices, break rooms, and conference rooms.
- In stock rooms where the lighting-power density (LPD) allowance is low at 0.6 W/ft^2 and occupancy sensors are required, the occupancy patterns and HVAC impacts will have a significant impact in determining if skylights will be cost-effective.

Therefore, if your ceiling height is above 15 ft in areas greater than 5000 ft^2 and you want to follow the prescriptive requirements of ASHRAE/IES Standard 90.1-2010 (ASHRAE 2010), you will need to install skylights that daylight at least 50% of the sales floor area in climate zones 1 through 5. In all climate zones, rooftop monitors may be used to achieve the minimum 50% of sales floor daylighted. For this Guide, daylighting applies to spaces 2500 ft^2 and greater.

ASHRAE/IES Standard 90.1-2010
Skylight Prescriptive Requirements

Maximum Skylight Fenestration Area:

- The total skylight area shall not exceed 5% of the gross roof area.

Minimum Skylight Fenestration Area in climate zones 1 through 5:

- Any enclosed space that is 5000 ft^2 and greater with ceiling heights greater than 15 ft shall have a total daylight area under skylights or rooftop monitors of at least half the floor area.
- The skylights shall provide a minimum skylight-to-daylight area under skylights of 3% with a skylight VT of at least 0.40 or provide a minimum skylight effective aperture of at least 1%.
- The skylights shall have a glazing material or diffuser with a measured haze value greater than 90% when tested according to ASTM D1003 (ASTM 2011).
- General lighting in the daylight area shall be automatically controlled in response to daylight.

DL1 *Daylighting Early in the Design Process* (Climate Zones: all)

In retail buildings, the program and site plan are the main drivers that establish the shape and footprint of the building. Planning criteria often result in creating deep floor plates that work well for rooftop monitors or skylights. Additionally, and often an afterthought, daylight through windows into offices, break rooms, and conference rooms can save energy and provide employees a connection to the outdoors.

Daylight strategies impact the design at different levels of scale in each phase of design and can be characterized by four categories.

Pre-design. During pre-design, the daylight strategies' focus is on building configuration studies and the shaping of the floor plate. The goal is to maximize access to windows and daylight in offices, break rooms, and conference rooms by orienting fenestration in a predominantly north- and south-facing direction.

In the sales floor area, rooftop monitors and skylights should be strategically placed to evenly light the space to 50% of the design footcandle target level on an annual basis.

Schematic design. During the schematic design phase, daylight strategies are about interiors, focusing on spatial considerations to optimize daylight penetration and defining ceiling height, layout, and partition wall transparency. The planning focus is directed toward coordinating space types where daylight is desired.

Design development. During the design development phase, the daylighting strategies' focus is on envelope design to optimize quantity and quality of daylight while minimizing solar gains. The interior design focus is on surface reflectivity and optimizing sales display layout to align with visual and thermal comfort requirements.

Construction documents (CDs). Coordination of electrical lighting includes the placement of photosensors and occupancy sensors for controlling automated daylight switching and dimmable ballasts.

DL2 *Daylighting Analysis Tools to Optimize Design* (Climate Zones: all)

This Guide is designed to help achieve energy savings of 50% without energy modeling, but energy and daylighting modeling programs make evaluating energy-saving trade-offs faster and daylighting designs far more precise.

Annual savings will have to be calculated with an annual whole-building energy simulation tool after the daylighting design tools have been used to determine the footcandles in the spaces and after toplighting has been appropriately sized. Current daylighting analysis tools do not help with heating and cooling loads or other energy uses; they predict only illumination levels and electric lighting use.

DL3 *Space Types, Layout, and Daylight* (Climate Zones: all)

The goal is to identify the areas that best lend themselves to daylight harvesting and to recommend layout strategies that allow locating rooftop monitors or skylights in sales and storage spaces. The potential of energy saving through daylighting varies and depends on program and space types, which can be broadly characterized by the following three categories of occupied spaces.

Sales floor. Significant energy can be saved in these spaces due to the high electric LPDs, but due to varying sales areas (clothing, sporting goods, electronics, jewelry, home furnishings, etc.) daylighting needs to be carefully coordinated with the desired retail image. The following bulleted tips apply to the sales floor:

- Space rooftop monitors or skylights edge to edge 1.4 times the floor to ceiling height.
- Dim the electric lighting in response to the available daylight by using open-loop photocells located in the rooftop monitors or skylights.
- Provide a skylight area of 3% to 5% of the roof area with a skylight VT of at least 0.40 (or provide a minimum skylight effective aperture of at least 1%).

Successful Daylight Integration in Retail Spaces

Lighting energy efficiency must be considered together with merchandising strategies. Some energy efficiency measures—daylighting, for example—are more easily justified in certain climate zones as part of merchandising strategies because of their long energy-only payback periods. This case study is a good example of successful integration of merchandising strategy and energy efficiency improvements, even though daylighting initially was hard to justify on energy cost savings alone.

Best Buy is a medium box retailer that has made an effort to offer more self-service options for customers over the past five years. This means that Best Buy stores need to be well lit for customers to find products. The stores are uniformly lit with a criterion of 70 footcandles (fc) at 2.5 ft above the finished floor (AFF) with key locations of higher illuminance (100 fc 2.5 ft AFF) to emphasize customer support or special product areas.

Design Strategy

Best Buy started using daylighting in California in response to Title 24 code requirements (CBSC 2011). Based on successful energy savings and shopper feedback, the company now uses daylighting in all stores, new and upgraded. Daylighting is used for the entire sales floor where ambient lighting is dimmed

Sales Floor with Ambient Lighting Off and Shaded Accent Lighting
Photography Credit: Dennis Schroeder, NREL

- If using skylights, the glazing material or diffuser should have a measured haze value greater than 90% when tested according to ASTM D1003.

Storage areas. While the storage electric LPD is low, daylighting large storage areas can be an effective solution because during daylight hours the electric lighting can be turned off. The following tips apply to storage areas:

- Space rooftop monitors or skylights edge to edge 1.4 times the floor to ceiling height.
- Switch the electric lighting in response to the available daylight by using open-loop photocells located in the rooftop monitors or skylights.
- Provide a skylight area of 3% to 5% of the roof area with a skylight VT of at least 0.40 (or provide a minimum skylight effective aperture of at least 1%).
- If using skylights, the glazing material or diffuser should have a measured haze value greater than 90% when tested according to ASTM D1003.

to OFF and the limited accent lighting used remains ON. To prevent ambient daylight from washing out accent lighting, Best Buy uses backlit panels and track lighting aimed at shaded products to effectively highlight key merchandise.

Lakewood, CO, Best Buy Store

In their new Lakewood, CO, store, Best Buy achieved the following levels:

- Installed LPD: LPD = 0.98 W/ft^2 providing a reduction from Code LPD = 35%
- EUI = 11 kBtu/ft^2/yr providing a reduction from Code Derived EUI = 58%

The strategies employed at this store include the following:

- Primarily ambient lighting (about 10% of installed lighting load is considered accent lighting).
- Selection of lamps with a high color temperature (5000 K) to match daylight from the skylights.
- Fixture efficacy of 89 initial lumens per watt.
- Daylighting in vestibules using sidelighting from entrance doors.
- Daylighting in checkout, all sales, car radio installation, storage, and receiving areas using skylights with a skylight-to-floor-area ratio (SFR) of 4%, visible light transmittance (VLT) of 60%, SHGC of less than 0.49, and U-factor of less than 0.82.
- A well-defined sequence of operations that directs installers and commissioning agents to properly zone and stage electric lighting according to daylighting requirements and timers. The sequence also dictates security system integration to allow for nighttime-ON only when managers enter the building.

Barriers to Energy Savings

Older stores have had installation errors and commissioning oversights that increased reported energy use. These types of selection, installation, and operations error with respect to the intended sequence of operations can show an increase in predicted energy use of up to 35% (Greden et al. 2007). Newer equipment in the Lakewood store was easier to install and operate, so there was only a 10% gap between predicted and metered lighting energy use. Because that difference was due to display lighting that was left on at night, the measurement and verification process provided simple time clock adjustments to correct the situation.

Offices and conference rooms. From an energy performance standpoint, the first priority is to locate offices and conference rooms on the perimeter, preferably in a north- and south-facing configuration. The following tips apply to the open office spaces:

- Locate workstations next to windows within the primary and secondary daylight zones to maximize daylight harvesting.
- Use local articulated task lights to supplement daylight and electric light.
- Use manual ON occupancy sensors with daylight override.

DL4 *Skylight Thermal Transmittance* (Climate Zones: all)

As an alternate to skylights, use rooftop monitors for skylighting. Never use east- or west-facing rooftop monitors due to excessive summer heat gain and the difficulty of controlling direct sunlight. Rooftop monitors with operable glazing may also help provide natural ventilation in temperate seasons. Typically, north-facing rooftop monitors have less than 20% of the heat gain of skylights but provide less than a third of the daylighting potential per square foot of prismatic skylights. Additional considerations include the following:

- Shade south-facing rooftop monitors and skylights with exterior/interior sun controls such as screens, baffles, or fins.
- Insulate the skylight curb above the roof line with rigid c.i. in conditioned spaces.
- In hot climates:
  - Use north-facing rooftop monitors for skylighting to eliminate excessive solar heat gain and glare.
  - Reduce thermal gain during the cooling season by using skylights with a low overall thermal transmittance (U-factor).
- In moderate and cooler climates:
  - Use either north- or south-facing rooftop monitors for skylighting to eliminate excessive solar heat gain and glare.
  - Reduce summer heat gain as well as winter heat loss by using skylights with a low overall thermal transmittance. Use a skylight frame that has a thermal break to reduce heat loss/gain and winter moisture condensation on the frame.

DL5 *Interactions* (Climate Zones: all)

Thermal gains and losses associated with skylights should be balanced with daylight-related savings achieved by reducing electric lighting consumption.

Skylight well height (side walls below the skylight) should be as short as possible. If a skylight well is over 2 ft high, splay skylight opening at 45° to maximize daylight distribution and minimize glare (see Figure 5-9).

Ceiling reflectance values should be a minimum of 80% to reduce contrast between skylight and ceiling.

DL6 *Expanded Recommendations for Electric Lighting Controls in Daylight Zones* (Climate Zones: all)

Additional considerations include the following:

- The daylight zone is the area of the skylight plus 70% of the floor-to-ceiling dimension in all directions from the edge of the skylight (see Figure 5-10).
- Sales floor area electric lights should automatically dim in response to daylight.
- In storage areas use photocell switching in response to daylight.

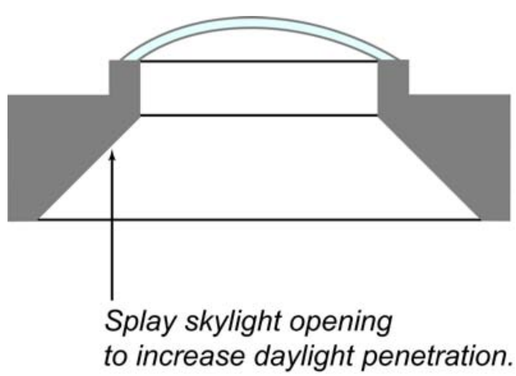


Figure 5-9 (DL5) Skylight (Horizontal Fenestration)

- Concentrate luminaires in groups around skylights; when daylight zones overlap, a single control zone may be used. The daylighting control system and/or photosensor should include a five-minute time delay or other means to avoid cycling caused by rapidly changing sky conditions and a one-minute fade rate to change the light levels by dimming.
  - *Dimming controls.* Specify dimming ballasts that dim down to at least 20% of full output. Photosensors should include a one-minute fade rate to change the light levels by dimming and should exhibit a slow, smooth, linear response. New lamps must be burned-in per manufacturer recommendation prior to dimming. Follow manufacturers' recommendations for setup and calibration setting.
  - *Switching controls.* Specify multilevel daylight switching to provide 100%/50%/0% light levels. Follow manufacturers' recommendations for setup and calibration setting.

DL7 *Photosensor Placement* (Climate Zones: all)

Photosensors used should be specified for indoor illumination range.

An "open-loop" system is one where the photocell responds only to daylight levels but is still calibrated to the desired light level received on the floor of the sales and storage areas. The best location for the photosensor is inside the skylight well.

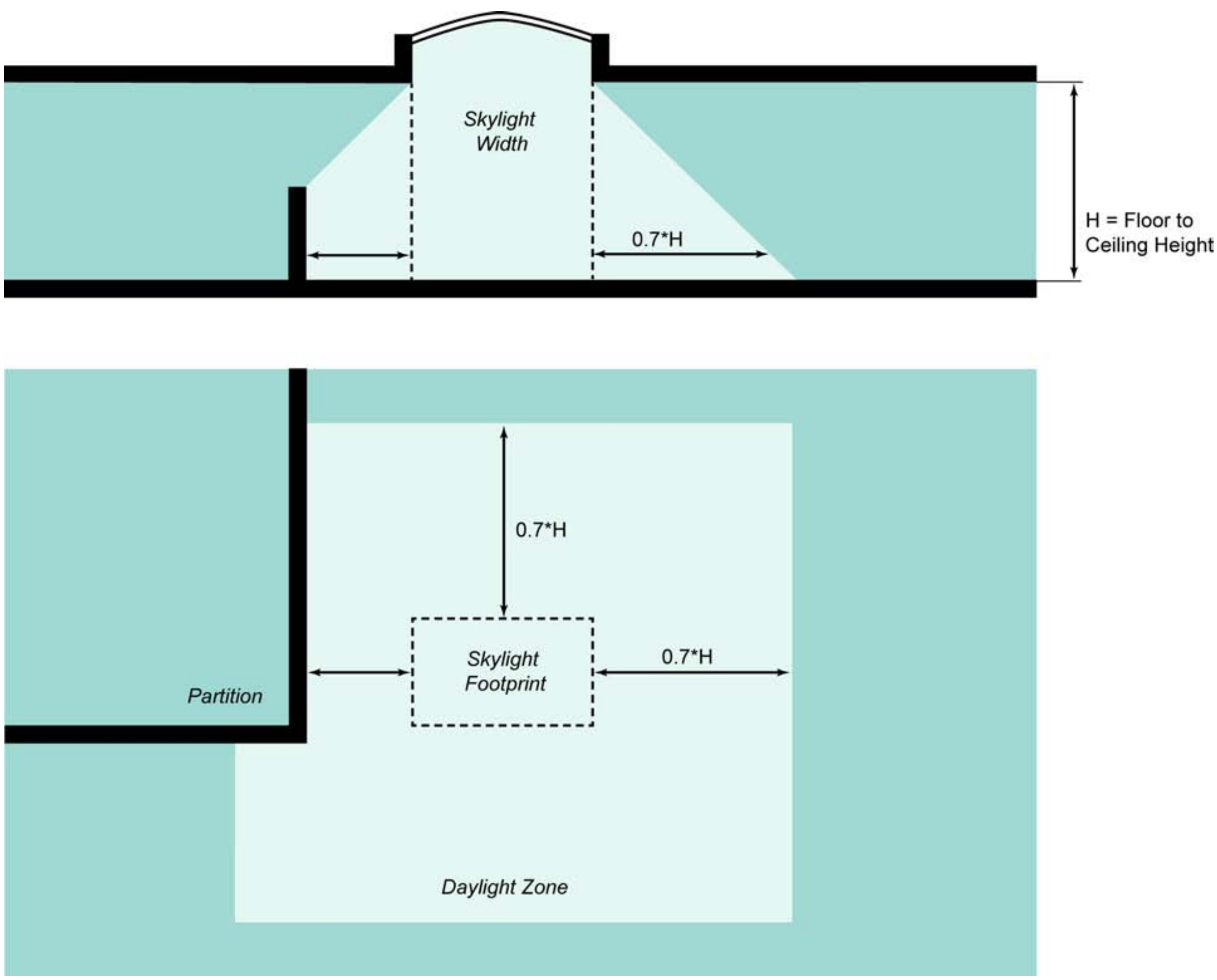


Figure 5-10 (DL6) Daylight Zone under Skylight

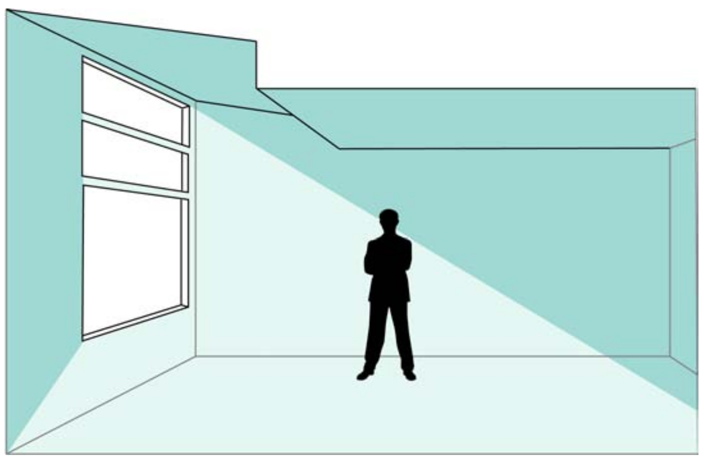
DL8 Sidelighting—Ceiling and Window Height (Climate Zones: all)

For good daylighting in office-type spaces, a minimum ceiling height of 9 ft is recommended. When daylighting is provided exclusively through sidelighting, it is important to elevate the ceiling on the perimeter and extend glazing to the ceiling. Additional reflectance to increase lighting levels can be achieved by sloping the ceiling up toward the outside wall. (See Figure 5-11.)

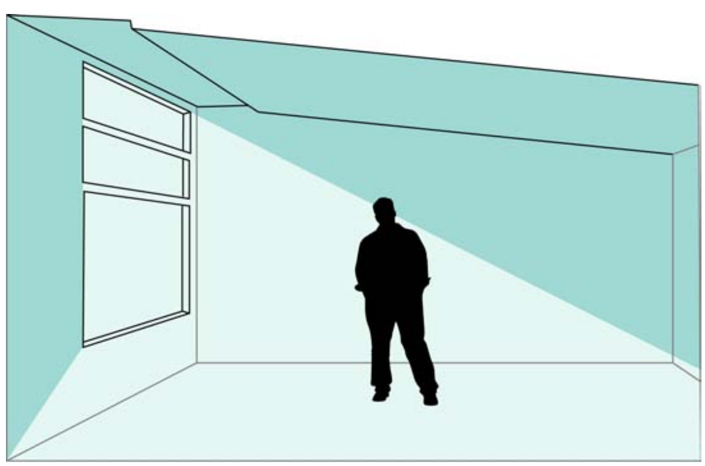
The effective aperture (EA) for sidelighting is the area of glazing in an unobstructed wall multiplied by the VT of vertical glazing, divided by the floor area in the daylight zone.

DL9 Calibration and Commissioning (Climate Zones: all)

Even a few days of occupancy with poorly calibrated controls can lead to permanent overriding of the system and loss of all savings. All lighting controls must be calibrated and commissioned after the finishes are completed and the racking and products are in place. Follow manufacturers' recommendations for setup and calibration setting (most photosensors require daytime and nighttime calibration settings). The photosensor manufacturer and the quality



(a)



(b)

Figure 5-11 (DL8) (a) Raised and (b) Sloped Ceiling at Façade

assurance (QA) provider should be involved in the calibration. Document the calibration and commissioning settings and calendar intervals for future recalibration. Systems should be checked for proper calibration and operation at least every two years.

DL10 *Daylight Levels* (Climate Zones: all)

Occupants expect higher combined light levels in daylighted spaces. Consequently, it is more acceptable to occupants when the electric lights are calibrated to dim or switch when the combined daylight and electric lighting exceeds 1.20 times the designed light level; i.e., if the ambient electric light level is designed for 50 maintained fc, the electric lights should begin to dim when the combined level is 60 fc (50 × 1.20 = 60). When using daylight switching, the electric lights should step down only when the initial designed light level is maintained after the step down.

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ELECTRIC LIGHTING DESIGN

GOALS FOR RETAIL LIGHTING

Lighting design for merchandising spaces should support the goals of attracting customers, facilitating merchandise evaluation, and enabling completion of the sale. These goals can be obtained in consort with lower LPDs through the use of high-efficacy light sources and good design practice.

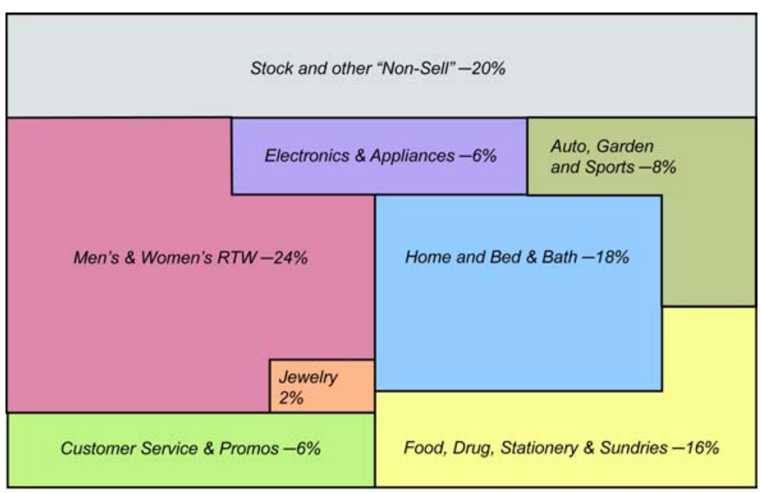
Ambient lighting. Uniform general illuminance for merchandising areas as recommended in IES RP-2-12 (IES 2012) ranges from 15 to 50 fc depending on the store type and merchandising strategies. Designing to the appropriate Illuminating Engineering Society (IES) recommended ambient footcandle levels will establish the framework for an effective accent lighting strategy that achieves accent lighting goals without sacrificing energy efficiency.

Perimeter lighting. Illuminance ratios of no more than 2:1 of ambient light levels are recommended for the creation of effective perimeter wall lighting. Effective perimeter lighting includes adequate illumination levels for merchandise evaluation as well as contributing to the perceived brightness within the space. Using T8 or T5 asymmetric wall-wash luminaries is an energy-effective option for creating perimeter lighting. Alternately, dedicated valance or casework with high-efficacy lighting is another energy-effective solution as long as automatic controls to turn the lighting off are included.

Accent lighting. Accent lighting can enhance merchandise color, texture, and detail, which aids in merchandise attraction as well as merchandise evaluation. To create visual contrast and interest, accent lighting ratios of 5:1 (accent to general ambient and/or perimeter) should be designed as recommended in IES RP-2-12. Effective accent lighting is best accomplished with point source directional luminaries such as ceramic metal halide (CMH) and solid-state lighting (SSL), which also represent the most energy-efficient accent option.

Other lighting features to consider that play important roles in merchandise recognition and the perceived lighted environment include decorative lighting (pendants, sconces, table lamps, etc.), internal casework lighting, and furniture/wall integrated lighting.

As shown in the plan schematic in Figure 5-12, there are different departments that may require different light levels and different lighting styles. Later in this chapter, the various space types are discussed in more detail, including basic lighting design recommendations (see EL20 to EL27).



Plan schematic for medium box retail footprint

Figure 5-12 Retail Space Planning Schematic

INTERIOR LIGHTING

Good Design Practice

EL1 Savings and Owner Acceptance **(Climate Zones: all)**

Lighting first and foremost must provide proper light levels and color quality to foster sales. These goals, however, need not nor should be counterproductive to good energy efficiency practices. Accomplishing lighting quality and quantity with the least amount of needed energy also aids in a successful retail environment and improved profitability. The LDPs in the Chapter 4 recommendation tables are based on IES recommended light levels using high-performance fluorescent lamps and fixtures for the general lighting and CMH or SSL for the accent lighting (IES 2011). To maximize energy savings this Guide does not recommend incandescent lamps.

EL2 Space Planning—Office, Conference, and Break Rooms **(Climate Zones: all)**

Wherever possible, locate offices, conference rooms, and break rooms on the outside wall of the building to provide employees a connection to the outdoors. Use manual ON occupancy sensors with a daylight override to save the most energy in these spaces.

EL3 Space Planning—Sales Floor and Circulation Aisles **(Climate Zones: all)**

Corporate space plans are often a given in medium to big box retail buildings, and these plans usually contain circulation aisles that extend deep into the store. Store designers place focal points and/or end walls where the aisle terminates or changes direction. This design technique creates focal corridors. Use of focal lighting to highlight a feature or end wall within a focal corridor draws customers deeper into the store.

EL4 Lighting Walls/Perimeter Lighting **(Climate Zones: all)**

Better eye adaptation, luminous comfort, and impressions of pleasantness and space can be achieved when light is distributed to the walls. Lighting vertical surfaces and walls also contributes to the visual effect of perceived brightness. The perceived brightness enforces the positive effects of a well-lit space, and without this brightness a space can look dark and under lighted, which may result in adding additional lighting, which in turn increases energy use. To effectively light surfaces and walls, use dedicated wall-wash luminaires. Alternately, applications that use direct coves or valance lighting or locate ambient lighting fixtures closer to walls are also acceptable options for wall lighting. There will be occurrences where it is desirable to use accent lighting for certain perimeter wall features. When placing fixtures, always consider the final location of the merchandise to be illuminated, not the wall surface behind the merchandise (see Figure 5-13). Techniques similar to those for lighting walls also are applicable to providing the vertical illumination required at mirrors in fitting rooms.

EL5 Additional Interior Lighting/Accent Lighting **(Climate Zones: all)**

The following additional LPDs, from the recommendation tables in Chapter 4, are available for adjustable lighting equipment that is specifically designed and directed to highlight merchandise (accent lighting) above and beyond the base 1.15 W/ft^2 allowance. (See EL16 for switching recommendations.)

