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

B. Liu
R.E. Jarnagin
D.W. Winiarski
W. Jiang
M.F. McBride
G.C. Crall

September 2006

Prepared for
U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Richland, Washington 99352

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EXECUTIVE SUMMARY

This Technical Support Document (TSD) describes the process and methodology for the development of the *Advanced Energy Design Guide for Small Retail Buildings* (AEDG-SR), a design guidance document intended to provide recommendations for achieving 30% energy savings in small retail buildings over levels contained in ANSI/ASHRAE/IESNA Standard 90.1-1999, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. The AEDG-SR is the second in a series of guides being developed by a partnership of organizations, including the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IESNA), the United States Green Buildings Council (USGBC), and the U.S. Department of Energy (DOE).

Each of the guides in the AEDG series provides recommendations and user-friendly design assistance to designers, developers and owners of small commercial buildings that will encourage steady progress towards net-zero energy buildings. The guides provide prescriptive recommendation packages that are capable of reaching the energy savings target for each climate zone in order to ease the burden of the design and construction of energy-efficient small commercial buildings

The AEDG-SR was developed by an ASHRAE Special Project committee (SP-110) made up of representatives of each of the partner organizations in eight months. This TSD describes the charge given to the committee in developing the retail guide and outlines the schedule of the development effort. The project committee developed two prototype retail buildings (strip mall and standalone retail) to represent the class of small retail buildings and performed an energy simulation scoping study to determine the preliminary levels of efficiency necessary to meet the energy savings target. The simulation approach used by the project committee is documented in this TSD along with the characteristics of the prototype buildings (which were based on current chain retail stores). The prototype buildings were simulated in the same climate zones used by the prevailing energy codes and standards to evaluate energy savings.

Prescriptive packages of recommendations presented in the guide by climate zone include enhanced envelope technologies, lighting and day lighting technologies and HVAC and SWH technologies. The report also documents the modeling assumptions used in the simulations for both the baseline and advanced buildings. Final efficiency recommendations for each climate zone are included, along with the results of the energy simulations indicating an average energy savings over all buildings and climates of approximately 37%.

NOMENCLATURE

AEDG-SO	Advanced Energy Design Guide for Small Office Buildings
AEDG-SR	Advanced Energy Design Guide for Small Retail Buildings
AFUE	annual fuel utilization efficiencies
AIA	American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.
CBECS	Commercial Building Energy Consumption Survey
cfm	cubic feet per minute
COP	coefficient of performance
DCV	demand-controlled ventilation
DOE	U.S. Department of Energy
DX	direct expansion
EER	energy efficiency ratio
EF	energy factors
EIA	Energy Information Administration
EPDM	ethylene-propylenediene-terpolymer membrane
ERV	energy recovery ventilators
Et	thermal efficiency
HIR	heat input ratio
HSPF	heating season performance factors
HVAC	heating, ventilation and air conditioning
IBC	International Building Code

IECC	International Energy Conservation Code
ICC	International Code Council
IESNA	Illuminating Engineering Society of North America
in.	inch
IPLV	integrated part load values
IR	infrared
LCC	life-cycle cost
LEED®	Leadership in Energy and Environment Design
LPD	lighting power densities
NAECA	National Appliance Energy Conservation Act
NOS	net occupied space
o.c.	on center
RE	recovery efficiency
RH	relative humidity
SC	shading coefficient
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
SP	single package
SSPC	Standing Standard Project Committee
SR	scalar ratio
SWH	service water heating
TC	technical committee
TMY	typical meteorological year

Tdb	dry-bulb temperature
Twb	wet-bulb temperature
UA	standby heat loss coefficient
UPWF	uniform present worth factors
USGBC	U.S. Green Building Council
USGS	U.S. Geological Service
VLT	visible light transmittance
w.c.	water column
WHAM	Water Heater Analysis Model
WWR	window-to-wall ratio

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1.0 INTRODUCTION

The *Advanced Energy Design Guide for Small Retail Buildings* (AEDG-SR) (referred to as the "Guide" in this report) was developed by a partnership of organizations, including the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IESNA), the United States Green Buildings Council (USGBC), and the Department of Energy (DOE). The Guide is intended to offer recommendations to achieve 30% energy savings and thus to encourage steady progress toward net-zero energy buildings. The baseline level energy use was set as buildings built at the turn of the millennium, which are assumed to be based on ANSI/ASHRAE/IESNA Standard 90.1-1999 (ANSI/ASHRAE/IESNA 1999), *Energy Standard for Buildings Except Low-Rise Residential Buildings (*referred to as the "Standard" in this report). ASHRAE and its partners are engaged in the development of a series of guides for small commercial buildings, with the AEDG-SR being the second in the series. Previously the partnership developed the *Advanced Energy Design Guide for Small Office Buildings: Achieving 30% Energy Savings Over ANSI/ASHRAE/IESNA Standard 90.1-1999* (AEDG-SO 2004), which was published in late 2004.

The purpose of the Guide is to provide user-friendly design assistance to design and architectural and engineering firms working for developers and owners of small retail buildings to achieve 30% energy savings over the baseline; such progress, in turn, will help realize eventual achievement of net-zero energy buildings. In addition, the Guide was intended to be useful to contractors and other construction professionals including design-build firms. Implicitly, the Guide recognizes that builders and designers, while complying with minimum energy code requirements, often lack the opportunity and the resources to pursue innovative, energy-efficient concepts in the design of small buildings. To address this need, the Guide presents clear, prescriptive recommendations that provide "a way, but not the only way" of reaching the energy savings target.

Retail buildings were chosen for the second guide because of the impact of their energy use in the commercial building sector. According to the Energy Information Administration's (EIA) Commercial Building Energy Consumption Survey (CBECS) in 2003, retail buildings account for 319 trillion Btu of energy use, or approximately 5.5% of the energy use of all commercial buildings (CBECS 2003). Small retail stores (less than 20,000 square feet (ft^2)) were singled out for the Guide both for consistency with the previous small office guide, as well as to help in bounding the scope of the effort necessary for development of the Guide. In particular, the Guide focuses on the following retail usages, which are representative of retail buildings with low plug loads, the absence of process loads, and relatively low ventilation rates:

- Strip malls
- Automobile dealers
- Building materials
- Garden supply and hardware stores

- Department stores
- Drug stores
- Furniture stores
- Home electronics stores
- Home furnishing
- Liquor stores
- Wholesale goods (except food).

These retail spaces are contrasted with some service facilities, which are excluded:

- Car washes
- Laundry and dry cleaning establishments
- Gasoline service stations
- Motor vehicle repair, service and maintenance buildings
- Personal service establishments
  - Barbers
  - Hair dressers
  - Manicurists.

Retail spaces are understood to pose particular challenges in three areas. The first is *lighting* to illuminate the space, point-of-sale displays, and the merchandise sold. The value of the merchandise displayed – the sale of which is the store's core function - is far higher than energy costs, and rational owners are unlikely to accept even the perception of reduced illumination quality. The second challenge in many retail spaces is *meeting ventilation requirements* with low-maintenance conventional unitary equipment. Many retail spaces have low occupancy [typically one employee per 1,000 ft^2, not counting customers (CBECS 2003)], but many others have significant sources of volatile organics (candles, soaps, etc) that may require augmented local or general ventilation. Of course, augmented ventilation may require particular attention to humidity control for some regions of the country. The third is the *disconnect* that often occurs between the original construction of the shell by the developer and the subsequent fit-out by the building tenant.

1.1 Charge to the Committee

The project committee selected to develop the Guide was charged by a steering committee made up of representatives of the partner organizations to include a timeline for the task, an energy savings goal, an intended target audience, and desired design assistance characteristics.

Timeline

- Complete document in 1 year

Goal

- 30% energy savings relative to buildings constructed to meet the energy requirements of Standard 90.1-1999
- Savings to be achieved in each climate location (not simply an average)
- Hard goal of 30% to be consistent with LEED® rating system
- Attain energy savings through packages of design measures

Target Audience

- Contractors
- Designers
- Developers
- Owners
- Those with limited design capabilities to achieve advanced energy savings

Desired Design Assistance

- Provide practical, prescriptive recommendations
- Format for ease of use
- Simplify recommendation tables
- Avoid code language
- Provide "how to" guidance to enhance recommendations
- Allow some flexibility for those accustomed to performance-based documents
- Address tenant improvements
- Provide case studies where appropriate.

1.2 Scope of the Document

The scope of the document is limited to retail buildings that are part of the Group M (mercantile) occupancy, as defined in the International Code Council (ICC) International Building Code (IBC), and that meets the following criteria:

- Does not exceed 20,000 gross square feet
- Does not exceed one story
- Has heating and cooling provided by unitary heating, ventilation and air conditioning (HVAC) equipment (packaged or split systems).

  Exclusions

- Restaurants and other retail service establishments with strong point sources from cooking or processes using chemicals *(Note: CBECS considers restaurants as a different class of buildings from retail)*
- Built-up systems using chillers and boilers
- Buildings with unusually high lighting levels (>3 watt/ft^2)
- Buildings with unusually high outside air ventilation rate (>1.5 cfm/ ft^2)

Recommendations contained in the AEDG-SR will apply primarily to new buildings, but may also be applied in their entirety to existing buildings undergoing renovation. They may be applied in part as recommendations for changes to one or more systems in existing buildings. Covered building components and systems include the building envelope; lighting and daylighting systems; unitary packaged and split mechanical equipment for heating, ventilating and cooling; building automation and control systems; service water heating for bathrooms and sinks; plug loads and cord-connected appliances and equipment; and building commissioning.

1.3 Project Committee Organization and Membership

The Guide was developed by a project committee administered under ASHRAE's Special Project procedures. The AEDG-SR project committee was designated as ASHRAE Special Project 110 (SP-110), and included membership from each of the partner organizations. The following table indicates the project committee members and the organizations that they represent.

Table 1-1 SP-110 Project Committee Organization Chart

Merle McBride – *Chairman*	
Ron Jarnagin	Ronald Kurtz
Vice Chairman	*IESNA Representative*
Don Colliver	Michael Lane
Steering Committee Ex Officio	*IESNA Representative*
Donald Brundage	Harry Misuriello
ASHRAE TC 2.8 Representative	*ASHRAE TC 7.6 Representative*
Charles Culp	Dan Nall
ASHRAE TC 9.5 Representative	*USGBC Representative*
Jay Enck	Paul Torcellini
USGBC Representative	*Consultant*
Katherine Hammack	Bruce Hunn
ASHRAE SSPC 90.1 Representative	*ASHRAE Staff Liaison*
David Hartke	
AIA Representative	

ASHRAE selected its committee members to further represent technical and standards project committees that had technical scopes that overlapped with the development of the Guide. ASHRAE Technical Committee (TC) 2.8 is the sustainability technical committee, TC 7.6 is the systems energy utilization technical committee, and TC 9.5 is the small commercial building technical committee. Each of the representative organizations were given the chance to provide peer review input on the various review drafts produced by the project committee. In effect, these representatives were intended to be the interface to their respective organizations to ensure a large body of input into the development of the document.

2.0 SP-110 DEVELOPMENT SCHEDULE AND MILESTONES

Following the guidance from the steering committee, the SP-110 committee developed a 1-year plan for completing the document. Key milestones in the development schedule center around the review periods for the various completion stages for the draft document. Utilizing a similar schedule to what was developed for the small office guide, the SP-110 committee planned for three peer review periods that corresponded with a 35% completion draft (conceptual review), a 65% completion draft (technical refinement review) and a 90% completion draft (final review for errors). Because the document was developed under the ASHRAE Special Project procedures, and not the standards development procedures, the reviews were not considered true "public" reviews. However, review copies were made available to all of the partner organizations, as well as the various bodies within ASHRAE represented by the membership on the project committee. In addition, interested members could download review copies from the ASHRAE web site. The following schedule outlines key dates in the development of the AEDG-SR.

Table 2-1 AEDG-SR Key Development Dates

Date	Event	Comment
10/22-23/2005	SP-110 Meeting #1	Initial organizational meeting
12/2-3/2005	SP-110 Meeting #2	Prepare 35% draft
12/5-16/2005	35% Draft Review Period	Milestone #1
12/30/2005	Conference call	Review peer review input
1/7-8/2006	SP-110 Meeting #3	Work on 65% draft
1/18/2006	Conference call	
2/3/2006	Conference call	Complete 65% draft
2/6-17/2006	65% Draft Review Period	Milestone #2
3/4-5/2006	SP-110 Meeting #4	Review peer review input
3/17/2006	Conference call	
4/4/2006	Conference call	Complete 90% draft
4/15-28/2006	90% Draft Review Period	Milestone #3
5/20-21/2006	Meeting #5	Review peer review input, begin completion of final draft
5/26/2006	Conference call	
6/2/2006	Conference call	
6/7/2006	Conference call	
6/14/2006	Conference call	SP-110 approval of final draft
6/15/2006	Transfer final draft to steering committee	Milestone #4
6/20/2006	Conference call	Steering committee approval of final draft

3.0 SIMULATION APPROACH AND ANALYTICAL TOOLS

This section describes the simulation approach and analytical tools that were used to assess and quantify the 30% energy saving goals by implementing the Guide's energy efficiency recommendations.

3.1 Simulation Approach

The purpose of this building energy simulation analysis is to assess and quantify the energy savings potential of the Guide's recommendations. To reach this goal, the first step is to conduct an initial scoping study. The scoping study evaluated the possible energy savings from the energy efficiency measures selected by the SP-110 committee for a limited set (four) climate locations. Section 4 in this report describes the scoping study in details. A 7,500-ft^2 strip mall retail building prototype consisting of three different stores was selected as the building prototype for the smaller end retail store. Section 4 of this report describes the basis for the decision on the small retail prototype.

After the selected energy-efficient technologies were demonstrated to achieve the 30% energy saving goal in the scoping study, the computer simulations were expanded to the full study, including two retail building prototypes for all 15 representative locations. A 15,000-ft^2 single-floor standalone prototype was developed, in addition to the strip mall prototype used in the scoping study. The strip mall prototype and standalone prototype represent the smaller end and higher end building sizes in the category of the small retail stores, respectively. Fifteen climate locations were selected to adequately represent the eight climate zones in the United States. Baseline model prototypes were developed in compliance with the prescriptive design options defined in ASHRAE Standard 90.1-1999. The advanced models were established based on the recommended energy-efficient technologies by the Guide. Sections 7 and 8 document the modeling input assumptions for the baseline models and the advanced models, respectively.

The last stage involves summarizing the energy simulation results for all locations and presenting the final energy saving recommendations by climate zones, as described in Section 9.

3.2 Simulation Tool Description

Following the simulation tool approach in the development of *Advanced Energy Design Guide for Small Office Buildings* (AEDG-SO), ASHRAE used eQUEST as the primary energy simulation tool for the energy analysis in the scoping study. The simulation engine within eQUEST is a private-sector version of DOE-2, the most widely used whole building energy simulation tool today. eQUEST combines the simulation engine with a building creation wizard, industry standard input defaults, and a graphical results display module. The user-friendly interface significantly reduced the time required to create the input decks, an advantage in meeting the ambitious progress schedule in the Guide's development. eQUEST calculates hour-by-hour building energy consumption over an entire year, using hourly weather data for the selected study location.

When moving to the full study, DOE-2.2 simulation program (the "simulation engine" contained within eQUEST) was used directly to facilitate the parametric simulation runs for all 30 cases, including both baseline and advanced cases in 15 climate locations, and for all 150 sensitivity simulation runs to develop the envelope criteria, as described in Section 9.

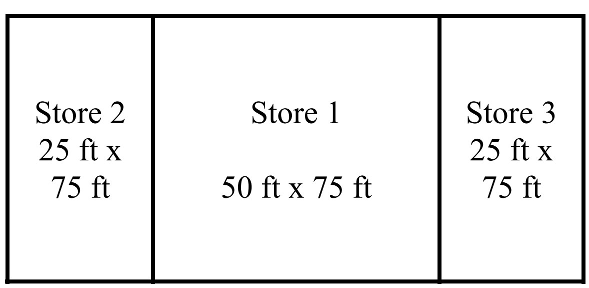
4.0 DOCUMENTATION OF INITIAL SCOPING STUDY

Following the proven model used in the development of the AEDG-SO, the project committee performed an initial scoping study to test the efficiency levels of the various building systems that would be necessary to reach the energy savings targets. By being able to develop an early assessment of the baseline and advanced energy use potential, the committee was then able to prioritize its activities for development of the Guide.

Much of the initial debate by the committee focused on the building configuration to be used for the simulation model. Building size and construction method were discussed at length. Because many retail stores today can be found in strip malls, the committee initially decided that a strip mall would be modeled, as well as a larger free standing store. Early in the process, the committee agreed that one of the primary discriminators among retail stores would be the lighting levels in the store. Retail lighting can vary from stores with 100% general lighting to stores with varying mixes of general and accent lighting. To span a range of different lighting schemes, the committee decided to develop the strip mall model with three stores that each had a different lighting scheme. One store was chosen to use 100% general lighting, a second store chosen to use a 75%/25% split between general and accent lighting, while the third store had a 50%/50% split between general and accent lighting.

Using three stores to represent the strip mall allowed the models to consider two stores with exterior envelope exposure on one side of the store and a common wall on the other side of the store. The center store in the strip mall had two walls as common walls with the two exterior stores. This created one store with two walls that were isolated from the exterior environment. Using more than three stores was deemed unnecessary because multiple interior stores would likely behave similarly from an energy standpoint, assuming lighting levels and occupancy patterns were the same.

The floor plan of the strip mall model was first estimated by the committee, and then confirmed as being reasonable by making measurements at several actual strip malls. The overall dimensions of the strip mall were set at 100-ft wide by 75-ft deep for a total area of 7,500 ft², with four bays, each being 25-ft wide by 75-ft deep. The two exterior stores were single-bay stores, and the center store was a double-bay store, as shown below.



To give further meaning to the building prototypes, the committee established some "representative" store-types that had lighting layouts similar to the prototype stores. For these building models, the following representative stores were chosen:

Store 1	Blockbuster Video	100% general lighting
Store 2	Radio Shack	75% general lighting, 25% accent lighting
Store 3	REI	50% general lighting, 50% accent lighting

The percentage of lighting shown above refers to the percentage of the floor space that would be lit by either general lighting or accent lighting. Actual lighting values for both the baseline and advanced buildings were derived using the space-by-space lighting method and utilized a mix of display space, circulation space and storage space. For each of the stores with accent lighting, the current additional lighting power allowances from Standard 90.1-1999 as baseline and from Standard 90.1-2004 (ANSI/ASHRAE/IESNA 2004) as advanced case were used.

Occupancy hours for each store came from the posted hours of operation at the representative store, and occupancy schedules were developed from values of peak occupancy from ASHRAE Standard 62-2001 (ANSI/ASHRAE 2001), and hourly occupancy profile estimates made by the store owners. Each of the three stores had different occupancy schedules and hours of operation. Heating and cooling equipment and lighting operational schedules were developed based on occupancy hours and information on employee arrival and departure schedules.

Each store was zoned as a single zone served by packaged rooftop unitary constant volume equipment with electric direct expansion (DX) cooling and gas heating. Each one of the stores was served by a single air conditioner sized to meet the store's load. The air conditioning units were operated with setback and setup control strategies, and ventilation air was supplied as required by Standard 62-2001. The HVAC system used a ducted supply and return system.

The strip mall exterior envelope consisted of 2x4 metal frame construction 16 in. on center with sheathing and external stucco covering. Glazing was limited to the entrance wall with a 70% window-to-wall ratio on the storefront orientation. Each window contained a 5-ft overhang for shading and weather protection. The floor to ceiling height was 11 ft, with a floor-to-roof deck height of 14 ft, leaving a 3-ft plenum. The roofing construction was a steel deck with rigid insulation protected by a membrane exterior surface. Each store had a slab-on-grade floor.

Values for the thermal and solar performance of the envelope measures, mechanical equipment efficiencies, and mechanical system requirements came from Standard 90.1-1999 for the baseline, and from the AEDG-SO for the advanced case. These values are found in Appendix A. The AEDG-SO measures were used for the scoping study since the advanced retail building was expected to perform somewhat similarly to the advanced office buildings, and the scoping study was designed only to get a quick estimate of the committee's ability to meet the energy savings target.

The strip mall prototype buildings were simulated in four diverse climates to test the range of savings potential. Climate locations used in the scoping study included Miami (hot and humid), Phoenix (hot and dry), Duluth (cold), and Seattle (cool moderate). These climate locations represented a subset of the full set of climate locations chosen for the overall analysis, and were expected to demonstrate the extremes of what might be achieved.

An illustrative three-dimensional model of the prototype strip mall is shown in Figure 4-1 for reference below. Each building was oriented with the entrance facing due south in each location to present a worst case energy use scenario resulting from solar loading.

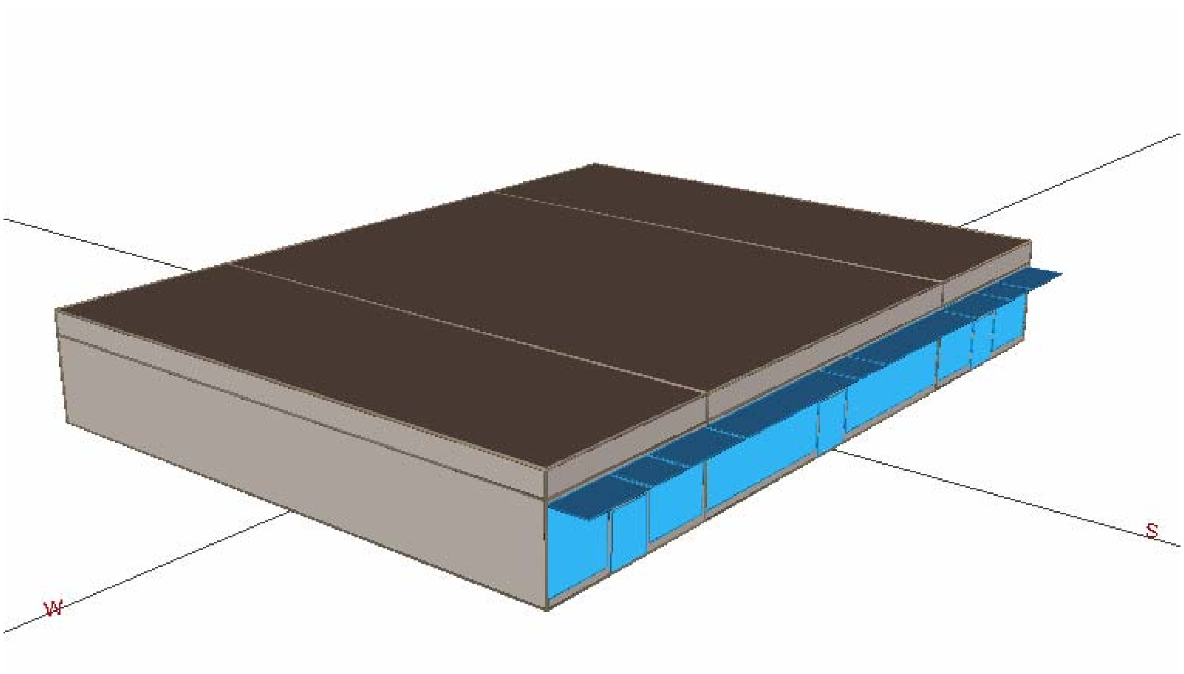


Figure 4-1 Three-Dimensional Model of the Strip Mall Prototype

Results of the simulation indicated the potential for reaching the energy savings goal in each of the climate extremes. As expected, Seattle proved to be the most difficult climate considered because of its fairly mild weather. The results for each of the climate locations are shown in Table 4-1 as follows:

Table 4-1 Energy Savings from Scoping Study on Three-Store Strip Mall

Climate Location	Whole Building Savings with Plugs, %	Whole Building Savings without Plugs, %
Miami	37.7	40.1
Phoenix	37.2	39.6
Seattle	29.5	31.5
Duluth	31.1	32.3

Energy savings are shown expressed in two different ways. The "savings without plugs" value indicates the savings when the plug loads are not included in the total loads of the building when calculating the percent savings. Plug loads are modeled for both the baseline and advanced cases so that their effect on the heating and cooling energy use is captured accurately. However, because plug loads are not addressed in the Guide's recommendations, the committee decided to evaluate savings for the case when plugs were not included in the denominator of the percent savings calculation, as well as the case when plugs are included in the denominator, to understand the difference in the results. The case where plug loads are included in the denominator is equivalent to the true percentage whole building energy savings. The results show that the savings percentage generally increases only by about 1.5% to 2.5% when plugs are not included in the denominator, indicating that plug loads in small retail are not a significant energy user.