- 0.6 W/ft^2 (sporting goods, small electronics)
- 0.9 W/ft^2 (furniture, clothing, cosmetics, artwork)
- 1.5 W/ft^2 (jewelry, crystal, china)
- 0.4 W/ft^2 (spaces not listed above)

The use of accent lighting to highlight all merchandise does not create the proper contrast ratios. Use accent lighting to highlight key merchandise locations or vignettes to "feature display" light levels (a minimum of three to a maximum of ten times the general and/or perimeter merchandise lighting level in the area of the display).

Along perimeters, accent lighting should be aimed up at 40° from vertical (straight down) to reduce reflected glare off specular surfaces. The aimed accent light should not exceed 45° from vertical, and attention should be given to both the direct and reflected characteristics of the light distribution. In areas open to customer view from multiple vantage points, the accent lighting should be aimed up at no more than 40° from vertical to reduce the possibility of direct glare visible to the customer (see Figure 5-13).

EL6 *Decorative Lighting* (Climate Zones: all)

Decorative lighting (wall sconces and pendant fixtures) can add visual interest and focus to the space, especially at the sales transaction area. These fixtures are included in the tabulation of the base LPD, and consideration should be given to energy-efficient solutions, including compact fluorescent, CMH, and SSL lighting.

EL7 *Casework Lighting* (Climate Zones: all)

Casework lighting is not included in the tabulation of the LPD as long as it is integrated into the casework and is installed by the casework manufacturer. Lighting for casework must remain sensitive to the energy goals of the space. Strong consideration should be given to energy-efficient or low-energy solutions, including linear fluorescent, fiber optic, and linear SSL sources.

EL8 *Office Task Lighting* (Climate Zones: all)

If the space planning recommendations in EL2 are followed by locating office spaces in the daylight zones, task lighting should not be needed during the daylight hours. In areas next

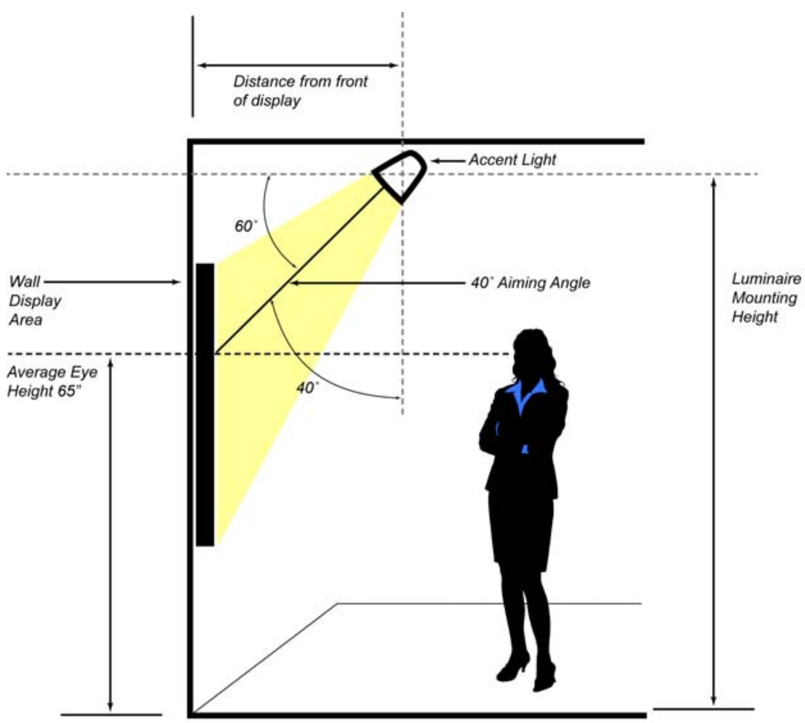


Figure 5-13 (EL4 and EL5) Accent Lighting Aimed at 40°

Perimeter Wall Accent Lighting

Early in 2010, the design and engineering groups at Macy's began testing light-emitting diode (LED) accent lights as potential replacements for traditional halogen accent lights in their stores. Large-scale tests in multiple departments were set up in several stores to evaluative LED display light options from four potential suppliers.

The four LED PAR-38 spotlight designs ranging from 11 to 13 W were evaluated against a 47 W halogen spotlight, which was their current base accent light model. For additional evaluation, the four LED types were also compared to a 25 W CMH accent light that was being used to highlight products in higher ceiling environments and in high utility rate markets.

The results of testing, as indicated in the composite model, demonstrated the LED lamps' ability to provide three to four times the "accent punch" in center beam footcandles while consuming only 25% to 30% of the energy used by the baseline halogen. Furthermore, when compared with the more powerful CMH accent light, the LEDs produced close to 70% to 90% of the punch (footcandles) while using 50% less energy.

Additional benefits of LED spotlights include exceedingly long lamp life (30,000 to 50,000 hours), precise beam control, and a range of available "white light" chromaticity with high color rendering.

Macy's is installing the LED display lighting to replace most halogen and some CMH display lights. More than 400,000 halogen bulbs have already been replaced with LED bulbs. Additional plans are in place to more than double that installation with another 400,000 LED lights planned in more than 400 store locations. Over the next two years, the retailer hopes to cut energy consumption on a kilowatt-hour-per-square-foot basis by 10% over current levels.

Composite Model of Testing Results

Reprinted with permission from Macy's; Photography by Amy Laughead-Riese to windows, task lights should be evaluated on a needs basis and should not be automatically installed at each workstation. Connect all task lights to plugstrips that have integrated local occupancy sensors to turn the lights off when the space is unoccupied.

Educate employees on the need to turn off task lights when they leave the space and periodically educate employees on the goal of saving energy by turning off task lights. Confirm that task lights are controlled and are turned off during daylight hours and when the occupant leaves the space during nondaylight hours.

EL9 *Light-Colored Interior Finishes* (Climate Zones: all)

Higher surface reflectance on ceilings, walls, and floors may increase store visibility through the front windows and will increase lighting levels, perceived brightness, and energy performance within the space. However, higher reflectance may not conform to a retailer's brand image. Energy savings outlined in this Guide are based on reflectance of 80-50-20 (ceiling-wall-floor). If the reflectance is lower, then additional attention to the ambient lighting energy requirements may be necessary. Avoid direct lighting of specular surfaces (mirrors, glass, polished metals, or polished stone) in customer areas, if possible; otherwise, carefully consider the reflected light component and its effect on the customer.

An 80%+ ceiling and 70%+ wall reflectance is preferred in daylight zones (see DL2). Reflectance values are available from paint and fabric manufacturers. Reflectance should be verified by the QA provider.

In addition, take the shape and finish of the ceiling into account. A flat painted or acoustical tile ceiling is the most efficient at reflecting light, making the space feel brighter; sloping ceilings and exposed roof structures, even if painted white, may significantly reduce the effective ceiling reflectivity, making the space feel darker.

Dark colors absorb light, making the space feel darker. To maximize inter-reflections and maintain higher light levels, color should be used as an accent and large colored surfaces should be avoided.

EL10 *Color Rendering Index* (Climate Zones: all)

The color rendering index (CRI) is a scale measurement identifying a lamp's ability, generally, to adequately reveal color characteristics. The scale maximizes at 100, with 100 indicating the best color-rendering capability. It is recommended that lamps specified for the ambient and accent lighting of retail merchandise have a CRI of 80 or greater to allow the consumer to effectively examine the color component of a product. Use of high color rendering light sources may also allow the lighting design to foster the required visual acuity with lower footcandles, which in turn may produce a lower LPD design.

EL11 *Color Temperature* (Climate Zones: all)

Color temperature is a scale identifying light source relative warmth or coolness—the higher the color temperature, the bluer the source. There are preliminary studies showing that higher color temperature light, in the 5000K range instead of the 3500K range, may provide better visual acuity; however, 5000K lamps may produce an artificially cool-looking building at night. The higher 5000K color temperature will also match the daylight from windows and skylights more closely than the lower 3500K color temperature sources.

Use 3000K, 3500K, or 4100K light sources as these color temperatures are available in multiple light sources and have gained customer recognition and acceptance. The decision as to which lamp color or multiple of lamp colors are used will be determined by merchandise objectives, brand identity, and operational considerations. For maximum energy utilization, use the highest-efficacy sources in each color temperature. Operational considerations may include creation of a purchasing plan to only buy one color temperature lamp to maintain color consistency during spot and/or group relamping.

Choosing Premium T8 Ballasts

When choosing a high-performance electronic ballast, look for the National Electrical Manufacturers Association (NEMA) Premium® mark on the ballast. This mark identifies ballasts that meet the Consortium for Energy Efficiency specifications for the most energy-efficient high-performance T8 ballasts available from ballast manufacturers. Generally the high-performance ballast will use 3 to 4 W less than a standard electronic ballast on a two-lamp T8 system.

NEMA Premium Ballast
Source: Michael Lane

EL12 Linear Fluorescent Lamps and Ballasts (Climate Zones: all)

To achieve the LPD recommendations in Chapter 4, high-performance T8 lamps and high-performance electronic ballasts are used for general lighting. The use of standard T8 and energy-saving T8 lamps will result in lower ambient light levels or an increased number of fixtures or lamps to achieve recommended light levels. Standard T8 and energy-saving T8 lamps also are available with lower CRI values than recommended in EL6, which may compromise the lighting solution.

T8 high-performance lamps. High-performance T8 lamps are defined, for the purpose of this Guide, as having a lamp efficacy of 90+ nominal lumens per watt, based on mean lumens divided by the cataloged lamp input watts. Mean lumens are published in lamp catalogs as the reduced lumen output that occurs at 40% of the lamp's rated life. High-performance T8s also are defined as having a CRI of 81 or higher and 94% lumen maintenance. The high-performance lamp is available in 32 W rapid start and 30 W, 28 W, and 25 W instant start lamps. Table 5-3 lists the average mean lumens per watt of the commonly manufactured 4 ft T8 lamps.

Ballasts. Only specify and install NEMA Premium ballasts. The NEMA Premium mark identifies ballasts that meet performance specifications for the most energy-efficient T8 ballasts available from ballast manufacturers. Generally the NEMA Premium ballast will use 5% less energy than standard electronic ballasts.

Ballast factor (BF) is a measure of the relative light output of the ballast. A BF of 1.0 would mean that the ballast is driving the lamp to produce 100% of the rated lamp lumens.

Table 5-3 4 ft T8 Lamps Meeting the 90+ Mean Lumens per Watt

T8 Lamp Description	Watts	Lumens		Mean LPW	Color Temp K
		Initial	Mean		
F32T8/RE70	32	2800	2613	82	3000, 3500, 4100
F32T8/RE70	32	2717	2535	79	5000
F32T8/RE80	32	2950	2807	88	3000, 3500, 4100
F32T8/RE80	32	2800	2660	83	5000
F32T8/RE80/HP	32	3100	2937	92	3000, 3500, 4100
F32T8/RE80/HP	32	3008	2848	89	5000
F32T8/25W/RE80	25	2458	2344	94	3000, 3500, 4100
F32T8/25W/RE80	25	2350	2241	90	5000
F32T8/28W/RE80	28	2725	2599	93	3000, 3500, 4100
F32T8/28W/RE80	28	2633	2509	90	5000
F32T8/30W/RE80	30	2850	2717	91	3000, 3500, 4100
F32T8/30W/RE80	30	2783	2653	88	5000

Note: Dark-shaded lamp types comply with the 90+ mean lumens per watt

Light output and wattage are related—the lower the BF the lower the wattage and the lower the light output. Normal BF ballasts are in the 0.85 to 1.0 range with most at 0.87 or 0.88. Low BF ballasts BFs below 0.85, can be used to reduce the light output and wattage of the system when the layout of the fixtures will overlight the space. High BF ballasts, with BFs above 1.0, can be used to increase the light output of the lamp in areas where the fixture layout will underlight the space—wattage will go up proportionally to the increased BF.

One-lamp, three-lamp, and four-lamp ballasts may be used but should have the same or better efficiency as the two-lamp ballast. Dimming ballasts do not need to meet this requirement.

The higher-output 3100 lumen lamps are visibly brighter than standard T8s. Using ballasts with a BF of 0.77 may provide more comfortable lamp brightness in direct luminaires where the lamp is visible without sacrificing efficiency.

Instant start ballasts. Instant start T8 ballasts provide the greatest energy savings options and the least costly option. Additionally, the parallel lamp operation allows one lamp to operate even if the other burns out.

> ***Caution:*** Instant start ballasts may reduce lamp life when controlled by occupancy sensors or daylight switching systems. However, even if the rated lamp life is reduced by 25%, if the lamp is off due to the occupancy sensor more than 25%, then the socket life (the length of time before the lamps are replaced) will be greater. If extended socket life is desired, consider programmed rapid start ballasts.

Programmed rapid start ballasts. Programmed rapid start ballasts use approximately 5% more power than instant start ballasts, but programmed rapid start ballasts are normally recommended on vacancy/occupancy sensor-controlled lamps due to increased lamp life and dimming capabilities. In this Guide programmed rapid start ballasts are not used to achieve the LPDs in Chapter 4; however, they may be used as long as the LPDs in Chapter 4 are not exceeded.

> ***Caution:*** Using programmed rapid start ballasts will result in slightly higher power consumption with the same light level. The wattage and light levels will need to be reduced in other areas to meet the LPD recommendations in Chapter 4.

T5 lamps and ballasts. T5HO and T5 lamps have initial lumens per watt that compare favorably to the high-performance T8. In addition, T5s use fewer natural resources (glass, metal, phosphors) than a T8 system with comparable lumen output. However, when evaluating the lamp and ballast at the "mean lumens" of the lamps, T5HO lamps perform more poorly. On instant start ballasts, high-performance T8s are 13% more efficient than T5s. In addition, since T5s have higher surface brightness and caution should be used when specifying open-bottom fixtures, it

Table 5-4 4 ft T5/T5HO Lamps Meeting the 90+ Mean Lumens per Watt

T5 Lamp Description	Watts	Lumens		Mean LPW	Color Temp, K
		Initial	Mean		
F54T5HO	54	5000	4600–4750	85–88	3000, 3500, 4100
F54T5HO	54	4800–4900	4410–4625	82–86	5000
F54T5HO (energy saver)	47–49	4800–5000	4410–4750	94–97	3000, 3500, 4100
F54T5HO (energy saver)	47–49	4600–4850	4230–4625	90–94	5000
F28T5	28	2900	2660–2750	95–98	3000, 35000, 4100
F28T5	28	2750–2840	2530–2641	90–94	5000
F28T5 (energy saver)	25–26	2900	2660–2750	102–110	3000, 3500, 4100

Note: Dark-shaded lamp types comply with the 90+ mean lumens per watt

may be difficult to achieve the LPD recommendation in Chapter 4 and maintain the desired light levels using current T5 technology as the primary light source. Table 5-4 lists the average mean lumens per watt of the commonly manufactured 4 ft T5/T5HO lamps.

EL13 *Ceramic Metal Halide (CMH)* (Climate Zones: all)

To achieve the LPD recommendations in Chapter 4, CMH lamps may be used for general ambient, accent lighting, and wall-washing. CMH lamps are defined, for the purpose of this Guide, as having a lamp efficacy of 50+ nominal mean lumens per watt and a CRI of 81 or greater. Use electronic ballasts on all CMH lighting.

EL14 *Solid-State Lighting (SSL), also referred to as Light-Emitting Diodes (LEDs)* (Climate Zones: all)

SSL is a solid-state semiconductor device that can produce a wide range of saturated colored light and can be manipulated with color mixing or phosphors to produce white light. To achieve the LPD recommendations in Chapter 4, SSL may be used for accent lighting.

White light SSL sources should be carefully evaluated for use in the lighting of retail merchandise, as color rendering and color temperature capabilities can vary widely by manufacturer. Products are now available that allow the adjustment of the intensity and the white color temperature, providing dynamic flexibility to the retail environment. They are not as efficient as T8 and T5 linear fluorescent at this time, although the technology is rapidly improving. The most recent offerings of SSL sources do perform favorably compared to lower wattage CMH lamps and will outperform most incandescent accent lighting.

Current SSLs are not the best option for the ambient lighting requirements of spaces in the retail models associated with this Guide. The ambient lighting for those spaces is based on T8 and T8 troffers and strip light luminaires with higher efficacy than similar footprint SSL luminaires. SSL luminaries, however, can be used effectively for casework and display integrated lighting. There may be applications in some spaces where smaller footprint downlights are desired and SSL or CFL lighting are both viable options. Effective accent and wall-washing strategies can be achieved using SSL, but intensity, color, and efficacy must be reviewed thoroughly. Single-color SSL is well suited to create interesting visual effects as it produces color more efficiently than filtering other white light sources with relatively low-e consumption.

Careful consideration should also be given to maintenance issues. SSL lamp life can offer advantages over other sources but does vary by color. In many cases, the SSL module cannot be replaced as a single lamp, like an incandescent source, for example; often the entire control board will have to be removed and replaced.

ASHRAE/IES Standard 90.1-2010 Occupancy Sensor Requirements

Occupancy sensors are required in ANSI/ASHRAE/IES Standard 90.1-2010 (ASHRAE 2010) in the following spaces:

- Classrooms, conference rooms, meeting rooms, and training rooms, employee lunch and break rooms, storage and supply rooms between 50 ft^2 and 1000 ft^2, rooms used for document copying and printing, office spaces up to 250 ft^2, restrooms, and dressing and locker rooms.

ASHRAE/IES Standard 90.1-2010 requires that occupancy sensors:

- Shall either be manual ON (vacancy sensor) or shall be controlled to automatically turn the lighting on to not more than 50% power
  - Exception: public corridors and stairwells, restrooms, primary building entrance areas and lobbies, and areas where manual ON operation would endanger the safety or security of the room or building occupants where full automatic ON is allowed

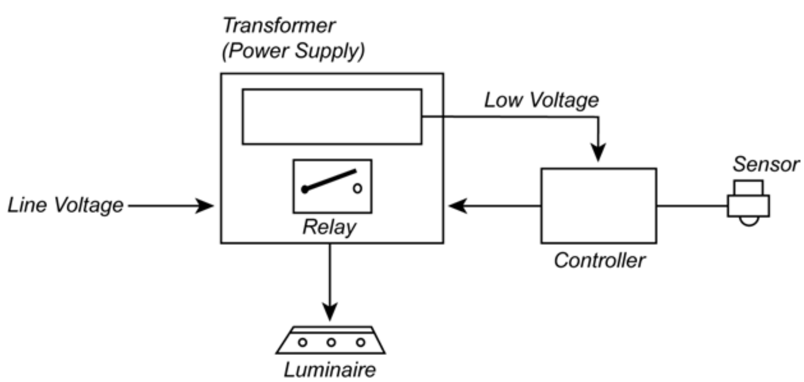


Figure 5-14 (EL15) Occupancy-Sensing Control

EL15 Occupancy Sensors (Climate Zones: all)

Use occupancy sensors in all nonsales areas and within the fitting rooms of sales areas with fitting rooms. The greatest energy savings are achieved with manual ON/automatic OFF vacancy sensors or automatic ON to 50% occupancy sensors. This avoids unnecessary operation when electric lights are not needed and greatly reduces the frequency of switching. It should not be possible for the occupant to override the automatic OFF setting of the vacancy or occupancy sensor. Unless otherwise recommended, factory-set occupancy sensors should be set for medium to high sensitivity and a 15 min time delay (the optimum time to achieve energy savings without excessive loss of lamp life). Review manufacturer's data for proper placement and coverage. Figure 5-14 shows a typical occupancy-sensing control setup.

The two primary types of occupancy sensors are infrared and ultrasonic. Infrared sensors are line-of-sight and should not be used in rooms where the user cannot see the sensor (e.g., storage areas with multiple aisles, restrooms with stalls). Ultrasonic sensors can be disrupted by high airflow and should not be used near air duct outlets.

Caution: Confirm that the occupancy sensor is set to manual ON operation during installation. Many manufacturers ship sensors with the default setting of automatic ON.

Private offices, conference rooms, and break rooms. In private offices, conference rooms, and break rooms in the daylight zone, dual circuit infrared wall box sensors with integrated daylight override should be preset for manual ON/automatic OFF operation or auto ON to 50%

(auto ON to 50% is achieved by using a dual-circuit occupancy sensor and having the first circuit set to auto ON and the second circuit set to manual ON). In private offices, conference rooms, and break rooms not in the daylight zone, use manual ON/automatic OFF without daylight override.

Other areas. In nondaylighted areas, ceiling-mounted occupancy sensors are preferred.

EL16 *Multilevel Switching* (Climate Zones: all)

For effective after-hours reduced lighting levels, specify luminaires with multiple lamps to be factory wired for inboard-outboard switching or inline switching. The objective is to have multiple levels of light uniformly distributed in the space. Avoid checkerboard patterns of turning every other fixture off in medium and large spaces. In open office and large open areas, avoid nonuniform switching patterns unless different areas of the large space are used at different times or for different functions.

EL17 *Exit Signs* (Climate Zones: all)

Use SSL exit signs or other sources that consume no more than 5 W per face. The selected exit sign and source should provide the proper luminance to meet all building and fire code requirements.

EL18 *Light Fixture Distribution* (Climate Zones: all)

For high ceiling sales and storage applications, use luminaires with substantially direct optics. These luminaires may employ reflectors to focus light downward and louvers to minimize glare when used on the sales floor. For office/conference and other nonsales areas, use high-performance lensed 2×4 fluorescent fixtures.

Extensive use of totally indirect luminaires or recessed direct-indirect (basket-type) fixtures, while a design option, may not achieve desired light levels and still meet the LPD goal from Chapter 4 and, if not properly used, can create inherent brightness/contrast problems. Therefore, while not the recommendation of this Guide, some retailers still may elect to use them for ambient lighting. If used, it is very important to exercise proper care and attention to ensure that luminaires with high efficiency and superior optical performance are selected. Proper placement of luminaires, including attention to maintaining recommended uniformity, is also very important.

When used for general lighting, use fixtures that are at least 70%.

EL19 *Overhead Glare Control* (Climate Zones: all)

Specify luminaires that have good glare control and that are properly shielded for customer comfort. In sales areas, use fixtures with cross louvers that shield the view of the lamp at angles greater than 45°. In storage areas, open fixtures may be used, but the upper reflector should allow 10% uplight. In office/conference and other nonsales areas, avoid T5 lamps in open-bottomed fixtures.

For glare reduction in sales areas, use fixtures with semispecular or specular cut-off cones or louvers. In storage areas use larger fixtures that spread the lights out over a bigger area rather than smaller fixtures with the same number of lamps. As an example, use an 8 ft long fixture with two lamps in cross section rather than a 4 ft long four-lamp cross-section fixture.

SAMPLE DESIGN LAYOUTS FOR RETAIL BUILDINGS

The watts-per-square-foot recommendations for LPD, shown in each recommendation table in Chapter 4, represent the individual LPD for each space type, but the base LPD may be combined into one average LPD for the building. However, the additional LPD allowances described in EL5 may not be combined and must be used for the specified application. The example designs described in EL20 to EL27 are *one way*, but *not the only way*, that this watts-per-square-foot limit can be met.

ASHRAE/IES Standard 90.1-2010
Lighting Control Requirements

ASHRAE/IES Standard 90.1-2010 requires that in all spaces the controlled lighting shall have at least one control step between 30% and 70% (inclusive) of full lighting power in addition to all OFF except in corridors, electrical/mechanical rooms, public lobbies, restrooms, stairways, and storage rooms.

The examples that follow are based on national "average" building space distribution. No building is average, and your building will have a different space allocation. Follow the recommendations below and adjust the space allocation to match your building.

EL20 *General Lighting in Merchandise Sales Areas* (Climate Zones: all)

The general lighting (Ambient fixture type in Figure 5-15) at 1.15 W/ft^2 provides the base level of lighting for the merchandise. Spill light from the merchandise general lighting will provide adequate lighting for the circulation paths. Also included in the base allowances is decorative/focus lighting at the sales transaction counter—this may be provided by pendants over (Decorative fixture type in Figure 5-15) and wall lighting behind (Perimeter and Case fixture types in Figure 5-15) the counter.

When/where merchandise sales areas include fitting rooms, attention to vertical illumination is required. The required vertical lighting may be provided by luminaires built into mirrors, luminaires with optics that direct light onto the vertical plane, or general lighting fixtures strategically placed between the customer and a mirror.

General lighting can be provided by a number of different types of fixtures.

- *Direct fixtures, open lensed, or parabolic*, designed as shown in Figure 5-15, will provide the highest footcandles for the space and will provide some positive shadowing on the product. However, if the displays are expected to change sometime after the installation, the fixtures may be misaligned to the displays. Consider an alternative layout with the fixtures running perpendicular to the displays. When used in fitting rooms with no other mirror lighting present, the fixtures should be placed so as to provide the proper vertical illumination.
- *Indirect fixtures, pendant and recessed indirect*, designed similarly to those shown in Figure 5-15, will not be display dependent but may look better running perpendicular to the display aisles. Indirect fixtures tend to provide a flat lighting effect and may have the potential to draw the customers' attention away from the display. In such instances task directed and/or accent light illumination may be needed. In fitting rooms indirect fixtures can provide desirable fill light, which will minimize undesirable shadowing. Additional dedicated vertical illumination for mirrors may be needed.

EL21 *Accent Lighting in Merchandise Sales Areas* (Climate Zones: all)

Follow recommendation EL5 for accent lighting LPD above the base power allowance. Use accent lighting (Accent fixture type in Figure 5-15) to highlight key merchandise locations or vignettes to "feature display" light levels (three to ten times the general merchandise lighting level in the area of the display). The use of accent lighting to highlight *all* merchandise does not create the proper contrast ratios.