Based on the initial results of the scoping study on the strip mall, the committee made the decision to forego a scoping study on the standalone prototype building because the preliminary scoping results indicated that achieving the desired savings results might be easily met in the strip mall. The strip mall should have had a more difficult time complying than the standalone store as a result of the common walls between adjacent stores. The common walls would reduce the potential savings from envelope measure enhancements. Even though the standalone store was not analyzed during the scoping study, it was included in the full study energy savings analysis when evaluating the impact of the final recommendations in the Guide.

Appendix A contains the detailed energy simulation input parameters in four climate locations for both baseline and advanced cases, as a part of the initial scoping study.

5.0 SELECTION OF CLIMATE LOCATIONS FOR FINAL GUIDE

The two *Advanced Energy Design Guides* developed to date have standardized climate zones that have been adopted by the International Energy Conservation Code (IECC) as well as ASHRAE for both residential and commercial applications. This results in a common set of climate zones for use in codes and standards. The common set of climate zones includes eight zones covering the entire United States and is shown in Figure 5-1 as follows. Climate zones are categorized by heating-degree-days (HDD) and cooling-degree-days (CDD), and range from the very hot zone 1 to the very cold zone 8. These climate zones may be mapped to other climate locations for international use. When the climate zones were being developed, they were further divided into moist and dry regions. *The Advanced Energy Design Guides* do not explicitly consider the moist and dry designations, but the actual climate locations used in the analysis of energy savings are selected to ensure representation of the moist and dry differences.

When the climate zones were being developed, specific climate locations (cities) were selected as being most representative of each of the climate zones. These representative climate locations were assigned construction weights based on using population from the U.S. Geologic Service's (USGS) Populated Places dataset as a surrogate for construction volume mapped to each climate location (USGS 2006). The weighted climate locations can then be used to aggregate savings results for the purpose of calculating national weighted energy savings. The 15 climate cities representative of the 8 climate zones are listed below:

Zone 1: Miami, Florida (hot, humid)
Zone 2: Houston, Texas (hot, humid)
Zone 2: Phoenix, Arizona (hot, dry)
Zone 3: Memphis, Tennessee (hot, humid)
Zone 3: El Paso, Texas (hot, dry)
Zone 3: San Francisco, California (marine)
Zone 4: Baltimore, Maryland (mild, humid)
Zone 4: Albuquerque, New Mexico (mild, dry)
Zone 4: Seattle, Washington (marine)
Zone 5: Chicago, Illinois (cold, humid)
Zone 5: Boise, Idaho (cold, dry)
Zone 6: Burlington, Vermont (cold, humid)
Zone 6: Helena, Montana (cold, dry)
Zone 7: Duluth, Minnesota (very cold)
Zone 8: Fairbanks, Alaska (extremely cold).

The following map in Figure 5-2 indicates the 15 climate locations chosen for the analysis of the guides.

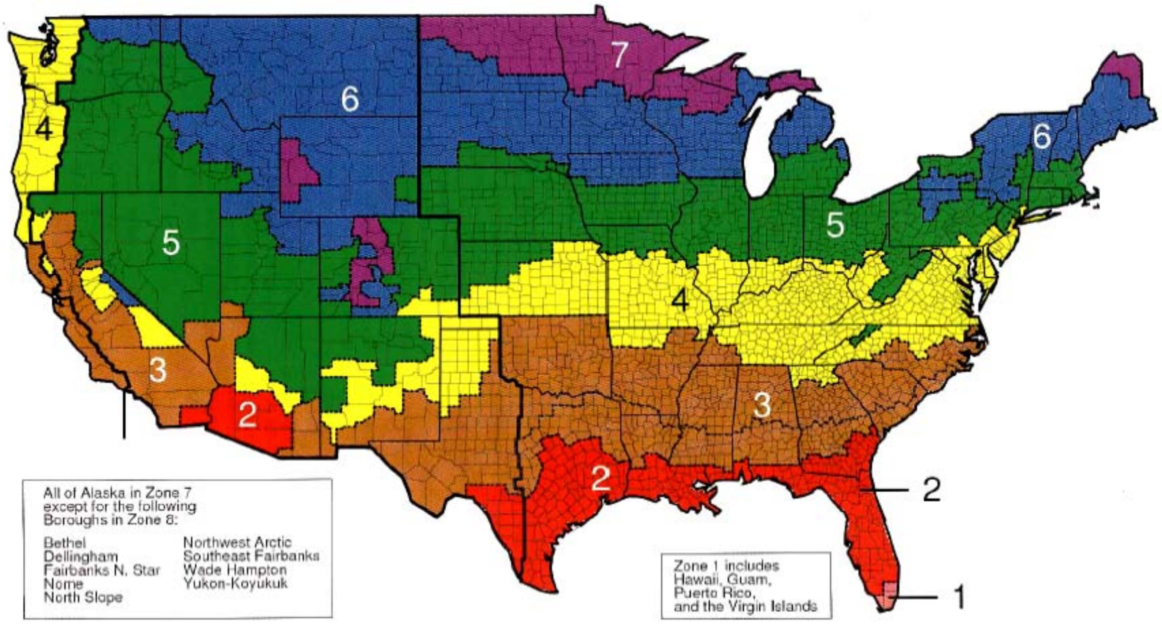


Figure 5-1 U.S. Department of Energy Developed Climate Zone Map

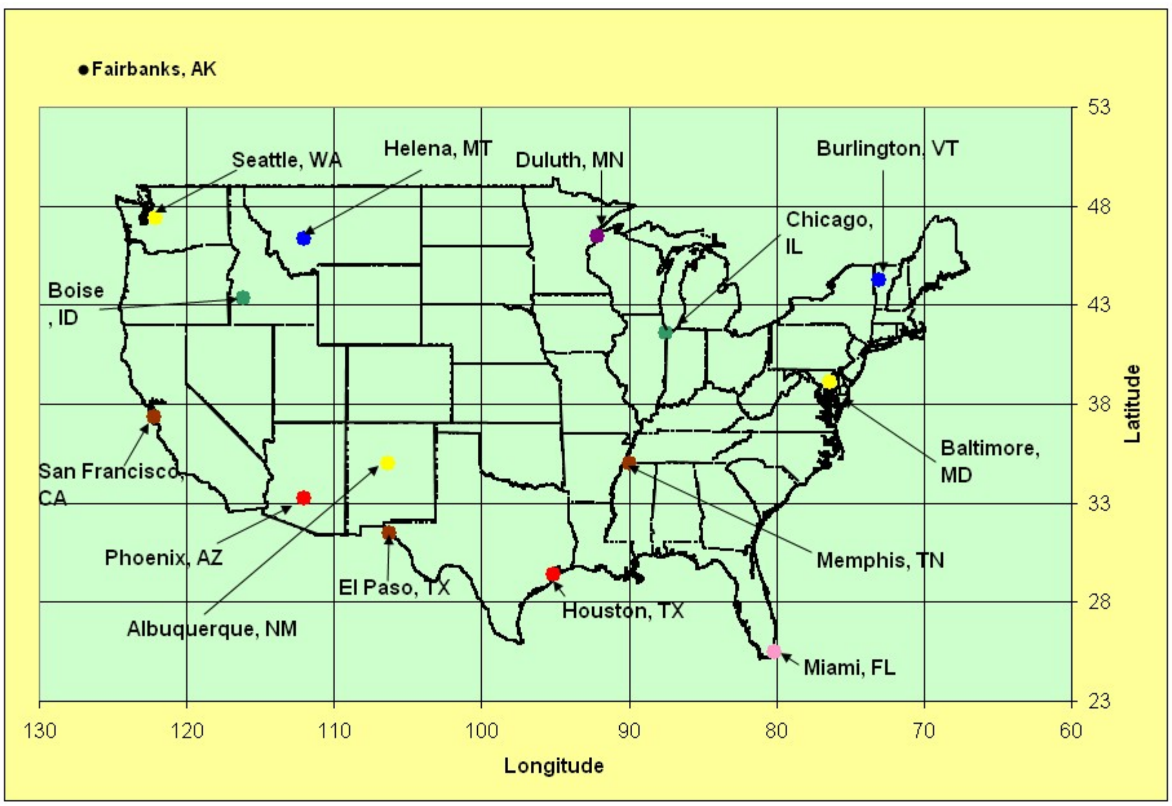


Figure 5-2 Representative Climate Locations in U.S.

6.0 SELECTION OF ENERGY SAVING TECHNOLOGIES

The project committee began the process of selecting energy savings technologies by looking at the technologies used in the AEDG-SO. As a starting point, the project committee used the recommendations from the AEDG-SO for performing its early rounds of scoping study analysis for the reasons explained in Section 4.0. The only initial exception to the use of the AEDG-SO technologies for the scoping study was in the area of the lighting power densities (LPD), which differ significantly from values used for office buildings in the AEDG-SO, primarily because of the need for additional accent lighting for merchandise display. The scoping study pointed out some areas in which the recommendations of the AEDG-SO were more stringent than necessary for the AEDG-SR. This was true for some of the envelope recommendations because retail buildings generally have lower overall window areas (and thus higher opaque envelope areas) and tend to be more dominated by the internal loads from lighting, people and ventilation than offices. The following sections briefly describe the process the committee used to choose the technologies for the final recommendations.

6.1 Envelope Technologies

As noted above, the envelope is less important for the more heavily internally loaded retail buildings. The committee adjusted the envelope criteria downward in some cases (primarily colder climates) to reflect this difference. In general, the committee chose the next assembly insulation level that was less stringent, and then the buildings were re-simulated to assess the impact of that choice. While envelope measures might have been somewhat less significant for retail buildings, the committee chose to focus on them because of their relatively long life as an energy saving measure.

Some envelope measures were changed from the technology used in the AEDG-SO. For example, the AEDG-SO provided recommendations for solar heat gain coefficient (SHGC) for vertical glazing by orientation, as well as varying the SHGC by climate. The orientation dependency allows for a different SHGC for north facing glazing, where direct solar loads are not present. Variation by climate zones reflects the differing impact of SHGC for the sunny, hot climates versus the colder climates. In the case of retail, vertical glazing is generally restricted to the storefronts on a single orientation, and the need for merchandise display tends to dictate clear glass only. Clear glass generally has a fairly high SHGC value, so the committee decided to recommend generally uniformly high values of SHGC in all climates.

The AEDG-SO also had a window orientation recommendation that attempted to influence the placement of glazing on orientations to reduce solar loading. This recommendation was, in effect, a recommended solar aperture that limited glazing on east and west orientations. Because of the nature of retail glazing discussed above, this recommendation was not used in the AEDG-SR.

To encourage the use of daylighting in the AEDG-SO, the window-to-wall ratio (WWR) was recommended to be no less than 20% and no more than 40%. For retail buildings the committee determined that this recommendation would not make much sense. Typical WWR values for retail buildings are frequently in the range of 8% to 15% because most, if not all, of the glazing is contained on a single orientation. As a result, the committee removed this recommendation from the Guide and only left the 40% maximum for WWR in place.

6.2 Lighting and Daylighting Technologies

The area of lighting and daylighting was one of the substantial differences between the AEDG-SO and the AEDG-SR. Retail lighting generally requires higher lighting levels (lumens) than office lighting because of the difference in use of the retail spaces. As a result, lighting power levels (LPD) are higher, both for general lighting as well as accent lighting. The committee chose to adopt the advanced lighting levels that were approved by addenda to the Standard 90.1-2004 (ANSI/ASHRAE/IESNA 2004). The lighting levels were developed by the Lighting Subcommittee of ASHRAE's Standing Standard Project Committee 90.1 (SSPC 90.1), and are documented in lighting spreadsheets available on the IESNA web site (IESNA 2005). The Lighting Subcommittee estimated the 2004 lighting levels would result in a 20% to 25% savings over the lighting levels in the 1999 Standard. The committee also added recommendations for exterior façade and illuminated signage lighting based on current lighting technologies.

In addition to the lighting levels, the committee addressed light source efficiencies by establishing either a minimum mean lumens/watt in the case of fluorescent lamps and ballasts, or a technology specification for accent lighting [halogen infrared (IR) lamps or ceramic metal halide], which drives the design towards efficient sources.

Lighting control recommendations were modified from those found in the AEDG-SO. Occupancy controls were limited to the non-sales areas of the retail building, thus limiting the maximum impact of these controls to between 20% and 30% of the gross floor area based on typical retail floor plans. The typical retail floor plans were reviewed based on a database of new building plans (NIC3) developed by Pacific Northwest National Laboratory (Richman et al. 2001.). Daylighting controls recommend fixtures within 10 ft of skylight edges versus 8 ft for the AEDG-SO. No recommendations were provided for daylighting from vertical glazing because this was deemed to be an inappropriate application. These areas are usually merchandising areas that need a consistent lighting level with high color rendering ability to showcase the products.

6.3 HVAC and Service Water Heating (SWH) Technologies

In general, the HVAC and SWH technologies were carried forward from the AEDG-SO. The AEDG-SR continued the approach of varying heating and cooling efficiencies by climate zone where possible, which represents a change from the policy maintained by the Standard, where equipment efficiencies remain constant across climates. The equipment efficiency values used in the AEDG-SO are also used in the AEDG-SR document because they were found to be sufficient to meet the energy savings targets. In addition, the AEDG-SR also continued the recommendations for integrated part load values (IPLV) for commercial cooling equipment because this represents a step forward from the Standard.

Economizer requirements were extended downward to equipment with capacities greater than 54,000 Btu/hr, resulting in additional energy savings for smaller capacity equipment in some climate zones. Motorized dampers for outdoor air control in off hours and CO_2 control to accomplish demand-controlled ventilation were both technologies that are recommended in the Guide. Each of these technologies has been demonstrated through simulation to achieve significant energy savings in retail buildings. In particular, demand-controlled ventilation works very well with the highly variable occupancy found in retail buildings compared to the fairly stable occupancy patterns found in office buildings. Duct systems have recommendations resulting in an improved design (lower friction rate), better sealing (seal class B), and improved thermal performance (interior locations and better insulation).

The SWH recommendations continue the focus on reduction of standby losses by improving energy factors (EF) or by utilizing instantaneous water heaters for fuel-fired applications. Electric instantaneous water heaters were considered and rejected as a result of concerns over increased electrical demand. When storage water heaters are used, the recommendations result in higher efficiencies for both gas and electric water heaters.

7.0 DEVELOPMENT OF BASELINE BUILDING ASSUMPTIONS

This section contains a topic-by-topic review of baseline building models and how the baseline building descriptions were assumed in DOE-2 modeling, including the building envelope characteristics, building internal loads and operating schedules, ventilation rates and schedules, HVAC equipment efficiency, operation, control and sizing, fan power assumptions, and service water heating. The use of specific trade names in this document does not constitute an endorsement of these products. It only documents the equipment that was used in our analysis for research purposes.

7.1 Selection of the Baseline Building Prototypes

To quantify the expected energy savings, the baseline prototypes of the small retail buildings were selected by the committee to meet the criteria of ASHRAE Standard 90.1-1999. The Standard provides the fixed reference point based on the Standard at the turn of the millennium for all the guides in this series. The primary reason for this choice as the reference point is to maintain a consistent baseline and scale for all the 30% AEDG series documents. A shifting baseline (i.e. use ASHRAE Standard 90.1-2004 as the baseline) between multiple documents in the AEDG series would lead to confusion among users about the level of energy savings achieved. In addition, the 1999 Standard is the latest version of ASHRAE Standard 90.1 that the Department of Energy has published its determination in the Federal Register indicating that Standard 90.1-1999 would improve commercial building energy efficiency by comparing it to Standard 90.1-1989, fulfilling DOE's mandate under the Energy Conservation Policy Act, as amended.

7.2 Baseline Building Envelope Characteristics

The project committee assumed, based on experience of those in the construction industry, that the strip mall prototype (7,500 ft^2) was constructed with steel-framed exterior walls, built-up roofs, and slab-on-grade floors. For the standalone prototype (15,000 ft^2), it was assumed that the exterior walls were concrete masonry units, and roofs and floors have the same construction as the strip mall prototype. These envelope structures represent common construction practice for small retail buildings in U.S. The assumptions were confirmed by a review of similar buildings in the Tri-Cities, Washington area. While these observations were clearly anecdotal, the stores used as examples (i.e. REI, Blockbuster, Radio Shack) are all part of national chains that tend to be constructed by firms with a national presence, which adds to the validity of the observations.

The baseline building envelope characteristics were developed to meet the prescriptive design option requirements in accordance with ASHRAE Standard 90.1-1999 Section 5.3. The following section describes the assumptions used for simulation modeling of the baseline building envelope construction, including the exterior walls, roofs, slab-on-grade floors, window glazing and doors, infiltration, and roof absorptivities.

The DOE-2.2 program can calculate the U-factor of opaque assemblies by defining the properties of materials, layers and construction. This method was used in this analysis to properly account for thermal mass impacts on the calculations of space loads.

7.2.1 Exterior Walls

Two types of exterior walls have been modeled in this analysis work, i.e. steel-framed walls in the strip mall retail buildings and mass walls in the free standing building. Steel-framed exterior walls were assumed to have a standard framing configuration, i.e. 2x4 steel stud framing at 16-in. on center with cavities filled with 16-in. wide insulation for 3.5-in. deep wall cavities. The performance of the insulation/framing layer was taken from Table A-21 in the Standard. The U-factor of the steel-framed wall includes:

- Exterior air film (R-0.17)
- 1-in. thick stucco (R-0.08)
- 0.625-in. thick gypsum board (R-0.56)
- Framing/cavity insulation (various by climate)
- Additional board insulation (various by climate)
- 0.625-in. thick gypsum board (R-0.56)
- Interior air film (R-0.68).

The mass wall was assembled assuming 8-in. medium weight concrete blocks with a density of 115 lb/ft^3 and solid grouted cores. The mass wall includes the following layers:

- Exterior air film (R-0.17)
- 8-in. concrete block, 115 lb/ft^3 (R-0.87)
- 1-in. metal clips with rigid insulation (various by climate)
- 0.5-in. thick gypsum board (R-0.45, if insulation is present)
- Interior air film (R-0.68).

R-values for most of the above layers were derived from Appendix B (*Assembly U-Factor, C-Factor, And F-Factor Determination)* of the Standard. Insulation R-values, cavity and continuous insulations, were selected to meet the insulation minimum R-value required in the Standard's Appendix B (*Building Envelope Requirements)*, as defined by climate range.

7.2.2 Roofs

Built-up roofs were used in both the strip mall and standalone prototypes, i.e., rigid insulation over a structural metal deck. The minimum U-factor includes R-0.17 for exterior air film, R-0 for metal deck, and R-0.61 for interior air film heat flow up. Added insulation is continuous and uninterrupted by framing. Roof insulation R-values were also set to match the minimum roof insulation requirements in Appendix B (*Building Envelope Requirements)* of the Standard, by climate.

7.2.3 Slab-On-Grade Floors

The base assembly for slab-on-grade floors is a slab floor of 6-in. concrete poured directly on to the earth. The bottom of the slab is 12-in. soil, with soil conductivity of 0.75 Btu/hr-ft²-°F. In contrast to the U-factor for other envelope assemblies, the F-factor is set to match the minimum requirements for slab-on-grade floors in Appendix B of the Standard, based on climate. F-factor is expressed as the conductance of the surface per unit length of building perimeter, in the unit of Btu/hr-°F-ft.

In the DOE-2 simulation program, an effective U-factor can be defined using U-EFFECTIVE keyword, to calculate the heat transfer through the slab-on-grade floors. U-EFFECTIVE is calculated using the following equation:

$$U - EFFECTIVE = \frac{F \times L_{PERIMETER}}{A_{FLOOR}} \tag{7.1}$$

where

F = the conductance of the floor per lineal foot of perimeter (Btu/hr-°F-ft)

$L_{PERIMETER}$ = the length of the perimeter portion of the floor exposed to outside air (ft)

A_{FLOOR} = the floor area of slab-on-grade floors (ft²).

7.2.4 Fenestration

Large glass areas are commonly found at the front of many small retail stores. Therefore, the committee assumed that the front façade contained all of the fenestration for the retail stores. The window-to-wall ratio (WWR) on the storefront orientation was set at 70% for both strip mall and standalone retail prototypes, based on the committee's judgment and inspection of similar strip malls and standalone retail buildings in the Tri-Cities, Washington area. There are no windows on the other three orientations in the modeling. The overall WWR of the entire building used in the modeling is 20% and 17%, for the strip mall and the standalone buildings, respectively.

Window U-factor and solar heat gain coefficient are set to match the fenestration performance criteria outlined in Appendix B of the Standard, by climate. DOE-2 program accepts shading coefficient (SC) as inputs to replace SHGC, and all SHGC values can be converted to SC using the following conversion factor:

$$SC = \frac{SHGC}{0.86} \qquad (7.2)$$

There are three ways of specifying window properties as inputs in DOE-2 simulation program:

1) Window Shading Coefficient Method - enter the window's U-factor, SC and visible transmittance

2) Window Library Method – select the window from the DOE-2 glazing library

3) Window Layers Method – define the window property layer-by-layer.

The window library method was used for this analysis work based on two reasons: 1) the shading coefficient method can not properly calculate the transmission/absorption angular dependence for multi-pane or coated glazing, resulting in the inaccurate solar heat gain calculations through glazing; and 2) the window layers method requires specifying actual window layers as inputs. Using the window layers method could be problematic in matching the maximum allowable U-factor and SHGC values in accordance with the Standard. The reason is that no actual windows exist to match some of the fenestration requirements in the Standard, for certain climates.

7.2.5 Air Infiltration

Building air infiltration is addressed indirectly in the Standard through the requirements in building envelope sealing, fenestration and doors air leakage, etc. The Standard does not specify the air infiltration rate. For this analysis, the infiltration rate was assumed to be 0.038 cfm/ft^2 of gross exterior wall, per 10 CFR Section 434.516.

The DOE-2 program offers five methods for addressing infiltration. Two options were rejected immediately (NONE and AIR-CHANGE using INF-CFM/SQFT) because they do not enable wind-speed adjusted modeling of infiltration. The RESIDENTIAL and Sherman-Grimsrud method were not considered because they are only compatible with the residential system, which was not the system used for this analysis. The CRACK method was rejected for lacking reliable data as inputs. Therefore, the wind-speed adjusted AIR-CHANGE/HR method was chosen because it offers the most straightforward way to implement the air filtration rate. However, it does not enable modeling of stack effects; but given the one-story retail model used, this deficiency was not considered significant.

In addition, the infiltration schedule was also incorporated in the modeling by assuming no infiltration when the HVAC system is switched "on", and infiltration is present when the HVAC system is switched "off".

7.2.6 Roof Absorptivities

The Standard does not specify either absorptance or other surface assumptions. The roof exterior finish was assumed to be a single-ply roof membrane with grey EPDM (ethylene-propylenediene-terpolymer membrane) in the baseline prototypes. Therefore, the solar reflectance was assumed to be 0.23, and the corresponding emittance was assumed to be 0.87, derived from a study by PG&E (Eilert 2000).

7.3 Baseline Building Internal Loads

Internal loads include heat generated from occupants, lights, and appliances (plug loads such as computers, printers, small beverage machines, etc.). Modeling the energy impacts of the building internal loads using the DOE-2 simulation program requires assumptions about the building internal load intensity and operation schedules. For the occupancy loads, the load intensity refers to the maximum occupancy at the peak time of a typical day. For lighting and plug loads, these loads are represented by a peak power density in watts per square foot.

Considering the variance of the small retail store building operations, three types of retail prototypes have been developed, including 1) Store 1 - general retail store like Blockbuster; 2) Store 2 - special retail store like Radio Shack; 3) Store 3 - upscale retail store like REI. The store operating schedules were developed based phone interviews with each type of retail store. Table 7-1 lists the representative small retail store operating hours. The internal load schedules were developed based on the surveyed operating hours. Appendix B in this report contains tables of the schedule profiles for each of the three retail types. Figure 7-1 shows a typical occupancy schedule for Store 1 open Monday through Sunday.