Highlight window displays, if present, to ten times the general merchandise lighting level to attract customers from outside the store. Window display lighting should be switched down to three times the general merchandise lighting level at night to help with eye adaptation when entering and exiting the store. It is important to incorporate sun shades, canopies, or another form of sun and glare control at display windows exposed to the outdoors. When this cannot be accomplished, it may be better to turn off window accent lights during daylight hours. Trying to accent

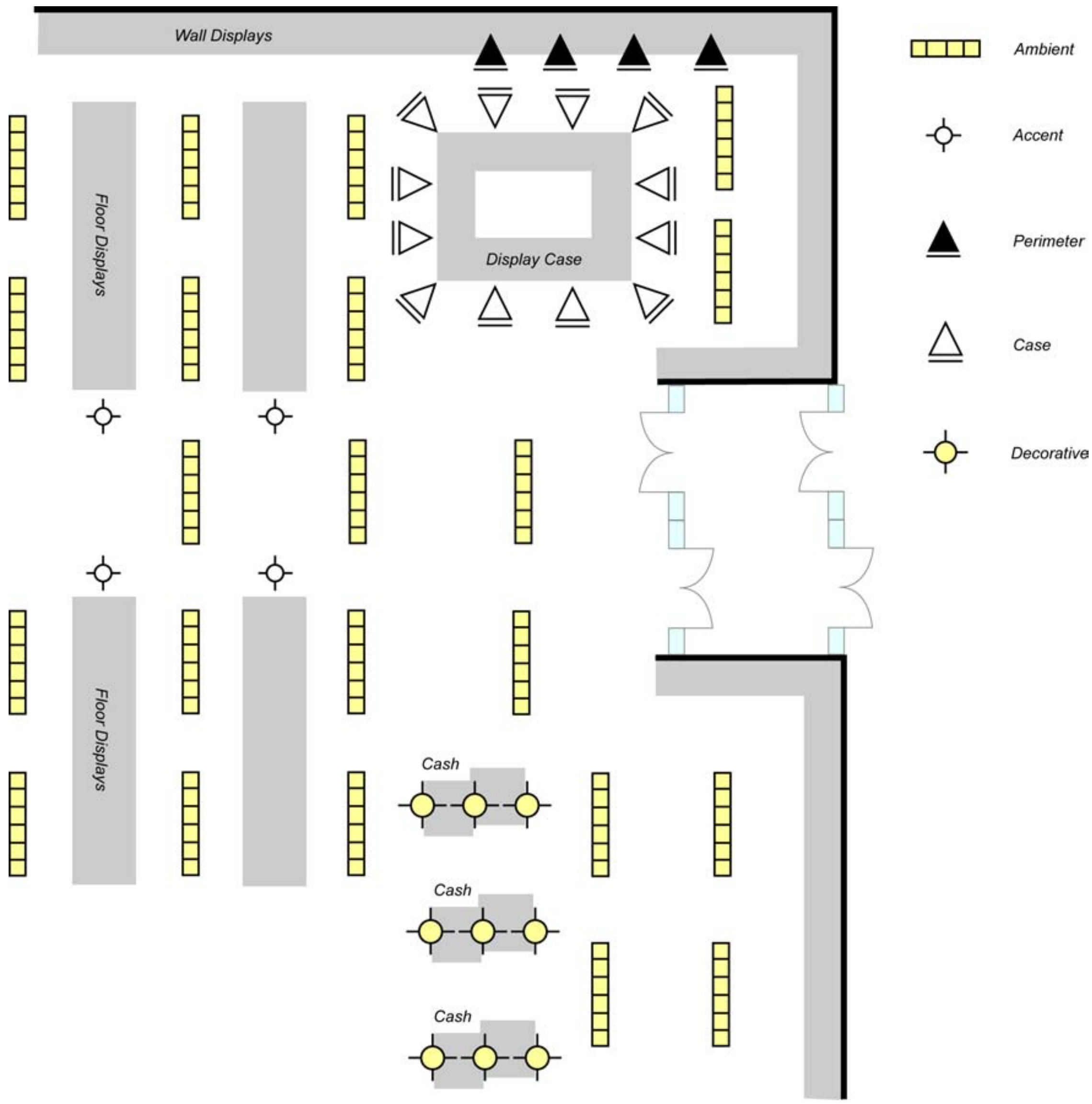


Figure 5-15 (EL20 through EL23) Layout for Lighting in Merchandise Sales Area

on top of extremely high ambient light levels, as associated with midday sunlight, requires excessive energy use as well as potential merchandise fading.

EL22 Perimeter Lighting in Merchandise Sales Areas (Climate Zones: all)

Follow the recommendation in EL5 for perimeter lighting LPD above the base power allowance. Use accent or wall-washers (Perimeter fixture type in Figure 5-15) to highlight key wall locations as well. It is especially important to highlight the back wall to draw customers' attention all the way to the back of the store. Perimeter lighting techniques also can be applied to fitting rooms as a tool to provide the desired vertical illumination at mirrors.

EL23 Casework Lighting in Merchandise Sales Areas (Climate Zones: all)

Casework lighting is not included in the tabulation of LPDs as long as it is integrated into the casework and is installed by the casework manufacturer. Follow recommendation EL2 for external casework accent lighting LPD above the base power allowance. Use accent lighting (Accent

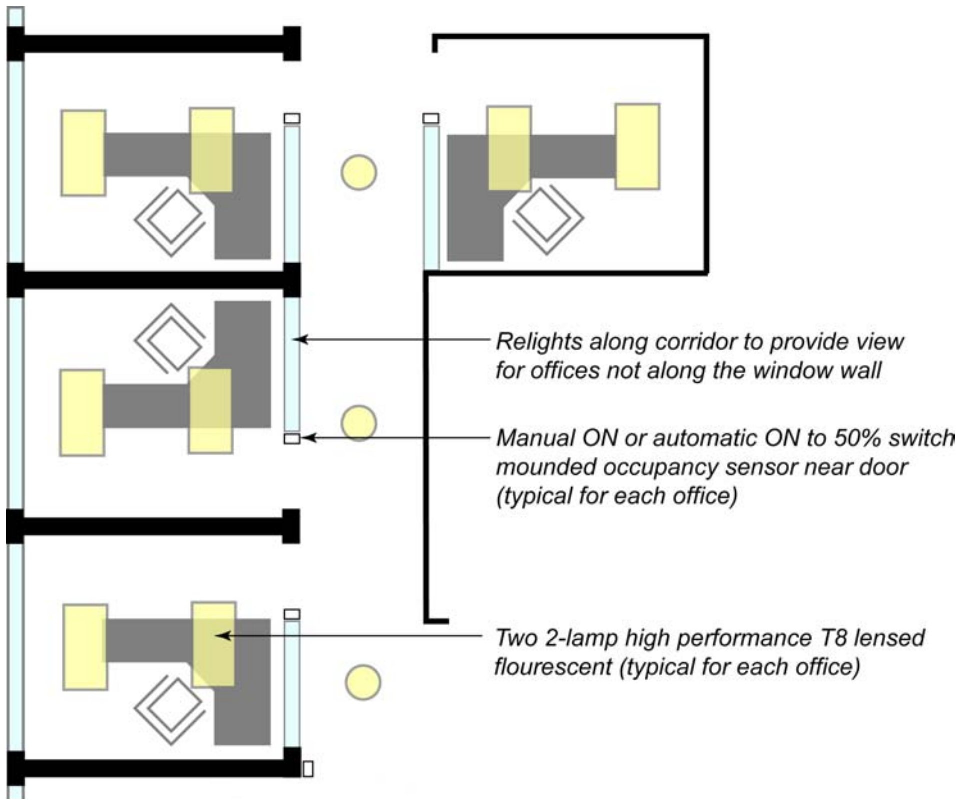


Figure 5-16 (EL24) Layout for Office

fixture type in Figure 5-15) to highlight key merchandise to "feature display" light levels (three to ten times the general merchandise). Lighting for casework must remain sensitive to the overall energy goals of the space and should be automatically controlled to shut off during nonbusiness hours. Strong consideration for internal display lighting should be given to energy-efficient or low-energy solutions, including linear fluorescent, fiber optic, and linear SSL sources.

EL24 *Offices* (Climate Zones: all)

The target lighting in private offices is 30 average maintained fc for ambient lighting with approximately 50 fc provided on the desktop by a combination of the electric lighting and daylighting. Supplemental task lighting is only required during nondaylight hours. A sample layout for a private office is shown in Figure 5-16. For office controls, specify manual ON or automatic ON to 50% occupancy sensors.

Private office plans should be limited to 0.90 W/ft^2.

EL25 *Conference/Meeting Rooms* (Climate Zones: all)

The target lighting in conference rooms is 30–40 average maintained fc. Conference rooms serve multiple functions that may require lighting layers and multiple lighting systems. Collective use of multiple systems tends to result in higher LPDs. Therefore, use of lighting controls is important. Controls to consider are dimming controls and separate switching of multiple systems. Specify manual ON or automatic ON to 50% occupancy sensors to meet ASHRAE/IESNA Standard 90.1 requirements.

Conference rooms should be limited to 0.95 W/ft^2. Figure 5-17 shows a typical conference room lighting layout.

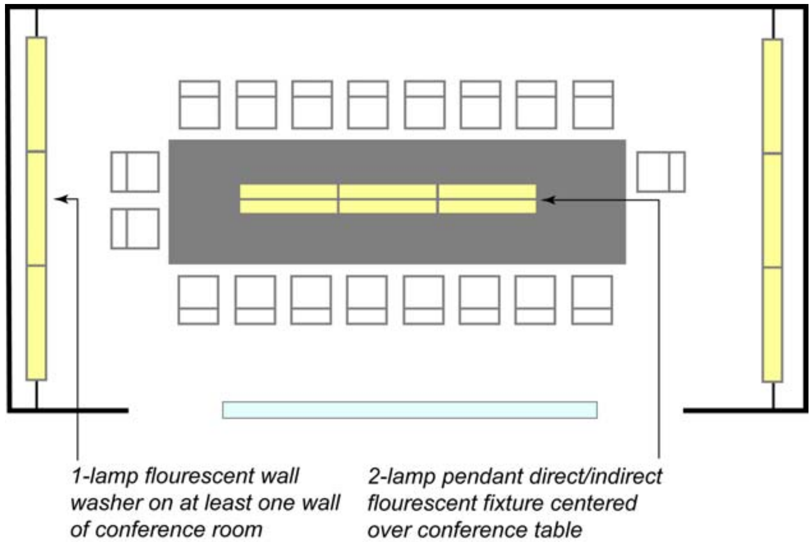


Figure 5-17 (EL25) Layout for Conference/Meeting Rooms

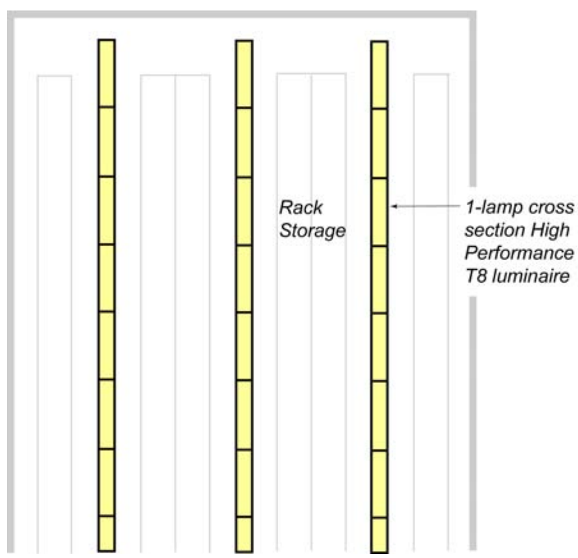


Figure 5-18 (EL25) Layout for Storage Areas

EL26 *Warehousing/Active Storage Areas* (Climate Zones: all)

The target lighting in storage areas is 20–25 average maintained fc. Storage areas account for approximately 20% of the floor area and should be limited to 0.65 W/ft^2, including circulation. Use occupancy sensors or timers where appropriate. Figure 5-18 shows typical lighting for a storage area.

EL27 *Other Spaces* (Climate Zones: all)

Lighting in the remaining floor space is composed of various functions, including lighting corridors, restrooms, electrical/mechanical rooms, break rooms, workshops, and others. Limit the connected lighting load in these spaces to 0.95 W/ft^2, which is equivalent to about one two-lamp high-performance T8 luminaire every 64 ft^2. Use occupancy sensors or timers where appropriate.

EL28 *Twenty-Four-Hour Lighting* (Climate Zones: all)

Night lighting or lighting left on 24 hours to provide emergency egress needs when the building is unoccupied should be designed to limit the total lighting power to no more than 2% of the general LPD. It should be noted that most jurisdictions also allow the application of occupancy-sensor controls on egress lighting to further reduce electricity associated with lighting an unoccupied building.

EXTERIOR LIGHTING

Good Design Practice

As per ANSI/ASHRAE/IES Standard 90.1-2010 (ASHRAE 2010), exterior LPDs are calculated using lighting zones. There are five zones as shown in Table 5-5. Most retail buildings fall into lighting zone 3.

Cautions: Calculate LPD only for areas that you intend to light. For this Guide, areas that are illuminated to less than 0.1 fc are assumed to not be lighted and should not be counted in the LPD allowance. For areas that are intended to be lighted, design with a maximum to minimum ratio of illuminance no greater than 30 to 1. Therefore, if the minimum light level is 0.1 fc then the maximum level, in that area, should be no greater than 3 fc.

For parking lot and grounds lighting, do not increase luminaire wattage in order to use fewer lights and poles. Increased contrast makes it harder to see at night beyond the immediate fixture location. Flood lights and wall-packs should not be used, as they cause hazardous glare and unwanted light encroachment on neighboring properties.

Limit poles to 20 ft mounting height and use luminaires that provide all light below the horizontal plane to help eliminate light trespass and light pollution.

EL29 *Exterior Lighting Power—Parking Lots and Drives* (Climate Zones: all)

Calculate only for paved areas, excluding grounds that are lighted to less than 0.1 fc.

- Limit exterior lighting power to 0.10 W/ft^2 for parking lots and drives in lighting zones 3 and 4.
- Limit exterior lighting power to 0.06 W/ft^2 in lighting zone 2.

Use parking lot fixtures with a bilevel switching driver that will reduce the power between midnight and 6:00 a.m. to no more than 25%.

Cautions: Parking lot lighting locations should be coordinated with landscape plantings so that tree growth does not reduce effective lighting from pole-mounted luminaires.

Parking lot lighting should not be significantly brighter than lighting of the adjacent street.

EL30 *Exterior Lighting Power—Walkways* (Climate Zones: all)

Exclude grounds that are lighted to less than 0.1 fc.

Limit exterior lighting power to 0.08 W/linear foot for walkways fewer than 10 ft wide and to 0.16 W/ft^2 for walkways 10 ft wide or greater, plaza areas, and special feature areas in lighting zones 3 and 4.

Limit exterior lighting power to 0.07 W/linear foot for walkways fewer than 10 ft wide and 0.14 W/ft^2 for walkways 10 ft wide or greater, plaza areas, and special feature areas in lighting zone 2.

EL31 *Decorative Façade Lighting* (Climate Zones: all)

Avoid the use of decorative façade lighting. If façade lighting is desired, limit the lighting power to the following:

- 0.075 W/ft^2 in lighting zones 3 and 4 for the area intended to be illuminated to a light level no less than 0.1 fc.
- 0.05 W/ft^2 in lighting zone 2 for the area intended to be illuminated to a light level no less than 0.1 fc.

Parking Lot Lighting


Parking Lot Comparing HPS (left) and LED (right) Lighting
Photography Courtesy of PNNL; Credit: Michael Myer

When choosing parking lot luminaires, it is important to choose a luminaire that provides low contrast ratios. Parking lots with high-pressure sodium (HPS) lighting have poor contrast ratios (28 to 1 maximum to minimum) with bright areas under the poles and darker areas between. These poor (high) contrast ratios produce a safety issue where drivers may not see pedestrians while backing out of parking spots because their eyes have adjusted to the bright lighting. Where the luminaires have been replaced with LED luminaires, the parking lot has dramatically better light distribution (3 to 1 maximum to minimum). LED installation, with low contrast ratios and 58% higher minimum light levels, provides a safer environment where the pedestrian/vehicular conflict is greatly reduced. Energy savings for this installation are 58% and the payback is approximately 3.5 years.

Table 5-5 Exterior Lighting Zones

Lighting Zone	Description
0	Undeveloped areas within national parks, state parks, forest land, rural areas, and other undeveloped areas as defined by the authority having jurisdiction
1	Developed areas of national parks, state parks, forest land, and rural areas
2	Areas predominantly consisting of residential zoning, neighborhood business districts, light industrial with limited nighttime use, and residential mixed-use areas
3	All other areas
4	High-activity commercial districts in major metropolitan areas as designated by the local jurisdiction

Program façade lighting to automatically turn off between the hours of midnight and 6:00 a.m. This does not include lighting of walkways or entry areas of the building that may also light the building itself.

EL32 *Sources* (Climate Zones: all)

- All parking lot fixtures should have a fixture efficiency of 50 lumens per watt or greater and use light sources with 65 CRI or greater.

- All grounds and building lighting should utilize pulse start metal halide, fluorescent, or CFL amalgam lamps with electronic ballasts.
- Standard HPS lamps are not recommended due to their reduced visibility and poor color-rendering characteristics.
- For colder climates, specify –20°F ballasts for linear fluorescent and amalgam CFL lamps for proper starting of the lamp.

EL33 *Controls* (Climate Zones: all)

Use photocells or astronomical time switches on all exterior lighting. If a building energy management system is being used to control and monitor mechanical and electrical energy use, it also can be used to schedule and manage outdoor lighting energy use.

Turn off exterior lighting not designated for security purposes when the building is unoccupied by incorporating a time clock control. Design the total exterior lighting power (power for parking, façades, building grounds, entry lights) to be reduced to 25% of the design level when no occupants are present between midnight and 6:00 a.m.

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PLUG LOADS

EQUIPMENT AND CONTROL GUIDELINES

PL1 *Connected Wattage* (Climate Zones: all)

In order to reduce connected wattage for plug load equipment, select equipment and appliances that are energy efficient. ENERGY STAR®-rated equipment typically has significantly lower operational wattage and may include improved sleep mode algorithms (EPA 2009). Illuminated signage, security monitors, desktop computers, laptops, desk printers, fax machines, copying machines, refrigerators, microwave ovens, coffee makers, and dishwashers are typical equipment types used in retail buildings that have ENERGY STAR ratings. Look for efficient models for equipment not rated by ENERGY STAR, such as point-of-sale equipment (cash registers, demagnetizers, scanners, scales, and conveyor belts) and security cameras. Retailers should specify energy-efficiency requirements for all equipment supplied by outside vendors, such as vending machines, beverage refrigerators, and self-service kiosks.

PL2 *Sales Floor Plug Specification* (Climate Zones: all)

The first step in reducing sales floor plug load energy consumption is to reduce the connected wattage. As stated in PL1, retailers should select ENERGY STAR-rated equipment whenever possible; if an ENERGY STAR-rated product is not available, possible selections should be evaluated and selected according to their efficiency. Additionally, items such as vending machines and beverage refrigerators should be consolidated and otherwise limited in number as much as possible.

A large portion of the connected plug load wattage in retail stores is supplied by outside vendors; accordingly, it is essential that retailers provide specifications to ensure that vendor-supplied equipment is as energy-efficient and controllable as possible. Wherever possible, equipment should be specified to have automatic standby and/or load-managing features. Vending machines can be specified to be delamped (or at least to have occupancy-sensor-based lighting control); refrigerated vending, including beverage refrigerators, can be specified to have load-managing systems that optimize compressor cycles based on occupancy. Self-service kiosks, such as price-check scanners, photo printing machines, and video rental machines, should be specified to have automatic standby modes.

See PL6 for sales floor plug load control strategies.

PL3 *Office Plug Load Specification* (Climate Zones: all)

Laptop computers are designed to operate efficiently to extend battery life, with characteristics such as lower connected wattage and effective power management. Laptops with an ENERGY STAR rating should be selected. Desktop computers generally use significantly more energy and may not be necessary for most applications. A typical desktop computer, not including monitor, may consume 100 W; a comparable laptop, on the other hand, may consume only 30 W (Lobato et al. 2011). In applications for which laptop computers are not appropriate, mini desktops can be substituted at comparable efficiency. Printing services should be consolidated to minimize the number of required devices. Use of multifunction devices that provide printing, copying, and faxing capabilities reduces power demand from multiple devices.

See PL6 for retail office plug load control strategies.

PL4 *Security System Plug Load Specification* (Climate Zones: all)

Security system plug loads can be significant and should not be overlooked when seeking to reduce overall plug load energy consumption. High-efficiency LED liquid crystal display (LCD) models should be specified for security monitors.

Security cameras, both interior and exterior, and associated equipment can also represent a significant load and should be carefully selected. Select security cameras designed to minimize parasitic loads. Consider operational requirements and factor in the energy use of necessary functionality, such as zooming. In general, static, nonheated cameras will use the least amount of energy. If camera motion is required, carefully consider the energy use required by the motors to pan and tilt. If heaters must be used (most likely in exterior applications), ensure that they operate only as needed to prevent moisture from building on the camera lens. The use of infrared cameras makes it unnecessary to light the viewing area. If infrared cameras are not appropriate for an application and lighting is needed, select low-light cameras and light the viewing area with low-illuminance, uniform lighting whenever possible to optimize lighting energy use and camera performance.

Occupancy-based control of security lighting is encouraged; the viewing area need not be illuminated unless there is motion to capture. Consider security lighting needs early in the design process to coordinate with architecture and site planning and reduce the need for security-specific lighting.

PL5 *LED Alternatives to Neon and Fluorescent Illuminated Signs and Graphics* (Climate Zones: all)

LED light source applications for illuminated signage, graphics, and decorative elements can drastically reduce the energy consumption generated by these design elements. Furthermore, LED systems often provide additional benefits such as reduced maintenance requirements, lower profile designs, and greater design flexibility. LEDs can be used to backlight and/or edge light illuminated graphics (images and signs) and can be inserted into diffuse flexible tubes to emulate neon or cold-cathode tubular lighting.

Used as direct replacements for fluorescent, cold-cathode, or neon, LED illuminated signs and graphics in static applications can produce desired design objectives with 40% to 70% less energy than traditional fluorescent, cold-cathode, or neon.

LED Display Lighting

Old Neon Display Sign

New LED Display Sign

Photography Courtesy of PNNL

Switching large display signs from fluorescent, cold-cathode, or neon lighting to LED light source systems can reduce energy usage by 40% to 70% without any loss of impact or visibility for the signage. LEDs can be used to backlight and/or edge light illuminated graphics (images and signs) and can be inserted into diffuse flexible tubes to emulate neon or cold cathode tubular lighting. A large assortment of LED colors as well as lenses and filters allow for many color options such as the red sign face illustrated at right. A wide range of white LEDs are also available, which would allow duplication of the original neon sign if desired.

Additional benefits of LED illuminated signs include reduced maintenance requirements, lower profile designs, and greater design flexibility.

Another application of LED technology to consider is the use of LCD dynamic displays with edge-lit LED lighting. The latest generation of 40 to 60 in. LED LCD monitors are very energy efficient, meeting or exceeding ENERGY STAR requirements. Energy consumption of an average ENERGY STAR-compliant LED LCD monitor is about the same as an equivalently sized fluorescent or neon backlit static light box. While there is minimal energy savings per unit, the LED LCD monitor can provide dynamic displays that may result in fewer units needed for a given message or visual effect. For example, the LED LCD monitor can serve as a sign as well as produce advertising and informational messages. With conventional static signs and light boxes, three, four, or more individual units may be required to communicate the same series of messages.

Table 5-6 provides a guideline for potential expected energy savings for LED lighting systems versus conventional fluorescent, cold-cathode, and neon counterparts.

PL6 Plug Load Controls and Strategies (Climate Zones: all)

Plug load control strategies, especially in retail applications where there is a significant amount of electronic product on display, can be as important or even more important than minimizing connected wattage in reducing overall plug load energy consumption. At a minimum, it is essential that all plug loads be turned off or put into standby outside of operating hours and when otherwise not in use. Many vendor-supplied items, such as vending machines, beverage refrigerators, and self-service kiosks, can be specified to have automatic standby modes; ENERGY STAR-rated computers are often equipped with low-power standby modes. Plug load equipment without automatic standby capability should be plugged into controllable power strips and/or electrical outlets such that they can be scheduled OFF outside of operating hours by the building automation system (BAS) or even by a simple timer switch; since most equipment consumes measurable (and sometimes significant) amounts of energy even when in standby mode, external power control is an advisable strategy for all equipment.

Consideration for plug load control should be made early in a project so that electrical circuiting can be used to group common power loads that have common ON-time requirements. This will allow more economical control from a BAS by switching multiple plug loads with a common circuit. Circuiting consideration should also be made for possible use with electrical demand-control strategies (reducing power consumption on a call from a utility provider). Grouping similar types of power loads on common circuits will ease the implementation and reduce the investment cost for demand control.