7.3.1 Occupancy Densities and Thermal Loads

The value of the peak occupancy for retail space, 30 persons per 1000 square foot of net occupied space, was derived from data in the ASHRAE Standard 62-2001. The reason that the committee chose use Standard 62-2001 rather than Standard 62.1-2004 was to keep consistent with the analysis work for the development of AEDG-SO. The committee assumed 50% net occupied space for the studied prototypes, based on the committee's judgment of design practices.

For the computer simulations, it is assumed that the occupant activity level was 450 Btu/hr per person for all the store types, including 250 Btu/hr sensible heat gain and 200 Btu/hr latent heat gain. These values represent the degree of activity in retail stores, i.e., standing, light work and walking, and were derived from Table 1 of Chapter 30 in the

ASHRAE 2005 Fundamentals Handbook, assuming that the occupant activity levels did not vary with climate.

Table 7-1 Small Retail Store Operating Hour Estimates

Store 1 - Blockbuster						
	Store Open Hours		*Daily*	*Daily Staff Extra Hrs.*	*Days*	*Total Hrs.*
	Open	*Close*	*Store Hrs.*			
M-Th	10:00 AM	11:00 PM	13	2	4	60
F-S	10:00 AM	12:00 PM	14	2	2	32
Su	10:00 AM	11:00 PM	13	2	1	15
				Total Weekly Hrs:		107
				Total Yearly Hrs:		5564
Store 2 - Radio Shack						
	Store Open Hours		*Daily*	*Daily Staff Extra Hrs.*	*Days*	*Total Hrs.*
	Open	*Close*	*Store Hrs.*			
M-F	9:00 AM	8:00 PM	11	2	5	65
S	9:00 AM	6:00 PM	9	2	1	11
Su	10:00 AM	5:00 PM	7	2	1	9
				Total Weekly Hrs:		85
				Total Yearly Hrs:		4420
Store 3 - REI						
	Store Open Hours		*Daily*	*Daily Staff Extra Hrs.*	*Days*	*Total Hrs.*
	Open	*Close*	*Store Hrs.*			
M-F	10:00 AM	8:00 PM	10	3	5	65
S	10:00 AM	6:00 PM	8	3	1	11
Su	11:00 AM	5:00 PM	6	3	1	9
				Total Weekly Hrs:		85
				Total Yearly Hrs:		4420

Notes and Assumptions:

-Store open hours based on calls to Tri-Cities, WA stores
http://www.rei.com/stores/index.jsp
-Staff extra hours estimated as 1 hour before opening and 1 hour after closing
-Staff extra hours for REI reported as 2 hours before and 1 hour after each day

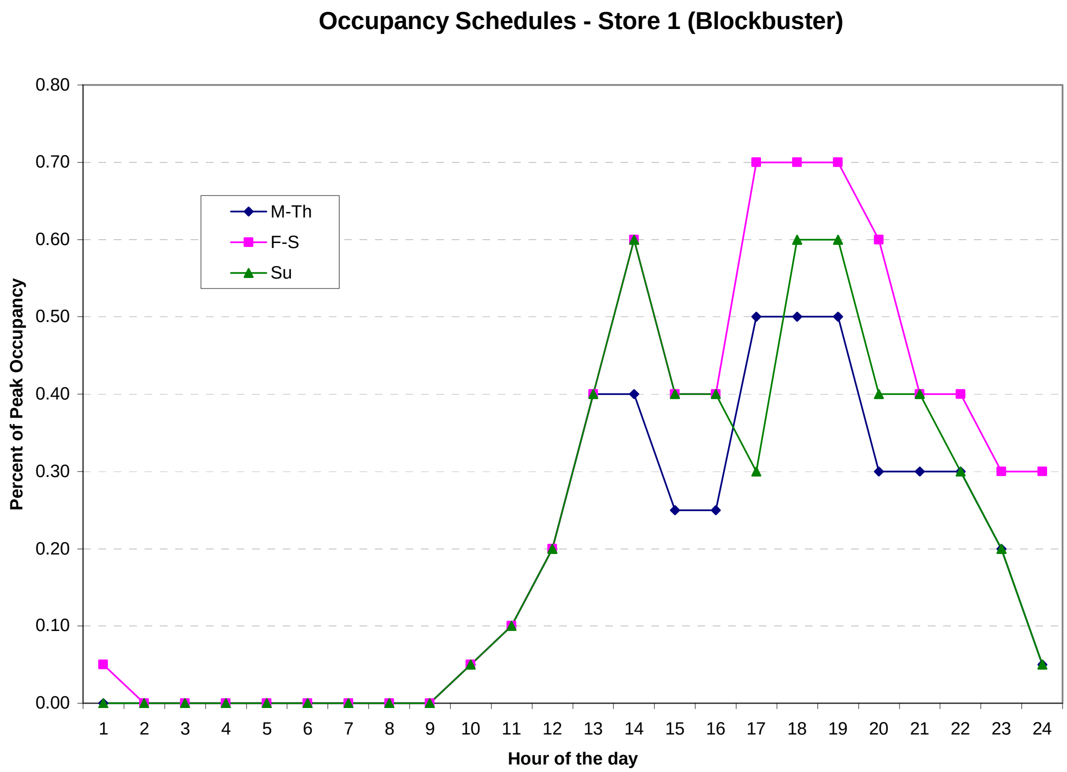


Figure 7-1 Typical Small Retail Store Occupancy Schedules

7.3.2 Lighting Power Densities

Merchandizing lighting is used to illuminate the space, point-of-sale displays, and the merchandise sold. Retail space interior lighting has a significant impact on the building energy use, and the lighting loads represent a large fraction of building energy loads. The lighting loads are represented in the simulation models by a peak lighting power density in watts per square foot. A wide range of lighting levels occurs for different retail applications, from a discount store to a high-end jewelry store.

The committee provided the base case lighting power densities for three representative retail stores, as shown in Table 7-2. The committee assumed that merchandising area occupies about 70% of total floor area, and the rest of area is shared by the active storage, office and other use of spaces. The baseline interior lighting power for each specific area is derived using the space-by-space method described in Standard 90.1-1999. The area-weighted LPD was calculated for each type of store and is used as the computer simulation inputs.

Table 7-2 Baseline Interior Lighting LPD (Standard 90.1 - 1999)

LPD (w/ft²)		**Store 1 (Blockbuster)** General Lighting		**Store 2 (Ratio Shack)** General + Accent		**Store 3 (REI)** General + Accent	
Space Description	**Space Allocation**	**No Accent Lighting**		**Accent at 1.6 w/ft²**		**Accent at 3.9 w/ft²**	
		LPD	Weighted LPD	**LPD**	Weighted LPD	**LPD**	Weighted LPD
Merchandising sales area	70%	2.10	1.47	2.10	1.47	2.10	1.47
Active storage	20%	1.10	0.22	1.10	0.22	1.10	0.22
Office	5%	1.50	0.08	1.50	0.08	1.50	0.08
Other spaces	5%	1.13	0.06	1.13	0.06	1.13	0.06
			1.82		1.82		1.82
Additional lighting	70%	0.00	0.00	1.60	1.12	3.90	2.73
			1.82 w/ft²		**2.94 w/ft²**		**4.55 w/ft²**

In addition to the merchandizing interior lighting, decorative façade lighting was also included in the simulations. This does not include lighting of walkways or entry areas of the building that may also light the building itself. Façade lighting can provide additional attention to the retailer and improve feelings of safety and security. Standard 90.1-1999 limits the maximum exterior lighting power density of 0.25 watts per square feet of illuminated façade area, i.e., the street-facing façade at the front of the stores.

7.3.3 Appliance (Plug) Loads

Small retail stores generally have appliance (plug) loads, normally used for office equipment (computers, monitors, copiers and printers etc.), beverage machines, and cash registers, etc. The plug loads will not only increase the electrical energy use, but have impacts on the thermal loads as well. It will increase the space cooling loads to offset the heat gains generated from the plug loads, and reduce the space heating loads as well.

Previous energy analysis work by Pacific Northwest National Laboratory (PNNL 2004) indicates that the peak plug loads for retail stores range from 0.2 W/ft² to 0.6 W/ft², and off-hour base loads range from 0.0 W/ft² to 0.2 W/ft². The peak and off-hour loads assumed for this analysis were 0.4 W/ft² and 0.02 W/ft², respectively. The typical retail building plug profile is the classic hat-shaped profile, with a single peak period occurring for most of the business hours and a much lower off-hour period. Figure 7-2 illustrates the plug load profile for type 2 retail store. Appendix A in this report contains all the plug load schedules used in the simulations.

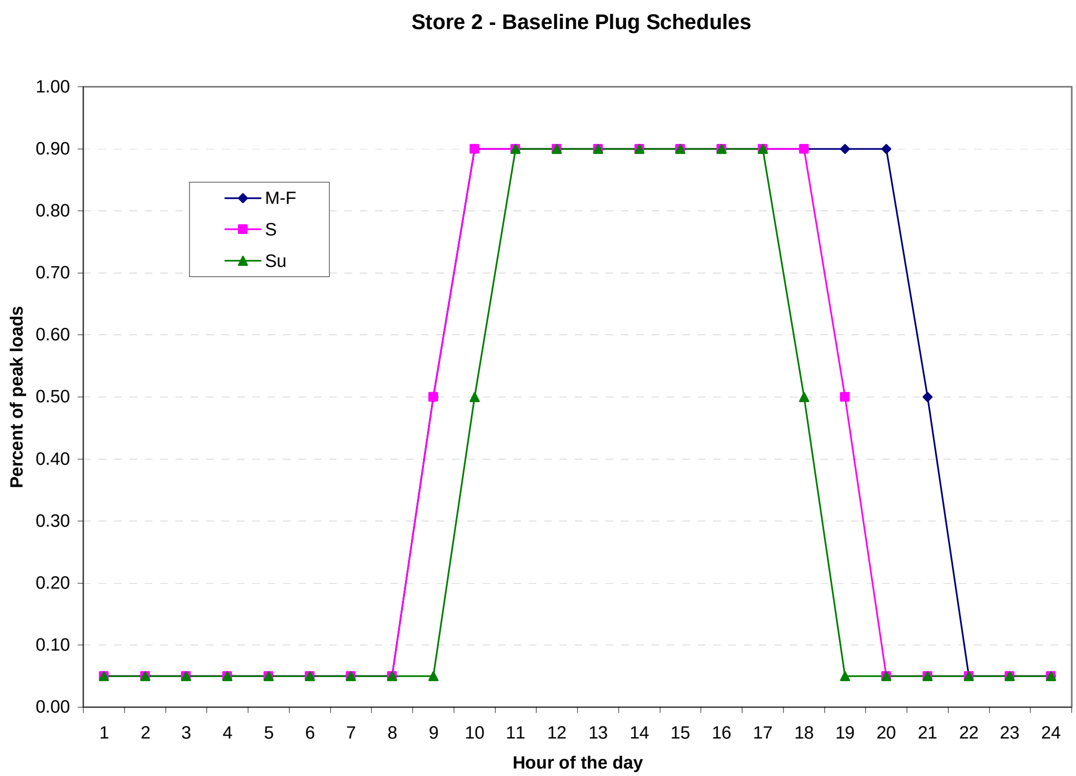


Figure 7-2 Typical Small Retail Store Plug Loads Schedules

7.4 Baseline Building HVAC Systems

The scope of this Guide covers small retail buildings up to 20,000 ft² that use unitary heating and air conditioning equipment. Buildings of this size with these HVAC system configurations represent a large fraction of small retail space in the United States (CBECS 2003). Single-zone unitary rooftop equipment is commonly used to provide thermal comfort to small retail stores. For the baseline case the equipment efficiencies were taken from the equipment efficiency tables in Standard 90.1-1999 as approved in June, 1999. A general design practice is to use multiple units to condition the store, with less duct work and the flexibility to maintain comfort in the event of partial equipment failure (ASHRAE 2003).

There are three single-zone packaged rooftop units in the strip mall prototypes, one unit serving each store. For the 15,000 ft² free standing prototype, it is assumed that three single-zone packaged units provide conditioned supply air to the entire building. There are three thermal zones in the building, and each unit is controlled by one thermal zone. All the packaged rooftop units are constant air volume systems, equipped with an electric direct expansion coil for cooling and a gas-fired furnace for heating.

Because both the strip mall and standalone prototypes are single-floor buildings with less than 20,000 ft² gross floor area, they qualify for the simplified approach option for HVAC systems. Meeting criteria (a) through (o) in Section 6.1.3 of Standard 90.1-1999 is considered in compliance with the requirement of Section 6 (*Heating, Ventilating, and Air Conditioning*).

7.4.1 Building Air Conditioning Operating Schedules

The air conditioning operating schedule is based on the building occupancy schedule, as described in Section 7.3. The fan is scheduled "on" 1 hour prior to the staff coming to the store to pre-condition the space, and the fan is scheduled "off" 1 hour after the store closes. For the strip mall prototype, the fan schedule varies for each store according to store hours. For the standalone model, only one fan schedule is used for all three packaged units. During off hours, the fan will shut off and only cycle "on" when the setback thermostat control calls for heating or cooling to maintain the setback temperature.

7.4.2 Heating and Cooling Thermostat Setpoints

Based on the inputs from the committee, the analysis for the Guide assumes 70°F heating setpoint and 75°F cooling thermostat setpoint during occupied hours. During off hours, thermostat setback control strategy is also applied in the baseline prototypes, assuming a 5°F temperature setback to 65°F for heating and 80°F for cooling.

7.4.3 Equipment Sizing and Efficiency

Equipment sizing refers to the method used to determine the cooling capacity of the DX cooling coil, and the heating capacity of the furnace in the packaged rooftop unit. The DOE-2 program has two methods to size the HVAC equipment, a*nnual-run method* and *design-day method*. In the annual-run method, the program determines the corresponding design peak heating or cooling loads using weather file data. When using the design-day method, two separate design days may be input, one for heating and one for cooling (LBNL, 2004). The program determines the design peak loads by simulating the buildings for a 24-hour period on each of the design days. The design peak loads are used by the subprogram for sizing HVAC equipment. This analysis work used the design-day method primarily for two reasons: 1) it is general practice for designers to choose design-day method for sizing the HVAC equipment; and 2) using design-day method will prevent the equipment oversizing to meet the extreme peak weather conditions occurring for a very short period time during a year.

The design-day data for all 15 climate locations was developed based on the "Weather Data" contained in the accompanying CD-ROM of ASHRAE 2005 Handbook of Fundamentals (ASHRAE 2005). In this data set, annual heating design condition is based on annual percentiles of 99.6. 99.6% values of occurrence represent that the dry-bulb temperature occurs or is below the heating design condition for 35 hours per year in cold conditions. Similarly, annual cooling design condition is based on dry-bulb temperature corresponding to 1% annual cumulative frequency of occurrence in warm conditions. And 1% values of occurrence mean that the dry-bulb temperature occurs or exceeds the cooling design condition for 88 hours per year. Additionally, the range of the dry-bulb temperature for summer is in compliance with ASHRAE Standard 90.1-1999. In DOE-2 simulations, design-day schedules can also be specified. To be consistent with the general design practice for HVAC equipment sizing, the internal loads (occupancy, lights, and plug loads) were scheduled as zero on the heating design day, and as maximum level on the cooling design day.

To meet the minimum energy-efficiency requirements of Standard 90.1-1999, the project committee recommended using two levels of cooling capacities (5- and 15-ton) for single-zone packaged unitary air conditioners. The 5-ton capacity level represents the low end of the capacity range for single packaged air conditioners. The 15-ton level is representative of larger systems at the high end of the capacity range. The Standard requires that the energy efficiency of single packaged unitary air conditioners at the 5- and 15-ton levels should be rated by the seasonal energy efficiency ratio (SEER) and energy efficiency ratio (EER), respectively. Therefore, the strip mall base case models adopt the minimum efficiency requirements of 9.7 SEER, representing a single package air conditioner with cooling capacity less than 65,000 Btu/hr. Similarly, for the standalone baseline models, the minimum efficiency of 9.5 EER was used for the 15-ton (180,000 Btu/hr) size category, after taking credit of 0.2 from the required EER 9.7 for units with heating sections other than electric resistance heat.

7.4.4 Fan Power Assumptions

The DOE-2 program calculates the fan energy consumptions by taking two parameters as inputs to the packaged unitary air conditioner model, i.e., total supply fan static pressure drops and fan/motor efficiency. For both the strip mall and standalone prototypes, the committee assumed that the HVAC system contains only a supply fan, and there is no return fan or central exhaust fan in the system based on the committee's experience with small retail buildings and current construction practice. This assumption is consistent with the most likely HVAC system design configurations for single-zone packaged rooftop air conditioners with constant-air-volume system.

To calculate the total supply fan static pressure drops, two elements have to be considered. These are internal static pressure drops and external static pressure drops. The internal static pressure is the static pressure drop across the packaged unitary equipment while operating, and was estimated based on the manufacturer's product performance data for 5-ton and 15-ton single packaged rooftop units with a gas furnace. The external static pressure calculation was based on the standard HVAC ductwork design method for representative duct runs served by 5- and 15-ton packaged unitary equipment. Table 7-3 summarizes the breakdown calculation of the fan total static pressure for both 5- and 15-ton equipment. A total fan static pressure of 1.11 in. w.c. was calculated for the 5-ton unit, representing the strip mall retail baseline prototype. For the standalone retail baseline prototype with the 15-ton unit, a total fan static pressure of 2.61 in. w.c. was calculated.

In addition, a fan efficiency of 60% and supply fan motor/drive efficiency of 85% were used for the modeling, based on manufacturer's product specifications for the same size motors. These two efficiencies provided a combined supply fan, motor, and drive efficiency of 51% as simulation inputs.

7.4.5 Ventilation Rates and Schedules

Outdoor air requirement for ventilation was used in the base case to meet ASHRAE Standard 62-2001. Standard 62-2001 has straightforward requirements for retail buildings. Street-level floors for retail stores have a requirement of 0.3 cfm/ft^2 ventilation, which was used in both strip mall and standalone prototypes. The committee believes that designers are more likely to follow the ventilation rates contained in Standard 62-2001, and there are no other readily available, credible data sources to support alternative ventilation rates in commercial buildings.

Standard 90.1-1999 Section 6.1.3 (*Simplified Approach Option for HVAC System*) does *not* require outdoor air systems equipped with motorized dampers that will automatically shut when the systems served are not in use. Therefore, hourly ventilation air schedules were developed in our prototypes to maintain the outside air damper at the minimum intake position both at the occupied and unoccupied hours. During the occupied hours, however, the outside air damper was scheduled to modulate 100% open if the economizer was operating.

7.4.6 Economizer Use

In accordance with Standard 90.1-1999, an economizer is not required if the system size is less than 65,000 Btu/hr in cooling capacity, regardless of the climate location. Therefore, the baseline systems of the strip mall prototypes, with cooling capacity normalized at 60,000 Btu/hr, have no economizer. For the standalone baseline buildings, normalized at 180,000 Btu/hr cooling capacity, the system was equipped with an economizer at some climate locations, in compliance with the Standard. Table 7-4 summarizes the requirements of economizers for each representative city.

Table 7-3 Baseline Building Calculated Total Fan Static Pressure Drops

Component	Strip Mall Prototype Baseline 5-ton Packaged Rooftop Unit (@2000 cfm)	Standalone Prototype Baseline 15-ton Packaged Rooftop Unit (@5250 cfm)
Internal Static Pressure (Inches Water Column)[1]		
Standard DX Coil	0.15	0.79
Gas Heating Section	0.13	0.51
2-in. Plated Filters[2]	0.15	0.29
Economizer[3]	0.00	0.16
Acoustical Curb	0.04	0.13
Subtotal of internal SP	0.47	1.88
External Static Pressure (Inches Water Column)[4]		
Diffuser	0.10	0.10
Supply Ductwork[5]	0.20	0.28
Return Ductwork[5]	0.05	0.06
Grille	0.03	0.03
Fan Outlet Transition	0.20	0.20
Subtotal	0.58	0.67
10 % Safety Factor	0.06	0.07
Subtotal of external SP	0.64	0.74
Total Static Pressure Drops	**1.11**	**2.61**

Notes:
1. Internal static pressure drops were derived from AAON product catalog for RK Series, last updated on July 1999.
2. Used average difference between the clean and dirty filters.
3. For standalone prototype baseline models, if economizer is not required by the Standard, the total static pressure drops will be 2.45 in. w.c., by deducting the pressure drop of 0.16 in.w.c. from 2.61 in. w.c..
4. External static pressure was calculated based on the typical duct runs served by the listed cooling capacities.
5. Used standard practice of 0.1 inch/100 ft friction rate for the baseline prototypes.

Table 7-4 Baseline Modeling Economizer Requirement (Standalone Prototype)

	Representative City	T_{wb}[1] (°F)	No. of Hours Between 8 AM and 4 PM with 55°F < T_{db} < 69°F	Climate Zone
Zone 1	Miami	77	259	no
Zone 2	Phoenix	70	746	yes
Zone 2	Houston	77	644[2]	no
Zone 3A	Memphis	77	851	yes
Zone 3B	El Paso	64	735	yes
Zone 3C	San Francisco	62	1796	yes
Zone 4	Baltimore	74	785[2]	no
Zone 4	Albuquerque	60	703	yes
Zone 4	Seattle	64	982	yes
Zone 5	Chicago	73	613	yes
Zone 5	Boise	63	647	yes
Zone 6	Helena	59	651	yes
Zone 6	Burlington	69	637	yes
Zone 7	Duluth	67	650	yes
Zone 8	Fairbanks	59	700[2]	yes

Notes:
1. Twb = 1% cooling design web-bulb temperature, derived from Standard 90.1-1999 Appendix D
2. Data is not available in Appendix D of 90.1-1999 and was created using *BinMaker*, a weather data program.

7.5 Service Hot Water System

The committee defined the baseline service hot water system for both the strip mall and the standalone prototype buildings as a gas-fired storage water heater that meets the minimum standards requirement for residential water heaters (with rated input power less than 75,000 Btu/hr) under Standard 90.1-1999. Gas water heaters were chosen for the baseline to be consistent with the use of gas for heating in the baseline prototype buildings. The reason to choose the residential water heater is that the peak hot water load is usually only from the use of lavatories in small retail stores. This limited hot-water demand can normally to be met by a residential water heater. The guide also provides the efficiency recommendation for the residential electric-resistant water heater. The recommended efficiency level for the advanced design guide is described in Section 8.4.

To estimate the energy performance of a service water heater with a storage tank, DOE-2 program requires the user to define the following key input variables as the operating parameters:

- the rated storage tank volume in gallons

- the rated input power in Btu/hr - the heating capacity of the burner used to meet the domestic hot water load and charge the tank
- the standby heat loss coefficient (UA) in Btu/hr-°F
- heat input ratio (HIR) – this is a ratio of gas heat input to heating capacity at full load. HIR in the inverse of the water hear thermal efficiency (E_t).

7.5.1 Storage Tank Size

The water heater storage tank volume was sized based on the methodology described in the 2003 ASHRAE Applications Handbook. The committee determined the maximum 10 lavatories will satisfy the needs for studied small retail buildings. Possible maximum hot water demand is determined by multiplying the number of fixtures with the hot-water demand per fixture in Table 8 of Chapter 49 *Service Water Heating (*ASHRAE 2003). Retail Merchandise is not listed as one of the building types in Table 8, and the closest building type with similar demand is office building. The hot-water demand for office building is 6 gal/h per fixture, resulting in the possible maximum demand of 60 gal/h. Plugging in the demand factor of 0.30 and the storage capacity factor of 2.0 from the same table, the storage tank capacity is calculated as 36 gallons. Therefore, a storage tank with rated capacity of 40 gallon is chosen as one of the baseline input variables.

7.5.2 Rated Input Power and Standby Heat Loss Coefficient

For residential water heaters, the minimum efficiency of heaters is required to meet the requirements by National Appliance Energy Conservation Act (NAECA), as expressed as energy factor (EF). Standard 90.1-1999 also refers to NAECA requirements for residential water heaters. Energy factor of a water heater was 0.54 EF using following equation required in the Standard:

$$EF = 0.62 - 0.0019 \times Rated\ Storage\ Tank\ Volume \tag{7.3}$$

Based on DOE's Appliance Standard Rulemaking for Residential Water Heater (DOE 2000), the corresponding input rate of 40-gallon water heater is 40,000 Btu/hr, with recovery efficiency (RE) of 76%. Furthermore, the Water Heater Analysis Model (WHAM) (DOE 2000) used in this rulemaking analysis estimated the standby heat loss coefficient (UA) of the heater using the following equation:

$$UA = \frac{\left(\frac{1}{EF} - \frac{1}{RE}\right)}{67.5 \times \left(\frac{24}{41094} - \frac{1}{RE \times P_{on}}\right)} \tag{7.4}$$

where

UA = standby heat loss efficient (Btu/hr-°F)

RE	=	recovery efficiency
P_{on}	=	rated input power (Btu/hr)
67.5	=	difference in temperature between stored water thermostat set point and ambient air temperature at the test condition (°F)
41094	=	daily heat content of the water drawn from the water heater at the test condition (Btu/day).

Plugging in the appropriate values for EF, RE, and P_{on} results in a UA of 14.044 Btu/hr-°F, as one of input variables in DOE-2 program.

7.5.3 Water Thermal Efficiency and Heat Input Ratio

For the residential water heater, the following equation allows calculation of water heater thermal efficiency E_t as 0.784, resulting in the heat input ratio (HIR) of 1.276.

$$E_t = \frac{UA \times 67.5 + P_{on} \times RE}{P_{on}} \tag{7.5}$$

8.0 DEVELOPMENT OF ADVANCED BUILDING ASSUMPTIONS

To quantity the potential energy savings from the recommended energy measures in the Guide, the advanced building models were simulated by implementing the energy-efficiency technologies noted below. This section contains a topic-by-topic review of advanced building models and how the recommended energy-efficiency measures were implemented into advanced DOE-2 modeling. The energy-efficiency measures include:

- Enhanced building opaque envelope insulation
- High performance window glazing
- Reduced lighting power density
- Demand ventilation control
- Automatic motorized damper control for outside air intake
- Lower pressure ductwork design
- Higher efficiency HVAC equipment
- Instantaneous service water heater.

8.1 Advanced Building Envelope Assumptions

The advanced building models had identical conditioned floor area and identical exterior dimensions and orientations as the baseline buildings, except the following components:

- Opaque assemblies - Opaque assemblies such as roof, walls, floors and doors were modeled as having the same heat capacity as the baseline buildings, but with the enhanced insulation R-values required in the Guide, as described in Table 10-1 in this report.

- Cool roof - Roof exterior finish was recommended by the committee to be a single-ply roof membrane with white EPDM (ethylene-propylenediene-terpolymer membrane) in the advanced building prototypes. Therefore, the solar reflectance used in the advanced cases was 0.69, and the corresponding emittance was 0.87, derived from a study by PG&E (Eilert 2000).

- Fenestration – The fenestration in the advanced case was modeled with the same window area as the baseline models. Permanent shading devices overhangs were also modeled. Fenestration U-factor was implemented to meet the minimum requirements for the climate, and the solar heat gain coefficient was set to the maximum allowed for the climate, as shown in Table 10-1 in this report.

8.2 Advanced Building Lighting Levels Assumptions

The committee chose to adopt the advanced lighting levels that were approved by addenda to the Standard 90.1-2004 (ANSI/ASHRAE/IESNA 2004). The committee calculated the advanced lighting levels power densities for the strip mall prototype, including each of three representative retail stores, as shown in Table 8-1. The advanced interior lighting power for each specific area is derived using the space-by-space method described in Standard 90.1-2004. There are no changes on the space allocation and assigned percentiles of floor area. The calculated area-weighted LPD was used as the computer simulation inputs for the strip mall prototype advanced cases. For the standalone prototype, the area-weighted LPD in Store 1 (with 100% general lighting) was used.

Table 8-1 Advanced Interior Lighting LPD (Standard 90.1-2004)

LPD (w/ft²)		**Store 1 (Blockbuster)** General Lighting		**Store 2 (Ratio Shack)** General + Accent		**Store 3 (REI)** General + Accent	
Space Description	**Space Allocation**	**No Accent Lighting**		**Accent at 0.58 w/ft²**		**Accent at 1.42 w/ft²**	
		LPD	Weighted LPD	**LPD**	Weighted LPD	**LPD**	Weighted LPD
Merchandising Sales Area	70%	1.51	1.06	1.51	1.06	1.51	1.06
Active storage	20%	0.65	0.13	0.65	0.13	0.65	0.13
Office	5%	0.95	0.05	0.95	0.05	0.95	0.05
Other spaces	5%	1.00	0.05	1.00	0.05	1.00	0.05
			1.28		1.28		1.28
Additional lighting	70%		0.00	0.58	0.41	1.50	1.05
			1.28 w/ft²		**1.69 w/ft²**		**2.33 w/ft²**

The exterior light power limit is 0.20 watts per square feet of illuminated area, per Standard 90.1-2004. This value was also adopted by the committee as the advanced building exterior lighting level.

No daylighting controls were incorporated into the advanced building simulation modeling for two reasons: 1) no recommendations were provided for daylighting from vertical glazing in retail buildings; and 2) the studied prototypes, both strip mall and standalone models, do not have skylights. The Guide does recommend dimming control for daylight harvesting under skylights, if skylights are present in the proposed retail stores. So, unlike the AEDG-SO, potential energy savings from daylight dimming controls were not demonstrated through simulation.

In addition, occupancy controls were also excluded in the simulations because this technology has limited application in retail buildings. The committee recommends applying occupancy controls only to the non-sales areas in retail buildings, thus limiting the maximum impact of these controls to between 20% and 30% of the gross floor area based on typical retail floor plans. As a result, building energy simulations show the energy savings for this application of occupancy controls to be insignificant.

Use of the Standard 90.1-2004 would have resulted in reduced energy savings due to the much lower values of retail lighting compared to the Standard 90.1-1999 baseline. The committee evaluated the overall average energy savings of both building prototypes in each of 15 climate locations and found that the average savings was 37% relative to the 1999 baseline and 30% relative to the 2004 baseline.

8.3 Advanced Building HVAC Systems

As described in Section 6.3 in this report, the energy efficient technologies that have been demonstrated through simulation include:

- Higher cooling and/or heating equipment efficiency levels
- Economizer application on smaller capacity equipment (>54,000 Btu/hr)
- Motorized dampers for outdoor air control during unoccupied hours
- Demand-controlled ventilation
- Lower friction rate ductwork design.

This section describes how these energy-efficient measures were modeled in DOE-2 program for the advanced buildings.

8.3.1 Higher HVAC Equipment Efficiency

The committee recommended the minimum cooling equipment efficiency of 13 SEER for 5-ton residential products normalized in the strip mall prototype. This recommendation is consistent with the requirements in the AEDG-SO. For 15-ton commercial products modeled in the standalone prototype, the equipment efficiency recommendation varies by climate change, i.e., 11.0 EER in zones 1 and 2, 10.8 EER in zones 3, 4 and 5 and remain the same level as Standard 90.1-1999 (9.5 EER) in zones 6, 7 and 8.

8.3.2 Air Economizer

Following the recommendation in the AEDG-SO, the committee recommended lowering the capacity threshold for air economizers from 65,000 Btu/hr to 54,000 Btu/hr for climate zones 3 through 6. Accordingly, the advanced systems of the strip mall prototype have economizers implemented in climate zones 3, 4, 5, and 6 only. For the standalone baseline buildings, the only change made was in Baltimore, located in zone 4. The 90.1-1999 baseline system does not require economizers, as shown in Table 7-4. However, an economizer was employed on air conditioners in the advanced system in Baltimore, as recommended in the Guide. Appendix B summarizes the key simulation parameters for both the baseline and advanced cases at each representative city, including economizer requirements.

8.3.3 Motorized Damper Control

As described in Section 7.4.5, Standard 90.1-1999 does *not* require motorized dampers to control the outdoor air intake during off hours (nor does Standard 90.1-2004). The Guide recommends use of motorized dampers to prevent outdoor air from entering during the unoccupied periods. To simulate the motorized damper control, hourly outdoor ventilation air schedules were modified in the advanced systems to follow a two-step control strategy: 1) during the occupied hours, maintain the outdoor air damper at the minimum intake position, or modulate 100% open if the system operates in the economizer mode; 2) during unoccupied (off) hours, automatically close the outdoor air damper to reduce unnecessary outside air intake into the building.

Motorized damper control can save significant energy, especially in cold climates when the unit may recirculate air to maintain setback temperature during the unoccupied period and the cold outdoor air has to be heated by the unit if no motorized damper is employed. It also helps to control the excess humid outdoor air introduced into the building during off hours in hot and humid climates.

8.3.4 Demand-Controlled Ventilation

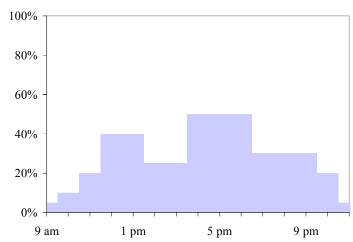
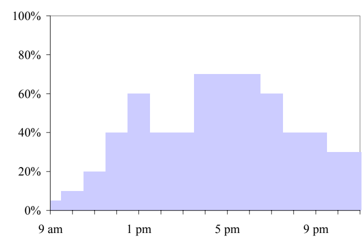
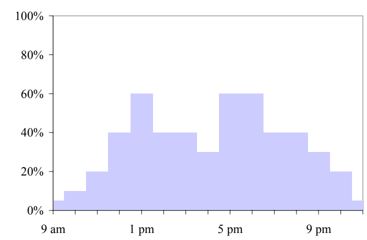
The committee recommends that demand-controlled ventilation (DCV) should be used in areas that have varying and high occupancy loads during the occupied periods to vary the amount of outdoor air based on occupancy. Demand-controlled ventilation can be accomplished by modulating the introduction of outdoor ventilation air to maintain a specific carbon dioxide (CO_2) level within a building. The potential energy savings through CO_2-based DCV systems in retail buildings can be significant. Minimum ventilation air rate is normally designed to satisfy the maximum occupancy in a space. However, there is a high percentage of time that a retail building is not fully occupied. Therefore, during these times of partial occupancy, heating and cooling energy savings can be realized by introducing less ventilation air to the space by implementing DCV.

For the simulation analysis, the committee decided to employ the DCV control strategy only to the larger 15,000-ft² standalone prototype, but not to the smaller 7,500-ft² strip mall prototype. It is usually stated that CO_2-based DCV provides a cost-effective means for achieving good energy savings for larger spaces with large variations in occupancy (Jeannette et al. 2006).

The DOE-2 program cannot explicitly model the CO_2-based DCV control strategy. To quantify the potential energy savings from DCV technology, the average ventilation air rate reduction by implementing DCV systems was calculated based on following steps:

- Step 1: Calculate the average percentage of design occupancy -- Table 8-2 illustrates the occupancy schedules for the standalone prototype building, as described in Section 7.3. The graph shows that the average percentage of design occupancy varies from a low of 29% during weekdays to a high of 42% on weekends. The weighted average design occupancy is about 33% on a weekly base.

Table 8-2 Standalone Prototype Building Occupancy Schedules

Monday –Thursday	Friday – Saturday	Sunday & Holidays
		
Average percentage of design occupancy = 29%	Average percentage of design occupancy = 42%	Average percentage of design occupancy = 33%

- Step 2: Identify the CO2-based DCV control strategy -- A research study by Jeannette et al. (2006) suggests applying lower and upper limits of minimum outdoor air to DCV systems as a design method, using ASRAE Standard 62.1-2004 (ANSI/ASHRAE 2004). ASHRAE Standard 62.1-2004 contains two components in requiring minimum outdoor ventilation air calculations, including the area-based component and the full-occupancy-based component. Lower ventilation air quantity can be calculated using the area-based component of the ventilation air requirements. And the area plus full-occupancy component can be used as the upper limit of the minimum air quantity required. For the 15,000-ft² standalone retail building, the minimum ventilation rate is required as 0.12 cfm/ft² in Table 6-1 of Standard 62.1-2004, resulting in the lower limit of 1800 cfm fresh air on zero occupants. The upper limit of the minimum ventilation air is calculated as 3600 cfm, based on the required combined outdoor air rate of 16 cfm/person, with default occupant density of 15 persons/1000 ft². The DCV control strategy is to maintain the minimum outdoor air at 1800 cfm when no customer present, and using CO_2-based DCV to modulate the outdoor air damper open in response to the increased occupants at peak periods, with an upper limit of 3600 cfm.

- Step 3: Calculate the average percentage of the ventilation air reduction -- Applying the 33% average design occupancy to the additional 1800 cfm required by the full-occupant methodology, the average actual fresh air needed in response to occupants is about 600 cfm. That means the DCV technology can reduce the average outdoor air from 3600 cfm to 2400 cfm, a reduction of more than 30%. Therefore, in the simulation modeling, 70% of baseline ventilation air rate was used as the ventilation rate of the advanced buildings to estimate the potential energy savings from DCV systems.

- Step 4: As described in Section 7.4.5, the baseline ventilation air rate of 4500 cfm total was computed in compliance with ASHRAE Standard 62-2001. Therefore, the average ventilation rate in the advanced cases is in total of 3150 cfm, a 30% reduction due to the implementation of CO_2-based DCV.

8.3.5 Lower Static Pressure Ductwork

To quantify the potential energy savings from the recommended improved ductwork design (low friction rate) in the simulation analysis, the supply fan external static pressure drops were re-calculated, based on a maximum ductwork friction rate no greater than 0.08 in. per 100 liner feet of duct run, as recommended by the Guide. The internal static pressure remained the same as the baseline calculation shown in Table 7-3. Table 8-3 summarizes the breakdown calculation of the fan total static pressure for both 5- and 15-ton equipment. The difference compared to the baseline calculation is shaded in Table 8-3, including static pressure drops through diffusers an registers, supply and return ductwork. In summary, a total fan static pressure of the 5-ton unit was reduced from 1.11 in. w.c. to 1.05 in. w.c., representing the strip mall retail advanced prototype. For the standalone retail advanced prototype with the 15-ton unit, a total fan static pressure of 2.48 in. w.c. was calculated compared to 2.61 in. w.c. in the baseline prototype.

Table 8-3 Advanced Building Calculated Total Fan Static Pressure Drops

	Advanced Strip Mall Retail	**Advanced Standalone Retail**
Component	**5-ton Packaged Rooftop Unit (@2000 cfm)**	**15-ton Packaged Rooftop Unit (@5250cfm)**
Internal Static Pressure (Inches Water Column)[1]		
Standard DX Coil	0.15	0.79
Gas Heating Section	0.13	0.51
2 in. Plated Filters[2]	0.15	0.285
Economizer	0.05	0.16
Acoustical Curb	0.04	0.125
Subtotal	0.52	1.87
External Static Pressure (Inches Water Column)[3]		
Diffuser	0.05	0.05
Supply Ductwork[4]	0.16	0.224
Return Ductwork[4]	0.04	0.048
Grille	0.03	0.03
Fan Outlet Transition	0.2	0.2
Subtotal	0.48	0.55
10 % Safety Factor	0.05	0.06
Subtotal	0.53	0.61
Total Static Pressure Drops	**1.05**	**2.48**

Notes:

1. Internal static pressure drops were derived from AAON product catalog for RK Series, July 1999
2. Used average difference between the clean and dirty filters
3. External static pressure was calculated based on the typical duct runs served by the listed cooling capacities.
4. Used best practice of 0.08 inch/100 ft friction rate for the advanced prototypes.

8.4 Service Water Heating

Following the recommendations in the AEDG-SO, this Guide presents two options for gas-fired water heaters in Table 10-3. These are a gas storage water heater with a 90% thermal efficiency (Et) or a gas instantaneous water heater with either a measured 81% Et or a 0.81 energy factor (EF) rating for NAECA covered water heaters. Additional recommendations are provided for electric water heaters, but these were not modeled as part of this exercise.

The advanced simulation models used a gas instantaneous water heater. The standby loss from the instantaneous water heater was modeled as negligible (0.0 Btu/hr.) This results in thermal efficiency essentially the same as the rated energy factor (EF), i.e., 0.81 Et. The HIR was then calculated as 1.235, as the inverse of Et.

In summary, the base and advanced water heater input variables in the DOE-2 program for both the 7,500 ft² and 15,000 ft² retail prototypes were:

	Heat Input Ratio	Storage Volume (gallons)	Rated Input Power (Btu/hr)	Tank Standby Loss UA (Btu/hr-°F)
Base	1.276	40	40,000	14.04
Advanced	1.235	0.0	40,000	0.0

As described in section 7.5, the Guide also includes the efficiency recommendation for the service water heating system using the electric-resistance water heater. For the electric-resistance water heater with capacity no larger than 12 kW, the minimum efficiency level required by the Standard 90.1-1999 is expressed in the term of Energy Factor (EF). The minimum EF of an electric water heater is calculated using following equation required in the Standard:

$$EF = 0.93 - 0.00132 \times Rated\ Storage\ Tank\ Volume \qquad (8.1)$$

The committee studied the manufacturer's reported data for the efficiency levels of the electric water heaters in the market and the plotted the reported data shown in Figure 8-1. The manufacture's reported data was derived from the California Energy Commission Appliance Database (CEC 2006). Furthermore, the committee recommended the higher efficiency metrics in the guide compared to the Standard requirement. The higher efficiency lever is expressed as the following equation:

$$EF = 0.99 - 0.0012 \times Rated\ Storage\ Tank\ Volume \quad (8.2)$$

The plots in Figure 8-1 shows the comparison of the difference efficiency levels for the residential electric-resistance water heaters, including the minimum efficiency requirement in the 1999 Standard, the minimum requirement in the 2004 Standard, and the recommended efficiency level by the Guide. The manufacturer's reported data proves that multiple manufacturers can produce the electric water heaters that meet the Guide's recommended efficiency levels.

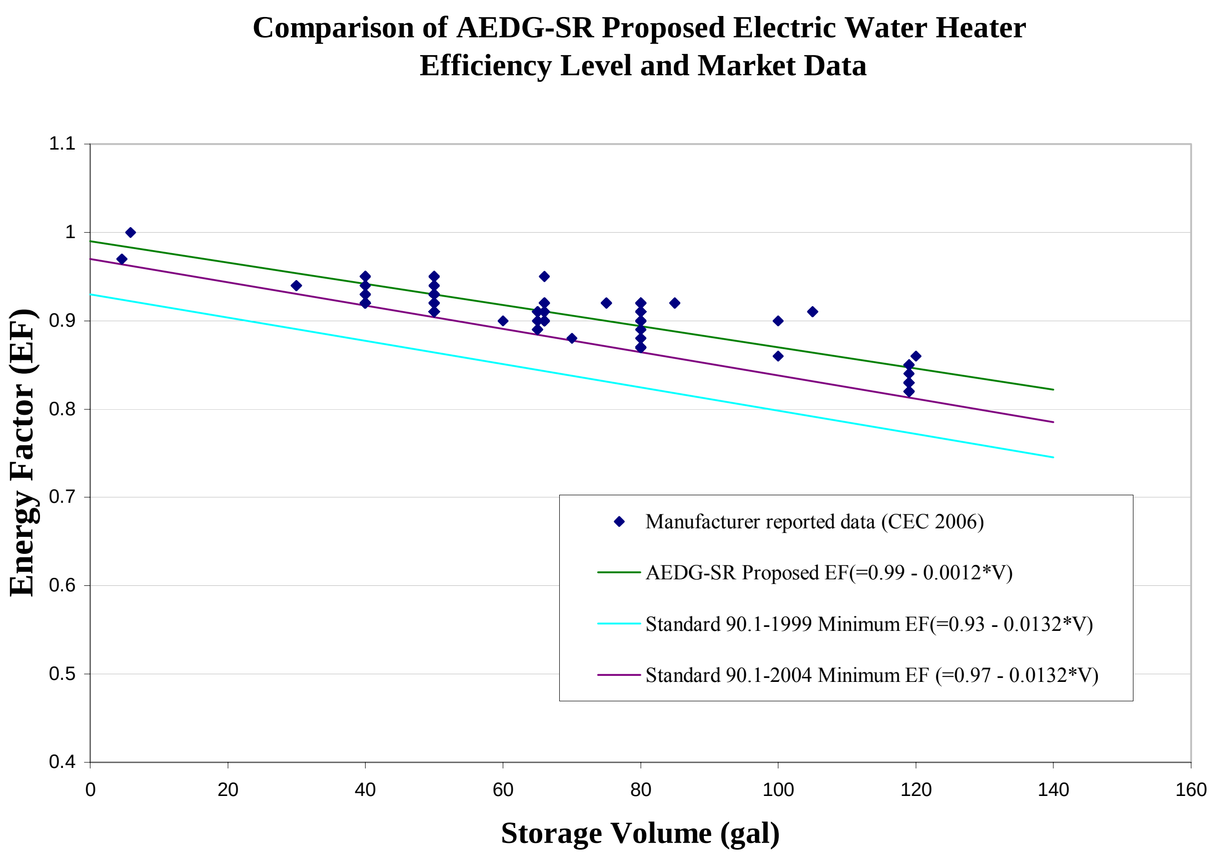


Figure 8-1 Comparison of Different Efficiency Levels of the Electric Water Heater

9.0 DEVELOPMENT OF THE ENVELOPE CRITERIA

The target of selecting envelope measures to achieve a 30% energy savings relative to Standard 90.1-1999 for the envelope criteria is challenging because the envelope measures in 90.1-1999 were developed using full life-cycle-cost (LCC) economics. The implication of this approach is that different combinations of the 90.1-1999 criteria for ceilings, walls, foundations and fenestration will define different levels of energy for the base cases. The sheer number of combinations of all the possible envelope measures prevents evaluation of each one. Thus, a simplified technical approach was needed that could be used to determine the envelope recommendations. The objective was to develop specific envelope recommendations for all of the envelope components in each of the eight climate zones.

9.1 Technical Approach

The technical approach was characterized by six major tasks.

Task 1 – Define Representative Buildings

The first task was to define typical or representative buildings. Two different size buildings were defined to address various uses and construction features. A 7,500 ft^2 strip mall with three individual retail stores was representative of the small size. A separate standalone building of 15,000 ft^2 represented the large building.

Task 2 – DOE-2 Sensitivity Runs

The second task was to complete a series of DOE-2 (LBNL 2004) simulations to determine the energy savings of various envelope packages in multiple climates. An experimental approach was used to bracket a broad range for each envelope component. Fifteen locations were selected that covered all eight climate zones.

Task 3 – Development of Linear Regression Models to Estimate the Envelope Energy

The third task was to develop a series of linear regression models that would be used to estimate the energy savings of the multiple envelope combinations for all of the cities. This technique provided a quick method to estimate energy savings, which allowed the entire envelope development process to proceed quickly, as opposed to completing DOE-2 simulations for all of the cases.

Task 4 – Application of the 90.1-1999 LCC Technique to Identify the Envelope Measures

The fourth task was to utilize the basic 90.1-1999 life-cycle-cost economic analysis to identify the envelope measures for each city (ASTM 2002). This process utilized the linear regression equations to determine the energy savings once the specific envelope measures were selected. The linear regression models approximated the energy savings so the final energy savings were bracketed by plus or minus one standard deviation to illustrate the absolute variability in achieving the 30% savings.

Task 5 – Selection of the LCC Metric for Each Climate Zone

The fifth task was to review all of the city results for the various LCC metrics by climate zone and select the single metric that would be used to set the final recommendations for the Guide.

Task 6 – Final Verification of the Envelope Measures

The sixth task was to use the proposed envelope measures for each city in DOE-2 simulations to determine whether the 30% energy target was achieved. This step was critical because it represented an integration of the final recommendations in the Guide for all of the measures including not only the envelope but also the lighting, HVAC and SWH.

9.2 Results

The results follow the six steps defined above.

Task 1 – Define Representative Buildings

There were two basic building designs analyzed, a 7,500-ft^2 strip mall with three separate stores (two were 25-ft wide x 75-ft deep and one was 50-ft wide x 75-ft deep) and a 15,000-ft^2 (120-ft wide x 125-ft deep) standalone building. The strip mall had a 14-ft floor-to-floor height and an 11-ft floor-to-ceiling height. The basic construction was a metal roof deck, metal-framed walls and a slab foundation. All of the fenestration was on the front of the mall with a window-to-wall ratio of 0.200. The standalone building had a 16-ft floor-to-floor height and a 12-ft floor-to-ceiling height. The basic construction was a metal roof deck, mass walls and a slab foundation. The window-to-wall ratio was 0.171. The fenestration in both buildings was limited to clear glass options so customers could see merchandise displayed.