Table 5-6 LED Lighting Systems Energy Savings

Type of Sign/Graphic	Base System LPD	LED Alternative LPD	Energy Saved
Surface Script Neon/Cathode Signs	7.5–10 W/lf	2.5–3.5 W/lf	60% to 75%
Face Illuminated Channel Letters	15.0–20.0 W/lf	1.2–1.8 W/lf	90% to 95%
Indirect Illuminated Channel Letters	15.0–20.0 W/lf	2.1–3.0 W/lf	85% to 90%
Light Box Signs and Graphics	7.5–8.5 W/ft^2	5.0–6.0 W/ft^2	40% to 50%
Decorative Script Neon/Cathode Signs	6.5–8.5 W/lf	2.5–3.5 W/lf	50% to 75%
Luminous Walls and Decorative Surfaces	3.5–4.5 W/lf	2.5–3.0 W/lf	30% to 45%
Dynamic Signs and Audio/Visual Graphic Boards*	7.5–8.5 W/ft^2	9.9–10.4 W/ft^2	50% to 70%

*Note: While dynamic media will use 15% to 35% more energy than baseline (i.e., static fluorescent light box), dynamic media can potentially replace three or four static media, thus providing a total energy savings.

Occupancy-Controlled Vending Machines

ENERGY STAR-rated vending machines include occupancy based control devices, and other vending machines can be retrofitted with add-on equipment. Ideal for back-of-store vending machines, these types of controls save energy by automatically powering down the machine when the area is unoccupied and then cycling on the cooling system at a predetermined interval in order to keep the product at the desired temperature.

Vending Machine with Occupancy Control
Photography courtesy of PNNL

Consider the use of occupancy-based control of devices to further reduce energy consumption when equipment is not in use. Occupancy-sensor-controlled plug strips can be used to control vending lighting and to power down monitors, including security monitors, and other items typically plugged in at employee workstations such as fans, chargers, and task lighting. ENERGY STAR-rated vending machines include this type of control or can be retrofitted with add-on equipment. Another approach well suited to employee office and common areas is to control selected room outlets with occupancy sensors (sensors can be shared between the electric lighting system and the controlled outlets). Education can encourage employees to plug in the majority of their equipment and/or appliances into the power-controlled outlets. Timer switches should be applied for central equipment that is unused during unoccupied periods but that should be available throughout occupied periods; examples include water coolers and central coffee makers. Network power management software can facilitate central control of office equipment (computers and multifunction printing, copying, and faxing devices), allowing for off-hour standby (or shutdown) with flexibility for software updates and maintenance.

When possible, the best plug load control strategy is to not plug equipment in at all. In many cases, electronics manufacturers can provide unpowered display models for small electronics (radios, alarm clocks, cell phones, etc.) that can avoid an installed plug load altogether.

PL7 *Parasitic Loads* (Climate Zones: all)

Reduce and eliminate parasitic loads. These loads include small energy usage from equipment that is nominally turned off but still uses a trickle of energy. Transformers that provide some electronic devices with low-voltage direct current from plug alternating current also draw power even when the equipment is off. Transformers are available that are more efficient and have reduced standby losses. Wall switch control of power strips noted in PL6 cut off all power to the plug strip, eliminating parasitic loads at that plug strip when the switch is controlled OFF. Newer power management surge protector outlet devices have low or no parasitic losses (Lobato et al. 2011).

PL8 *Unnecessary Equipment* (Climate Zones: all)

Identify and eliminate equipment that qualifies as "nice to have" but is not fundamental to the core function of the business. For example, vending machines and beverage refrigerators can often be consolidated through more efficient placement, and mechanically cooled drinking fountains can be replaced with noncooled alternatives.

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SERVICE WATER HEATING (SWH)

GENERAL RECOMMENDATIONS

WH1 *Service Water Heating—General* (Climate Zones: all)

Retail building service water heating requirements, without food service, are typically very low and confined to restrooms, janitor closets, and break rooms. Typically, the most prevalent service water heating (SWH) issue is the wait time for hot water delivery, especially when the water heater is remote from the end use. A remedy for long wait times for SWH systems is a pumped return to ensure immediate hot water delivery. The hot water load in a retail building is so low, however, that pump return energy and heat loss through the piping may outweigh the actual energy consumption for producing the required hot water. For facilities employing handwashing sinks only, instantaneous water heaters typically result in lowest energy consumption. For facilities with showers, tank-type heaters allow hot water requirements to be met with lower heating capacity.

Solar service water heating or heat recovery is an acceptable option but is not required to meet the 50% savings discussed in this Guide.

WH2 *System Descriptions* (Climate Zones: as indicated below)

Gas-fired storage water heater (climate zones: all): a water heater with a vertical or horizontal water storage tank. A thermostat controls the delivery of gas to the heater's burner. The heater requires a vent to exhaust the combustion products. An electronic ignition is recommended to avoid the energy losses from a standing pilot.

Gas-fired instantaneous water heater (climate zones: all): a water heater with minimal water storage capacity. Such heaters require vents to exhaust the combustion products. An electronic ignition is recommended to avoid the energy losses from a standing pilot. Instantaneous, point-of-use water heaters should provide water at a constant temperature regardless of input water temperature.

Electric resistance storage water heater (climate zones: all): a water heater consisting of a vertical or horizontal storage tank with one or more immersion heating elements. Thermostats controlling heating elements may be of the immersion or surface-mounted type.

Electric resistance instantaneous water heater (climate zones: all): a compact undercabinet or wall-mounted water heater with an insulated enclosure and minimal water storage capacity. A thermostat controls the heating element, which may be of the immersion or surface-mounted type. Instantaneous, point-of-use water heaters should provide water at a constant temperature regardless of input water temperature.

Heat pump electric water heater (climate zones: ❶ ❷ ❸): a storage-type water heater using rejected heat from a heat pump as the heat source. Water storage is required because the heat pump is typically not sized for the instantaneous peak demand for service hot water, even in a retail building. The heat source for the heat pump may be the interior air (such as that from a motor or switching room), which is beneficial in cooling-predominant climates; the circulating loop for a WSHP system, also beneficial in cooling-dominated climates; or a ground-coupled hydronic loop. Heat pump water heaters should show a coefficient of performance (COP) of at least 3.0.

WH3 *Sizing* (Climate Zones: all)

The water heating system should be sized to meet the anticipated peak hot water load. For a retail building without food service, hot water usage may be limited to handwashing by customers and employees, which might represent a very small load. Calculate the hot water demand based on the sum of the fixture units served by each unit according to local code.

While hot water temperature requirements for restrooms and break rooms of a retail building vary by local and state codes within the range of 100°F to 120°F, note that production of service hot water at temperatures below approximately 135°F may result in bacterial growth within storage-type water heaters.

WH4 *Equipment Efficiency* (Climate Zones: all)

Efficiency levels are provided in this Guide for gas instantaneous, gas-fired storage, and electric resistance storage water heaters. For gas-fired instantaneous water heaters, the energy factor (EF) and thermal efficiency (E_t) levels are the same because there are no standby losses. The incorporation of condensing technology is recommended for gas instantaneous water heaters to achieve a minimum E_t of 0.90% and an EF of 0.90.

The recommended efficiency levels for gas-fired storage water heaters also require condensing technology ($E_t > 90\%$ or EF > 0.80).

The construction of a condensing water heater as well as the water heater venting must be compatible with the acidic nature of the condensate for safety reasons. Disposal of the condensate should be done in a manner compatible with local building codes.

Efficiency metrics for high-efficiency electric storage water heaters (EFs) are also provided in this Guide. These efficiency metrics represent premium products that have reduced standby losses. Table 5-7 summarizes required EFs for electric storage water heaters of various storage capacities based upon the equation for EF shown in the recommendation tables in Chapter 4.

Electric instantaneous water heaters are an acceptable alternative to high-efficiency storage water heaters. Electric instantaneous water heaters are more efficient than electric storage water heaters and minimize piping losses. However, their impact on building peak electric demand can be significant and should be taken into account during design. Where unusually high hot water loads (e.g., showers) are present during periods of peak electrical use, electric storage water heaters are recommended over electric instantaneous water heaters.

WH5 *Location* (Climate Zones: all)

The water heater should be close to the hot water fixtures to avoid the use of a hot water return loop or of heat tracing on the hot water supply piping. Potential locations for gas-fired water heaters may be limited by flue and combustion air and local code requirements.

Accommodation of renewable or free heat sources will most often necessitate a centralized service water heating system, since these sources are likely to be from a single point. Similarly, full utilization of the renewable or free source often requires a storage tank since the heating load may not coincide with the heat available from the source. These systems should be designed carefully so that parasitic energy consumption for circulation loops does not offset energy conservation gains from the renewable or free resource.

WH6 *Pipe Insulation* (Climate Zones: all)

All SWH piping should be installed in accordance with accepted industry standards. Insulation levels should be in accordance with the recommended levels in the climate-specific

Table 5-7 Electric Water Heater Energy Factors

Storage Volume	EF Requirement
30 gal	0.95
40 gal	0.94
50 gal	0.93
65 gal	0.91
75 gal	0.90
80 gal	0.89
120 gal	0.85

recommendation tables in Chapter 4, and the insulation should be protected from damage. Include a vapor retardant on the outside of the insulation.

RESOURCE

ASHRAE. 2007. *ASHRAE Handbook—HVAC Applications*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

HVAC SYSTEMS AND EQUIPMENT

HVAC SYSTEM TYPES

Although many types of HVAC systems could be used in retail buildings, this Guide prescriptively covers the following four system types, each of which has demonstrated applicability to this building type and the ability to meet the 50% savings criteria through extensive energy modeling:

- Multiple-zone, packaged variable-air-volume (VAV) direct expansion (DX) rooftop air conditioners with hot water coil, indirect gas furnace, or electric resistance heat and convection heat at the zone level (see HV3).
- Single-zone, packaged constant-air-volume (CAV) DX air conditioners with gas-fired heat or hot water coil with DOAS. This Guide uses *DOAS* and *100% outdoor air system (100% OAS)* interchangeably (see HV4).
- Single-zone, packaged air-source heat pump system with electric resistance supplemental heat with DOAS (see HV5).
- Single-zone WSHP with DOAS (see HV6).

Unique recommendations are included for each HVAC system type in the climate-specific recommendation tables in Chapter 4. It is noted that in some climate zones, achievement of the 50% savings criteria is dependent on higher-efficiency components.

Good Design Practice

HV1 *Cooling and Heating Loads* (Climate Zones: all)

Heating and cooling system design loads used to size systems and equipment should be calculated in accordance with generally accepted engineering standards and handbooks such as *ASHRAE Handbook—Fundamentals* (ASHRAE 2009a). Heating and cooling loads should be calculated for the specific project, incorporating local design weather conditions, specifics of the actual building, and the impact of any energy conservation measures that reduce heating and cooling loads, including ENERGY STAR appliances and daylight-responsive lighting controls. Any safety factor applied should be done cautiously and applied only to internal loads to prevent oversizing of equipment. For retail buildings that are part of a large portfolio, established precedent with measured internal loads may eliminate the necessity of safety factors. In addition, the incorporation of electronically commutated motors will result in reduced HVAC loads. Thus, careful attention to the new loads is important; even precedent from a large portfolio will provide its own safety factor. If the unit is oversized and the cooling capacity reduction is limited, short cycling of compressors could occur and the system may not have the ability to dehumidify the building properly; in addition, oversized equipment may operate less efficiently.

HVAC system and equipment sizing should incorporate the following considerations:

- Include the capacity for meeting space loads.
- Include the capacity for cooling and dehumidifying the required maximum flow of ventilation air.
- Include the capacity for heating the minimum flow of ventilation air. Outdoor air (OA) must be heated to room temperature in heating mode, and the heat required must be included in the heating load calculation.
- Recognize that the sensible heat ratios for these high-performance buildings are likely to be much lower than those for conventional buildings.

- Take into account the reduction of cooling and heating loads and the subsequent reduction of mechanical equipment size when energy recovery is used for ventilation air.
- Ensure that VAV systems are configured to maintain minimum required ventilation airflow during all operating conditions in accordance with ANSI/ASHRAE Standard 62.1 (ASHRAE 2010a).

HV2 *Certification of HVAC Equipment* (Climate Zones: all)

Rating and certification by industry organizations is available for various types of HVAC equipment. In general, certification is provided by industry-wide bodies that develop specific procedures to test the equipment to verify performance; ANSI/ASHRAE/IES Standard 90.1 (ASHRAE 2010b) has requirements for units for which certification programs exist. Certifications that incorporate published testing procedures and transparency of results are much more reliable for predicting actual performance than are certifications that are less transparent. For types of equipment for which certification is available, preference should be given to certified products. Examples of equipment types that have recognized certifications include packaged heat pumps, packaged air-conditioning units, gas furnaces and boilers, cooling towers, and water heaters.

For products for which certification is not available or that have not been subjected to certification available for their type of equipment, the products should be rigorously researched for backup of performance claims made by the supplier. The project team should determine by what procedure the performance data was developed and establish any limitations or differentials between the testing procedure and the actual use.

Determining the actual operational efficiency of products may require information beyond that provided by the certification process. For example, the relative impact on annual energy performance of the various components of packaged air-conditioning equipment (i.e., supply fans, refrigeration circuits, heat rejection components) changes based upon the actual requirements of the HVAC load. The certification of the packaged unit, however, standardizes the contribution of these components to the rating.

HV3 *Packaged VAV DX Rooftop Air Conditioners with Hot Water Coil, Indirect Gas Furnace, or Electric Resistance Heat* (Climate Zones: all)

Variable-volume systems can serve either a single zone or multiple zones. Single-zone variable-volume units directly control the whole unit with thermostats. Multiple-zone systems utilize thermostatic variable-volume terminals to maintain temperature in each thermal zone. The variable-volume terminals are connected by a ductwork distribution system (HV18) to the rooftop unit, which provides cooing and ventilation. Convection space heaters are provided in each zone.

Optimal control of single-zone variable-volume units depends upon the type of unloading for the refrigeration compressor of the unit. In no case should the thermostat control a single throttling air damper to modulate supply air volume, but it should directly control the fan variable-speed drive. Units with stepped unloading (reciprocating compressors or multiple fixed-capacity scroll compressors) should use the thermostat to control compressor unloading, and the fan speed should be modulated automatically to maintain the supply air temperature (SAT) setpoint. Units with variable-speed compressors or with continuously unloading scroll compressors should have direct thermostatic control of the fan speed, and compressor unloading can be controlled to maintain the SAT setpoint.

The components of the rooftop unit are factory designed and assembled and include OA and return-air dampers, filters, fans, a cooling coil, a heating source, compressors, a condenser, and controls. The components of the VAV zone terminal units are also factory designed and assembled and include an airflow-modulation device, controls, and possibly a heating coil, fan, or filter.

Variable-volume dampers for multiple-zone VAV units increase supply fan pressure by as much as 1 in. w.c., so they should be limited to applications with multiple discrete areas exhibiting significant independent variation of cooling loads. Large open sales floors are more efficiently conditioned with one or more single-zone unit.

VAV terminal units are typically installed in the ceiling plenum above the occupied space or adjacent corridor. However, the equipment should be located to meet the acoustical goals of the space. Terminals should be located to minimize fan power, ducting, and wiring.

Variable-volume packaged units should meet or exceed the efficiency levels listed in Table 5-8 and in the recommendation tables in Chapter 4. The cooling equipment also should meet or exceed the part-load efficiency level, where specified.

Indirect gas-fired furnaces should have at least an 80% efficiency level as required in ASHRAE/IES Standard 90.1. Requirements for zone heating are shown in the recommendation tables in Chapter 4. For systems using gas-fired boilers, condensing boilers should be used (HV12, HV27).

For packaged VAV DX systems, fan power is incorporated into the energy efficiency ratio (EER) calculation. To achieve the required level of energy efficiency, air supply and delivery systems for the multiple-zone packaged VAV units should not exceed 1.8 in. w.c. external static pressure (ESP) and should include variable-frequency drives (VFDs) or other features that result in improved part-load performance. Pressure drops in the air delivery system for single-zone packaged VAV systems should not exceed 0.7 in. w.c. ESP. A reduced design SAT of 52°F is used to lower system airflow and the resultant pressure drop when the duct is sized for a typical SAT of 55°F. To enhance economizer operation, SAT is reset up to 58°F in climate zones 1–3 and 61°F in other climate zones when external conditions permit economizer operation. In climate zones with a large number of hours of economizer operation, units should be selected with consideration of increased fan efficiency.

Units should have air-side economizers in all climate zones except climate zone 1, with control based on either dry-bulb temperature sensors or enthalpy sensors. See the recommendation tables in Chapter 4 for the requirements in each climate zone.

For VAV systems, the minimum supply airflow to a zone must comply with local codes and the current versions of ASHRAE Standard 62.1 (for minimum OA flow) and ASHRAE/IES Standard 90.1 (for minimum turndown before reheat is activated).

Use the recommendation tables in Chapter 4 to determine the requirements for indirect evaporative precooling or ventilation air heat recovery. Ventilation optimization, a combination of zone demand-controlled ventilation (DCV) and system ventilation reset using the provisions of ASHRAE Standard 62.1, reduces OA minimum flow in occupied mode.

HV4 *Packaged CAV DX Air Conditioner with Gas-Fired Heat or Hot Water Coil with DOAS* (Climate Zones: all)

In this system, a single packaged DX rooftop unit serves each thermal zone. The components of the rooftop unit are factory designed and assembled and include OA and return-air

Table 5-8 DX Cooling-Only Equipment Efficiency Levels

Size Category	Cooling Efficiency
<65,000 Btu/h	15.0 SEER
65,000–135,000 Btu/h	11.5 EER 12.8 IEER
135,000–240,000 Btu/h	11.5 EER 12.3 IEER
240,000–760,000 Btu/h	10.5 EER 11.3 IEER
≥760,000 Btu/h	9.7 EER 10.9 IEER

* SEER = seasonal energy efficiency ratio, EER = energy efficiency ratio, IEER = integrated energy efficiency ratio.

dampers, filters, fans, a cooling coil, a heating source, compressors, a condenser, and controls. A single thermostat controls the unit to maintain temperature within the space, including modulation of heating or cooling delivered to the space, cycling the unit off when conditioning is not required, and changing between heating and cooling modes. OA is provided continuously by a DOAS (HV7) so that ventilation and dehumidification are not contingent upon constant operation of the constant-volume air-conditioning unit. A variation of this system utilizes constant-volume recirculating DX units to meet space-sensible heating and cooling loads and a separate mixed-air VAV unit to meet ventilation, dehumidification, and some sensible loads.

The packaged unit should meet or exceed the efficiency levels listed in Table 5-8 and in the recommendation tables in Chapter 4. The cooling equipment should also meet or exceed the part-load efficiency level, where specified.

Indirect gas-fired furnaces should be high efficiency and have at least an 80% efficiency level as required in ASHRAE/IES Standard 90.1. Requirements for zone heating are shown in the recommendation tables in Chapter 4. For systems using gas-fired boilers, condensing boilers should be used.

For packaged constant-volume DX systems, fan power is incorporated into the EER calculation. To achieve the required level of energy efficiency, pressure drops in the air delivery systems for packaged constant-volume units should not exceed 0.7 in. w.c. ESP. A reduced design SAT of 52°F is used to lower system airflow and the resultant pressure drop when the duct is sized for a typical SAT of 55°F. To enhance economizer operation, SAT is reset up to 58°F in climate zones 1–3 and 61°F when exterior conditions allow economizer operation. In climate zones with a large number of hours of economizer operation or heating operation, units should be selected with consideration of increased fan efficiency.

Units should have air-side economizers in all climate zones except climate zone 1, with control based on either dry-bulb temperature sensors or enthalpy sensors. See the recommendation tables in Chapter 4 for the requirements in each climate zone.

Use the recommendation tables in Chapter 4 to determine the requirements for indirect evaporative precooling or ventilation air heat recovery. Ventilation optimization, a combination of zone DCV and system ventilation reset using the provisions of ASHRAE Standard 62.1, reduces OA in occupied mode.

HV5 *Packaged Air-Source Heat Pump System (or Split Heat Pump System) with Electric Resistance Supplemental Heat with DOAS* (Climate Zones: all)

In this system, a separate packaged heat pump unit (or split heat pump fan coil) is used for each thermal zone. This type of equipment is available in pre-established increments of capacity. The components are factory designed and assembled and may include OA and return-air dampers, fans, filters, a heating source, a cooling coil, a compressor, controls, and an air-cooled condenser. The heating source is provided by reversing the refrigeration circuit to operate the unit as a heat pump to be supplemented by electric resistance heating if heat pump heating capacity is reduced below required capacity by low exterior air temperatures. Indirect-fired gas furnaces can be used as an alternative heat source with heat pumps but cannot operate to supplement the heat pump output. This alternative was not evaluated for this Guide.

The systems evaluated for this Guide treat recirculated air only, so that the unit fans can be cycled with load without interrupting ventilation air supply. Dehumidified ventilation air is provided continuously by a DOAS or a separate mixed-air VAV unit. The DOAS may also be a heat pump system (see HV7).

The components can be assembled as a single package (such as a rooftop unit) or a split system that separates the evaporator and condenser/compressor sections. Single packaged units are typically mounted on the roof or at grade level outdoors. Split systems typically consist of an outdoor unit with compressor and OA coupled coil and one or more indoor units with fan, filters, indoor coil, and condensate removal system. The indoor units also may be located outdoors; if so, they should be mounted on the roof curb over the roof penetration for ductwork to avoid installing ductwork outside the building envelope. The equipment should be located to meet the acoustical goals of the space while minimizing fan power, ducting, and wiring.

Performance characteristics vary among heat pump manufacturers, and the selected heat pump equipment should match the calculated heating and cooling loads (sensible and latent), also taking into account the importance of providing adequate dehumidification under part-load conditions (see HV9). The equipment should be listed as being in conformance with electrical and safety standards, with its performance ratings certified by a nationally recognized certification program.

For packaged constant-volume heat pump systems, fan power is incorporated into the EER calculation. To achieve the required level of energy efficiency, pressure drops in the air delivery systems for packaged constant-volume units should not exceed 0.7 in. w.c. ESP. A reduced design SAT of 52°F is used to lower system airflow and the resultant pressure drop when the duct is sized for a typical SAT of 55°F. To enhance economizer operation, SAT is reset up to 58°F in climate zones 1–3 and 61°F when exterior conditions allow economizer operation.

The fan energy is included in the calculation of the EER for heat pump equipment, based upon standard rating procedures of Air-Conditioning, Heating, and Refrigeration Institute (AHRI) that include an assumed external air delivery pressure drop (AHRI 2007, 2008). Pressure drops in the air delivery system, including ductwork, diffusers, and grilles, should not exceed 0.7 in. w.c.

The packaged unit should meet or exceed the efficiency levels listed in Table 5-9.

Of critical importance for this type of system is the minimum outdoor temperature at which the unit can provide the required heating capacity to meet the building heating load. Heat pump products are available that are rated to provide as much as 70% of their AHRI-rated capacity (47°F outdoor dry-bulb temperature, 70°F indoor dry-bulb temperature) at –4°F OA temperature. In general, heat pump units selected for an application should be rated to provide some heating at the 99.6% heating design OA temperature for the site, if available. Units meeting the above criteria should also be sized to meet 100% of the building internal heating requirement (not including OA heating) at the 98% heating design OA temperature.

HV6 *Water-Source Heat Pump (WSHP) with DOAS* (Climate Zones: all)

Typically, a separate WSHP is used for each thermal zone. This type of equipment is available in pre-established increments of capacity. The components are factory designed and assembled and include a filter, a fan, a refrigerant-to-air heat exchanger, a compressor, a refrigerant-to-water heat exchanger, and controls. The refrigeration cycle is reversible, allowing the same components to provide cooling or heating.

In a traditional WSHP system, all the heat pumps are connected to a common water loop. A fluid cooler such as a closed-circuit cooling tower and a fluid heater such as a hot-water

Table 5-9 Constant-Volume Heat Pump Efficiency Levels

Primary Space Heating and Cooling			
Size Category Air-Source Heat Pump	**Cooling Efficiency**	**Heating Efficiency***	
<65,000 Btu/h	15.0 SEER 12.0 EER	9.0 HSPF	
65,000–135,000 Btu/h	11.5 EER 12.8 IEER	47°F db/43°F wb outdoor air	3.4 COP
		17°F db/15°F wb outdoor air	2.4 COP
135,000–240,000 Btu/h	11.5 EER 12.3 IEER	47°F db/43°F wb outdoor air	3.2 COP
		17°F db/15°F wb outdoor air	2.1 COP
≥240,000 Btu/h	10.5EER 11.3 IEER	47°F db/43°F wb outdoor air	3.2 COP
		17°F db/15°F wb outdoor air	2.1 COP

* HSPF = heating seasonal performance factor, db = dry bulb, wb = wet bulb, COP = coefficient of performance.

boiler also are installed in this loop to maintain the temperature of the water within a desired range. See HV12 and HV27 for required equipment efficiencies. The circulation loop should have a variable-speed pump and may include a controller to reset circulating loop temperature according to exterior and operating conditions.

OA is conditioned and delivered by a separate DOAS and ducted directly to the occupied spaces. Depending on the climate, the DOAS unit may include components to filter, cool, heat, dehumidify, or humidify the OA (see HV7).

The equipment should be located to meet the acoustical goals of the space and minimize fan power, ducting, and wiring. Compressor noise, however, may present challenges for meeting acoustical criteria and may require acoustic separation to meet these goals.

Packaged WSHPs four tons and above should incorporate a two-stage or variable-speed compressor with variable-speed fans and a multistage thermostat. The unit should be controlled so that airflow will modulate with compressor staging. The following lists the required efficiencies for the WSHP based on staging:

- Single-stage, fewer than four tons: cooling EER 15.0, heating COP 5.0
- Single-stage with variable-speed motor: cooling EER 16.4, heating COP 5.2
- Two-stage, part-load less than 70% and full-load greater than 70%: cooling EER, part-load/full-load 17.6/15.0, heating COP 5.7/5.0

The fan energy is included in the calculation for the EER for WSHP equipment based on standard rating procedures (AHRI/ASHRAE 2005) that include an assumed external air delivery pressure drop. Pressure drops in the air delivery system, including ductwork, diffusers, and grilles, should not exceed 0.7 in. w.c.