Task 2 - DOE-2 Sensitivity Runs

The sensitivity runs served two purposes: first, to verify that the 30% energy savings could be achieved using envelope measures that are readily available, and to provide a data base for development of the linear regression energy models. The starting point was to determine the envelope criteria from 90.1-1999 for the strip mall in each of the 15 cities (see Table 9.1).

Table 9-1 Standard 90.1-1999 Envelope Criteria

Envelope	Metric	City and Climate Bins									
		Miami	Phoenix Houston	Memphis El Paso	San Francisco	Baltimore Albuquerque	Seattle	Chicago Boise	Burlington Helena	Duluth	Fairbanks
		2	5	10	12	13	14	17	19	22	24
Above deck	U	0.063	0.063	0.063	0.093	0.063	0.063	0.063	0.063	0.0.63	0.048
Steel walls	U	0.124	0.124	0.124	0.124	0.124	0.124	0.084	0.084	0.064	0.064
Mass walls	U	0.580	0.0580	0.151	0.151	0.151	0.151	0.123	0.104	0.090	0.080
Unheated slab	U	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.73	0.54
Opaque door	U	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.5
Ufen-fixed	U	1.22	1.22	0.57	1.22	0.57	0.57	0.57	0.57	0.57	0.46
SHGCall	SHGC	0.25	0.25	0.25	0.61	0.39	0.39	0.39	0.39	0.49	NR
Above deck	R	15	15	15	15	15	15	15	15	15	20
Steel walls	R	13	13	13	13	13	13	13+ 3.8	13+ 3.8	13+ 3.8	13+ 3.8
Unheated slab	R	0	0	0	0	0	0	0	0	0	10 @ 24"
DOE-2											
Ufen-fixed	U	1.11	1.11	0.57	1.11	0.57	0.57	0.57	0.57	0.57	0.42
SHGCall	SHGC	0.86	0.86	0.76	0.86	0.76	0.76	0.76	0.76	0.76	0.44

The list of cities, climate bins and climatic data extracted from the TMY-2 (Marion and Urban 1995) files are presented in Table 9.2.

Table 9-2 List of Cities, Climate Bins and TMY-2 Climatic Data

No.	City	ST	Climate 90.1	Climate Bin	HDD65	CDD50	Avg. Solar Radiation - Btu/ft²-day North	East	South	West	Hor	Annual DBT-°F	Sum W >0.010
1	Miami	FL	2	1	140	9462	442	884	938	834	1543	75.76	112.3741
2	Phoenix	AZ	5	2	1153	8222	429	1065	1264	1057	1827	72.55	14.5658
3	Houston	TX	5	2	1552	7061	409	772	886	800	1398	68.09	86.6598
4	El Paso	TX	10	3	2597	5430	433	1088	1252	1025	1822	64.06	17.7176
5	Memphis	TN	10	3	3106	5323	401	843	1018	845	1460	62.08	55.2159
6	San Francisco	CA	12	3	3236	2489	379	810	1092	909	1501	55.56	0.5455
7	Albuquerque	NM	13	4	4362	3884	425	1090	1308	991	1765	55.84	10.6261
8	Seattle	WA	14	4	4867	1957	327	595	816	662	1058	51.58	1.6327
9	Baltimore	MD	13	4	4911	3722	369	746	977	763	1279	54.70	35.3474
10	Boise	ID	17	5	6001	2682	377	874	1108	879	1406	50.47	0.5412
11	Chicago	IL	17	5	6449	2954	374	739	926	728	1238	49.55	25.2063
12	Helena	MT	19	6	7815	1854	361	806	1056	785	1244	44.30	1.3152
13	Burlington	VT	19	6	7902	2215	370	705	935	729	1189	44.98	16.9696
14	Duluth	MN	22	7	10215	1313	369	729	991	730	1169	37.74	10.3260
15	Fairbanks	AK	24	8	14172	876	308	596	865	582	807	26.47	0.4235

Next, a design of experiment strategy was used to define a range of construction options for the strip mall. The roof reflectance was 0.65 for climate zones 1 through 3 and 0.23 for climate zones 4 through 8. Table 9.3 presents the envelope measures used for the strip mall. The SHGC for the front door was 0.81.

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Table 9-3 Sensitivity Runs for Strip Mall

Run No.	Above Deck R	Wall - Steel R	Wall - Steel U	Door U	Slab F	WWR	Fen. U	SHGC	Orien.
1	20	13	0.124	0.7	0.73	0.200	0.67	0.49	W
2	25	13+8	0.062	0.7	0.45	0.200	0.67	0.49	W
3	35	13+20	0.036	0.7	0.16	0.200	0.67	0.49	W
4	20	13	0.124	0.7	0.73	0.200	0.31	0.20	W
5	25	13+8	0.062	0.7	0.45	0.200	0.31	0.20	W
6	35	13+20	0.036	0.7	0.16	0.200	0.31	0.20	W
7	25	13+8	0.062	0.7	0.45	0.200	0.67	0.49	N
8	25	13+8	0.062	0.7	0.45	0.200	0.31	0.20	N

The results of all the sensitivity runs for the strip mall are presented in Figure 9.1.

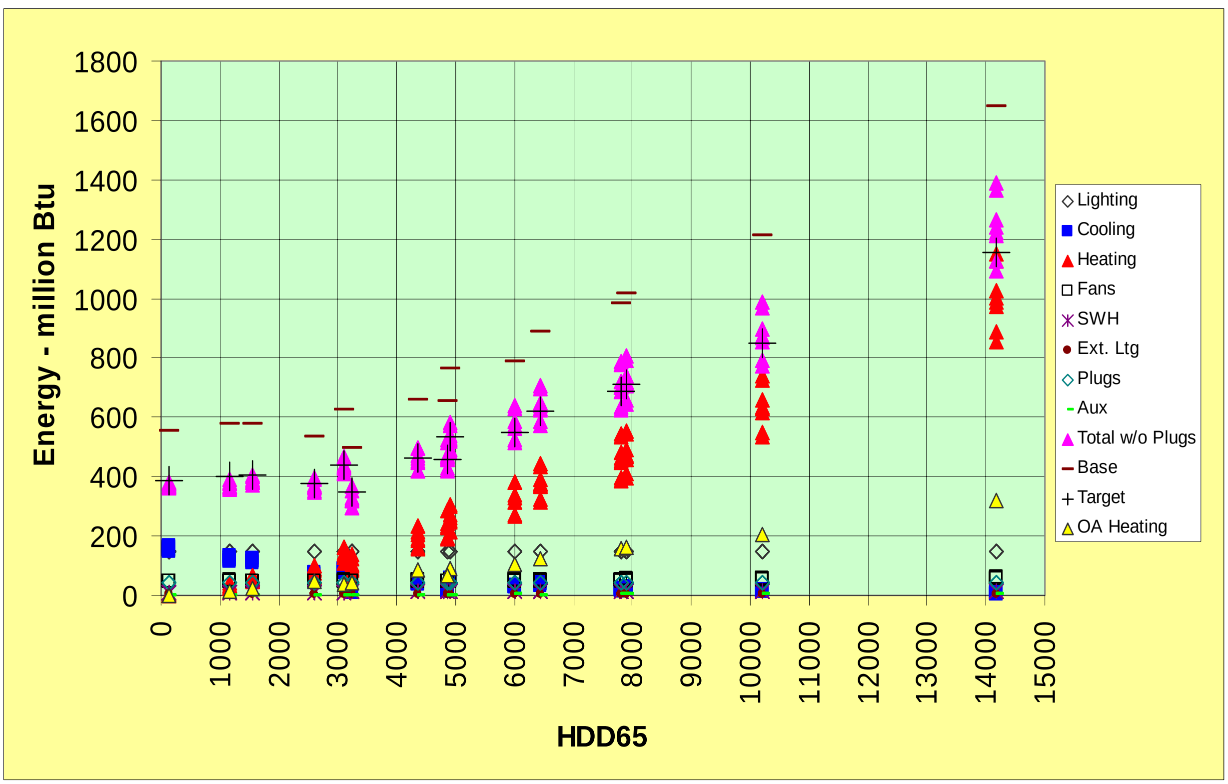

Figure 9-1 7,500-ft² Strip Mall Energy Use

The baseline energy consumption for each city is presented as a dash or horizontal line. The 30% energy savings target is shown as a cross. The energy use of the individual components such as lighting, fans, service water heating, exterior lights, plug loads, outside air, auxiliary as well the heating and cooling of the envelope measures are also shown by separate symbols. The key point is that the mix of measures identified in the sensitivity analysis was able to achieve the 30% energy savings in each of the cities.

Task 3 – Development of Linear Regression Models to Estimate the Envelope Energy

The development of the linear regression models is presented in Appendix C.

Task 4 – Application of the 90.1-1999 LCC Technique to Identify the Envelope Measures

Application of the 90.1-1999 LCC technique was used to provide a uniform and consistent procedure for development of the envelope recommendations. The first step in understanding the general procedure is to review the concept of economic optimization. The simplest example is that of envelope components whose thermal performance is characterized by a single parameter such as a U-factor for above grade components, a C-factor for below grade components and an F-factor for concrete slabs. Their recommendations are determined in a simple economic optimization procedure. An example of a roof with insulation entirely above deck will be presented to illustrate this procedure for all opaque components. The second example will focus on the thermal performance of fenestration, which is characterized by two parameters (U-factor and SHGC).

A. Opaque Components

The fundamental economic concept used in setting the envelope criteria is that the energy savings of any feature over some time period must justify the increased first cost of the feature. The best way to understand this step is to present the fundamental economic theory and equations. This concept is implemented using LCC analysis. The details of how LCC is implemented can easily be demonstrated. In simple terms, the LCC economics requires that the incremental energy cost savings over some time period must meet or exceed the incremental first costs. In equation form, the LCC economics can be stated as:

$$FYS_h \times A \times P_h \times S_h + FYS_c \times A \times P_c \times S_c \geq \Delta FC \times A \times S_2 \qquad (9.1)$$

where

- FYS_h = first year energy savings per unit area, heating (therms)
- A = area (ft^2)
- P_h = price of energy, heating (\$0.66/therm)
- S_h = economic scalar, heating (dimensionless)
- FYS_c = first year energy savings per unit area, cooling (kWh)
- P_c = price of energy, cooling (\$0.08/kWh)
- S_c = economic scalar, cooling (dimensionless)
- ΔFC = incremental first cost for energy conservation measures (dollars)
- S_2 = economic scalar for first costs (dimensionless).

The term "scalar" was borrowed from standard mathematical terminology meaning that it is only a number that has a value or magnitude as opposed to a vector, which has both magnitude and direction. In economic terms, the "scalar" is used in the same manner as uniform present worth factors (UPWF) in LCC analyses. However, there are two fundamental differences used in developing the "scalars" compared to UPWF. First, the fuel escalation rates do not need to be uniform over the economic life; they can change in blocks of time or they can change on an annual basis. Second, the "scalars" also account for the tax implications in that energy costs can be deducted from income when calculating taxes at the federal and state levels. The complete development and sensitivity analyses on "scalars" can be found in McBride (1995). Continuing the incremental economic development Equation 9.1 can be divided by S_2 to yield:

$$FYS_h \times A \times P_h \times \frac{S_h}{S_2} + FYS_c \times A \times P_c \times \frac{S_c}{S_2} \geq \Delta FC \times A \tag{9.2}$$

where

$\frac{S_h}{S_2}$ = economic scalar ratio, heating (dimensionless)

$\frac{S_c}{S_2}$ = economic scalar ratio, cooling (dimensionless).

For purposes of the standard development, the heating and cooling economic scalar ratios were assumed to be equal and simply called scalar ratios (SR). Expanding the first year energy saving terms for both heating and cooling produces:

$$\begin{aligned}&(U_1 - U_2) \times A \times Hcoef \times HDD_{65} \times P_h \times SR + (U_1 - U_2) \times A \\ &\times (Ccoef_1 \times CDD_{50} + Ccoef_2) \times P_c \times SR \geq \Delta FC \times A\end{aligned} \tag{9.3}$$

where

U_1 = reference or base case U-factor (Btu/hr-ft^2-^{o}F)
U_2 = upgraded or improved U-factor (Btu/hr-ft^2-^{o}F)
$Hcoef$ = heating energy savings regression coefficient (Btu/HDD_{65}-ΔU)
HDD_{65} = heating-degree-days to base 65^{o}F
SR = scalar ratio (dimensionless)
$Ccoef_1$ = cooling energy savings regression coefficient (kWh/CDD_{50}-ΔU)
$Ccoef_2$ = cooling energy savings regression constant (kWh/ΔU)
CDD_{50} = cooling-degree-days to base 50^{o}F

Equation 9.3 can be divided by the area, which produces:

$$\begin{aligned}&(U_1 - U_2) \times Hcoef \times HDD_{65} \times P_h \times SR + (U_1 - U_2) \\ &\times (Ccoef_1 \times CDD_{50} + Ccoef_2) \times P_c \times SR \geq \Delta FC\end{aligned} \tag{9.4}$$

The heating and cooling energy savings regression coefficients were derived from extensive analysis of typical or representative buildings in multiple climatic locations using hourly building simulation programs. They are summarized in Table C6.10.3 of Standard 90.1-1999.

The quantity (U_1-U_2) can be divided through Equation 9.4 to produce:

$$Hcoef \times HDD_{65} \times P_h \times SR + (Ccoef_1 \times CDD_{50} + Ccoef_2) \times P_c \times SR \geq \frac{\Delta FC}{(U_1 - U_2)} \tag{9.5}$$

The left-hand side of the Equation 9.5 is set once a class of construction and a specific city is specified along with the SR. Then, the issue is to find the specific construction that satisfies the right-hand side of the equation, which can also be expressed as ΔFC/ΔU or in differential form as dFC/dU. This was accomplished using the list of construction options and first costs that were used to develop Standard 90.1-1999 (see Table 9.4 as a partial example). The complete data base of opaque constructions is presented in Appendix D.

Table 9-4 Roof Criteria for Attic and Other

Roof Criteria: Attic and Other				**R**	**+ R**		
			Display			**Actual**	
I-P Description	**S-I Description**	**Cost**	**U-factor**	**Rval**	**Pos t**	**U-factor**	**dFC/d U**
NR	NR	0	0.6135	0	0	0.6135	0.00
R-13.0	R-2.3	0.23	0.0809	13	0	0.0809	0.43
R-19.0	R-3.3	0.29	0.0528	19	0	0.0528	2.14
R-30.0	R-5.3	0.4	0.0339	30	0	0.0339	5.82
R-38.0	R-6.7	0.5	0.0269	38	0	0.0269	14.29
R-49.0	R-8.6	0.66	0.0210	49	0	0.0210	27.12
R-60.0	R-10.6	0.77	0.0172	60	0	0.0172	28.95
R-71.0	R-12.5	0.9	0.0146	71	0	0.0146	50.00

B. Fenestration Components

The LCC for fenestration is:

$$LCC_i = FC_i \times WWR + FYC_h \times P_h \times SR + FYC_c \times P_c \times SR \tag{9.6}$$

where

LCC_i = life-cycle cost (dollars)
FC_i = first cost of fenestration option (dollars)
WWR = window-to-wall ratio (dimensionless)
FYC_h = first year energy consumption, heating (therms)
$FYCc$ = first year energy consumption, cooling (kWh).

The equations used to predict the energy performance of the fenestration are more complex than those for the non-fenestration construction options. The complete development can be found in Eley and Kolderup (1992). The regression equation used to predict the fenestration heating season energy consumption is:

$$FYC_h = h_0 + h_1 \times HDD_{65} + h_2 \times WWR \times HDD_{65} \times U_i + h_3 \times WWR \times HDD_{65} \times SC_i \qquad (9.7)$$

where

- U_i = U-factor for the i[th] fenestration (Btu/hr-ft^2-^{o}F)
- SC_i = shading coefficient of the i[th] fenestration (dimensionless)
- $h_0, h_1 \ldots h_3$ = coefficients determined through regression analysis.

The regression equation used to predict the fenestration cooling season energy consumption is:

$$\begin{aligned} FYC_h &= c_0 + c_1 \times HDD_{65} + c_2 \times CDD_{50} + c_3 \times WWR \times HDD_{65} \times SC_i \\ &+ c_4 \times WWR \times CDD_{50} \times SC_i + kWh_{\lg ht} \end{aligned} \qquad (9.8)$$

where

- $c_0, c_1 \ldots c_4$ = coefficients determined through regression analysis
- kWh_{lght} = annual electricity used for lighting per square foot of wall area (kWh/yr-ft^2).

The equation for the lighting energy is:

$$kWh_{\lg ht} = \frac{P_L \times H_L \times (1 - K_d)}{1000} \qquad (9.9)$$

where

- P_L = lighting power in the perimeter zone per square foot of wall area (W/ft^2)
- H_L = annual hours of lighting operation with no consideration to daylighting savings (hr/yr)
- K_d = daylight savings fraction from Equation 9.10 (dimensionless).

The daylight savings fraction is:

$$K_d = \left(\varphi_1 + \varphi_2 \times \frac{C}{Tvis_i} \right) \times \left[1 - e^{(\varphi_3 + \varphi_4 \times C) \times WWR \times Tvis_i} \right] \qquad (9.10)$$

where

- $Tvis_i$ = visible light transmission of the i[th] fenestration construction (dimensionless)
- C = design illumination (foot candles)
- $\varphi_1, \ldots \varphi_4$ = coefficients determined through regression analysis.

Equation 9.6 was used to determine the LCC for all of the fenestration options presented in Appendix C for each value of SR for each city. The fenestration option that resulted in the minimum LCC was used as the recommended construction. The complete data base of opaque constructions presented in Appendix D. The complete data base of fenestration options presented in Appendix E.

C. Overall Analysis

Thus, the overall analysis was to select a SR that can then be used in Equations 9.5 and 9.6 to find a specific construction. The construction performance is then used in the regression equations presented in Appendix C to determine the energy use. After the energy use is determined, the total energy savings is calculated for that value of the SR. The SR is then increased, and then the analysis is repeated until the target 30% energy savings is achieved.

Task 5 – Selection of the LCC Metric for Each Climate Zone

The fifth task was to review all of the city results for the various SR by climate zone and select a single SR for each climate zone that would be used to develop the final envelope recommendations for the Guide. The energy savings are presented as percentages from the base case using the average results from the linear regression equations as well as plus and minus one standard deviation (+/- 1SD) from the average. The SD for the regression equations was 2.62% (see Figure 9.2). Miami is the only city in climate zone 1, and it achieved the 30% savings at a SR of 8. Because there are multiple cities in climate zones 2 through 6, each city was analyzed to determine the SR that achieved the 30% savings (see Table 9.5). For example, climate zone 2 has Phoenix and Houston, which achieve the 30% savings at different SR values. Phoenix achieves the 30% savings at a SR of 8, while Houston achieves the 30% savings at a SR of 14. Both cities meet the 30% savings at a SR of 14. However, at a SR of 12, the Phoenix savings is 30% and the Houston savings is 29% on average. Considering that the SD of the linear regression equations is 2.62%, there is some variability as to the actual energy savings. This variability was studied in each climate zone and professional judgment was used to define the SR that would be used to determine the envelope recommendations.

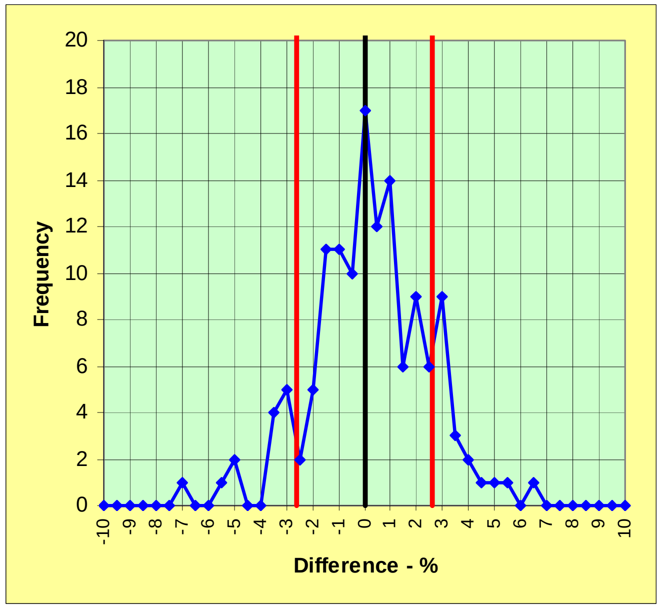

Figure 9-2 Distribution of Total Energy Difference, Regression – DOE-2 (%)
Standard Deviation = 2.62

Table 9-5 Energy Savings by Scalar Ratio

	SR =	8			10			12			14		
CZ	**City**	**-1SD**	**Avg**	**+1SD**	**-1SD**	**Avg**	**+1SD**	**-1SD**	**Avg**	**+1SD**	**-1SD**	**Avg**	**+1SD**
1	Miami	27%	31%	34%	28%	31%	35%	28%	31%	35%	28%	32%	35%
2	Phoenix	26%	30%	33%	28%	31%	35%	28%	31%	35%	29%	32%	36%
2	Houston	24%	27%	31%	24%	27%	31%	26%	29%	32%	27%	30%	34%
3	El Paso	14%	18%	22%	14%	18%	22%	17%	21%	24%	21%	25%	28%
3	Memphis	17%	20%	23%	17%	20%	23%	23%	26%	29%	25%	28%	31%
3	San Fran.	17%	21%	25%	27%	31%	35%	27%	31%	35%	27%	31%	35%
4	Albuquerque	14%	17%	20%	19%	22%	25%	23%	26%	28%	27%	30%	32%
4	Seattle	15%	18%	21%	15%	18%	21%	18%	21%	24%	24%	27%	29%
4	Baltimore	21%	23%	26%	24%	26%	29%	28%	31%	33%	28%	31%	33%
5	Boise	15%	18%	20%	19%	22%	24%	24%	27%	29%	24%	27%	29%
5	Chicago	22%	24%	26%	24%	26%	28%	26%	29%	31%	28%	30%	32%
6	Helena	20%	22%	24%	22%	24%	26%	27%	29%	31%	27%	29%	31%
6	Burlington	20%	22%	24%	25%	27%	29%	27%	29%	31%	29%	31%	33%
7	Duluth	19%	21%	22%	24%	26%	28%	25%	27%	28%	26%	28%	30%
8	Fairbanks	25%	26%	27%	26%	28%	29%	30%	31%	32%	31%	32%	33%

Table 9-6 Energy Savings by Scalar Ratio (Continued)

SR =		16			18			20			22		
CZ	**City**	**-1SD**	**Avg**	**+1SD**	**-1SD**	**Avg**	**+1SD**	**-1SD**	**Avg**	**+1SD**	**-1SD**	**Avg**	**+1SD**
1	Miami	29%	32%	36%	29%	33%	36%	29%	33%	36%	29%	33%	36%
2	Phoenix	31%	34%	38%	31%	34%	38%	32%	35%	38%	32%	36%	39%
2	Houston	29%	32%	35%	29%	32%	36%	30%	33%	37%	30%	33%	37%
3	El Paso	21%	25%	28%	24%	27%	31%	24%	27%	31%	24%	27%	31%
3	Memphis	27%	30%	33%	27%	30%	33%	28%	31%	34%	29%	32%	35%
3	San Fran.	33%	36%	40%	33%	36%	40%	34%	38%	42%	34%	38%	42%
4	Albuquerque	27%	30%	33%	27%	30%	33%	28%	31%	33%	30%	33%	36%
4	Seattle	24%	27%	29%	24%	27%	29%	26%	29%	32%	26%	29%	32%
4	Baltimore	29%	31%	34%	31%	33%	36%	32%	35%	37%	32%	35%	37%
5	Boise	27%	30%	32%	27%	30%	32%	29%	31%	34%	29%	31%	34%
5	Chicago	29%	32%	34%	31%	33%	36%	31%	34%	36%	31%	34%	36%
6	Helena	28%	30%	32%	30%	32%	34%	30%	32%	34%	31%	33%	35%
6	Burlington	29%	31%	33%	31%	33%	35%	32%	34%	35%	33%	35%	36%
7	Duluth	28%	30%	32%	30%	32%	34%	30%	32%	34%	32%	34%	35%
8	Fairbanks	31%	32%	33%	33%	34%	35%	34%	35%	36%	34%	35%	36%

SR =		24			26			28			30		
CZ	**City**	**-1SD**	**Avg**	**+1SD**	**-1SD**	**Avg**	**+1SD**	**-1SD**	**Avg**	**+1SD**	**-1SD**	**Avg**	**+1SD**
1	Miami	30%	33%	37%	30%	33%	37%	30%	33%	37%	30%	33%	37%
2	Phoenix	32%	36%	39%	32%	36%	39%	32%	36%	39%	32%	36%	39%
2	Houston	31%	34%	37%	31%	34%	37%	31%	34%	37%	31%	34%	38%
3	El Paso	25%	29%	33%	26%	29%	33%	26%	29%	33%	26%	29%	33%
3	Memphis	29%	32%	35%	29%	32%	35%	29%	32%	35%	30%	34%	37%
3	San Fran.	34%	38%	42%	36%	39%	43%	38%	41%	45%	38%	41%	45%
4	Albuquerque	30%	33%	36%	30%	33%	36%	30%	33%	36%	31%	34%	36%
4	Seattle	28%	31%	34%	29%	32%	34%	29%	32%	34%	29%	32%	34%
4	Baltimore	32%	35%	37%	32%	35%	37%	32%	35%	37%	34%	37%	39%
5	Boise	29%	31%	34%	30%	32%	35%	32%	34%	37%	32%	34%	37%
5	Chicago	32%	34%	37%	33%	35%	37%	34%	36%	39%	35%	37%	39%
6	Helena	32%	34%	36%	34%	36%	38%	34%	36%	38%	34%	36%	38%
6	Burlington	33%	35%	36%	34%	36%	38%	34%	36%	38%	34%	36%	38%
7	Duluth	32%	34%	36%	33%	34%	36%	33%	35%	37%	33%	35%	37%
8	Fairbanks	34%	35%	37%	34%	35%	37%	34%	36%	37%	34%	36%	37%

Table 9.6 presents a summary of the SR for each city, as well as the final SR used to develop the envelope recommendations. There are three cities in both climate zones 3 and 4, which further added to the difficulty in selecting a single SR that would achieve the 30% energy savings. El Paso did not achieve the 30% savings on average at any SR value. At a SR of 26, the energy savings reached their maximum values.