Per ASHRAE/IES Standard 90.1, the WSHP unit should incorporate a solenoid valve to shut off flow of circulating loop water through the unit when the compressors are de-energized. The unit should also cycle fans off when no conditioning is called for.

HVAC EQUIPMENT CONSIDERATIONS

HV7 *Dedicated Outdoor Air Systems (100% Outdoor Air Systems)* **(Climate Zones: all)**

DOASs can reduce energy use by decoupling the dehumidification and conditioning of ventilation air from sensible cooling and heating in the zone.

The OA is conditioned by a separate DOAS that is designed to dehumidify the OA and to deliver it dry enough (with a low enough dew point) to offset space latent loads, thus providing space humidity control (Mumma 2001; Morris 2003). The DOAS also can be equipped with high-efficiency filtration systems. DOASs work in conjunction with additional HVAC equipment that heats or cools recirculated air to maintain space temperature, including air-cooled air conditioners, air-source heat pumps, or WSHPs.

There are many possible DOAS configurations (see Figure 5-19 for a few typical ones). Some of the considerations for choosing DOAS as shown in Figure 5-19 are HVAC system type, the requirement for sensible or enthalpy recovery, the zoning of the system, and the availability of exhaust airstreams in relation to each other. The salient energy-saving features of DOASs are the separation of ventilation air conditioning from zone air conditioning, the ease of implementation of energy recovery, and the ability to sufficiently ventilate the space.

DOASs are most often used in conjunction with single-zone systems, such as packaged CAV, packaged air-source heat pump, and WSHP systems. VAV systems do not typically have a separate ventilation system, as they are often selected to handle both the building and ventilation loads. However, VAV systems can be designed with a DOAS to reduce energy use.

DOASs reduce energy use in primarily three ways: 1) they avoid the high OA intake airflows at central air handlers needed to satisfy the multiple spaces equation of ASHRAE Standard 62.1, 2) they eliminate (or nearly eliminate) simultaneous cooling and reheat that would otherwise be needed to provide adequate dehumidification in humid climates, and 3) they allow the conditioning unit to cycle with load without interrupting ventilation airflow (with

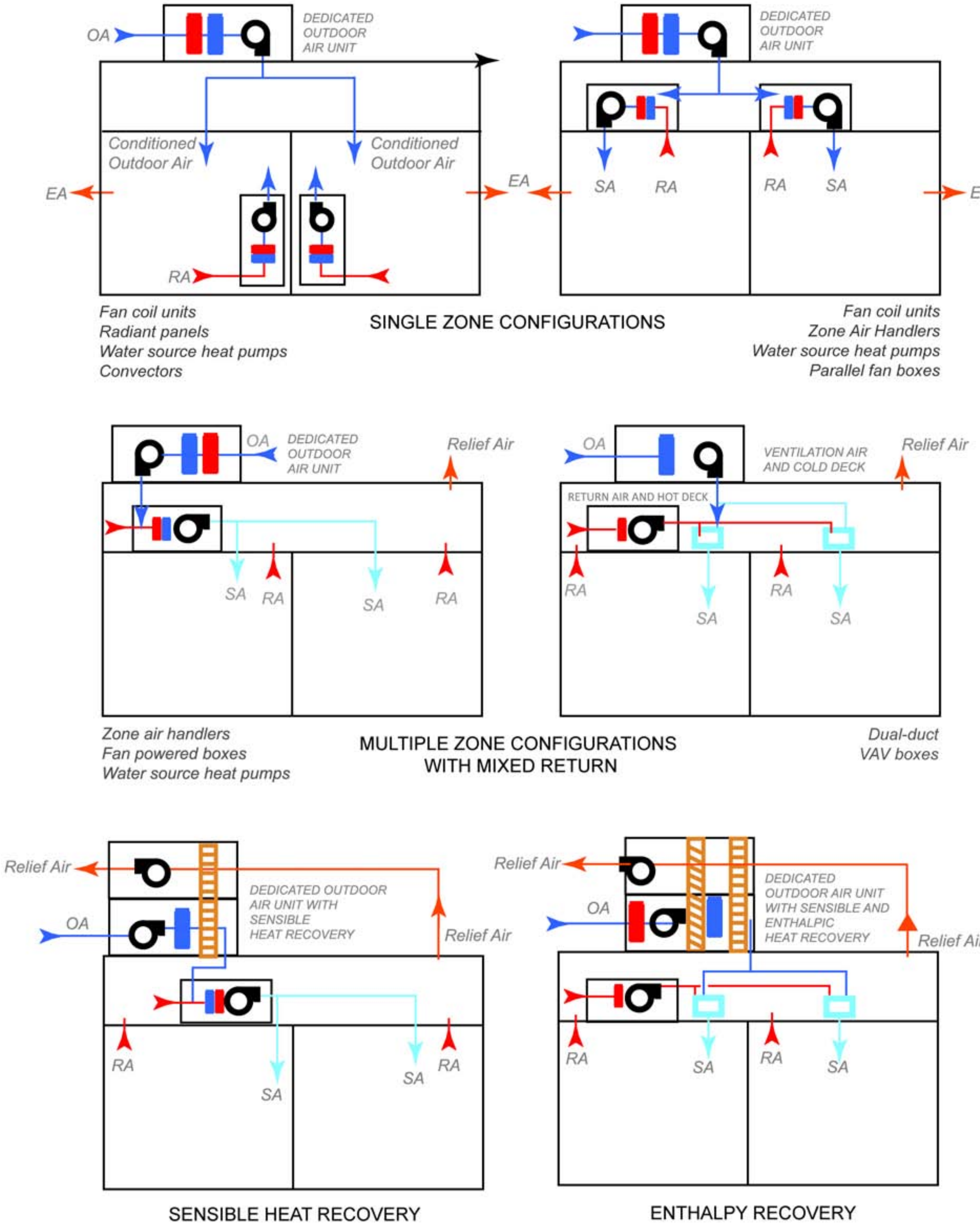


Figure 5-19 (HV7) Examples of DOAS Configurations

constant-volume zone DX air conditioners or heat pumps). A drawback of many DOASs is that they cannot directly provide air-side economizing because they are sized for maximum required ventilation airflow. Economizing required by ASHRAE/IES Standard 90.1-2010 should be provided by alternative methods such as water-side economizers within the HVAC system or air-side economizers directly to the space.

The supply air temperature, and thus the dew-point temperature, for the DOAS should be set sufficiently low that the ventilation airflow is sufficient to maintain the desired dew-point temperature in the space. In retail sales spaces, required ventilation airflow per ASHRAE Standard 62.1-2010 is 15.5 cfm/person at the design occupant density of 15 persons per 1000 ft^2 in the sales area. With a 15.5 cfm/person ventilation rate, a supply air dew-point temperature of no more than 51°F is required to maintain a space dew-point temperature maximum of 57°F. With occupant density at the more common density of 150 ft^2/person, resulting in a minimum ventilation rate of 25.5 cfm/person, the required maximum supply air dew-point temperature would be approximately 53°F to maintain the desired space dew-point temperature.

If ventilation air from the DOAS is delivered to the space separately from the conditioning air system, the ventilation air ductwork system should be designed to ensure that adequate ventilation is provided over the entire area served by the ventilation system.

Consider delivering the conditioned OA cold (not reheated to neutral) whenever possible and reheat only when needed. Providing cold (rather than neutral) air from the DOAS offsets a portion of the space sensible cooling loads, allowing the terminal HVAC equipment to be downsized and use less energy (Shank and Mumma 2001; Murphy 2006). Reheating the dehumidified air (to a temperature above the required dew point) may be warranted

- if reheat consumes very little energy (using energy recovery, solar thermal source, etc.) and none of the zones are in cooling mode,
- if all of the zones are in heating mode, or
- if, for those zones in cooling mode, the extra cooling energy needed (to offset the loss of cooling due to delivering neutral-temperature ventilation air) is offset by higher-efficiency cooling equipment and the reduction in heating energy needed for those zones in heating mode (this is more likely to be true on an annual basis if reheat in the DOAS is accomplished via air-to-air or condenser heat recovery).

In addition, implementing reset control strategies and exhaust air energy recovery (see HV10) can help minimize energy use.

Packaged heating and cooling equipment for DOAS applications should meet or exceed the efficiency levels listed in Table 5-10. Cooling equipment should also meet or exceed the part-load efficiency level, where specified. Boilers providing hot water for hydronic coils in DOAS units should meet efficiency requirements in HV12. Presently there is no energy performance rating standard for 100% outdoor air systems. In order to meet the 50% energy savings of this Guide, all DOASs must incorporate energy recovery systems so that the incoming air condition is similar to the condition of incoming mixed air in a conventional system. This Guide specifies performance for DOASs (with heat recovery) at the standard AHRI conditions used to determine EERs and heating seasonal performance factors (HSPFs) for conventional mixed-air systems. These performance values for mixed-air systems are relevant to DOAS systems with enthalpy recovery because the post-recovery intake air for the system is similar in temperature and humidity ratio to AHRI standard rating conditions. Gas furnaces should be high efficiency, providing a minimum 80% efficiency.

Exhaust-air heat recovery is necessary for use of heat pump DOASs in locations with low design heating temperatures. Most heat pump units do not operate well with low entering OA temperatures. The use of exhaust heat recovery will temper the OA by recovery heat from the exhaust airstream to raise the incoming ventilation air to a temperature more compatible with heat pump operation.

Systems delivering 100% OA have many different configurations. The air delivery system should be configured for no more than 1.0 in. w.c. external static pressure drop for systems

Table 5-10 DOAS Cooling and Heating Equipment Efficiencies*

Primary Space Heating and Cooling			
Size Category	**Cooling Efficiency**	**Heating Efficiency**	
Air-Source Heat Pump			
<65,000 Btu/h	15.0 SEER 12.0 EER	9.0 HSPF	
65,000–135,000 Btu/h	11.5 EER 12.8 IEER	47°F db/43°F wb outdoor air	3.4 COP
		17°F db/15°F wb outdoor air	2.4 COP
135,000–240,000 Btu/h	11.5 EER 12.3 IEER	47°F db/43°F wb outdoor air	3.2 COP
		17°F db/15°F wb outdoor air	2.1 COP
≥240,000 Btu/h	10.5 EER 11.3 IEER	47°F db/43°F wb outdoor air	3.2 COP
		17°F db/15°F wb outdoor air	2.1 COP
VAV DX, Gas Heat			
<65,000 Btu/h	15.0 SEER	80%	
65,000–135,000 Btu/h	11.5 EER 12.8 IEER	80%	
135,000–240,000 Btu/h	11.5 EER 12.3 IEER	80%	
240,000–760,000 Btu/h	10.5 EER 11.3 IEER	80%	
≥760,000 Btu/h	9.7 EER 10.9 IEER	80%	
Water to Water Heat Pump			
Any Size	13.8 EER, 86°F EWT	3.8 COP, 68°F EWT	
		3.1 COP, 50°F EWT	

* SEER = seasonal energy efficiency ratio, EER = energy efficiency ratio, IEER = integrated energy efficiency ratio, HSPF = heating seasonal performance factor, db = dry bulb, wb = wet bulb, EWT = entering water temperature, COP = coefficient of performance

with constant ventilation supply and no more than 1.8 in. w.c. external static pressure drop for systems providing multiple-zone DCV. For units that do not have EER ratings per AHRI, fans should be selected for a minimum 65% mechanical efficiency and motors at no less than 93% efficiency.

HV8 *Evaporative Condensers* (Climate Zones: 2B 3B 4B 5B)

Evaporative condensers as a part of or added to packaged cooling units can be considered to improve energy efficiency in dry climates. These devices take advantage of the low ambient wet-bulb temperature in order to improve energy efficiency by coupling convective heat rejection with the evaporation of water off of wetted heat rejection condenser coils. In dry climates, up to 40% reduction in energy use can result.

Generally speaking, all of the wetted components and the condenser section should be designed for corrosion resistance to ensure reasonable equipment life. Drawbacks to the system include extra first costs, extra weight that arises from the extra equipment and the water in the sump, additional controls, and the need to provide water treatment regimens.

HV9 *Part-Load Dehumidification* (Climate Zones: all)

Constant-volume systems (small packaged rooftop units, DX split systems, fan-coils, WSHPs, etc.) supply a zone with a constant amount of air regardless of the cooling load. The system matches sensible capacity to the sensible load; dehumidification capacity is coincidental. As the load diminishes, the system delivers ever warmer supply air, periodically delivers completely uncooled and completely nondehumidified air, or, if the unit cycles off, delivers no dehumidification. Dehumidification occurs at a much reduced rate either because the coil is only intermittently active or because the air temperature off the coil (and thus the supply air dew-point temperature) is raised. As a result, in humid outdoor conditions the space dew-point temperature will tend to increase under part-load conditions, unless the supply air is cooled to an appropriate dew-point temperature and then reheated.

In a typical single-compressor DX application coil, cooling periodically cycles off (through de-energizing the compressor) to avoid overcooling. For a typical system, during the period that the coil is inactive, OA delivered to the space may be excessively humid. While de-energizing the fan during the time that cooling is disabled would avoid loss of humidity control, it also would fail to deliver the required ventilation to the space. With a conventional constant-volume system, the choice is among loss of humidity control, failure to meet ventilation standards, or reheat to maintain space dry-bulb temperature.

Following are *some* (but *not all*) of the possible methods for providing part-load dehumidification.

For single-zone air conditioner or heat pump packaged units or split systems (see HV4 and HV5). Packaged rooftop units (or split systems) should utilize a DOAS (see HV7) to dehumidify the OA so that it is dry enough (has a low enough dew point) to offset the latent loads in the spaces. This helps avoid high indoor humidity levels without additional dehumidification enhancements in the local heat pump units.

For WSHPs or Ground-Source Heat Pumps (GSHPs) (see HV6 and HV33). The DOAS (see HV7) should be designed to dehumidify the OA so that it is dry enough (has a low enough dew point) to offset the latent loads in the spaces. This helps avoid high indoor humidity levels without additional dehumidification enhancements in the WSHP units. Alternatively, some WSHPs could be equipped with hot-gas reheat for direct control of space humidity.

For multiple-zone, packaged VAV rooftop units (see HV3). VAV systems typically dehumidify effectively over a wide range of indoor loads as long as the VAV rooftop unit continues to provide cool, dry air at part-load conditions. One caveat: use caution when resetting the SAT upward during the cooling season. Warmer supply air means less dehumidification at the coil and higher humidity in the space. If the SAT reset is used, include one or more zone humidity sensors to disable the reset if the relative humidity within the space exceeds 60%.

HV10 *Exhaust Air Energy Recovery* (Climate Zones: all)

Exhaust air energy recovery can provide an energy-efficient means of reducing the latent and sensible OA cooling loads during peak summer conditions. It also can reduce the OA heating load in mixed and cold climates. HVAC systems that use exhaust air energy recovery should be resized to account for the reduced OA heating and cooling loads (see ASHRAE 2008a).

Where exhaust air energy recovery is required in the Chapter 4 climate-specific tables, the selected device should have a total effectiveness as specified in Table 5-11. Note that in some climates energy recovery is not required.

The performance levels in Table 5-11 should be achieved with no more than 0.70 in. w.c. static pressure drop through the wheel on the supply side and 0.80 in. w.c. static pressure drop through the wheel and required filtration on the exhaust side. Sensible energy recovery devices transfer only sensible heat. Common examples include coil loops, fixed-plate heat exchangers, heat pipes, and sensible energy rotary heat exchangers (sensible energy wheels). Total energy recovery devices transfer not only sensible heat but also moisture (or latent heat)—that is, energy stored in water vapor in the airstream. Common examples include total energy rotary heat exchangers (also known as *total energy wheels* or *enthalpy wheels*) and fixed-membrane

Table 5-11 Total System Effectiveness with Energy Recovery

Condition	Effectiveness (%)		
	Sensible	Latent	Total
Heating at 100% airflow	78	70	75
Heating at 75% airflow	83	77	82
Cooling at 100% airflow	80	71	75
Cooling at 75% airflow	84	78	82

heat exchangers (see Figure 5-20). Energy recovery devices should be selected to avoid cross-contamination of the intake and exhaust airstreams. For rotary heat exchangers, avoidance of cross-contamination typically includes provision of a purge cycle in the wheel rotation and maintenance of the intake system pressure higher than the exhaust system pressure.

An exhaust-air energy recovery device can be packaged in a separate energy recovery ventilator (ERV) that conditions the OA before it enters the air-conditioning unit or the device can be integral to the air-conditioning unit.

For maximum benefit, the system should provide as close to balanced outdoor and exhaust airflows as is practical, taking into account the need for building pressurization and any exhaust that cannot be ducted back to the energy recovery device.

Exhaust for energy recovery may be taken from spaces requiring exhaust (using a central exhaust duct system for each unit) or directly from the return airstream (as with a unitary accessory or integrated unit). (See also HV17.)

Where an air-side economizer is used along with an ERV, add bypass dampers (or a separate OA path) to reduce the air-side pressure drop during economizer mode. ERVs should be turned off during economizer mode to avoid transferring any heat between airstreams during mild outdoor conditions. Where energy recovery is used without an air-side economizer, the ERV should still be controlled to prevent unwanted transfer of heat between airstreams.

In cold climates, follow the manufacturer's recommendations for frost prevention.

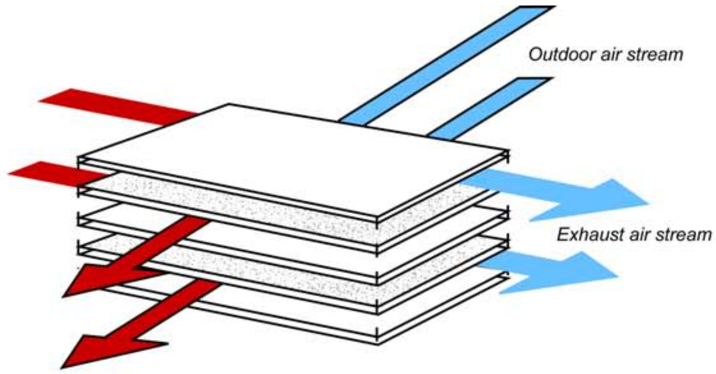
HV11 *Indirect Evaporative Cooling* (Climate Zones: ❷B ❸B ❹B ❺B)

In dry climates, incoming ventilation air can be precooled using indirect evaporative cooling. For this strategy, the incoming ventilation air (the primary airstream) is not humidified; instead, a separate stream of air (the secondary or heat rejection stream) is humidified, dropping its temperature, and is used as a heat sink to reduce the temperature of the incoming ventilation air.

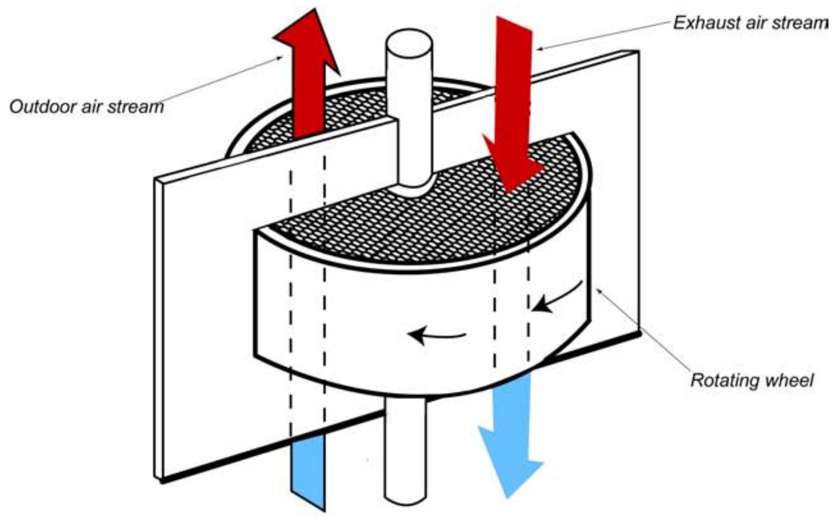
The source of the heat rejection stream of air can be either OA or exhaust air from the building. If the air source is exhaust air, this system becomes an alternative for exhaust air heat recovery (HV10).

Sensible heat transfer between the ventilation airstream and the evaporatively cooled secondary airstream can be accomplished using plate or tubular air-to-air heat exchangers, heat pipes, or a pumped fluid loop between air coils in each stream (often called a *runaround loop*). For indirect evaporative coolers that utilize exhaust air as the secondary stream, the evaporative cooler also can provide sensible heat recovery during the heating season. If a runaround loop is used for heat transfer both for indirect evaporative cooling and heat recovery, the circulating fluid should incorporate antifreeze levels appropriate for the location's design heating temperature.

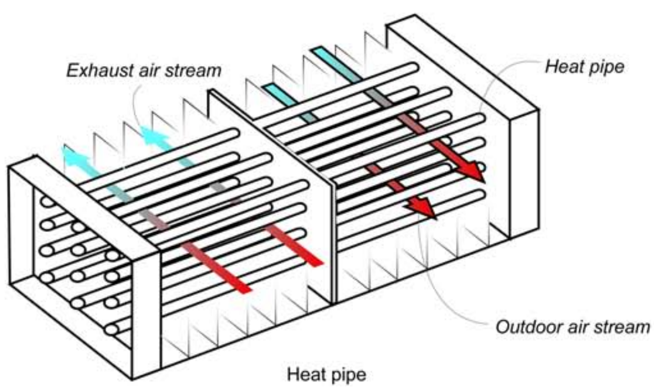
Indirect evaporative cooling has the advantage that indoor air quality (IAQ) is not affected, as the evaporative cooling process is not located within the indoor airstream. Air quality is not as critical for the exhausted secondary airstream as it is for the ventilation airstream entering the occupied space.



Fixed-plate heat exchanger (crossflow)



Rotary Heat Exchanger (wheel)



Heat pipe

Figure 5-20 (HV10) Examples of Exhaust Air Energy Recovery Devices

Indirect evaporative coolers should be selected for at least 90% evaporative effectiveness for the evaporatively cooled airstream and for at least 65% heat transfer efficiency between the two airstreams.

Indirect evaporative coolers also should be selected to minimize air pressure drop through the heat exchangers. For example, a heat pipe indirect evaporative cooler using exhaust air for the heat rejection stream should have a pressure drop through the supply side, not including filtration, of no more than 0.5 in. w.c. and no more than 0.85 in. w.c. for the exhaust sprayed coil.

HV12 *Cooling and Heating Equipment Efficiencies* (Climate Zones: all)

The cooling and heating equipment should meet or exceed the efficiency levels listed in the climate-specific recommendation tables in Chapter 4. The cooling equipment should also meet or exceed the part-load efficiency level where specified. In some cases, recommended equipment efficiencies are based on system size (capacity).

There are many factors involved in making a decision whether to use gas or electricity, such as the availability of service, utility costs, operator familiarity, and the impact of source energy use. Efficiency recommendations for both types of equipment are provided in the recommendation tables in Chapter 4 to allow the user to choose.

Space-heating water boilers. All gas-fired boilers specified for space heating should be of the condensing type with a minimum efficiency of 90% at 125°F return hot-water temperature. Zone heat transfer equipment should be sized based on 140°F entering hot-water temperature and as large a temperature drop through the air heating coil as possible. Boilers should be operated with a maximum leaving hot-water temperature of 140°F and should incorporate a leaving hot-water temperature reset control based on total heating load. (See HV27.)

Closed-circuit cooling towers (for WSHP systems). Closed-circuit cooling towers should be selected for a maximum 10°F approach of cooling tower leaving water temperature to design wet-bulb temperature. Towers also should be selected for fan energy input at full load of no more than 120 W per nominal ton of capacity. Cooling tower fan motors larger than one horsepower should be equipped with variable-speed drives (VSDs).

HV13 *Ventilation Air* (Climate Zones: all)

The zone-level outdoor airflows and the system-level intake airflow should be determined based on the most recent edition of ASHRAE Standard 62.1 but should not be less than the values required by local code unless approved by the authority having jurisdiction. The number of people used in computing the breathing zone ventilation rates should be based on known occupancy, local code, or the default values listed in ASHRAE Standard 62.1.

> ***Cautions*:** The occupant load, or exit population, used for egress design to comply with the fire code is typically much higher than the zone population used for ventilation system design. Using occupant load rather than zone population to calculate ventilation requirements can result in significant overventilation, oversized HVAC equipment, and excess energy use.

Buildings with multiple-zone recirculating ventilation systems can be designed to account for recirculated OA as well as system population diversity using the Ventilation Rate Procedure of ASHRAE Standard 62.1. In effect, the multiple-zone recirculating ventilation system design approach allows ventilation air to be calculated on the basis of how many people are *in the building* (system population at design) rather than the sum of how many people are *in each space* (sum of peak zone population at design). Using the Ventilation Rate Procedure can reduce the energy required to condition ventilation air in retail buildings. Refer to *62.1-2010 User's Manual* for specific guidance (ASHRAE 2010c).

An alternative to the Ventilation Rate Procedure is the Indoor Air Quality Procedure, which provides for performance-based design of ventilation systems based upon actual contaminant generation in the space. See ASHRAE Standard 62.1-2010, Section 6.3, for a description of this method. This method optimizes the amount of ventilation air to meet threshold contaminant values based upon calculations or tests of similar spaces to meet established threshold contaminant values. For facilities with very low product off-gassing levels, this procedure may result in lower OA ventilation rates than the Ventilation Rate Procedure. Ventilation rates determined by product off-gassing of contaminants typically will be constant compared with variable rates determined by occupancy in the Ventilation Rate Procedure. Designers should evaluate the energy consumption consequences of these two methods of determining ventilation rates.