Table 9-7 Summary of SR and Final Values

CZ	City	-1 SD	AVG	+1 SD	Final
1	Miami	24	8	8	8
2	Phoenix	16	8	8	12
2	Houston	20	14	8	12
3	El Paso	30	26	18	18
3	Memphis	30	16	14	18
3	San Francisco	16	10	10	18
4	Albuquerque	22	16	14	20
4	Seattle	30	24	20	20
4	Baltimore	18	12	12	20
5	Boise	26	16	16	16
5	Chicago	18	14	12	16
6	Helena	18	16	12	14
6	Burlington	18	14	12	14
7	Duluth	18	16	14	16
8	Fairbanks	12	12	12	12

Task 6 – Final Verification of the Envelope Measures

Once the final SR values were identified for each climate zone, all envelope recommendations were then determined. The final table of envelope recommendations and the collective energy savings of all the measures are presented in Section 10.

10.0 FINAL RECOMMENDATIONS AND ENERGY SAVINGS RESULTS

This section contains the final recommendations approved by the project committee for AEDG-SR, as well as the energy savings results that are achieved as a result of applying these recommendations to the prototype buildings. The recommendations are applicable for all small retail buildings within the scope of the Guide as a means of demonstrating the 30% energy savings. The Guide recognizes that there are other ways of achieving the 30% energy savings, and offers these recommendations as "*a way, but not the only way*" of meeting the energy savings target. When a recommendation contains the designation "NR", then the Guide is providing no recommendation for this component or system. In these cases, the requirements of Standard 90.1-1999 or the local code (whichever is more stringent) will apply.

10.1 Final Energy Savings Recommendations

This section describes the final energy savings recommendations in the AEDG-SR. The recommendations are grouped into envelope measures, lighting and daylighting measures, and HVAC and SWH measures.

10.1.1 Envelope Measures

The envelope measures cover the range of assemblies for both the opaque and fenestration portions of the building. Opaque elements include the roof, walls, floors and slabs, as well as opaque doors. Fenestration elements include the vertical glazing (including doors) and skylights. For each building element, there are a number of components for which the Guide presents recommendations. In some cases, these components represent an assembly, such as an attic or a steel-framed wall, and in other cases, the components may relate to the allowable area, such as the window-to-wall ratio for the building.

Recommendations for each envelope component are contained in Table 10-1, and are organized by climate zone, ranging from the hot zone 1 to the cold zone 8. Consistent with the movement from the hotter to colder zones, the insulation requirements (R-value) increase as the climates get colder, and corresponding thermal transmittance (U-factor) decreases. Control of solar loads is more critical in the hotter, sunnier climates, and thus the solar heat gain coefficient tends to be more stringent (lower) in zone 1 and higher in zone 8. The exception to this is the case of vertical glazing, where the SHGC is relatively uniform across all zones. This is because of the need for clear glazing on storefronts to increase visibility of the merchandise within the store.

In several additional cases, the recommendations are constant across all climate zones, which suggests an insensitivity to climate. The recommendations for both the maximum window-to-wall area and the maximum skylight area demonstrate this. These areas are limited to reduce overall energy use regardless of the climate.

Table 10-1 AEDG-SR Final Energy Savings Recommendations – Building Envelope

Item	Component	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
Roof	Insulation entirely above deck	R-15 c.i.	R-15 c.i.	R-20 c.i.	R-20 c.i.	R-20 c.i.	R-20 c.i.	R-25 c.i.	R-25 c.i.
	Metal building	R-19	R-19	R-13 + R-19	R-13 + R-19	R-13 + R-19	R-13 + R-19	R-16 + R-19	R-16 + R-19
	Attic and other	R-30	R-38	R-38	R-38	R-38	R-38	R-60	R-60
	Single rafter	R-30	R-38	R-38 + R-5 c.i.	R-38 + R-5 c.i.	R-38 + R-5 c.i.	R-38 + R-5 c.i.	R-38 + R-10 c.i.	R-38 + R-10 c.i.
	Solar reflectance index	78	78	78	NR	NR	NR	NR	NR
Walls	Mass (HC > 7 Btu/ft2)	NR	R-7.6 c.i.	R-11.4 c.i.	R-13.3 c.i.	R-13.3 c.i.	R-13.3 c.i.	R-15.2 c.i.	R-15.2 c.i.
	Metal building	R-13	R-13	R-13 + R-13	R-13 + R-13	R-13 + R-13	R-13 + R-13	R-13 + R-13	R-13 + R-13
	Steel framed	R-13	R-13	R-13 + R-7.5 c.i.	R-13 + R-7.5 c.i.	R-13 +R-7.5 c.i.	R-13 + R-7.5 c.i.	R-13 + R-7.5 c.i.	R-13 +R-10 c.i.
	Wood framed and other	R-13	R-13	R-13	R-13 + R-3.8 c.i.	R-13 + R-7.5 c.i.	R-13 + R-7.5 c.i.	R-13 + R-7.5 c.i.	R-13 + R-7.5 c.i.
	Below-grade walls	NR	NR	NR	R-7.5 c.i.	R-7.5 c.i.	R-7.5 c.i.	R-7.5 c.i.	R-7.5 c.i.
Floors	Mass	R-4.2 c.i.	R-6.3 c.i.	R-10.4 c.i.	R-12.5 c.i.	R-12.5 c.i.	R-12.5 c.i.	R-14.6 c.i.	R-14.6 c.i.
	Steel framed	R-19	R-19	R-30	R-30	R-30	R-30	R-38	R-38
	Wood framed and other	R-19	R-19	R-30	R-30	R-30	R-30	R-30	R-30
Slabs	Unheated	NR	NR	NR	NR	R-10 for 24 in.	R-10 for 24 in.	R-15 for 24 in.	R-15 for 24 in.
	Heated	R-7.5 for 12 in.	R-7.5 for 12 in.	R-7.5 for 12 in.	R-7.5 for 12 in.	R-10 Full Slab	R-10 Full Slab	R-15 Full slab	R-15 Full slab
Doors Opaque	Swinging	U-0.70	U-0.70	U-0.70	U-0.50	U-0.50	U-0.50	U-0.50	U-0.50
	Non-swinging	U-1.45	U-1.45	U-0.50	U-0.50	U-0.50	U-0.50	U-0.50	U-0.50
Vertical glazing including doors	Area (percent of gross wall)	40%	40%	40%	40%	40%	40%	40%	40%
	Thermal transmittance	U-0.69	U-0.49	U-0.41	U-0.38	U-0.38	U-0.38	U-0.38	U-0.38
	Solar heat gain coefficient (SHGC)	0.44	0.40	0.41	0.41	0.41	0.41	0.41	0.41
	Exterior sun control (S, E, W only)	Projection factor > 0.5	Projection factor > 0.5	Projection factor > 0.5	Projection factor > 0.5	Projection factor > 0.5	Projection factor > 0.5	Projection factor > 0.5	Projection factor > 0.5
Skylights	Area (percent of gross roof)	3%	3%	3%	3%	3%	3%	3%	3%
	Thermal transmittance	U-1.36	U-1.36	U-0.69	U-0.69	U-0.69	U-069	U-0.69	U-0.58
	Solar heat gain coefficient (SHGC)	0.19	0.19	0.16	0.32	0.36	0.46	0.64	0.64

10.1.2 Lighting and Daylighting Measures

For lighting and daylighting, the measures are not climate dependent. As such, the same recommendation is provided for each of the climate zones. Recommendations are provided for interior lighting (including additional light power allowances and daylighting), as well as exterior lighting, in Table 10-2.

Table 10-2 AEDG-SR Final Energy Savings Recommendations – Lighting

Item	Component	Zones 1-8
Interior Lighting	Lighting power density (LPD)	1.3 W/ft^2
	Linear fluorescent with high-performance electronic ballast	91 mean lumens/watt
	All other sources	50 mean lumens/watt
	Dimming controls for daylight harvesting under skylights	Dim fixtures within 10 ft of skylight edge
	Occupancy controls	Auto-off all non-sales rooms
	Interior room surface reflectances	80%+ on ceilings, 70%+ on walls in locations with daylighting
Additional Interior Lighting for Sales Floor	Additional LPD for adjustable lighting equipment that is specifically designed and directed to highlight merchandise and is automatically controlled separately from the general lighting	0.4 W/ft^2 (spaces not listed below) 0.6 W/ft^2 (sporting goods, small electronics) 0.9 W/ft^2 (furniture, clothing, cosmetics, and artwork) 1.5 W/ft^2 (jewelry, crystal, china)
	Sources	Halogen IR or ceramic metal halide
Exterior Lighting	Facade and externally illuminated signage lighting	0.2 W/ft^2

Interior lighting recommendations include a maximum lighting power density for general lighting, as well as additional lighting power allowances for accent lighting to enhance and highlight certain types of merchandise. Use of the additional lighting power allowances is limited to the merchandising areas for the merchandise indicated, and accent lighting must have separate controls from the general lighting. Additional recommendations cover the minimum performance of the light sources and ballasts (minimum mean lumens/watt) as well as the minimum technology for use in accent lighting (halogen infrared or ceramic metal halide). Occupancy and daylighting control recommendations are provided, as well as recommendations for surface reflectance values to enhance daylighting.

Exterior lighting recommendations include a maximum LPD for facade lighting, as well as illuminated signage.

10.1.3 HVAC and SWH Measures

HVAC measures include recommendations for minimum heating and cooling equipment efficiencies for both residential and commercial products because both of these types of products are used in small retail applications. The cooling equipment efficiencies are expressed in seasonal energy efficiency ratios (SEER) for residential products and energy efficiency ratios (EER) for commercial products. Additionally, commercial cooling products have integrated part load values (IPLV) that express their performance during part load operation. Heating equipment efficiencies for residential products are expressed as annual fuel utilization efficiencies (AFUE) for gas furnaces and heating season performance factors (HSPF) for heat pumps. Heating efficiencies for commercial products are expressed as thermal efficiencies (E_t) and combustion efficiencies (E_c) for furnaces and coefficients of performance (COP) for heat pumps.

Cooling equipment efficiencies generally are higher in the hotter climates and lower in the colder climates for commercial products. For residential products, the efficiencies are constant across the climate zones because the efficiencies were set by the project committee at the highest level for which there were available products from multiple manufacturers. These levels have been adopted by federal law as the minimum mandatory manufacturing standards.

Heating equipment efficiencies generally are higher in colder climates, where higher equipment efficiencies are available from multiple manufacturers. For residential heat pumps, the efficiencies are constant across the zones for the reasons noted in the paragraph above. For single package (SP) unitary equipment, the heating efficiencies are constant across climates because higher efficiency equipment is not available from multiple manufacturers. For residential-sized gas furnaces in split systems, the heating efficiencies increase in the colder climates because the product is available at the higher efficiency levels from multiple manufacturers.

Table 10-3 AEDG-SR Final Energy Savings Recommendations – HVAC and SWH

Item	Component	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
HVAC	Air conditioner (0-65 KBtuh)	13.0 SEER	13.0 SEER	13.0 SEER	13.0 SEER	13.0 SEER	13.0 SEER	13.0 SEER	13.0 SEER
	Air conditioner (>65-135 KBtuh)	11.3 EER 11.5 IPLV	11.3 EER 11.5 IPLV	11.0 EER 11.4 IPLV	11.0 EER 11.4 IPLV	11.0 EER 11.4 IPLV	NR	NR	NR
	Air conditioner (>135-240 KBtuh)	11.0 EER 11.5 IPLV	11.0 EER 11.5 IPLV	10.8 EER 11.2 IPLV	10.8 EER 11.2 IPLV	10.8 EER 11.2 IPLV	NR	NR	NR
	Air conditioner (>240 KBtuh)	10.6 EER 11.2 IPLV	10.6 EER 11.2 IPLV	10.0 EER 10.4 IPLV	10.0 EER 10.4 IPLV	10.0 EER 10.4 IPLV	NR	NR	NR
	Gas furnace (0-225 KBtuh - SP)	80% AFUE or Et	80% AFUE or Et	80% AFUE or Et	80% AFUE or Et	80% AFUE or Et	80% AFUE or Et	80% AFUE or Et	80% AFUE or Et
	Gas furnace (0-225 KBtuh - Split)	80% AFUE or Et	80% AFUE or Et	80% AFUE or Et	80% AFUE or Et	90% AFUE or Et	90% AFUE or Et	90% AFUE or Et	90% AFUE or Et
	Gas furnace (>225 KBtuh)	80% Ec	80% Ec	80% Ec	80% Ec	80% Ec	80% Ec	80% Ec	80% Ec
	Heat pump (0-65 KBtuh)	13.0 SEER 7.7 HSPF	13.0 SEER 7.7 HSPF	13.0 SEER 7.7 HSPF	13.0 SEER 7.7 HSPF	13.0 SEER 7.7 HSPF	13.0 SEER 7.7 HSPF	13.0 SEER 7.7 HSPF	13.0 SEER 7.7 HSPF
	Heat pump (>65-135 KBtuh)	10.6 EER 11.0 IPLV 3.2 COP	10.6 EER 11.0 IPLV 3.2 COP	10.6 EER 11.0 IPLV 3.2 COP	10.6 EER 11.0 IPLV 3.2 COP	10.6 EER 11.0 IPLV 3.2 COP	NR	NR	NR
	Heat pump (>135 KBtuh)	10.1 EER 11.5 IPLV 3.1 COP	10.1 EER 11.5 IPLV 3.1 COP	10.1 EER 11.0 IPLV 3.1 COP	10.1 EER 11.0 IPLV 3.1 COP	10.1 EER 11.0 IPLV 3.1 COP	NR	NR	NR
Economizer	Air conditioners & heat pumps-SP	NR	NR	Cooling capacity > 54 KBtuh	Cooling capacity > 54 KBtuh	Cooling capacity > 54 KBtuh	Cooling capacity > 54 KBtuh	NR	NR
Ventilation	Outdoor air damper	Motorized control	Motorized control	Motorized control	Motorized control	Motorized control	Motorized control	Motorized control	Motorized control
	Demand control	CO_2 sensors	CO_2 sensors	CO_2 sensors	CO_2 sensors	CO_2 sensors	CO_2 sensors	CO_2 sensors	CO_2 sensors
Ducts	Friction rate	0.08 in. w.c./100 feet	0.08 in. w.c./100 feet	0.08 in. w.c./100 feet	0.08 in. w.c./100 feet	0.08 in. w.c./100 feet	0.08 in. w.c./100 feet	0.08 in. w.c./100 feet	0.08 in. w.c./100 feet
	Sealing	Seal class B	Seal class B	Seal class B	Seal class B	Seal class B	Seal class B	Seal class B	Seal class B
	Location	Interior only	Interior only	Interior only	Interior only	Interior only	Interior only	Interior only	Interior only
	Insulation level	R-6	R-6	R-6	R-6	R-6	R-6	R-6	R-8
Service Water Heating	Gas storage (> 75KBtuh)	90% Et	90% Et	90% Et	90% Et	90% Et	90% Et	90% Et	90% Et
	Gas Instantaneous	0.81 EF or 81% Et	0.81 EF or 81% Et	0.81 EF or 81% Et	0.81 EF or 81% Et	0.81 EF or 81% Et	0.81 EF or 81% Et	0.81 EF or 81% Et	0.81 EF or 81% Et
	Electric storage (≤12 kW and > 20 gal)	EF > 0.99 – 0.0012xVolume	EF > 0.99 – 0.0012xVolume	EF > 0.99 – 0.0012xVolume	EF > 0.99 – 0.0012xVolume	EF > 0.99 – 0.0012xVolume	EF > 0.99 – 0.0012xVolume	EF > 0.99 – 0.0012xVolume	EF > 0.99 – 0.0012xVolume
	Pipe insulation (d<1½ in./ d≥1½ in.)	1 in./ 1½ in.	1 in./ 1½ in.	1 in./ 1½ in.	1 in./ 1½ in.	1 in./ 1½ in.	1 in./ 1½ in.	1 in./ 1½ in.	1 in./ 1½ in.

HVAC measures also include system recommendations, such as lowering the capacity threshold for economizers to 54,000 Btu/hr for climate zones 3 through 6, providing motorized dampers to control the introduction of outdoor air during off hours, and recommendations for the design, sealing, and location of ductwork. Only the economizer recommendations are climate dependent.

SWH measures include recommendations for the use of instantaneous water heaters for fuel-fired applications and enhanced efficiencies for storage applications. In addition, recommendations are provided for enhanced pipe insulation values.

10.2 Energy Savings Results

Once the project committee determined the final recommendations, the prototype small retail buildings were simulated in each of the 15 climate locations to determine if the 30% energy savings goal was achieved. Results of these simulations are provided in Figures 10-1 and 10-2 for the strip mall prototype and in Figures 10-3 and 10-4 for the standalone prototype. In all cases the savings are relative to the baseline energy use from Standard 90.1-1999. For each prototype building, results are presented for both the case of whole building energy use with plug loads included in the denominator and the case of whole building energy use without the plug loads included in the denominator (as the committee considers the savings). Regardless of the method used for presenting the results, both the strip mall and standalone building prototypes met the 30% savings goal in all climates.
The strip mall prototype performs better than the standalone prototype for several reasons. First, the strip mall included two stores that utilized accent lighting, and accent lighting recommendations for the Guide were fairly aggressive. This results in greater savings for stores with accent lighting versus stores with general lighting. In addition, the economizer recommendations in the Guide impacted the strip mall more than the standalone in certain climates because the larger standalone building already had economizer requirements from the Standard as a result of the larger cooling equipment in that building.

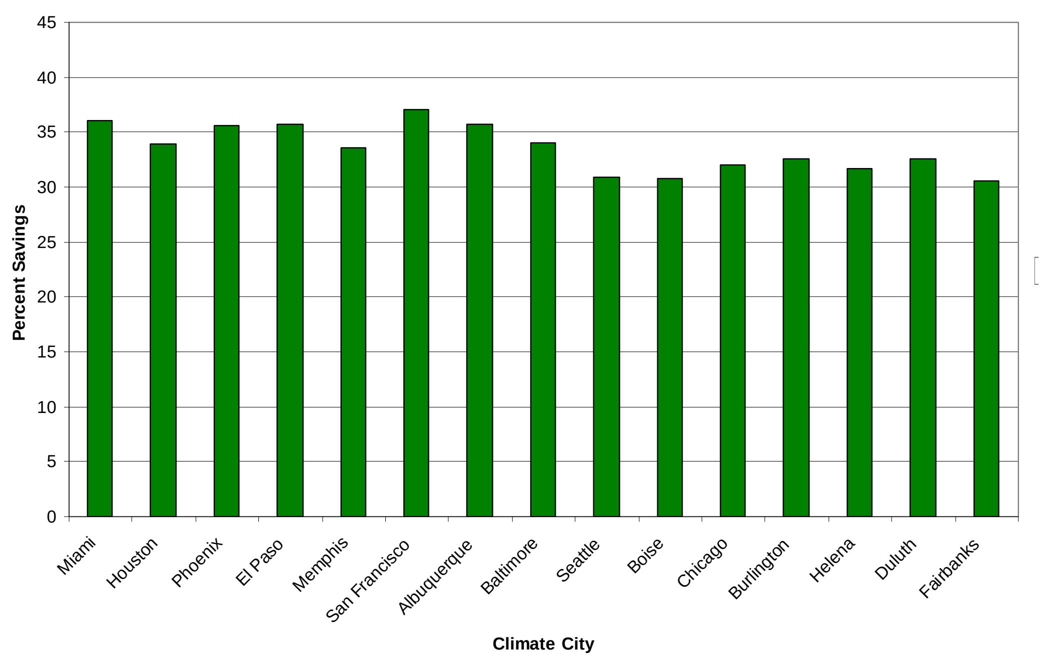

Figure 10-1 Strip Mall Energy Savings (plugs in denominator)

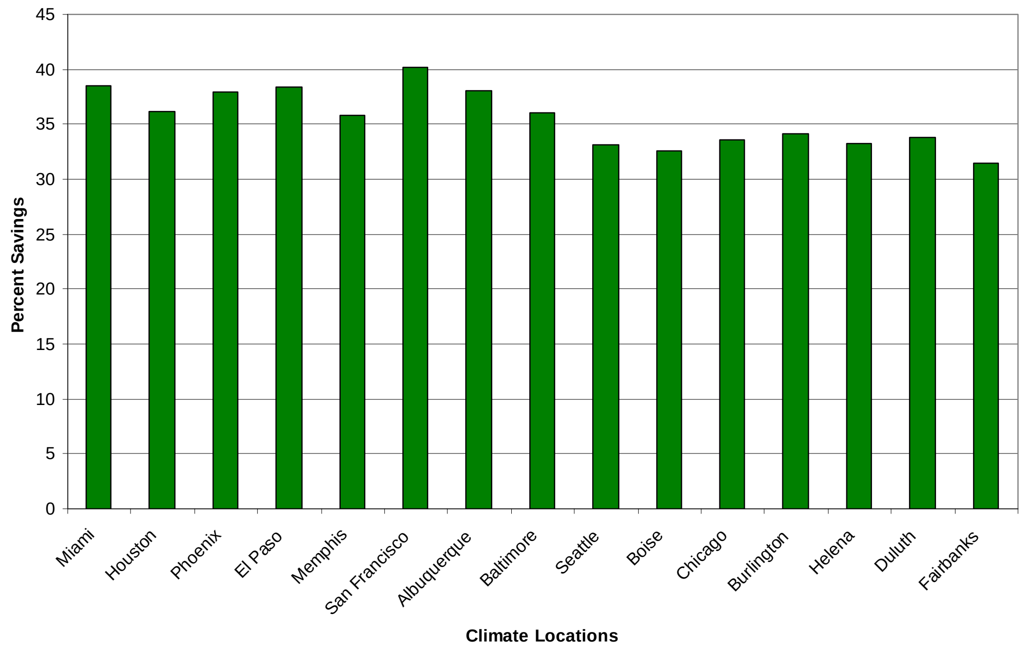

Figure 10-2 Strip Mall Energy Savings (plugs not in denominator)