For all zones, time-of-day schedules in the BAS should be used to introduce ventilation air only when a zone is expected to be occupied.

For packaged single-zone air-source air conditioners and heat pumps, WSHPs, or GSHPs (see HV4, HV5, HV6, and HV33). The DOAS (see HV7) should deliver the conditioned OA directly to the intake of each individual heat pump (where it mixes with recirculated air, either in the ductwork prior to the heat pump or in a mixing plenum attached to the heat pump), or to the supply side of each WSHP (where it mixes with supply air from the heat pump before being delivered to the zone). Units should be configured such that ventilation air can be delivered to the space even when the unit fan is not running, allowing the unit to cycle for load without interrupting ventilation supply.

For multiple-zone, packaged VAV rooftop units (see HV3). Each rooftop unit should have an OA intake through which OA is introduced and mixes with the recirculated air prior to being conditioned and delivered to the zones.

HV14 *Economizers* (Climate Zones: ❷ ❸ ❹ ❺ ❻ ❼ ❽)

Economizers, when recommended, help save energy by providing free cooling when ambient conditions are suitable to meet all or part of the cooling load. In humid climates, consider using enthalpy or dew point based controls (versus dry-bulb temperature based controls) to help ensure that unwanted moisture is not introduced into the space. See the climate-specific recommendation tables in Chapter 4 for economizer recommendations by climate zone.

Nondedicated OA systems should be capable of modulating the OA, return air, and relief air dampers to provide up to 100% of the design supply air quantity as OA for cooling. (See HV7 for a discussion of DOASs.) A motorized OA damper should be used instead of a gravity damper to prevent unwanted OA from entering during unoccupied periods when the unit may recirculate air to maintain setback or setup temperatures. For all climate zones, the motorized OA damper should be closed during the entire unoccupied period, except when it may open in conjunction with unoccupied economizer cycle operation or a preoccupancy purge cycle.

Periodic maintenance (at least annually), including recalibration of sensors, is important with economizers, as dysfunctional economizers can cause substantial excess energy use because of malfunctioning dampers or sensors (see HV31).

HV15 *Demand-Controlled Ventilation (DCV)* (Climate Zones: all)

DCV can reduce the energy required to condition OA for ventilation. To maintain acceptable IAQ, the setpoints (limits) and control sequence must comply with ASHRAE Standard 62.1 (ASHRAE 2010a). Refer to Appendix A of the *62.1 User's Manual* for specific guidance (ASHRAE 2007b).

DCV controls should vary the amount of OA in response to the need in a zone. The amount of OA could be controlled by 1) a time-of-day schedule in the BAS, 2) an occupancy sensor (such as a motion detector) that indicates when a zone is occupied or unoccupied, or 3) a carbon dioxide (CO_2) sensor as a proxy for ventilation airflow per person that measures the change in CO_2 levels in a zone relative to the levels in the OA. A controller will then operate the OA, return air, and relief air dampers to maintain proper ventilation. For options 1 and 2, ventilation rates for the occupied period should be based upon full occupancy and should be calculated in accordance with Section 6 of ASHRAE Standard 62.1. For option 3, the full-load ventilation rate should be calculated according to Section 6 of ASHRAE Standard 62.1 and ventilation rate reductions should be controlled according to Informative Appendix C of ASHRAE Standard 62.1.

CO_2 sensors should be used in zones that are densely occupied and have highly variable occupancy patterns during the occupied period, such as conference rooms or meeting areas. For the other zones, occupancy sensors should be used to reduce ventilation when a zone is temporarily unoccupied. For all zones, time-of-day schedules in the BAS should be used to introduce ventilation air only when a zone is expected to be occupied.

Multiple-zone recirculating systems (such as VAV systems) require special attention to ensure adequate OA is supplied to all zones under varying loads. Because ventilation air is only a fraction of the total supply air, densely occupied zones with relatively low sensible cooling loads may be inadequately ventilated. CO_2 sensors in these zones can be used to adjust the OA fraction of the VAV system or determine minimum supply airflow rates that might require reheating to maintain adequate ventilation and space temperature setpoints.

Employing DCV in a DOAS requires an automatic damper, a CO_2 sensor, and an airflow measurement device for each DCV zone. If the automatic damper selected is of the pressure-independent type, it has flow measurement capability by definition.

Control of a DCV system to match airflow volume to occupancy requires a continuous search algorithm for the controller. The controller continuously calculates the volume required in the space based upon the measured CO_2 concentration differential and then updates the volume setpoint to the pressure-independent damper controller. The following equation gives the required volume in the space based upon the measured CO_2 differential:

$$V'_{ot} = \frac{R_a \times A_z}{(E_z - (R_p \times (C_R - C_{OA})/(8400 \times m)))}$$

where

V'_{ot}	=	required airflow volume at any point in time
R_a	=	zone area ventilation rate (.12 cfm/ft^2 for sales areas in ASHRAE Standard 62.1-2010)
A_z	=	area of the zone
E_z	=	air distribution effectiveness of the zone
R_p	=	zone people ventilation rate (7.5 cfm/person for sales areas in ASHRAE Standard 62.1-2010)
C_R	=	measured CO_2 concentration at the room
C_{OA}	=	measured CO_2 concentration of the outdoor air
m	=	metabolic level for occupants of the space (m = 1.6 for shopping or light activity)

The above equation has been extracted from the *62.1 User's Manual*. The control system for the DOAS must be able to calculate the required ventilation rate for each zone based upon the above equation then reset the flow setpoint for the zone to the calculated value. The procedure for a multizone VAV system is somewhat more complicated. The system will require a flow measurement device on the OA inlet for the VAV air handler. The controller must then calculate the actual OA flow to each control zone based upon the percentage of OA in the supply air to the zone. The system must calculate the required OA flow for each zone using the above equation and then must modulate the OA damper to change the supply OA percentage until all zones receive at least the minimum required OA flow.

Inaccurate CO_2 sensors can cause excessive energy use or poor IAQ, so they need to be calibrated as recommended by the manufacturer (see HV16).

Finally, when DCV is used, the system controls should prevent negative building pressure. If the amount of air exhausted remains constant while the intake airflow decreases, the building may be under a negative pressure relative to the outdoors. When air is exhausted directly from the zone (e.g., from restrooms or a janitorial closet), the DCV control strategy must avoid reducing intake airflow below the amount required to replace the air being exhausted.

HV16 *Carbon Dioxide (CO_2) Sensors* (Climate Zones: all)

The number and location of CO_2 sensors for population-based DCV can affect the ability of the system to accurately determine the building or zone occupancy. A minimum of one CO_2 sensor per zone is recommended for systems with greater than 500 cfm of OA. Multiple sensors may be necessary if the ventilation system serves spaces with significantly different occupancy expectations. Where multiple sensors are used, the ventilation should be based on the sensor recording the highest concentration of CO_2.

Sensors used in individual spaces should be installed on walls within the space. Multiple spaces with similar occupancies may be represented by an appropriately located sensor in one of the spaces. The number and location of sensors should take into account the sensor manufacturers' recommendations for their particular products as well as the projected usages of the spaces. Sensors should be located such that they provide a representative sampling of the air within the occupied zone of the space. For example, locating a CO_2 sensor directly in the flow path from an air diffuser would provide a misleading reading concerning actual CO_2 levels (and corresponding ventilation rates) experienced by the occupants.

The OA CO_2 concentration can fluctuate significantly in urban areas. OA CO_2 concentration should be monitored using a CO_2 sensor located near the position of the OA intake. CO_2 sensors should be certified by the manufacturer to have an accuracy to within ±50 ppm (factory calibrated. CO_2 sensors should be calibrated on a regular basis per the manufacturer's recommendations or every six months (per ASHRAE Standard 62.1).

HV17 *Exhaust Air Systems* (Climate Zones: all)

Zone exhaust airflows (for restrooms, janitorial closets, and break rooms) should be determined based on the current edition of ASHRAE Standard 62.1 but should not be less than the values required by local code unless approved by the authority having jurisdiction.

Central exhaust systems for restrooms, janitorial closets, and break rooms should be interlocked to operate with the air-conditioning system, except during unoccupied periods. Such a system should have a motorized damper that opens and closes with the operation of the fan. The damper should be located as close as possible to the duct penetration of the building envelope to minimize conductive heat transfer through the duct wall and avoid having to insulate the entire duct. During unoccupied periods, the damper should remain closed and the exhaust fan turned off, even if the air-conditioning system is operating to maintain setback or setup temperatures. Consider designing exhaust ductwork to facilitate recovery of energy (see HV10) from exhaust taken from spaces with air quality classification of 1 or 2 (e.g., restrooms) per Table 6.1 of ASHRAE Standard 62.1.

Exhaust systems should be designed to minimize energy consumption because of their continuous operation. Ductwork should be designed for low pressure drop per HV18. Exhaust or relief fans with a brake horsepower rating greater than 5 bhp should be selected with a Fan Efficiency Grade (FEG) of 67 or better and selected within 10 points of peak efficiency per AMCA Standard 205-10 (AMCA 2011).

HV18 *Ductwork Design and Construction* (Climate Zones: all)

Low-energy-use ductwork design involves short, direct, and low-pressure-drop runs. The number of fittings should be minimized and should be designed with the least amount of turbulence produced. (In general, the first cost of a duct fitting is approximately the same as 12 ft of straight duct that is the same size as the upstream segment.) Unwanted noise in the ductwork is a direct result of air turbulence. Round duct is preferred over rectangular duct. However, space (height) restrictions may require flat oval ductwork to achieve the low-turbulence qualities of round ductwork. Alternatively, two parallel round ducts may be used to supply the required airflow.

Air should be ducted through low-pressure ductwork with a system pressure classification of less than 2 in. w.c. Rigid ductwork is necessary to maintain low pressure loss and reduce fan energy. When a unit is serving multiple zones, supply air should be ducted to diffusers in each individual space.

In general, the following sizing criteria should be used for duct system components: diffusers and registers, including balancing dampers, should be sized with a static pressure drop not to exceed 0.08 in. w.c. Oversized ductwork increases installed cost but reduces energy use due to lower pressure drop.

- Supply ductwork should be sized with a pressure drop no greater than 0.08 in. w.c. per 100 lf
- Return ductwork should be sized with a pressure drop no greater than 0.04 in. w.c. per 100 lf
- Exhaust ductwork should be sized with a pressure drop no greater than 0.05 in. w.c. per 100 lf
- Flexible ductwork should be of the insulated type and should be
    - limited to connections between duct branches and diffusers,
    - limited to connections between duct branches and VAV terminal units,
    - limited to 5 ft (fully stretched length) or less,
    - installed without any kinks,
    - installed with a durable elbow support when used as an elbow, and
    - installed with no more than 15% compression from fully stretched length

Hanging straps, if used, need to use a saddle to avoid crimping the inside cross-sectional area. For ducts 12 in. or smaller in diameter, use a 3 in. saddle; those larger than 12 in. should use a 5 in. saddle.

Long-radius elbows and 45° lateral take-offs should be used wherever possible. The angle of a reduction transition should be no more than 45° (if one side is used) or 22.5° (if two sides are used). The angle of expansion transitions should be no more than 15° (laminar air expands approximately 7°).

Returning air to a central location (as in a multiple-zone recirculating system) is necessary to reap the benefits of exhaust air energy recovery and reduce ventilation air due to system population diversity (see HV10 and HV13). Fully ducted return systems are expensive and must be connected to a single air handler (or the return ducts must be interconnected) to function as a multiple-zone recirculating system. Open plenum return systems are less expensive but must be carefully designed and constructed to minimize infiltration of humid air from the outdoors (Harriman et al. 2001).

Infiltration in the ceiling plenum can be reduced by using a relief fan to maintain plenum pressure at about 0.05 in. w.c. higher than atmospheric pressure (see HV28). Lowering indoor humidity levels as well can reduce the risk of condensation (see HV9). In addition, exhaust duct systems should be properly sealed to minimize infiltration.

Caution: Ductwork should not be installed outside the building envelope. Ductwork connected to rooftop units should enter or leave the unit through an insulated roof curb around the perimeter of the unit's footprint. Flexible duct connectors should be used to prevent sound transmission and vibration.

Duct board should be airtight (Seal Class A, from ASHRAE/IES Standard 90.1 [ASHRAE 2010b]) and should be taped and sealed with products that maintain adhesion (such as mastic or foil-based tape). Duct static pressures should be designed and equipment and diffusers should be selected not to exceed noise criteria for the space (see HV30 for additional information on noise control).

HV19 *Duct Insulation* (Climate Zones: all)

The following ductwork should be insulated:

- All supply air ductwork
- All return air ductwork located above an insulated ceiling and below the roof
- All OA ductwork

- All exhaust and relief air ductwork between the motor-operated damper and penetration of the building exterior

In addition, all airstream surfaces should be resistant to mold growth and resist erosion, according to the requirements of ASHRAE Standard 62.1 (ASHRAE 2010a).

Exception: In conditioned spaces without a finished ceiling, only the supply air main ducts and major branches should be insulated. Individual branches and runouts to diffusers in the space being served do not need to be insulated, except where it may be necessary to prevent condensation.

HV20 *Duct Sealing and Leakage Testing* (Climate Zones: all)

The ductwork should be sealed for Seal Class A from ASHRAE/IES Standard 90.1 (ASHRAE 2010b). All duct joints should be inspected to ensure they are properly sealed and insulated, and the ductwork should be leak-tested at the rated pressure. The leakage should not exceed the allowable cubic feet per minute per 100 ft^2 of duct area for the seal and leakage class of the system's air quantity apportioned to each section tested. See HV18 for guidance on ensuring the air system's performance.

HV21 *Fan Motor Efficiencies* (Climate Zones: all)

Motors for fans should meet NEMA premium efficiency motor guidelines (NEMA 2006) when available. Electrically commutated motors may be an appropriate choice for many small units to increase efficiency.

Fan systems should meet or exceed the efficiency levels listed in this chapter and in the recommendation tables in Chapter 4. Depending on the HVAC system type, the efficiency level is expressed in terms of either a maximum power (W) per cubic feet per meter of supply air (for systems where fan power is not included in the packaged HVAC unit efficiency calculation) or a maximum ESP loss (for packaged systems where fan power is included in the EER calculation).

HV22 *Thermal Zoning* (Climate Zones: all)

Retail buildings may have a limited number of zones, with the general shopping space arbitrarily divided into zones based upon the HVAC distribution scheme. Special-purpose areas, such as offices, work rooms, or special sales areas with significantly different lighting, equipment loads, or occupant density than the general sales area should be controlled as separate zones.

Zoning also can be accomplished with multiple HVAC units or a central system that provides independent control for multiple zones. The temperature sensor for each zone should be installed in a location that is representative of the entire zone.

When using a multiple-zone system (such as a VAV system), avoid using a single air handler (or rooftop unit) to serve zones that have significantly different occupancy patterns. Using multiple air handlers allows air handlers serving unused areas of the building to be shut off, even when another area of the building is still in use. An alternate approach is to use a BAS to define separate operating schedules for these areas of the building, thus shutting off airflow to the unused areas while continuing to provide comfort and ventilation to areas of the building that are still in use.

The number of spaces in a zone and the locations of the temperature sensors (thermostats) will affect the control of temperature in the various spaces of a zone. Locating the thermostat in one room of a zone with multiple spaces provides feedback based only on the conditions in that room. Locating a single thermostat in a large open area may provide a better response to the conditions of a zone with multiple spaces. Selecting the room or space that will best represent the thermal characteristics of the space due to both external and internal loads will provide the greatest comfort level for occupants.

To prevent misreading of the space temperature, zone thermostats should not be mounted on exterior walls. Where this is unavoidable, use an insulated sub-base for the thermostat. In spaces with high ceilings, consider using ceiling fans or high/low air distribution to reduce temperature stratification during the heating season.

Proper zoning not only aids in energy efficiency but also can help increase occupant comfort in the space. The six primary factors that must be addressed when defining conditions for thermal comfort are:

- Metabolic rate
- Clothing insulation
- Air temperature
- Radiant temperature
- Air speed
- Humidity

HV23 *System-Level Control Strategies* (Climate Zones: all)

Control strategies can be designed to help reduce energy. Having a setback temperature for unoccupied periods during the heating season or a setup temperature during the cooling season can help save energy by avoiding the need to operate heating, cooling, and ventilation equipment. While programmable thermostats allow each zone to vary the temperature setpoint based on time of day and day of the week, they also allow occupants to override these setpoints or ignore the schedule altogether (by using the "hold" feature), reducing the potential for energy savings. A more sustainable approach is to equip each zone with a zone temperature sensor and then use a system-level controller that coordinates the operation of all components of the system. This system-level controller contains time-of-day schedules that define when different areas of the building are expected to be unoccupied. During these times, the system is shut off and the temperature is allowed to drift away from the occupied setpoint.

A pre-occupancy ventilation period can help purge the building of contaminants that build up overnight from the off-gassing of products and packaging materials, if the ventilation strategy has not previously been determined by the Indoor Air Quality Procedure of ASHRAE Standard 62.1. Cool temperatures at night also can help precool the building. In humid climates, however, care should be taken to avoid bringing in humid OA during unoccupied periods.

Buildings with multiple-zone recirculating ventilation systems can be designed to account for recirculated OA as well as system population diversity using the equations found in ASHRAE Standard 62.1. (See HV13.)

Optimal start uses a system-level controller to determine the length of time required to bring each zone from the current temperature to the occupied setpoint temperature. Then, the controller waits as long as possible before starting the system so that the temperature in each zone reaches occupied setpoint just in time for occupancy. This strategy reduces the number of hours that the system needs to operate and saves energy by avoiding the need to maintain the indoor temperature at occupied setpoint when the building is unoccupied.

In a VAV system, SAT reset should be implemented to minimize overall system energy use. This requires considering the trade-off between compressor, reheat, and fan energy as well as the impact on space humidity levels. If SAT reset is used in a humid climate, include one or more zone humidity sensors to disable reset if space relative humidity becomes excessive. Relative humidity above 65% may result in mold growth, so a control strategy with appropriate sensors (dew point, relative humidity) should be incorporated to avoid this condition.

Control systems should include the following:

- Control sequences that easily can be understood and commissioned
- A user interface that facilitates understanding and editing of building operating parameters and schedules
- Sensors that are appropriately selected for range of sensitivity and ease of calibration

- Means to effectively convey the current status of systems operation and of exceptional conditions (faults)
- Means to record and convey history of operations, conditions, and efficiencies
- Means to facilitate diagnosis of equipment and systems failures
- Means to document preventive maintenance

HV24 *Testing, Adjusting, and Balancing* (Climate Zones: all)

After the system has been installed, cleaned, and placed in operation, it should be tested, adjusted, and balanced in accordance with ANSI/ASHRAE Standard 111 (ASHRAE 2008b) or the Sheet Metal and Air Conditioning Contractor's National Association (SMACNA) testing, adjusting, and balancing manual (SMACNA 2002).

Testing, adjusting, and balancing will help to ensure that correctly sized diffusers, registers, and grilles have been installed, that each space receives the required airflow, and that the fans meet the intended performance. The balancing subcontractor should certify that the instruments used in the measurement have been calibrated within 12 months before use. A written report should be submitted for inclusion in the operation and maintenance (O&M) manuals.

HV25 *Commissioning (Cx)* (Climate Zones: all)

After the system has been installed, cleaned, and placed in operation, it should be commissioned to ensure that the equipment meets the intended performance and that the controls operate as intended. See Appendix C for more information on commissioning.

HV26 *Filters* (Climate Zones: all)

Particulate air filters are typically included as part of factory-assembled HVAC equipment and should have at least a Minimum Efficiency Reporting Value (MERV) of 6, based on testing procedures described in ASHRAE Standard 52.2 (ASHRAE 2007c).

As explained in *Indoor Air Quality Guide: Best Practices for Design, Construction and Commissioning* (ASHRAE 2009b), EPA maps areas not in compliance (nonattainment) with the National Ambient Air Quality Standards (NAAQS) (EPA 2008a, 2008b). PM2.5 particles are those smaller than 2.5 µm in diameter. In PM2.5 nonattainment areas (virtually all major metropolitan areas), use MERV 11 filters for OA. Use a filter differential pressure gauge to monitor the pressure drop across the filters and send an alarm if the predetermined pressure drop is exceeded.

If high-efficiency filters are to be used, consider using lower-efficiency filters during the construction period. When construction is complete, all filters should be replaced before the building is occupied.

HV27 *Hydronic Heating Systems* (Climate Zones: all)

Condensing boilers can operate at up to 97% efficiency and can operate efficiently at part load. To achieve these high efficiency levels, condensing boilers require that return water temperatures be maintained between 70°F and 120°F, where the boiler efficiency ranges from 97% to 91%. This fits well with hydronic systems that are designed with ΔTs greater than 20°F (the optimal ΔT is 30°F to 40°F). The higher ΔTs allow smaller piping and less pumping energy. Because condensing boilers work efficiently at part load, VFDs can be used on the pumps to further reduce energy use.

Condensing boiler capacity can be modulated to avoid losses caused by cycling at less than full load. This encourages the installation of a modular (or cascade) boiler system, which allows several small units to be installed for the design load but allows the units to match the load for maximum efficiency of the system.

HV28 *Relief versus Return Fans* (Climate Zones: all)

Relief (rather than return) fans should be used when necessary to maintain positive building pressurization at approximately 0.05 in. w.c. Relief fans reduce overall fan energy compared with return fans, as long as return dampers are sized correctly. However, if return duct static pressure drop exceeds 0.5 in. w.c., return fans may be needed.

Cautions

HV29 *Heating Sources* (Climate Zones: all)

Many factors come into play in deciding whether to use gas or electricity for heating, including availability of service, utility costs, operator familiarity, and the impact of source energy use.

Forced-air electric resistance and gas-fired heaters require a minimum airflow rate to operate safely. These systems, whether stand-alone or incorporated into an air-conditioning or heat pump unit, should include factory-installed controls to shut down the heater when there is inadequate airflow that can result in high temperatures.

Ducts and supply-air diffusers should be selected based on discharge air temperatures and airflow rates.

HV30 *Noise Control* (Climate Zones: all)

Acoustical requirements may necessitate attenuation of the supply and/or return air, but the impact on fan energy consumption also should be considered and, if possible, compensated for in other duct or fan components. Acoustical concerns may be particularly critical in short, direct runs of ductwork between the fan and supply or return outlet (see Figure 5-21).

Location of air-conditioning or heat pump units and design of noise-attenuating separations should recognize acoustic requirements of adjacent spaces (see Figure 5-22).

ASHRAE Handbook—HVAC Applications (ASHRAE 2007d) is a potential source for recommended background sound levels in the various spaces that make up retail buildings.

HV31 *Proper Maintenance* (Climate Zones: all)

Regularly scheduled maintenance is an important part of keeping the HVAC system in optimum working condition. Neglecting preventive maintenance practices can quickly negate energy savings expected from the system design. ASHRAE/ACCA Standard 180 provides minimum requirements for maintenance and inspection and should be used to help develop a routine maintenance program for the building (ASHRAE 2008c).

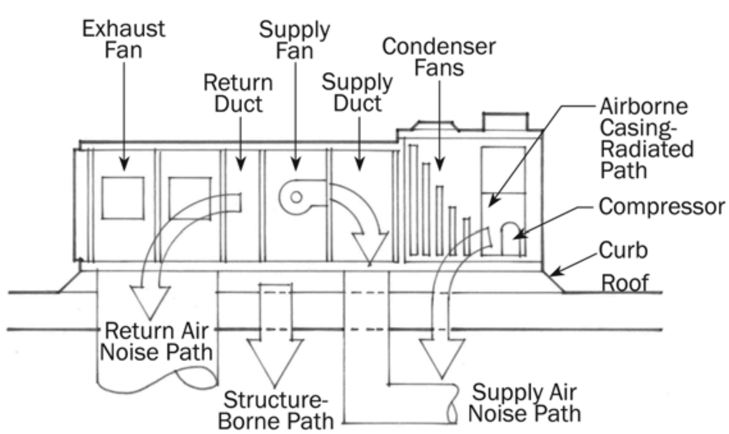


Figure 5-21 (HV30) Typical Noise Paths for Rooftop-Mounted HVAC Units

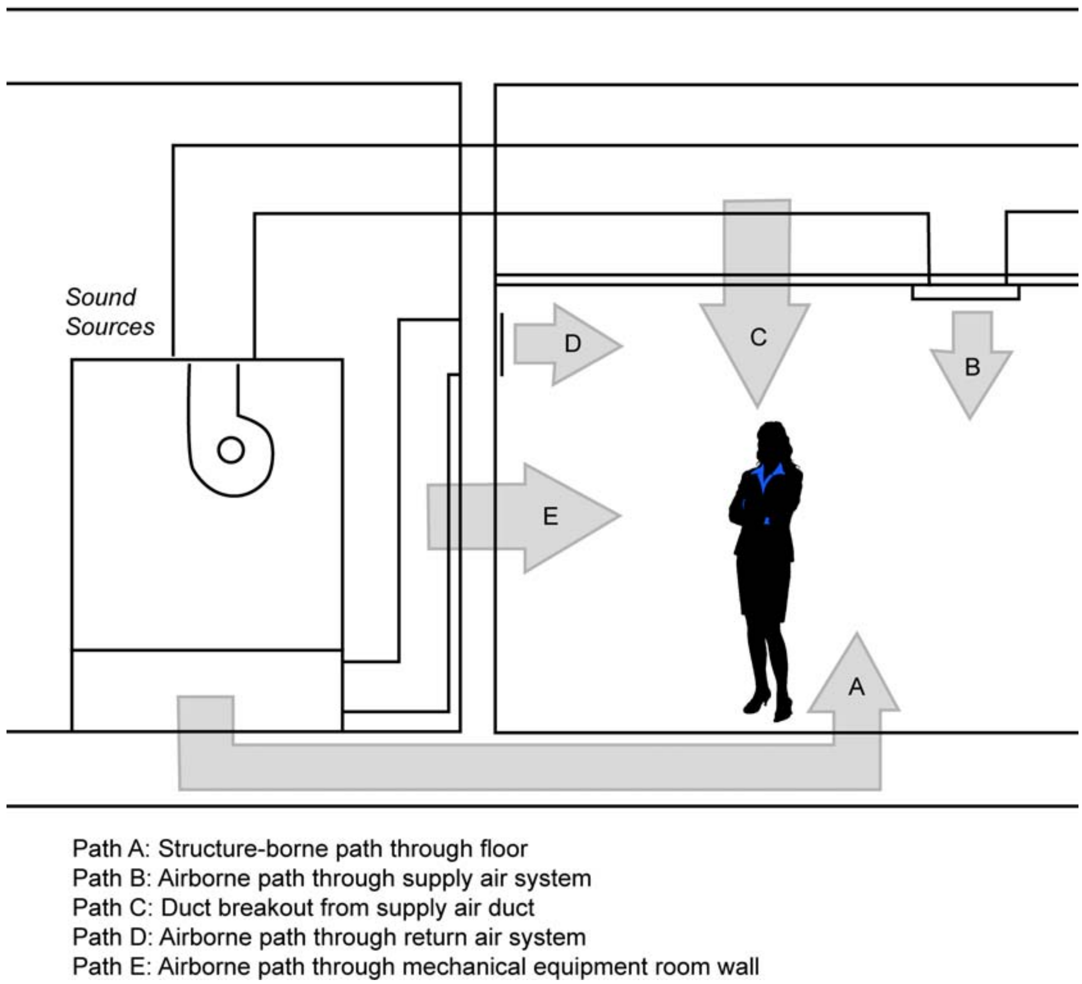


Figure 5-22 (HV30) Typical Noise Paths for Interior-Mounted HVAC Units

All filters should be inspected monthly and should be cleaned or replaced when the pressure drop exceeds the filter manufacturer's recommendations for replacement or when visual inspection indicates the need for replacement. Energy recovery devices need to be inspected at least annually and cleaned periodically to maintain performance. Dampers, valves, louvers, and sensors must all be periodically inspected (at least semi-annually) and calibrated to ensure proper operation. This is especially important for OA dampers and CO_2 sensors. Inaccurate CO_2 sensors can cause excessive energy use or poor IAQ, so they need to be calibrated as recommended by the manufacturer.

A BAS can be used to notify O&M staff when preventive maintenance procedures should be performed. This notification can be triggered by calendar dates, runtime hours, the number of times a piece of equipment has started, or sensors installed in the system (such as a pressure switch that indicates when an air filter is too dirty and needs to be replaced). Increase frequency of inspections if indicators of unacceptable performance are found during two successive inspections.

Annual coil cleaning should be scheduled to maintain desired coil air approach temperature and to avoid additional air pressure drop.

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QUALITY ASSURANCE (QA)

QA, including Cx, will help ensure that a building functions in accordance with its design intent and thus meets the performance goals established for it. Quality assurance should be an integral part of the design and construction process as well as the continued operation of the facility. General information on QA and Cx is included in Chapter 2, and Appendix C provides examples for the commissioning process.

COMMISSIONING

QA1 *Design and Construction Team* (Climate Zones: all)

Selection of the design and construction team members is critical to a project's success. Owners need to understand how team dynamics can play a role in the building's resulting performance. Owners should evaluate qualifications, past performance, cost of services, and availability of the candidates in making their selection. Owners need to be clear in their expectations of how team members should interact. It should be clear that all members should work together to further team goals. The first step is to define members' roles and responsibilities. This includes defining deliverables at each phase during the design and commissioning processes.

QA2 *Selection of Quality Assurance Provider* (Climate Zones: all)

Quality assurance is a systematic process of verifying the Owner's Project Requirements (OPR), operational needs, and Basis of Design (BoD) and ensuring that the building performs in accordance with these defined needs. The selection of a QA provider should include the same evaluation process the owner would use to select other team members. Qualifications in providing QA services, past performance of projects, cost of services, and availability of the candidate are some of the parameters an owner should investigate and consider when making a selection. Owners may select a member of the design or construction team as the QA provider. While there are exceptions, most designers are not comfortable operating and testing assemblies and equipment and most contractors do not have the technical background necessary to evaluate performance. Commissioning requires in-depth technical knowledge of the building envelope and the mechanical, electrical, and plumbing systems and operational and construction experience. This function is best performed by a third party responsible to the owner because political issues often inhibit members of the design or construction teams from fulfilling this responsibility.

QA3 *Owner's Project Requirements and Basis of Design* (Climate Zones: all)

The OPR details the functional requirements of a project and the expectations of how the facility will be used and operated. This includes strategies and recommendations selected from this Guide (see Chapter 4) that will be incorporated into the project, anticipated hours of operation provided by the owner, and BoD assumptions.

The OPR forms the foundation of the team's tasks by defining project and design goals, measurable performance criteria, owner directives, budgets, schedules, and supporting information in a single, concise document. The QA process depends on a clear, concise, and comprehensive OPR. Development of the OPR requires input from all key facility users and operators. It is critical to align the complexity of the systems with the capacity and capability of the facility staff.

The next step is for the design team members to document how their design responds to the OPR information. This document is the BoD. It records the standards and regulations, calculations, design criteria, decisions and assumptions, and the system descriptions. The narrative must clearly articulate the specific operating parameters required for the systems to form the basis for later quality measurements. Essentially, it is the engineering background information that is not provided in the construction documents that map out how the architects and engineers end up with their designs. For example, it should state key criteria such as future expansion and redundancy considerations. It should include important criteria such as what codes, standards, or guidelines are being followed for the various engineered systems, including ventilation and energy. It provides a good place to document owner input needed for engineered systems, such as identifying what electrical loads are to be on emergency power.

QA4 *Design and Construction Schedule* (Climate Zones: all)

The inclusion of QA activities in the construction schedule fulfills a critical part of delivering a successful project. Identify the activities and time required for design review and performance verification to minimize time and effort needed to accomplish activities and correct deficiencies.

QA5 *Design Review* (Climate Zones: all)

The commissioning authority (CxA)/QA provider gives a fresh perspective that allows identification of issues and opportunities to improve the quality of the construction documents and verify that the OPR is being met. Issues identified can be more easily corrected early in the project, providing potential savings in construction costs and reducing risk to the team.

QA6 *Defining Quality Assurance at Pre-Bid* (Climate Zones: all)

The building industry has traditionally delivered buildings without using a verification process. Changes in traditional design and construction procedures and practices require education of the construction team that explains how the QA process will affect the various trades bidding the project. It is extremely important that the QA process be reviewed with the bidding contractors to facilitate understanding of and to help minimize fear associated with new practices. Teams who have participated in the Cx process typically appreciate the process because they are able to resolve problems while their manpower and materials are still on the project, significantly reducing delays, callbacks, and associated costs while enhancing their delivery capacity.

These requirements can be reviewed by the Architect and Engineer of Record at the prebid meeting, as defined in the specifications.

QA7 *Verifying Building Envelope Construction* (Climate Zones: all)

The building envelope is a key element of an energy-efficient design. Compromises in assembly performance are common and are caused by a variety of factors that easily can be avoided. Improper placement of insulation, improper sealing or lack of sealing at air barriers, poorly selected or performing glazing and fenestration systems, incorrect placement of shading devices, misplacement of daylighting shelves, and misinterpretation of assembly details can significantly compromise the energy performance of the building (see “Cautions” sections throughout this chapter). The value of the Cx process is that it is an extension of the quality control processes of the designer and contractor as the team works together to produce quality energy-efficient projects.

QA8 *Verifying Lighting Construction* (Climate Zones: all)

Lighting plays a significant role in the energy consumption of the building. Lighting for all of the space types should be reviewed against an anticipated schedule of use throughout the day.

QA9 *Verifying Electrical and HVAC Systems Construction* (Climate Zones: all)

Performance of electrical and HVAC systems are key elements of this Guide. How systems are designed as well as installed affect how efficiently they will perform. Collaboration between the entire design team is needed to optimize the energy efficiency of the facility. Natural daylight and artificial lighting will impact the heating and cooling loads with respect to both capacity and operation mode. The design reviews should pay close attention to the fact that proper installation is just as important as proper design. Making sure the installing contractor’s foremen understand the owner's goals, the QA process, and the installation details is a key factor to system performance success. A significant part of this process is a careful and thorough review of product submittals to ensure compliance with the design. It is in everyone's best interest to install the components correctly and completely the first time. Trying to inspect quality into a project is time consuming and costly and usually doesn't result in quality. It's much better to ensure all team members are aligned with the QA process and goals. Certainly, observations and inspections during construction are necessary. The timing is critical to ensure that problems are identified at the beginning of each system installation. That minimizes the number of changes (time and cost) and leaves time for corrections.

QA10 *Performance Testing* (Climate Zones: all)

Performance testing of systems is essential to ensure that commissioned systems are functioning properly in all modes of operation; after all, regardless of how effective a given design strategy may be, potential performance only can be realized through proper implementation. Unlike most appliances these days, none of the mechanical/electrical systems in a new facility are "plug and play." If the team has executed the Cx plan and is aligned with the QA goals, the performance testing will occur quickly and only minor issues will need to be resolved. Owners with O&M personnel can use the functional testing process as a training tool to educate their staff on how the systems operate as well as for system orientation prior to training.

QA11 *Substantial Completion* (Climate Zones: all)

Substantial completion is achieved when life safety systems have been implemented and verified and the facility is ready to be occupied. All of the systems should be operating as intended. Expected performance only can be accomplished when all systems operate interactively to provide the desired results. As contractors finish their work, they will identify and resolve many performance problems. The CxA/QA provider verifies that the contractor maintained a quality control process by directing and witnessing testing and then helps to resolve remaining issues.

QA12 *Final Acceptance* (Climate Zones: all)

Final acceptance generally occurs after the Cx/QA issues in the issues log have been resolved except for minor issues the owner is comfortable with resolving during the warranty period.

QA13 *Establish Building Operation and Maintenance (O&M) Program* (Climate Zones: all)

Continued performance and control of O&M costs require a maintenance program. The O&M manuals provide information that the O&M staff uses to develop this program. Detailed O&M system manual and training requirements are defined in the OPR and executed by the project team to ensure the O&M staff has the tools and skills necessary. The level of expertise typically associated with O&M staff for buildings covered by this Guide is generally much lower than that of a degreed or licensed engineer, and they typically need assistance with development of a preventive maintenance program. The CxA/QA provider can help bridge the knowledge gaps of the O&M staff and assist the owner with developing a program that will help ensure continued performance. The benefits associated with energy-efficient buildings are realized when systems perform as intended through proper design, construction, operation, and maintenance.

MEASUREMENT AND VERIFICATION (M&V)

QA14 *Monitor Post-Occupancy Performance* (Climate Zones: all)

Establishing measurement and verification (M&V) procedures for actual building performance after a building has been commissioned can identify when corrective action and/or repair is required to maintain energy performance. Utility consumption and factors affecting utility consumption should be monitored and recorded to establish building performance during the first year of operation.

Variations in utility usage can be justified based on changes in conditions typically affecting energy use, such as weather, occupancy, operational schedule, maintenance procedures, and equipment operations required by these conditions. While most buildings covered in this Guide will not use a formal M&V process, tracking the specific parameters listed above does allow the owner to quickly review utility bills and changes in conditions. Poor performance is generally obvious to the reviewer when comparing the various parameters. CxA/QA providers typically can help owners understand when operational tolerances are exceeded and can provide assistance in defining what actions may be required to return the building to peak performance.

Another purpose of the post-occupancy evaluation (POE) is to determine actual energy performance of low-energy buildings to verify design goals and document real-world energy savings. Additionally, the POE provides lessons learned in the design, technologies, operation, and analysis techniques to ensure these and future buildings operate at a high level of performance over time. For details and some case studies and lessons learned, refer to the published National Renewable Energy Laboratory (NREL) report (Torcellini et al. 2006).

QA15 *M&V Electrical Panel Guidance* (Climate Zones: all)

Designing the electrical distribution system to be submetered reduces complexity, minimizes the number of meters, shortens installation time, and minimizes rewiring. Disaggregate electrical panels (put lights together on one panel, HVAC on another, miscellaneous loads on a third, etc.), and repeat for emergency circuits. Meter as much as possible at the main distribution panel and repeat for emergency circuits to minimize installation and wiring costs. Consider using electrical panels with integral submeters to reduce capital costs. Integrate testing of the meters into the Cx plan to ensure that the submetering system is operating correctly.

QA16 *M&V Data Management and Access* (Climate Zones: all)

Detailed M&V systems can result in an overwhelming amount of data. The success of an M&V system depends on proper management of this data. Collect submetered data at resolutions appropriate for the intended use. For example: save 1 min data for one day to aid with equipment troubleshooting and identify failures; save data at 5 min intervals for one week to help analyze the building schedules; and save 15 min data for at least one year to help with benchmarking, to determine annual energy performance, to compare to the original energy model (weather variance removed), and to compare end-use benchmarks. In general, make sure you have sufficient data resolution to determine electricity demand information and equipment failures.

To ensure ease of interoperability and consistency with other submetering efforts for a portfolio of buildings, comply with the metering standard of the existing buildings. If one does not exist, consider developing a metering standard that documents interoperability and accessibility requirements. In addition, allow for external consultants and design team members to easily access the metered data remotely.

QA17 *M&V Benchmarking* (Climate Zones: all)

An owner should benchmark utility bills and submetered data to ensure energy performance targets are met and should be prepared to repeat this exercise monthly. CxA/QA providers typically can help owners understand when operational tolerances are exceeded and can help determine actions to return the building to peak performance. Benchmarking a facility can identify poor performance in multiple ways. Submetered data can be benchmarked against previous trends, energy models, or other facilities with submetered data. Monthly energy performance should be benchmarked against historic performance and other facilities in a portfolio or other, similar facilities. Annual energy performance should be benchmarked using EPA's ENERGY STAR Portfolio Manager and the energy targets provided in this Guide (see Chapter 4)(EPA 2011).

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ADDITIONAL BONUS SAVINGS

OTHER HVAC SYSTEM TYPES

HV33 *GSHP with DOAS* (Climate Zones: all)

This variation of the WSHP system takes advantage of the high thermal capacitance of the earth to store heat rejected into the ground during the cooling cycle as a resource for the heating cycle. In general, successful implementation of a ground-coupled heat pump system requires relative balance between the amount of heat extracted from the ground for the heating cycle and the amount of heat rejected into the ground for the cooling cycle. An appropriately sized ground-coupling system will result in lower heat rejection temperature during the cooling cycle compared with cooling tower heat rejection. While the lower heat extraction temperature of a ground-coupled system compared with fuel-fired makeup typically results in a lower COP, performance is improved by the fact that no energy is consumed for makeup heating.

Performance characteristics of selected GSHP units should be the same as the WSHP specifications listed in HV6. GSHP units used with a closed-loop well system should have a rated low-temperature heating capability at a minimum temperature not more than 30°F. The circulating fluid for a closed-loop ground-coupled heat pump system should incorporate an antifreeze additive to prevent icing of the loop.

External air pressure drop for these units, as with WSHPs, should be limited to 0.7 in. w.c.

Following are some considerations for incorporation of a ground-coupled heat pump:

- Balance of winter heating loads with summer cooling loads
- Accurate determination of heat diffusivity of earth in contact with the ground-coupled heat transfer system, at a minimum through use of a test well to determine the nature of ground strata and ground water levels
- Adequate sizing of the ground-coupling system, using accurate ground thermal diffusivity information to limit minimum supply water temperature during the winter and maximum supply water temperature during the summer

Ensure appropriate design and control of the hydronic circulation system to optimize pumping energy and maximize heat pump annual heating and cooling efficiency.

RENEWABLE ENERGY

RE1 *Photovoltaic (PV) Systems* (Climate Zones: all)

Photovoltaic (PV) systems have become an increasingly popular option for on-site electric energy production for energy cost savings in retail buildings. These systems require very little maintenance and have long lifetimes but are often difficult to cost-justify without alternative financing and leveraging available incentives. However, the average cost of PV systems has declined significantly in recent years. PV systems can be effectively used in retail buildings in almost all climate zones in the U.S. Figure 5-23 shows the PV solar energy resources in the U.S.

Options for installing PV systems include rooftop (including collectors integrated with the roofing membrane), ground-mounted, or as the top of a covered parking system. Unshaded south-facing standing seam metal roofs or flat membrane roofs offer the simplest and most cost-effective mounting surfaces for rooftop PV systems. Ensure roof structures are adequate for the added weight of the PV system and be aware of any rooftop warranty implications from adding PV systems. Use roof mounting systems that do not penetrate the continuous insulation of the roof deck, such as a self-ballasted racking system. To allow for easy installation of PV systems on the roofs of retail buildings, provide extra conduit from the roof to the inverters, typically located in either an electrical room or a secure outdoor location. Also ensure the main electrical distribution system, from the main distribution panel to the building transformer, has the capability of carrying additional PV wiring.

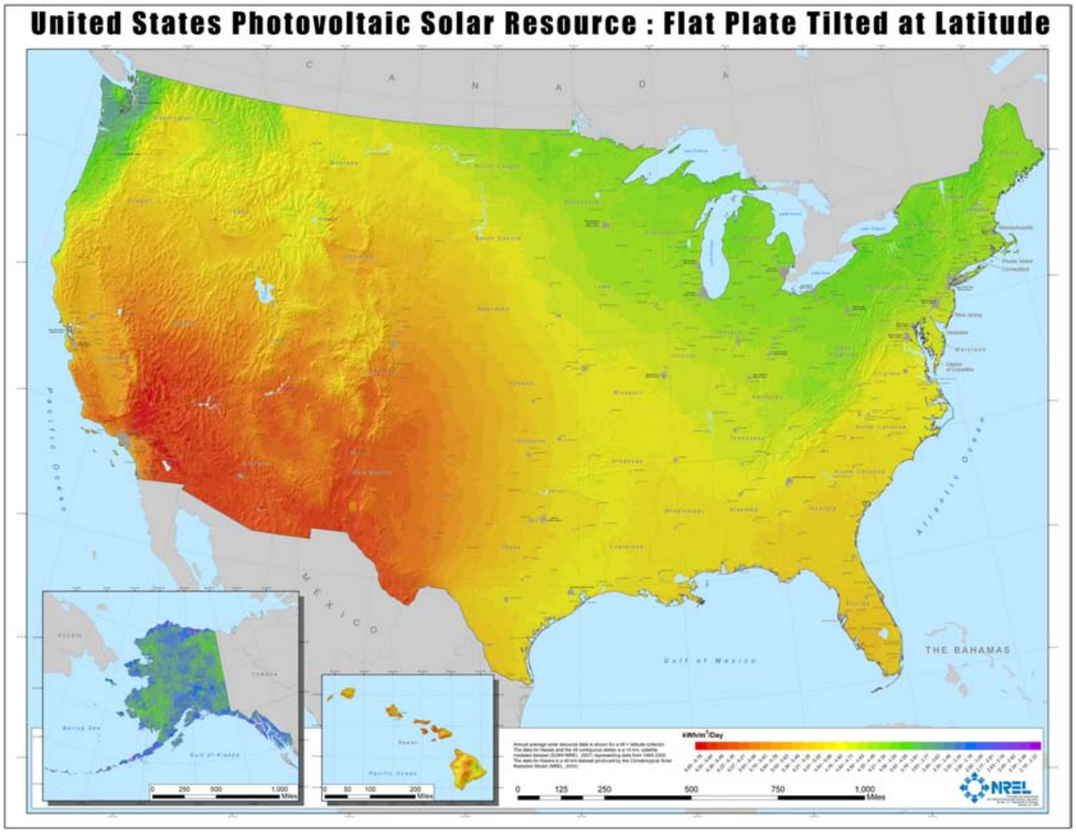

Figure 5-23 (RE1) Photovoltaic Solar Resources of the U.S.
Source: National Renewable Energy Laboratory
www.nrel.gov/rredc/pvwatts/site_specific.html

There are many unique funding opportunities for PV systems in retail buildings. In addition to the many rebate programs offered by state and local utility companies, there are often significant incentives, loans, grants, and buyback programs for PV systems in retail buildings. The Database for State Incentives for Renewables & Efficiency (NREL 2011a) shows some opportunities available to retailers in various states.

There are numerous tools available for modeling energy production from PV systems. One such tool is NREL's PVWatts™ calculator, available on the NREL website as part of their Renewable Data Resource Center (NREL 2011b). The tool determines the energy production and cost savings of grid-connected PV energy systems throughout the world. It allows retail building designers, installers, and manufacturers to easily develop estimates of the performance of PV installations.

RE2 *Wind Turbine Power* (Climate Zones: all)

Wind energy is one of the lowest-priced renewable energy technologies available today, costing between \$0.05–\$0.11 per kilowatt-hour, depending upon the wind resource and project financing of the particular project. For retail buildings, small-to-medium-sized wind turbines are typically considered. These turbines range from 4 to 200 kW and are typically mounted on towers from 50 to 100 ft tall and connected to the utility grid through the building's electrical distribution system.

One of the first steps to developing a wind energy project is to assess the area's wind resources and estimate the available energy. It can be determined from wind resource maps if an area of interest should be further explored. Note that the wind resource at a micro level can vary significantly; therefore, a professional evaluation of the specific area of interest should be performed.

The map in Figure 5-24 shows the annual average wind power estimates at 50 m above ground. It combines high- and low-resolution datasets that have been screened to eliminate land-based areas unlikely to be developed due to land use or environmental issues. In many states, the wind resource has been visually enhanced to better show the distribution on ridge crests and other features. Estimates of the wind resource are expressed in wind power classes ranging from Class 1 (lowest) to Class 7 (highest), with each class representing a range of mean wind power density or equivalent mean speed at specified heights above the ground. This map does not show Classes 1 and 2, as Class 1 areas are unsuitable and Class 2 areas are marginal for wind energy development. In general, at 50 m, wind power Class 4 or higher can be useful for generating wind power. More detailed state wind maps are available at the Wind Powering America Web site (DOE 2011).

Although wind turbines themselves do not take up a significant amount of space, they need to be installed an adequate distance from the nearest building for several reasons, including turbulence reduction (which affects efficiency), noise control, and safety. It is essential that coordination occurs between the owner, design team, and site planner to establish the optimal wind turbine location relative to the other facilities on the site.

The three largest complaints about wind turbines are noise, hazard to birds, and aesthetic appearance. Most of these problems have been resolved or greatly reduced through technological

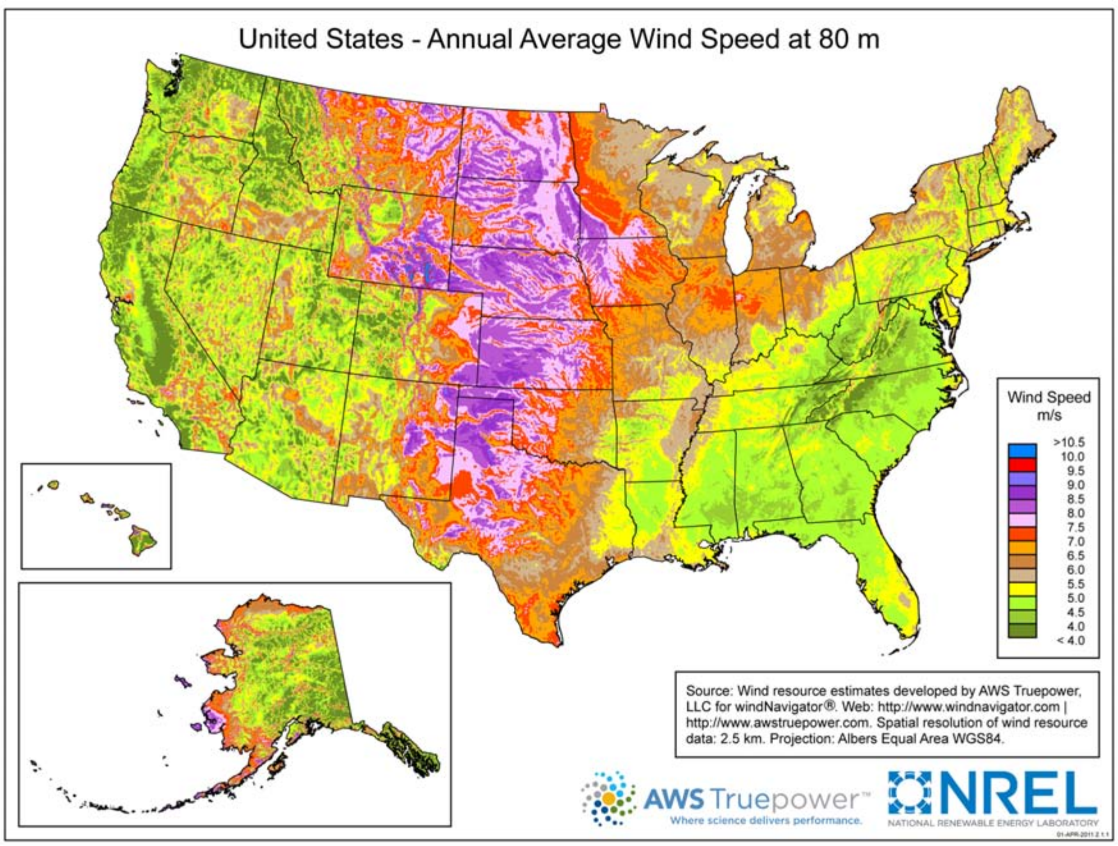

Figure 5-24 (RE2) Average Annual Wind Power Estimates
Source: DOE, Wind Powering America
www.windpoweringamerica.gov/wind_maps.asp

development or through proper siting of wind turbines. Most small wind turbines today have an excellent safety record. An important factor to consider is how the wind turbine controls itself and shuts itself down. Can operators shut it off and stop the turbine when they want or need to do so? This is extremely important and, unfortunately, there are very few small turbines that have reliable means to stop the rotor on command. The few that do may require you to do so from the base of the tower—not exactly where you want to be if the turbine is out of control in a wind storm. Look for a system that offers one or more means to shut down and preferably stop the rotor remotely.