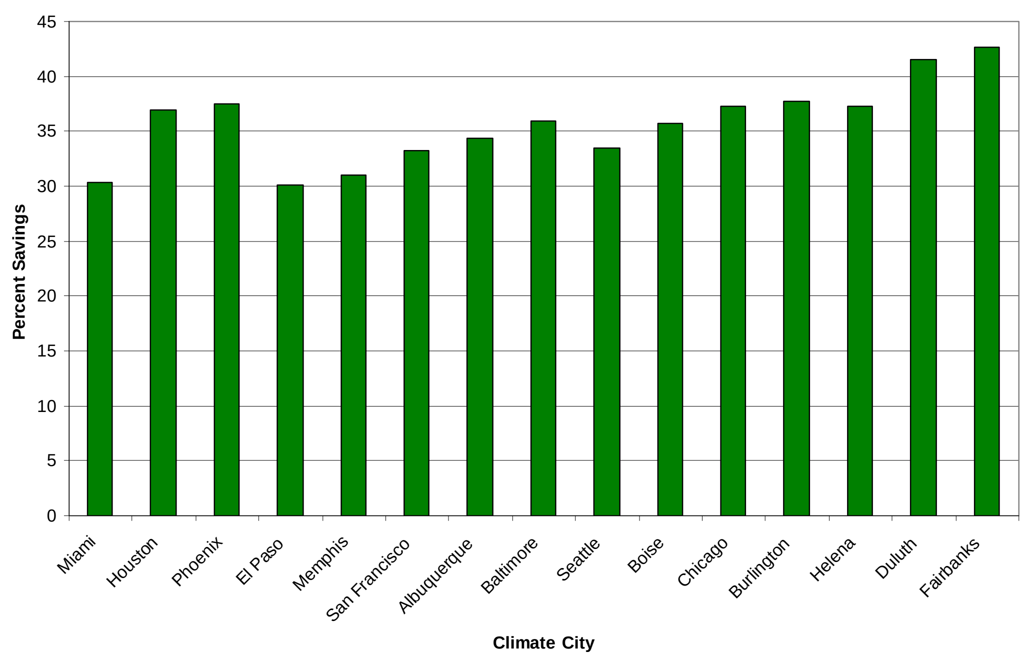

Figure 10-3 Standalone Energy Savings (plugs in denominator)

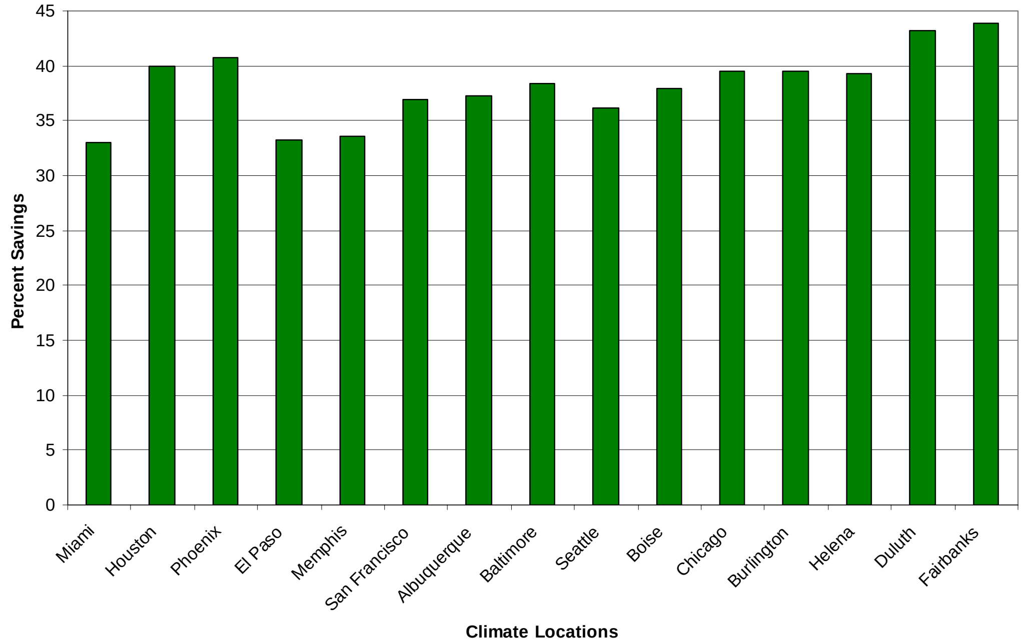

Figure 10-4 Standalone Energy Savings (plugs not in denominator)

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APPENDIX A

Simulation Input Assumptions for Scoping Study

APPENDIX A – Simulation Input Assumptions for Scoping Study

Table A-1 Strip Mall Small Retail Energy Modeling Assumptions – Key Inputs Consistent by Climate Changes

Characteristic		Baseline Model	AEDG Model	Data Source/Remarks
General				
	Building Type	3 Tenant Strip Mall	Same	
	Gross Floor Area	7,500 sq. ft. total (100 ft x 75 ft) Store 1: 3,750 sq. ft. (50 ft x 75 ft) Store 2: 1,875 sq. ft. (25 ft x 75 ft) Store 3: 1,875 sq. ft. (25 ft x 75 ft)	Same	Committee inputs
	Operation Hours	Varies by store and day of week Store 1: Su-T 10 am – 11 pm F-S 10 am – 12 am Store 2: M-F 9 am – 8 pm S 9 am – 6 pm Su 10 am – 5 pm Store 3: M-F 10 am – 8 pm S 10 am – 6 pm Su 11 am 5 pm	Same	Representative retail store operation hours verified by field survey.
Architectural Features				
	Configuration/Shape			
	Aspect Ratio	Overall building 1.33 to 1 Store 1: 1.5 to1 Store 2: 3 to 1 Store 3: 3 to 1	Same	
	Zoning	1 zone per store	Same	
	Number of Floors	1	Same	
	Window-to-Wall Ratio	70% on street-facing exterior wall (equivalent to 20% of the entire building)	Same	
	Floor-to-Ceiling Height:	11 ft	Same	General practice
	Floor-to-Floor Height:	14 ft	Same	General practice

Characteristic	Baseline Model	AEDG Model	Data Source/Remarks
Infiltration Rate	- 0.038 cfm/sf of the gross exterior walls	Same	ASHRAE 90.1-1989 (ASHRAE/IESNA 1989) Section 13.7.3.2
Infiltration Schedule	Varies by store based on fan schedule	Same	Off when the HVAC fan is on
Exterior Walls			
Structure	2x4 steel stud walls, 16 in. o.c.	Same	Committee inputs
Exterior Finish	Stucco over insulation and OSB	Same	
Insulation	Varies by climate locations. See Appendix A Table A-2		Base: ASHRAE 90.1-1999 AEDG: *AEDG for Small Office*
Overall U-factor	Varies by climate locations. See Appendix A Table A-2		ASHRAE 90.1-1999 Table A-10
Roof			
Structure	Steel deck with rigid insulation	Same	Committee inputs
Exterior Finish	Single-ply roof membrane	Same	
Insulation	Varies by climate locations. See Appendix A Table A-2		Base: ASHRAE 90.1-1999 AEDG: *AEDG for Small Office*
Overall U-factor	Varies by climate locations. See Appendix A Table A-2		ASHRAE 90.1-1999 Table A-1
Emissivity	Varies by climate locations. See Appendix A Table A-2		Base: Grey single-ply membranes (Eilert.P. 2000) AEDG: *AEDG-SO*
Solar Reflectance	Varies by climate locations. See Appendix A Table A-2		
Slab-On-Grade Floor			
Floor Insulation	Varies by climate locations. See Appendix A Table A-2		Base: ASHRAE 90.1-1999 AEDG: *AEDG for Small Office*
Floor F-factor	Varies by climate locations. See Appendix A Table A-2		ASHRAE 90.1-1999 Table A-16
Fenestration/Windows			
Window Type	Single-pane clear w/alum. frame	Double-pane clear low-e	
Total U-factor	Varies by climate locations. See Appendix A Table A-2		Base: ASHRAE 90.1-1999 AEDG: *AEDG-SO*
SHGC	Varies by climate locations. See Appendix A Table A-2		

Characteristic		Baseline Model	AEDG Model	Data Source/Remarks
	Actual DOE-2 Glazing Input	Varies by climate locations. See Appendix A Table A-2		
	Window Shading/Overhangs	PF = 0.5 (5 ft depth overhang)	Same	Base: 90.1-1999 (C) Exception to 5.5.4.3
	Opaque Doors			
	Total U-factor	Varies by climate locations. See Appendix A Table A-2		Base: ASHRAE 90.1-1999 Table B-2 AEDG: *AEDG-SO*
Building Internal Loads				
	Occupancy			
	Number of Occupancy	30 P/1000 ft² of net occupied space (NOS); assume 50% NOS Store 1: max. 56 people Store 2: max. 28 people Store 3: max. 28 people	Same	Committee Inputs ASHRAE Standard 62-2001 (ANSI/ASHRAE 2001)
	Occupancy Schedule	Varies by stores See Appendix A Table A-3	Same	
	People Sensible Heat Gain	250 Btu/hr-person	Same	ASHRAE 2005 Fundamentals Chapter 30.4 Table 1
	People Latent Heat Gain	200 Btu/hr-person	Same	
	Lighting			
	Light Source	General: standard T-8s w/ electronic ballasts Accent: halogen incandescent Store 1: 100% general Store 2: 75% general+25% accent Store 3: 50% general+50% accent	General: high performance T-8s w/ 2nd generation electronic ballast Accent: ceramic metal halide Store 1: 100% general Store 2: 75% general+25% accent Store 3: 50% general+50% accent	Base: General practice AEDG: Committee inputs
	Peak Lighting Power, w/sf	Store 1: 2.94 w/sf Store 2: 2.94 w/sf Store 3: 3.75 w/sf	Store 1: 1.74 w/sf Store 2: 1.71 w/sf Store 3: 2.55 w/sf	Base: ASHRAE 90.1-1999 AEDG: Committee inputs
	Lighting Schedule	Varies by stores See Appendix A Table A-3	Same	Base: AEDG: - Based on committee input, lighting schedule is modified to match the average energy savings
	Occupancy Sensors	No	Same	
	Daylighting Responsive Lighting Control	No	Same	AEDG: Committee inputs

Characteristic		Baseline Model	AEDG Model	Data Source/Remarks
	Skylights	No	Same	
	Office Equipment			
	Equipment Schedule	Varies by stores See Appendix A Table A-3	Same	
	Peak Load, w/sf	0.4 w/sf of gross floor area	Same	From the previous energy analysis work for the *Commercial Unitary Air Conditioners Appliance Standard Rulemaking*
HVAC System				
	HVAC System Type	Single-package rooftop unit w/ constant air volume, electric DX cooling with gas-fired furnace	Same	Committee inputs
	Number of Thermal Zones	1 HVAC comfort zones per store	Same	
	Number of HVAC Units	3 (serving 3 stores)	Same	
	Space T-stat Set Point	75°F cooling / 70°F heating	Same	
	Space T-stat Setback/Setup	80°F cooling / 65°F heating	Same	
	Cooing Equip Efficiency	SEER = 9.7 EER = 8.7 (5-ton unit)	SEER = 13.0 EER = 11.3 (5-ton unit)	Base: ASHRAE 90.1-1999 Table 6.2.1B AEDG: *AEDG –SO*
	Heating Equip Efficiency	E_t = 74%	E_t = 80%	Base: ASHRAE 90.1-1999 Table 6.2.1E AEDG: *AEDG-SO*
	Outside Air Supply	- 0.30 cfm/sf for 80% retail area - 0.15 cfm/sf for 20% storage area - Average 0.27 cfm/sf	Same	Committee & ASHRAE Standard 62-2001 Table 2
	Ventilation Control Mode	Outside air damper remains open at minimum position during unoccupied periods	Outside air damper automatically shut off during unoccupied periods	Base: Outside air damper control is not required for 2-story buildings and below by ASHRAE 90.1-1999. AEDG: *AEDG for Small Office* zone 1
	Return Air Path	Ducted	Same	
	Duct Losses	None	Same	
	Economizer	No	Varies by climate locations. See Appendix A Table A-2	Base: ASHRAE 90.1-1999 AEDG: *AEDG for Small Office*
	Design Supply Air	Minimum 0.5 cfm/sf	Minimum 0.5 cfm/sf	General practice: provides a minimum acceptable air turnover rate for zones
	Air-to-Air ERV	None	Same	

Characteristic	Baseline Model	AEDG Model	Data Source/Remarks
Fan Static Pressure	Store 1: 1.25 in. w.c. Store 2: 1.0 in. w.c. Store 3: 1.0 in. w.c.	Store 1: Same Store 2: Same Store 3: Same	Committee inputs
Fan Schedule	Varies by store 1 hour before and after the occupancy schedule	Same	
Service Water Heating			
Water Heater Type	Gas storage water heater	Gas instantaneous water heater	
Tank Capacity, gallon	40	0	General design practice
Supply Temperature, °F	120	120	General design practice
Hot Water Demand, daily	1.0 gal/person/day	1.0 gal/person/day	ASHRAE 2003 HVAC Applications Handbook Chapter 49.11 Table 6
SWH Efficiency	E_t = 78.4%	E_t =81.0 %	Base: - ASHRAE 90.1-1999 Table 7.2.2 - UA calculated based on standby loss in Table 7.2.2 of ASHRAE 90.1-1999 and 68°F temperature difference AEDG: - Instantaneous direct vent gas water heater - *AEDG for Small Office* zone 1
Tank UA, Btu/hr-F	14.04	0.0	
SHW Schedule	Corresponding to Store 1 Occ Sch	Same	General design practice

Table A-2 Strip Mall Small Retail Energy Modeling Assumptions – Key Inputs Varied by Climate Changes

Characteristic	Miami, FL		Phoenix, AZ		Seattle, WA		Duluth, MN	
	Baseline Model	Advance Model	Baseline Model	Advance Model	Baseline Model	Advance Model	Baseline Model	Advance Model
Architectural Features								
Exterior Walls								
Insulation	R-13.0 cavity	Same	R-13.0 cavity	Same	R-13 cavity	R-13 + R-7.5 ci	R-13 + R-7.5 ci	Same
Overall U-factor	0.124	Same	0.124	Same	0.124	0.064	0.064	Same
Roof								
Insulation	R-15.0 ci	Same	R-15.0 ci	Same	R-15 ci	R-20 ci	R-15 ci	R-20 ci
Overall U-factor	0.063	Same	0.063	Same	0.063	0.048	0.063	0.048
Emissivity	0.87	0.86	0.87	0.86	0.87	Same	0.87	Same
Solar Reflectance	0.23 (grey EPDM)	0.65 (white T-EPDM)	0.23 (grey EPDM)	0.65 (white T-EPDM)	0.23 (grey EPDM)	Same	0.23 (grey EPDM)	Same
Slab-On-Grade Floor								
Floor Insulation	None	Same	None	Same	None	Same	None	R-15 for 24 in. rigid insulation
Floor F-factor	0.73	Same	0.73	Same	0.73	Same	0.73	0.52
Fenestration/Windows								
Window Type					Double-pane clear w/alum. frame	Double-pane low-e clear	Double-pane clear w/alum. frame	Double-pane low-e clear
Total U-factor	1.22	0.56	1.22	0.45	0.57	0.42	0.57	0.33
SHGC	No requirement	0.35	No requirement	0.31	No requirement	0.46	No requirement	0.49
Actual DOE-2 Glazing Input	Glazing Code = 1000 U=1.11; SHGC = 0.86	Glazing Code = 2660 U=0.42; SHGC = 0.44	Glazing Code = 1000 U=1.11; SHGC = 0.86	Glazing Code = 2660 U=0.42; SHGC = 0.44	Glazing Code = 2000 U=0.57; SHGC = 0.76	Glazing Code = 2660 U=0.42; SHGC = 0.44	Glazing Code = 2000 U=0.57; SHGC = 0.76	Glazing Code = 2661 U=0.30; SHGC = 0.44
Opaque Doors								

Characteristic		Miami, FL		Phoenix, AZ		Seattle, WA		Duluth, MN	
		Baseline Model	Advance Model	Baseline Model	Advance Model	Baseline Model	Advance Model	Baseline Model	Advance Model
	Total U-factor	0.70	Same	0.70	Same	0.70	Same	0.70	0.50
HVAC System									
	Economizer	No	Same	No	Same	No	Yes	No	Same

Table A-3 AEDG Small Retail Energy Modeling Internal Load Schedules

Store 1 - Blockbuster

		1 12-1a	**3** 2-3a	**4** 3-4a	**5** 4-5a	**6** 5-6a	**7** 6-7a	**8** 7-8a	**9** 8-9a	**10** 9-10a	**11** 10-11a	**12** 11-12p	**13** 12-1p	**14** 1-2p	**15** 2-3p	**16** 3-4p	**17** 4-5p	**18** 5-6p	**19** 6-7p	**20** 7-8p	**21** 8-9p	**22** 9-10p	**23** 10-11p	**24** 11-12a
Lights	**M-Th**	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.50
	F-S	0.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
	Su	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.50
Plugs	**M-Th**	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.50
	F-S	0.50	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	Su	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.50
Occ	**M-Th**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.20	0.40	0.40	0.25	0.25	0.50	0.50	0.50	0.30	0.30	0.30	0.20	0.05
	F-S	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.20	0.40	0.60	0.40	0.40	0.70	0.70	0.70	0.60	0.40	0.40	0.30	0.30
	Su	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.20	0.40	0.60	0.40	0.40	0.30	0.60	0.60	0.40	0.40	0.30	0.20	0.05

Table A-3 AEDG Small Retail Energy Modeling Internal Load Schedules (continued)

Store 2 – Radio Shack

		1 12-1a	**3** 2-3a	**4** 3-4a	**5** 4-5a	**6** 5-6a	**7** 6-7a	**8** 7-8a	**9** 8-9a	**10** 9-10a	**11** 10-11a	**12** 11-12p	**13** 12-1p	**14** 1-2p	**15** 2-3p	**16** 3-4p	**17** 4-5p	**18** 5-6p	**19** 6-7p	**20** 7-8p	**21** 8-9p	**22** 9-10p	**23** 10-11p	**24** 11-12a
Lights	**M-F**	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.50	0.05	0.05	0.05
	S	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.50	0.05	0.05	0.05	0.05	0.05
	Su	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.50	0.05	0.05	0.05	0.05	0.05	0.05
Plugs	**M-F**	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.50	0.05	0.05	0.05
	S	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.50	0.05	0.05	0.05	0.05	0.05
	Su	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.50	0.05	0.05	0.05	0.05	0.05	0.05
Occ	**M-F**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.10	0.20	0.40	0.30	0.20	0.20	0.50	0.50	0.50	0.20	0.05	0.00	0.00	0.00
	S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.10	0.20	0.40	0.60	0.40	0.30	0.40	0.30	0.05	0.00	0.00	0.00	0.00	0.00
	Su	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.10	0.20	0.40	0.40	0.30	0.20	0.10	0.05	0.00	0.00	0.00	0.00	0.00	0.00

Table A-3 AEDG Small Retail Energy Modeling Internal Load Schedules (continued)

Store 3 - REI

		1	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
		12-1a	2-3a	3-4a	4-5a	5-6a	6-7a	7-8a	8-9a	9-10a	10-11a	11-12p	12-1p	1-2p	2-3p	3-4p	4-5p	5-6p	6-7p	7-8p	8-9p	9-10p	10-11p	11-12a
Lights	**M-F**	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.50	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.50	0.05	0.05	0.05
	S	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.50	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.50	0.05	0.05	0.05	0.05	0.05
	Su	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.50	0.95	0.95	0.95	0.95	0.95	0.95	0.50	0.05	0.05	0.05	0.05	0.05	0.05
Plugs	**M-F**	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.50	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.50	0.05	0.05	0.05
	S	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.50	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.50	0.05	0.05	0.05	0.05	0.05
	Su	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.50	0.50	0.50	0.90	0.90	0.90	0.90	0.90	0.90	0.50	0.05	0.05	0.05	0.05	0.05	0.05
Occ	**M-F**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11	0.43	0.46	0.71	0.50	0.69	0.54	0.71	0.34	0.37	0.26	0.11	0.00	0.00	0.00
	S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11	0.58	0.71	0.74	0.77	0.80	0.74	0.67	0.54	0.11	0.00	0.00	0.00	0.00	0.00
	Su	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11	0.11	0.43	0.46	0.50	0.69	0.54	0.34	0.11	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX B

Simulation Input Assumptions for Final Guide

APPENDIX B – Simulation Input Assumptions for Final Guide

Table B-1 Standalone Small Retail Building Simulation Input Assumptions for Final Guide

Case	Location	Wall R-value	Roof R-value	Roof Solar Reflectance	Floor F-factor	Opaque Door U-value	Street-facing WWR	Glazing U-Value	SHGC	Code	U-value	SHGC	Min OA Damper Control	Design OA CFM Per Zone	econ_control	Supply Fan Total SP (in.)	Cooling EER	Furnace Eff.	SWH UA	SWH Eff.	Exterior Ltg w/ft² of façade
Standalone_Base_Miami	Miami	R-0	R-15	0.23	F-0.73	0.70	67.5%	1.22	NR	1000	1.11	0.86	no	1500	no	2.45	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Miami	Miami	R-0	R-15	0.65	F-0.73	0.70	67.5%	0.69	0.44	2660	0.42	0.44	yes	1050	no	2.32	11.0	0.80	0.00	0.810	0.20
Standalone_Base_Phoenix	Phoenix	R-0	R-15	0.23	F-0.73	0.70	67.5%	1.22	NR	1000	1.11	0.86	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Phoenix	Phoenix	R-7.6	R-15	0.65	F-0.73	0.70	67.5%	0.49	0.40	2660	0.42	0.44	yes	1050	yes	2.48	11.0	0.80	0.00	0.810	0.20
Standalone_Base_Houston	Houston	R-0	R-15	0.23	F-0.73	0.70	67.5%	1.22	NR	1000	1.11	0.86	no	1500	no	2.45	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Houston	Houston	R-7.6	R-15	0.65	F-0.73	0.70	67.5%	0.49	0.40	2660	0.42	0.44	yes	1050	no	2.32	11.0	0.80	0.00	0.810	0.20
Standalone_Base_Memphis	Memphis	R-5.7	R-15	0.23	F-0.73	0.70	67.5%	0.57	NR	2000	0.57	0.76	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Memphis	Memphis	R-11.4	R-20	0.65	F-0.73	0.70	67.5%	0.41	0.41	2660	0.42	0.44	yes	1050	yes	2.48	10.8	0.80	0.00	0.810	0.20
Standalone_Base_El-Paso	El Paso	R-5.7	R-15	0.23	F-0.73	0.70	67.5%	0.57	NR	2000	0.57	0.76	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_El-Paso	El Paso	R-11.4	R-20	0.65	F-0.73	0.70	67.5%	0.41	0.41	2660	0.42	0.44	yes	1050	yes	2.48	10.8	0.80	0.00	0.810	0.20
Standalone_Base_San-Francisco	San Francisco	R-5.7	R-10	0.23	F-0.73	0.70	67.5%	1.22	NR	1000	1.11	0.86	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_San-Francisco	San Francisco	R-11.4	R-20	0.65	F-0.73	0.70	67.5%	0.41	0.41	2660	0.42	0.44	yes	1050	yes	2.48	10.8	0.80	0.00	0.810	0.20
Standalone_Base_Baltimore	Baltimore	R-5.7	R-15	0.23	F-0.73	0.70	67.5%	0.57	NR	2000	0.57	0.76	no	1500	no	2.45	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Baltimore	Baltimore	R-13.3	R-20	0.23	F-0.73	0.50	67.5%	0.38	0.41	2661	0.30	0.44	yes	1050	yes	2.48	10.8	0.80	0.00	0.810	0.20
Standalone_Base_Albuquerque	Albuquerque	R-5.7	R-15	0.23	F-0.73	0.70	67.5%	0.57	NR	2000	0.57	0.76	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Albuquerque	Albuquerque	R-13.3	R-20	0.23	F-0.73	0.50	67.5%	0.38	0.41	2661	0.30	0.44	yes	1050	yes	2.48	10.8	0.80	0.00	0.810	0.20
Standalone_Base_Seattle	Seattle	R-5.7	R-15	0.23	F-0.73	0.70	67.5%	0.57	NR	2000	0.57	0.76	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Seattle	Seattle	R-13.3	R-20	0.23	F-0.73	0.50	67.5%	0.38	0.41	2661	0.30	0.44	yes	1050	yes	2.48	10.8	0.80	0.00	0.810	0.20
Standalone_Base_Chicago	Chicago	R-7.6	R-15	0.23	F-0.73	0.70	67.5%	0.57	NR	2000	0.57	0.76	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Chicago	Chicago	R-13.3	R-20	0.23	F-0.54	0.50	67.5%	0.38	0.41	2661	0.30	0.44	yes	1050	yes	2.48	10.8	0.80	0.00	0.810	0.20
Standalone_Base_Boise	Boise	R-7.6	R-15	0.23	F-0.73	0.70	67.5%	0.57	NR	2000	0.57	0.76	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Boise	Boise	R-13.3	R-20	0.23	F-0.54	0.50	67.5%	0.38	0.41	2661	0.30	0.44	yes	1050	yes	2.48	10.8	0.80	0.00	0.810	0.20
Standalone_Base_Helena	Helena	R-9.5	R-15	0.23	F-0.73	0.70	67.5%	0.57	NR	2000	0.57	0.76	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Helena	Helena	R-13.3	R-20	0.23	F-0.54	0.50	67.5%	0.38	0.41	2661	0.30	0.44	yes	1050	yes	2.48	9.5	0.80	0.00	0.810	0.20
Standalone_Base_Burlington	Burlington	R-9.5	R-15	0.23	F-0.73	0.70	67.5%	0.57	NR	2000	0.57	0.76	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Burlington	Burlington	R-13.3	R-20	0.23	F-0.54	0.50	67.5%	0.38	0.41	2661	0.30	0.44	yes	1050	yes	2.48	9.5	0.80	0.00	0.810	0.20
Standalone_Base_Duluth	Duluth	R-11.4	R-15	0.23	F-0.73	0.70	67.5%	0.57	NR	2000	0.57	0.76	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Duluth	Duluth	R-15.2	R-25	0.23	F-0.52	0.50	67.5%	0.38	0.41	2661	0.30	0.44	yes	1050	yes	2.48	9.5	0.80	0.00	0.810	0.20
Standalone_Base_Fairbanks	Fairbanks	R-13.3	R-20	0.23	F-0.54	0.50	67.5%	0.46	NR	2660	0.42	0.44	no	1500	yes	2.61	9.5	0.80	14.04	0.784	0.25
Standalone_Adva_Fairbanks	Fairbanks	R-15.2	R-25	0.23	F-0.52	0.50	67.5%	0.38	0.41	2661	0.30	0.44	yes	1050	yes	2.48	9.5	0.80	0.00	0.810	0.20