Using energy modeling, the electric energy consumption of a building can be estimated. Using this data in conjunction with the financial detail of the project, including the rebates, the owner and designer must then choose the correct size turbine that meets their needs. Note that the closer the match of the turbine energy output to the demand, the more cost-effective the system will be. Make sure that all costs are listed to give a total cost of ownership for the wind turbine. This includes the wind turbine, tower, electrical interconnection, controls, installation, maintenance, concrete footings, guy wires, and cabling.

In addition to evaluating the initial cost of the turbine, it is extremely important to consider the federal and state policies and incentive programs that are available. The Database for State Incentives for Renewables & Efficiency (NREL 2011a) provides a list of available incentives, grants, and rebates. Also critical to the financial success of a wind turbine project is a favorable net metering agreement with the utility.

RE3 *Transpired Solar Collector* (Climate Zones: ❸ ❹ ❺ ❻ ❼)

A transpired solar collector is a renewable energy technology that, when coupled with a mechanical system, provides free heating of the air. As illustrated in Figure 5-25, the system is composed of a perforated metal panel with an air cavity between the panel and the exterior wall. As the panel absorbs solar radiation, air is drawn into the cavity. As the air passes over the surface of the wall, the air is warmed.

Warm air is drawn into the mechanical system during heating mode. The free heating of the air can significantly reduce the demand for electric or fossil fuel heating. When heated air is not desired, a bypass damper allows the system to relieve the warm air out of the cavity. Equally important, a separate outdoor air location is required at these times to provide ventilation air using ambient temperature air rather than the warm air in the transpired solar collector.

Since buildings often go through a morning warm-up, east- and south-facing walls are most suitable for transpired solar collector installations. In very cold climates, a west-facing wall may also be suitable.

RE4 *Power Purchase Agreements* (Climate Zones: all)

A primary barrier to the use of various on-site renewable energy strategies is the high initial capital investment cost. One way to finance and thus implement such a strategy is through a power purchase agreement. Retailers have successfully implemented renewable energy systems, such as pv, wind, and solar hot water, using these financing programs.

Power purchase agreements involve a third party who will design, install, own, operate, and maintain the power generation asset. The retailer then contracts to purchase the energy produced by the generation system, usually for a long period of time. This arrangement allows the retailer to avoid the high first cost and keeps the balance sheet clear of obligation. It also locks in an energy price, thus hedging the cost of energy over time from fluctuations in the prices of other energy sources. The agreements are complicated, with many considerations, and require negotiation by people familiar with the complexities, both from an engineering perspective as well as from legal and financial perspectives.

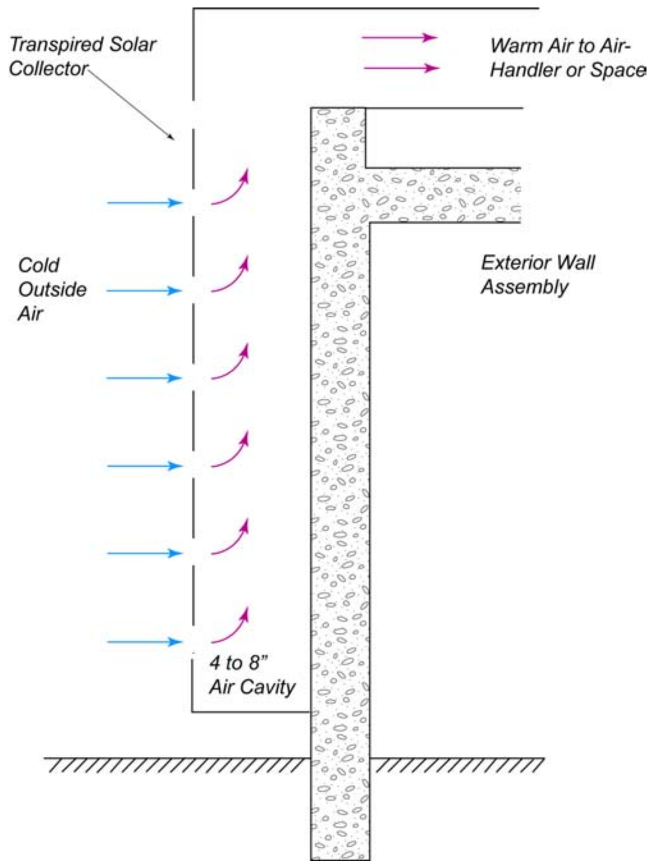

Figure 5-25 (RE3) Transpired Solar Collector

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Appendix A—Envelope Thermal Performance Factors

A

Each climate zone recommendation table in Chapter 4 presents a prescriptive construction option for each opaque envelope measure. Table A-1 presents U-factors for above-grade components and F-factors for slab-on-grade floors that correspond to each prescriptive construction option. Alternative constructions would be equivalent methods for meeting the recommendations of this Guide provided they are less than or equal to the thermal performance factors listed in Table A-1.

Table A-1 Opaque Construction Options

Roof Assemblies	
R	U
Insulation Above Deck	
20	0.048
25	0.039
30	0.032
35	0.028
Metal Building	
19 +10 FC	0.057
19 + 11 Ls	0.035
25 + 11 Ls	0.031
30 + 11 Ls	0.029
25+11+11 Ls	0.026

Slabs	
R-in.	F
Unheated	
15 - 24	0.52
20 - 24	0.51
Heated	
7.5 - 12	1.02
10 - 24	0.90
15 - 24	0.86
20 - 24	0.843
20 - 48	0.688
25 - 48	0.671

Walls, Above Grade	
R	U
Mass Walls	
5.7	0.151
7.6	0.123
9.5	0.104
11.4	0.090
15.4	0.071
17.0	0.067
19.0	0.063
Steel Framed	
13 + 7.5 c.i.	0.064
13 + 10.0 c.i.	0.057
13 + 12.5 c.i.	0.049
13 + 15.0 c.i.	0.043
13 + 18.8 c.i.	0.037
Metal Building	
0 + 9.8 c.i.	0.094
0 + 13.0 c.i.	0.072
0 + 15.8 c.i.	0.060
0 + 19.0 c.i.	0.050
0 + 22.1 c.i.	0.044
0 + 25.0 c.i.	0.039

Floors	
R	U
Mass	
10.4 c.i.	0.074
12.5 c.i.	0.064
14.6 c.i.	0.056
16.7 c.i.	0.050
20.9 c.i.	0.042
23.0 c.i.	0.038
Steel Framed	
30	0.038
38	0.032
49	0.027
60	0.024

c.i. = continuous insulation
F = slab edge heat loss coefficient per foot of perimeter, Btu/h·ft·°F
FC = filled cavity
Ls = liner system
R = thermal resistance, h·ft^2·°F/Btu
R-in. = R-value followed by the depth of insulation in inches
U = thermal transmittance, Btu/h·ft^2·°F

Appendix B— International Climatic Zone Definitions

B

Table B-1 shows the climate zone definitions that are applicable to any location. The information is from ANSI/ASHRAE/IES Standard 90.1-2010, Normative Appendix B, Table B-4 (ASHRAE 2010). Climate zone information for specific cities in Canada, Mexico, and other international cities can be found in the same appendix and is also available on the AEDG Web page (www.ashrae.org/aedg) in the "Additional Information" section. Weather data is needed in order to use the climate zone definitions for a particular city. Weather data by city is available for a large number of international cities in the 2009 *ASHRAE Handbook—Fundamentals* (ASHRAE 2009).

Table B-1 International Climatic Zone Definitions

Climate Zone Number	Name	Thermal Criteria*
1A and 1B	Very Hot–Humid (1A) Dry (1B)	9000 < CDD50°F
2A and 2B	Hot–Humid (2A) Dry (2B)	6300 < CDD50°F ≤ 9000
3A and 3B	Warm–Humid (3A) Dry (3B)	4500 < CDD50°F ≤ 6300
3C	Warm–Marine (3C)	CDD50°F ≤ 4500 AND HDD65°F ≤ 3600
4A and 4B	Mixed–Humid (4A) Dry (4B)	CDD50°F ≤ 4500 AND 3600 < HDD65°F ≤ 5400
4C	Mixed–Marine (4C)	3600 < HDD65°F ≤ 5400
5A, 5B, and 5C	Cool–Humid (5A) Dry (5B) Marine (5C)	5400 < HDD65°F ≤ 7200
6A and 6B	Cold–Humid (6A) Dry (6B)	7200 < HDD65°F ≤ 9000
7	Very Cold	9000 < HDD65°F ≤ 12600
8	Subarctic	12600 < HDD65°F

*CDD = cooling degree-day, HDD = heating degree-day.

DEFINITIONS

Marine (C) Definition—Locations meeting all four of the following criteria:

- Mean temperature of coldest month between 27°F and 65°F
- Warmest month mean < 72°F
- At least four months with mean temperatures over 50°F
- Dry season in summer. The month with the heaviest precipitation in the cold season has at least three times as much precipitation as the month with the least precipitation in the rest of the year. The cold season is October through March in the Northern Hemisphere and April through September in the Southern Hemisphere.

Dry (B) Definition—Locations meeting the following criterion:

- Not marine and $P < 0.44 \times (T - 19.5)$
  where
  P = annual precipitation, in.
  T = annual mean temperature, °F

Moist (A) Definition—Locations that are not marine and not dry.

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Appendix C— Commissioning Information and Examples

C

Following are examples of what a commissioning scope of services and a responsibility matrix (Table C-1) might include. Project teams should adjust these to meet the needs of the owner and project scope, budget, and expectations.

COMMISSIONING SCOPE OF SERVICES

INTRODUCTION

Commissioning (Cx) is a quality assurance (QA) process with four main elements. First, the architectural and engineering (A&E) team must clearly understand the building owner's goals and requirements for the project. Next, the A&E team must design systems that support or respond to those requirements. The construction team must understand how the components of the system must come together to ensure that the system is installed correctly and performs as intended. Last, the operators of the system must also understand how the system is intended to function and have access to information that allows them to maintain it as such. This process requires more coordination, collaboration, and documentation between project team members than traditionally has been provided.

The intent of this appendix is to help provide an understanding of the tasks, deliverables, and costs involved. An independent commissioning authority (CxA), one that is contracted directly with the building owner, will be the building owner's representative to facilitate the Cx process and all of its associated tasks. The CxA will lead the team to ensure everyone understands the various tasks, the roles they play, and the desired outcome or benefit for following the Cx process. The systems required to be commissioned are those that impact the use of energy. Project team members responsible for the design or installation of those systems will have the majority of the Cx work. The majority of the field work will be the responsibility of the mechanical, electrical, and control contractors.

Cx of a new building will ultimately enhance the operation of the building. Reduced utility bills, lower maintenance costs, and a more comfortable and healthier indoor environment will result. Cx focuses on creating buildings that are as close to the owners' and users' objectives (as delineated in the Owner's Project Requirements [OPR]) as possible. Early detection and resolution of potential issues are the keys to achieving a high-quality building without increasing the total effort and cost to the team members. Resolving design issues early will significantly reduce efforts during construction. Finding mistakes after installation or during start-up are costly to everyone. Checklists will assist the contractors during installation, and installation issues will be detected early. Early detection will reduce the amount of rework required compared to late detection at final inspection. This will also benefit the owner and occupants since the building will work as intended from day one of operation.

SYSTEMS

The systems under this scope of services include the following:

- The entire heating, ventilating, and air-conditioning (HVAC) system (boilers, chillers, pumps, piping, and air distribution systems).
- The building automation system (BAS) for the HVAC system.
- The domestic hot-water system.
- The electrical systems (lighting and receptacle systems, electrical panels, transformers, motor control centers, electrical motors, and other electrical items excluding emergency power systems).
- The building envelope as it relates to energy efficiency (insulation, wall framing—thermal bridging, air leakage, glazing solar and thermal characteristics, and fenestration framing—thermal bridging).

These listed systems will be commissioned by the tasks described in the “Commissioning Tasks” section of this chapter.

DELIVERABLES

The following deliverables are part of the Cx scope of services:

- Cx Plan
- OPR
- CxA’s design review
- Construction installation checklists
- CxA’s site visit reports
- System functional performance tests
- Systems manual
- Owner training
- Cx report
- Systems warranty review
- Final Cx report

SCHEDULE

Cx begins in the early stage of design and continues through building operation. The following sections detail the specific step-by-step activities that owners, designers, and construction team members need to follow in each phase of the project’s delivery.

Planning Phase

- Document OPR (project intent)
- Develop Commissioning Plan
- Specify architect/engineer Cx requirements
- Assist with the architect/engineer selection process

Design Phase

- Verify that the design meets the OPR
- Write Cx specifications

Construction Phase

- Verify that the submittals meet OPR
- Verify that the installation meets OPR
- Verify that the components function as required
- Facilitate training of building operators

Acceptance Phase

- Verify that the systems work as required and meet OPR
- Verify that the OPR are met throughout the building
- Develop systems manual
- Review contractors' operation and maintenance (O&M) and systems manuals

Operational Phase

- Warranty review
- Verify that the operation of the building is optimal

COMMISSIONING TASKS

Commissioning Plan

The CxA will write the Commissioning Plan and detail the Cx tasks and schedule for executing the Commissioning Plan tasks. In addition, the communication channels will be listed and samples of all forms, procedures, and checklists used for the project will be provided. The Cx responsibilities of each of the project team members will be listed. The Commissioning Plan will be updated as the project progresses and as forms, procedures, checklists, schedules, agendas, reports, etc., are finalized or revised. These updates will be distributed at major milestones to all project team members.

Owner's Project Requirements (OPR)

The OPR document describes the main expectations the owner wants the project to meet. As the owner usually wants to meet most of the expectations of all stakeholders, input from a representative of each stakeholder is beneficiary.

For the referenced project the CxA will facilitate and write the OPR with input from the owner.

Commissioning Specifications

The Cx specifications will clearly state what will be expected from the contractors. This will include activities the contractor needs to participate in and documentation procedures required throughout the construction period. Sample forms and procedures will be provided to show the contractors visuals of what they will need to complete in the construction and acceptance phases. The Cx specifications will also include the training requirements as well as the documentation needed to develop the systems manual.

The CxA will provide the requirements for Cx in the construction phase to be integrated into the specifications.

Basis of Design (BoD)

The Basis of Design (BoD) includes all engineering and architectural calculations and assumptions on how to design the systems such that the OPR are met. This document will be written by the architect and engineers and will be reviewed by the CxA for completeness and quality. Comments will be provided if any pertinent information is missing or if more details are needed. The BoD will need to be updated if any changes occur during the project. This is needed to inform all project team members about revised assumptions and new directions the project is heading in.

Design Review

During the design review, the CxA will focus on verifying that the OPR will be met. In addition, the design documents will be reviewed for constructability, operability, and maintainability. The review will take place at 70% completion and be back-checked for resolution of issues at 95% and design completion. An effort will be made to resolve all design issues throughout the remaining design phase and verify that they have been resolved in the later design submittals and the construction documents (CDs).

The design review also will focus on the selection, evaluation, and choice of the main systems. Review the design documents against the OPR to verify that the project will meet the intent of the owner. Any choices, conclusions, or design details that deviate from the OPR will be brought to the attention of the owner and the general contractor. Additional information will be requested when documentation is insufficient to support the conclusions and choices or when required design assumptions or calculations have not been provided.

Energy efficiency is achieved by verifying the design and operation of the systems and by making the building owner aware of alternative building systems and equipment options.

Examples of building systems that will be evaluated include the following:

- Building envelope
- Building ventilation
- Lighting
- Office equipment
- HVAC equipment
- Control systems and strategies
- HVAC distribution systems
- Domestic hot-water systems
- Water use
- Occupancy schedules
- Utility rate structures

Installation Checklist Database

A checklist database will be established for all components included in the commissioned systems. The checklists will focus on providing the contractor guidance about critical requirements during installation to clearly establish the expectations of the installations.

The CxA will design these checklists to minimize the paperwork for the contractors but at the same time to cover the critical installation issues.

Construction Verification

The CxA will facilitate monthly on-site construction meetings to ensure all design, construction, and building owner representatives understand the process, the desired outcomes, and the roles/responsibilities of the various team members. The CxA will focus on training and on the Cx process during construction while at these site visits. During the construction review, the CxA will focus on verifying that the Cx process is being followed by statistical sampling and verifying that the construction checklists are completed and submitted as required. The CxA will also verify that the record drawings are on site and are being updated with any deviations in installations compared to the construction drawings. In addition, the construction progress will be evaluated against the established OPR. The CxA will verify that the Cx process is proceeding as intended during the construction phase and will review the site visit reports and Cx meeting minutes. The CxA will notify the building owner and general contractor if the Cx process is not progressing as intended by identifying and resolving issues. The day-to-day follow-up will be the responsibility of the general contractor and the subcontractors.

Review Submittals

The CxA will review the submittals concurrently with the architect and engineers. Any observed deviations from the OPR will be noted and submitted to the architect and engineers to be evaluated and submitted with their comments back to the contractor. The architect and engineers' submittal review process will also be evaluated. A selection of the architect and engineers' submittals responses will be reviewed to verify that any deviations from the design documents are properly addressed. The CxA must understand the general contractor's project delivery process and its impact on the submittal review step.

Training

The training agenda format will be submitted by the engineers to the general contractor and owner to schedule the required training sessions. The CxA will review this training agenda and attend a key training session. Each training session will be evaluated after completion of the training. Any deviations from the expected competence level of the O&M staff will be discussed with the owner and contractors, and the remaining training agendas will be revised to accommodate any lacking knowledge.

Systems Performance

The systems performance tests will be completed as soon as all submittals for the systems manual have been received and all installation checklists have been completed. These systems performance tests will focus on the installed systems' capabilities to meet the design intent. The CxA will document the procedures required for these tests and submit these test procedures to the general contractor for the project team's and general contractor's review. The subcontractors are responsible for ensuring that all systems can meet the specified requirements and for demonstrating that the systems are able to perform all procedures successfully. The CxA will witness a representative number of systems performance tests to verify that all systems work as intended. If any of the systems performance tests are unsatisfactory, these systems and a representative number of other similar systems will be required to be retested at the contractors' expense.

Review Systems Manual

The general contractor will generate the systems manual based on the subcontractor submittals for the installed equipment and the test and start-up results. The CxA will review this systems manual and provide any comments to the general contractor.

Commissioning Report

The Cx report will summarize the results of the Cx activities for the project. This Cx report will essentially be the Commissioning Plan with all the results of the Cx activities. The initial Cx report will be submitted two weeks after substantial completion, and the final report will be submitted one year after substantial completion. This is the responsibility of the CxA.

Operation and Warranty Review

The operation and warranty review will be completed at 10 months after completion. The review will focus on the experiences of the O&M staff with the building operation and evaluate the systems performance and operation relative to the OPR. Any deviations from the original operational intent and any component failures will be noted and addressed with the owner's representative. A report will be issued to the owner with suggested actions to take.

Table C-1 Sample Commissioning Scope Matrix—Responsibilities and Schedule

Responsibility						Project Phase				Commissioning Task
Architect	Engineer	General Contractor / Construction Manager	Subcontractors	CxA	Owner	Predesign	Design	Construction	Operation	
						X				**Designate CxA (qualifications apply)**
										Provide name, firm, and experience information for the CxA
						X				**Develop the OPR; include the following:**
										Primary purpose, program, and use of proposed project
										Project history
										Program needs, future expansion, flexibility, quality of materials, and construction and operational cost goals
										Environmental and sustainability goals
										Energy efficiency goals
										Indoor environmental quality requirements
										Equipment and system expectations
										Building occupant and O&M personnel requirements
						X				**Develop and Implement a Commissioning Plan**
										Cx program overview
										Goals and objectives
										General project information
										Systems to be commissioned
										Cx team
										Team members, roles, and responsibilities
										Communication protocol, coordination, meetings, and management
										Description of Cx process
										Document the OPR
										Prepare the BoD
										Document the Cx review process
										Develop systems functional test procedures
										Review contractor submittals
										Verify systems performance
										Report deficiencies and resolution processes
										Develop the systems manual
										Verify the training of operations
										Accept the building systems at substantial completion
										Review building operation after final acceptance

Table C-1 Sample Commissioning Scope Matrix—Responsibilities and Schedule ***(Continued)***

Responsibility						Project Phase				
Architect	**Engineer**	**General Contractor / Construction Manager**	**Subcontractors**	**CxA**	**Owner**	**Predesign**	**Design**	**Construction**	**Operation**	**Commissioning Task**
							X			**BoD**
										Include narrative of systems to be commissioned
										Document design assumptions
										Reference applicable standards and codes
							X			**Cx requirements in CDs (include in specifications)**
										Specify Cx team involvement
										Specify contractors' responsibilities
										Specify submittals and submittal review procedures for Cx process/systems
										Specify O&M documentation requirements
										Specify meetings documentation process and responsibilities
										Specify construction verification procedures and responsibilities
										Specify start-up plan development and implementation
										Specify responsibilities and scope for functional performance testing
										Specify criteria for acceptance and closeout
										Specify rigor and requirements for training
										Specify scope for warranty review site visit
							X			**Conduct Cx Design Review**
										Review and update OPR for clarity, completeness, and adequacy
										Review BoD for all issues identified in OPR
										Review design documents for coordination
										Review design documents for compliance with OPR and BoD
										If multiple reviews are performed, check compliance with previous review comments
								X		**Review of Contractor Submittals**
										Review all product submittals to make sure they meet BoD, OPR, and O&M requirements
										Evaluate submittals for facilitating performance testing
										Review all contractor submittals for compliance with design intent and CDs

Table C-1 Sample Commissioning Scope Matrix—Responsibilities and Schedule *(Continued)*

Responsibility						Project Phase				Commissioning Task
Architect	Engineer	General Contractor / Construction Manager	Subcontractors	CxA	Owner	Predesign	Design	Construction	Operation	
								X		**Verify Installation and Performance of the Systems to be Commissioned**
										Perform installation inspection (prefunctional checklist)
										Perform system performance testing (functional test)
										Evaluate results compared to OPR and BoD
								X		**Complete Summary Cx Report**
										Executive summary
										Document history of system deficiencies/issues
										Record system performance test results
								X		**Develop Systems Manual**
										Develop systems manual in addition to O&M manuals submitted by contractor
										Include in systems manual:
										Final version of BoD
										System single-line diagrams
										As-built sequence of operations, control drawings, and original setpoints
										Operating instructions for integrated building systems
										Recommended schedule of maintenance requirements and frequency
										Recommended schedule for retesting of commissioned systems
										Blank testing forms from original Commissioning Plan for retesting
										Recommended schedule for calibrating sensors and actuators
					X			X	X	**Project Training Requirements**
										Create project training requirements document with owner
										Participate in project training session
										Ensure O&M staff and occupants receive required training and orientation
										Create and document post-training survey
										Verify and document that training requirements are met
					X				X	**8–10 Month Warranty Walk-Through**
										Perform a warranty systems review within 10 months after substantial completion
										Resolve any issues found
										Create a plan for resolution of outstanding Cx-related issues

Advanced Energy Design Guide for Medium to Big Box Retail Buildings

This guide was prepared under ASHRAE Special Project 135.

Advanced Energy Design Guide for Medium to Big Box Retail Buildings is the third in a series designed to provide recommendations for achieving 50% energy savings over the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004. The energy savings target of 50% is the next step toward achieving a net zero energy building, which is defined as a building that, on an annual basis, draws from outside resources equal or less energy than it provides using on-site renewable energy sources. ANSI/ASHRAE/IESNA Standard 90.1-2004 provides the fixed reference point and serves as a consistent baseline and scale for all of the 50% Advanced Energy Design Guides.

This Guide focuses on box retail buildings ranging in size from 20,000 ft^2 to 100,000 ft^2 and applies to general merchandise, specialty, department, and other types of stand-alone retail buildings. Space types covered include vestibules, administrative and office, sales floor areas, fitting rooms, corridors, break rooms, restrooms, and stocking areas. This Guide does not cover large centralized refrigeration systems, commercial kitchens, or restaurants.

The specific energy-saving recommendations are summarized in a single table for each climate zone and will allow contractors, consulting engineers, architects, and designers to easily achieve advanced levels of energy savings without detailed energy modeling or analyses.

In addition, this Guide provides information on integrated design, including best practices, as a necessary component in achieving 50% energy savings. A chapter on energy modeling and benchmarking strategies is also included to guide teams who do not wish to follow the specific energy-saving recommendation tables.

Those looking for help in implementing the climate-specific recommendations of this guide will find an expanded section of tips and approaches in the "How to Implement Recommendations" chapter. These tips are cross-referenced with the recommendation tables. This chapter also includes additional "bonus" recommendations that identify opportunities to incorporate greater energy savings into the design of the building.

Case studies and technical examples throughout the guide illustrate the recommendations and demonstrate the technologies in real-world applications.

For more information on the entire Advanced Energy Design Guide series, please visit www.ashrae.org/aedg.

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