Table B-2 Strip Mall Small Retail Building Simulation Input Assumptions for Final Guide

Case	Location	Wall R-value	Roof R-value	Roof Solar Reflectance	Floor F-factor	Opaque Door U-value	Street-facing WWR	90.1 & AEDG Glazing U-Value	90.1 & AEDG Glazing SHGC	DOE-2 Glazing Inputs Code	DOE-2 Glazing Inputs U-value	DOE-2 Glazing Inputs SHGC	Min OA Damper Control	econ_control	Supply Fan Total Static Pressure (in.)	SWH UA	SWH Eff.	Cooling EER	Furnace Eff.	Exterior Ltg w/ft² of façade
StripMall_Base_Miami	Miami	R-13	R-15 ci	0.23	F-0.73	0.70	70%	1.22	NR	1000	1.11	0.86	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Miami	Miami	R-13	R-15 ci	0.65	F-0.73	0.70	70%	0.69	0.44	2660	0.42	0.44	yes	no	1.00	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Phoenix	Phoenix	R-13	R-15 ci	0.23	F-0.73	0.70	70%	1.22	NR	1000	1.11	0.86	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Phoenix	Phoenix	R-13	R-15 ci	0.65	F-0.73	0.70	70%	0.49	0.40	2660	0.42	0.44	yes	no	1.00	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Houston	Houston	R-13	R-15 ci	0.23	F-0.73	0.70	70%	1.22	NR	1000	1.11	0.86	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Houston	Houston	R-13	R-15 ci	0.65	F-0.73	0.70	70%	0.49	0.40	2660	0.42	0.44	yes	no	1.00	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Memphis	Memphis	R-13	R-15 ci	0.23	F-0.73	0.70	70%	0.57	NR	2000	0.57	0.76	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Memphis	Memphis	R-13 +R-7.5 ci	R-20 ci	0.65	F-0.73	0.70	70%	0.41	0.41	2660	0.42	0.44	yes	yes	1.05	0.00	0.810	11.3	0.8	0.20
StripMall_Base_El-Paso	El Paso	R-13	R-15 ci	0.23	F-0.73	0.70	70%	0.57	NR	2000	0.57	0.76	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_El-Paso	El Paso	R-13 +R-7.5 ci	R-20 ci	0.65	F-0.73	0.70	70%	0.41	0.41	2660	0.42	0.44	yes	yes	1.05	0.00	0.810	11.3	0.8	0.20
StripMall_Base_San-Francisco	San Francisco	R-13	R-10 ci	0.23	F-0.73	0.70	70%	1.22	NR	1000	1.11	0.86	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_San-Francisco	San Francisco	R-13 +R-7.5 ci	R-20 ci	0.65	F-0.73	0.70	70%	0.41	0.41	2660	0.42	0.44	yes	yes	1.05	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Baltimore	Baltimore	R-13	R-15 ci	0.23	F-0.73	0.70	70%	0.57	NR	2000	0.57	0.76	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Baltimore	Baltimore	R-13 +R-7.5 ci	R-20 ci	0.23	F-0.73	0.50	70%	0.38	0.41	2661	0.30	0.44	yes	yes	1.05	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Albuquerque	Albuquerque	R-13	R-15 ci	0.23	F-0.73	0.70	70%	0.57	NR	2000	0.57	0.76	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Albuquerque	Albuquerque	R-13 +R-7.5 ci	R-20 ci	0.23	F-0.73	0.50	70%	0.38	0.41	2661	0.30	0.44	yes	yes	1.05	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Seattle	Seattle	R-13	R-15 ci	0.23	F-0.73	0.70	70%	0.57	NR	2000	0.57	0.76	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Seattle	Seattle	R-13 +R-7.5 ci	R-20 ci	0.23	F-0.73	0.50	70%	0.38	0.41	2661	0.30	0.44	yes	yes	1.05	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Chicago	Chicago	R-13 +R-3.8 ci	R-15 ci	0.23	F-0.73	0.70	70%	0.57	NR	2000	0.57	0.76	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Chicago	Chicago	R-13 +R-7.5 ci	R-20 ci	0.23	F-0.54	0.50	70%	0.38	0.41	2661	0.30	0.44	yes	yes	1.05	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Boise	Boise	R-13 +R-3.8 ci	R-15 ci	0.23	F-0.73	0.70	70%	0.57	NR	2000	0.57	0.76	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Boise	Boise	R-13 +R-7.5 ci	R-20 ci	0.23	F-0.54	0.50	70%	0.38	0.41	2661	0.30	0.44	yes	yes	1.05	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Helena	Helena	R-13 +R-3.8 ci	R-15 ci	0.23	F-0.73	0.70	70%	0.57	NR	2000	0.57	0.76	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Helena	Helena	R-13 +R-7.5 ci	R-20 ci	0.23	F-0.54	0.50	70%	0.38	0.41	2661	0.30	0.44	yes	yes	1.05	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Burlington	Burlington	R-13 +R-3.8 ci	R-15 ci	0.23	F-0.73	0.70	70%	0.57	NR	2000	0.57	0.76	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Burlington	Burlington	R-13 +R-7.5 ci	R-20 ci	0.23	F-0.54	0.50	70%	0.38	0.41	2661	0.30	0.44	yes	yes	1.05	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Duluth	Duluth	R-13 +R-7.5 ci	R-15 ci	0.23	F-0.73	0.70	70%	0.57	NR	2000	0.57	0.76	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Duluth	Duluth	R-13 +R-7.5 ci	R-25 ci	0.23	F-0.52	0.50	70%	0.38	0.41	2661	0.30	0.44	yes	no	1.00	0.00	0.810	11.3	0.8	0.20
StripMall_Base_Fairbanks	Fairbanks	R-13 + R-7.5 ci	R-20 ci	0.23	F-0.54	0.50	70%	0.46	NR	2660	0.42	0.44	no	no	1.11	14.04	0.784	8.7	0.74	0.25
StripMall_Adva_Fairbanks	Fairbanks	R-13 +R-10 ci	R-25 ci	0.23	F-0.52	0.50	70%	0.38	0.41	2661	0.30	0.44	yes	no	1.00	0.00	0.810	11.3	0.8	0.20

APPENDIX C

Development of the Linear Regression Equations

APPENDIX C – Development of the Linear Regression Equations

C.1 Objective

The objective was to develop a linear regression model for annual energy usage in a prototypical small retail building. The regression model could then be used to develop recommendations for envelope options to achieve 30% energy reduction relative to ASHRAE 90.1-1999.

C.2 Approach

The starting point for this task was to calculate annual energy consumption data for a prototype small retail building. A number of cases were examined and DOE-2 results were available.

The approach was to develop individual linear regression equations for each component of energy usage and then combine them into an overall model. The five components of energy usage addressed were heating energy, cooling energy, fan energy, service hot water, and auxiliary energy.

C.3 Heating Energy

The heating model calculated heating energy by regressing five variables and took the following form:

$$\begin{aligned} \textit{Heating Energy} = \quad & C_0 \\ & + C_1 \times \textit{Conduction} \\ & + C_2 \times \textit{Ventilation} \\ & - C_3 \times \textit{Solar Fenestration} \\ & - C_4 \times \textit{Solar Roof} \\ & - C_5 \times \textit{Internals} \end{aligned} \tag{C.1}$$

where

$C_0, C_1 \ldots C_5$ = regression coefficients

The constants are determined by regression. The units for heating energy for this analysis are millions of Btu per year (MBtu/yr), and the variables are constructed to have units of MBtu/yr so that the regression constants ($C_1 - C_5$) are dimensionless. Also note that the solar and internal terms represent energy gains to the space and subtract from the heating energy requirement.

Conduction loss through the envelope (opaque and fenestration) areas was assumed to be proportional to the overall UA of the building. The variable that accounted for this conduction, therefore, took the form:

$$Conduction = \frac{U_o A_o \times HDD_{65} \times 24}{AFUE \times CF} \tag{C.2}$$

where

U_oA_o	= overall UA of the building envelope (Btu/hr-ºF)
HDD_{65}	= heating degree-days (base 65°F) per year for the location
$AFUE$	= the annual fuel utilization efficiency of the heating equipment
CF	= conversion factor (10^6 Btu/MBtu).

The ventilation variable was intended to account for the energy required to heat ventilation and infiltration air. On an hourly basis, this would vary strongly with the ventilation schedule, but on an annual basis, it was assumed to be proportional to the average ventilation flow per the following:

$$Ventilation = \frac{1.1 \times Avgcfm \times HDD_{65} \times 24}{AFUE \times CF} \tag{C.3}$$

where

$Avgcfm$	= weighted average air flow for ventilation and infiltration
1.1	= density × specific heat × 60 min/hr for moist air.

The solar fenestration variable was intended to account for the solar heat gain to the building through fenestration. This term took the form:

$$Solar\ Fenestration = \frac{A_o SHGC_o \times (SOLAR_n \times \%N + SOLAR_w \times PF \times \%W + SOLAR_s \times PF \times \%S) \times 365 \times \%HEAT}{AFUE \times CF} \tag{C.4}$$

where

A_oSHGC_o	= the overall fenestration area times solar heat gain coefficient (ft^2)
$SOLAR_n$	= average daily solar incidence on north facing surfaces (Btu/day-ft^2)
$\%N$	= fraction of fenestration area that is north facing
$SOLAR_w$	= average daily solar incidence on east/west facing surfaces (Btu/day-ft^2)
$\%W$	= fraction of fenestration area that is east or west facing
$SOLAR_s$	= average daily solar incidence on south facing surfaces (Btu/day-ft^2)
$\%S$	= fraction of fenestration area that is south facing
PF	= projection factor for fenestration
$\%Heat$	= fraction of year heating is required ($= \frac{HDD_{65}}{HDD_{65} + CDD_{65}}$)

Note that no projection factor is included for north facing fenestration.

The solar roof variable was developed to account for differences in the solar absorptance and long wave emittance of various roof treatments. This term took the form:

$$Solar\ Roof = \frac{(\alpha \times \frac{E}{24 \times h_o} - 7) \times U_{roof} \times A_{roof} \times 24 \times 365 \times \%HEAT}{AFUE \times CF} \qquad (C.5)$$

where

α	= solar absorptance of the roof surface
E	= average daily horizontal solar incidence (Btu/day-ft^2)
h_o	= surface heat transfer coefficient (assumed to be 3.0 Btu/hr-ft^2-^{o}F)
U_{roof}	= overall heat transfer coefficient for roof (Btu/hr-ft^2-^{o}F)
A_{roof}	= roof area (ft^2)

Note that the value of 7^{o}F is the "long wave correction" term used here for horizontal surfaces (see ASHRAE 2005 Handbook of Fundamentals Pg 30.22).

The fifth variable was developed to account for the internal gains to the building and took the form:

$$Internals = \frac{(Lights + Plugs + Fans + \frac{People \times Sensible \times FLEOH \times 52}{CF}) \times \%HEAT}{AFUE} \qquad (C.6)$$

where

Lights	= average annual lighting energy (MBtu/yr)
Plugs	= average annual plug energy (MBtu/yr)
Fans	= average annual fan energy (MBtu/yr)
People	= number of occupants (at design)
Sensible	= sensible heat gain from people (250 Btu/hr-person)
FLEOH	= full load equivalent occupancy hours (hr/week).

Note here that the factor of 52 converts full load equivalent occupancy hours (hrs/week) to hours per year.

The Excel linear regression routine REGRESS was used to calculate the coefficients for these variables. Results, along with the associated statistical measures, are given in Table C-1 as below.

Table C-1 Heating Model Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-12.79641862	4.127401103	-3.100357417	0.002325666
Conduction	1.049664231	0.02711033	38.71823863	5.19864E-78
Ventilation	0.778163482	0.022801305	34.12802373	6.85546E-71
Solar Fenestration	0.628962371	0.094858727	6.630516645	6.26618E-10
Solar Roof	1.333708631	0.166260201	8.021815353	3.30937E-13
Internals	0.266740574	0.029630787	9.00214278	1.19743E-15

Figure C-1 plots the regression result versus the corresponding DOE-2 result. The standard error of this regression was 18.8 MBtu/yr.

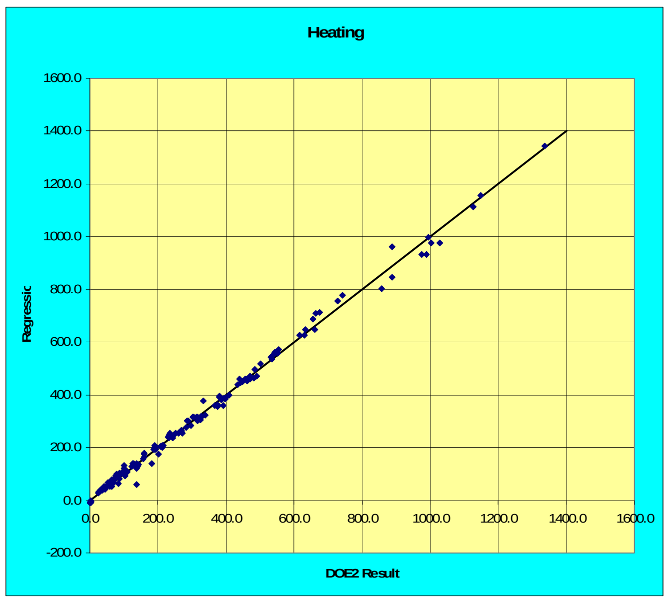

Figure C-1 Heating Regression

C.4 Cooling Energy

The cooling model was developed in a similar fashion and regressed cooling energy (MBtu/yr) against seven variables as follows:

$$\begin{aligned} Cooling\ Energy = \quad & C_0 \\ & + C_1 \times Conduction \\ & + C_2 \times Ventilation\ (sensible) \\ & + C_3 \times Ventilation\ (latent) \\ & + C_4 \times Solar\ Fenestration \\ & + C_5 \times Solar\ Roof \\ & - C_6 \times Economizer \\ & + C_7 \times Internals \end{aligned} \quad \text{(C.7)}$$

where

$C_0, C_1 \ldots C_7$ = regression coefficients

The cooling model adds terms to account for latent loading and for the benefits of an economizer cycle.

Conduction gain through the envelope (opaque and fenestration) areas was again assumed to be proportional to the overall UA of the building. The conduction variable, therefore, took the form:

$$Conduction = \frac{U_o A_o \times CDD_{65} \times 24}{COP \times CF} \quad \text{(C.8)}$$

where

U_oA_o = overall UA of the building envelope (Btu/hr-°F)
CDD_{65} = cooling degree-days (base 65°F) per year for the location
COP = the average coefficient of performance of the cooling system
CF = conversion factor (10^6 Btu/MBtu).

The ventilation (sensible) variable was used to account for the sensible energy required to cool ventilation and infiltration air. As before, it was assumed to be proportional to the average ventilation flow per the following:

$$Ventilation\ Sensible = \frac{1.1 \times Avgcfm \times CDD_{65} \times 24}{COP \times CF} \quad \text{(C.9)}$$

where

$Avgcfm$ = weighted average air flow for ventilation and infiltration
1.1 = density × specific heat × 60 min/hr for moist air.

A ventilation (latent) variable was added to account for the energy required to remove moisture from the ventilation and infiltration air. As before, it was assumed to be proportional to the average ventilation flow. It was also assumed to be proportional to a weather term (SUMDW) defined to approximate the amount of latent cooling required for a particular location.

$$Ventilation\ Latent = \frac{4{,}840 \times Avgcfm \times SUMD}{COP \times CF} \tag{C.10}$$

where

Avgcfm	= weighted average air flow for ventilation and infiltration (cfm)
4,840	= the air latent heat factor (Btu/hr-cfm)
SUMDW	= a weather parameter defined as the annual summation of the hourly ΔW_s
ΔW	= the difference between the outdoor air humidity ratio and 0.01 (if positive) .

The value of SUMDW was calculated for the various locations from hourly weather tapes. A value of indoor humidity ratio of 0.01 was selected as the base for the SUMDW calculation because this value roughly represents a typical summertime indoor air condition (e.g. 75°F, 55% RH).

The solar fenestration variable was intended to account for the solar heat gain to the building through fenestration.

$$Solar\ Fenestration = \frac{A_o SHGC_o \times (SOLAR_n \times \%N + SOLAR_w \times PF \times \%W + SOLAR_s \times PF \times \%S) \times 365 \times \%COOL}{COP \times CF} \tag{C.11}$$

where

A_oSHGC_o	= the overall fenestration area times Solar Heat Gain Coefficient (ft^2)
$SOLAR_n$	= average daily solar incidence on north facing surfaces (Btu/day-ft^2)
%N	= fraction of fenestration area that is north facing
$SOLAR_w$	= average daily solar incidence on east/west facing surfaces (Btu/day- ft^2)
%W	= fraction of fenestration area that is east or west facing
$SOLAR_s$	= average daily solar incidence on south facing surfaces (Btu/day-ft^2)
%S	= fraction of fenestration area that is south facing
PF	= projection factor for fenestration
%COOL	= fraction of year cooling is required ($= \frac{CDD_{65}}{HDD_{65} + CDD_{65}}$)

Note that no projection factor is included for north facing fenestration.

The solar roof variable accounts for the solar absorptance and transmission of solar energy through the building roof. As before, the variable took the form:

$$Solar\ Roof = \frac{(\alpha \times \frac{E}{24 \times h_o} - 7) \times U_{roof} \times A_{roof} \times 24 \times 365 \times \%COOL}{COP \times CF} \qquad (C.12)$$

where

α	= solar absorptance of the roof surface
E	= average daily horizontal solar incidence (Btu/day- ft^2)
h_o	= surface heat transfer coefficient (assumed to be 3.0 Btu/hr-ft^2-^{o}F)
U_{roof}	= overall heat transfer coefficient for roof (Btu/hr-ft^2-^{o}F)
A_{roof}	= roof area (ft^2).

The value of 7^{o}F is the "long wave correction" term used here for horizontal surfaces (see ASHRAE 2005 Handbook of Fundamentals Pg 30.22).

A variable was needed to account for the fact that some of the cases considered used economizer cycles to provide "free cooling" during hours when the outdoor temperature was below the return air temperature. This variable took the form:

$$Economizer = \frac{ECON \times \frac{CDD_{50}}{CDD_{65}}}{COP} \qquad (C.13)$$

where

$ECON$	= a flag to indicate whether economizer was present (1=yes, 0=no)

Note that the ratio of degree days was selected because it was found to provide some indication of the "free cooling" available in a particular location. Also note that the variable differs from the others in that it is dimensionless. Thus, the regression constant for this variable (C_6) will have units of MBtu/yr.

The final cooling variable was developed to account for the internal gains to the building and took the form:

$$Internals = \frac{(Lights + Plugs + Fans + \frac{People \times Total \times FLEOH \times 52}{CF}) \times \%COOL}{COP} \qquad (C.14)$$

where

Lights	= average annual lighting energy (MBtu/yr)
Plugs	= average annual plug energy (MBtu/yr)
Fans	= average annual fan energy (MBtu/yr)
People	= number of occupants (at design)

Total	= total (sensible and latent) gain from people (450 Btu/hr-person)
FLEOH	= full load equivalent occupancy hours.

Note here that the factor of 52 converts full load equivalent occupancy hours (hr/week) to hours per year.

As before, the Excel linear regression routine REGRESS was used to calculate the coefficients for these variables. Results, along with the associated statistical measures, are given in Table C-2 as below.

Table C-2 Cooling Model Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	17.38087275	1.163151729	14.94291098	6.23962E-31
Conduction	0.506150201	0.196243874	2.579189821	0.010919684
Ventilation-Sensible	0.22137761	0.157972846	1.401364952	0.163286787
Ventilation-Latent	0.101824745	0.013262581	7.677596201	2.38932E-12
Solar Fenestration	0.680673215	0.298277798	2.282010999	0.023975066
Solar Roof	0.611809274	0.565768672	1.081377078	0.281362468
Economizer	1.44392346	0.279320061	5.169422684	7.82542E-07
Internals	0.795498705	0.112641121	7.06224064	6.72236E-11

Figure C-2 plots the regression result versus the corresponding DOE-2 result. The standard error of this regression was 8.0 MBtu/yr.

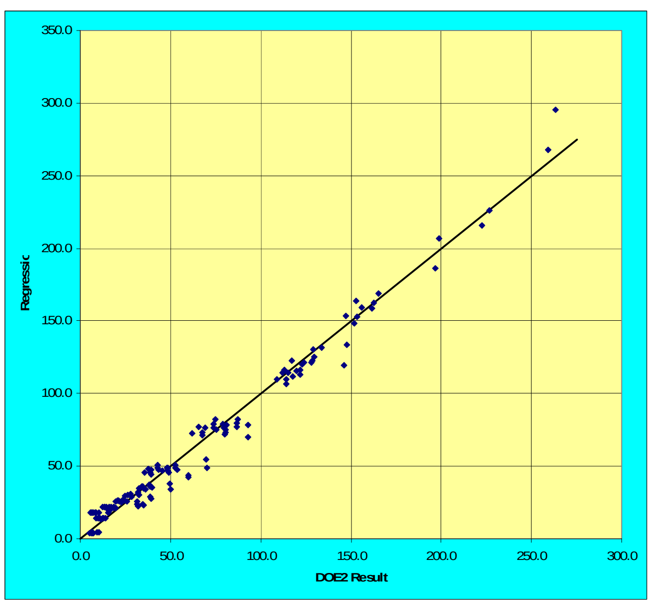

Figure C-2 Cooling Regression

C.3 Service Water Heating

The energy required to provide service hot water was assumed to be proportional to the amount of water used (a constant for the cases examined in this analysis) and negatively correlated to the average ground water temperature. Studies have indicated that average annual ground water temperatures can be approximated by average annual air temperature for a location. Hence, the model for service water heating took the simple form:

$$SHW = C_0 + C_1 \times T_{annual} \qquad (C.15)$$

where

T_{annual} = annual average outdoor temperature (^{o}F).

As before, the Excel linear regression routine REGRESS was used to calculate the coefficients. Results, along with the associated statistical measures, are given in Table C-3 as below.

Table C-3 Service Water Heating Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	16.87273799	0.025229204	668.7780528	1.8329E-259
T_{annual}	-0.086209271	0.000452801	-190.3911869	7.9001E-179

Figure C-3 plots the regression results versus the corresponding DOE-2 result. The standard error of the service water heating regression was 0.07 MBtu/yr.

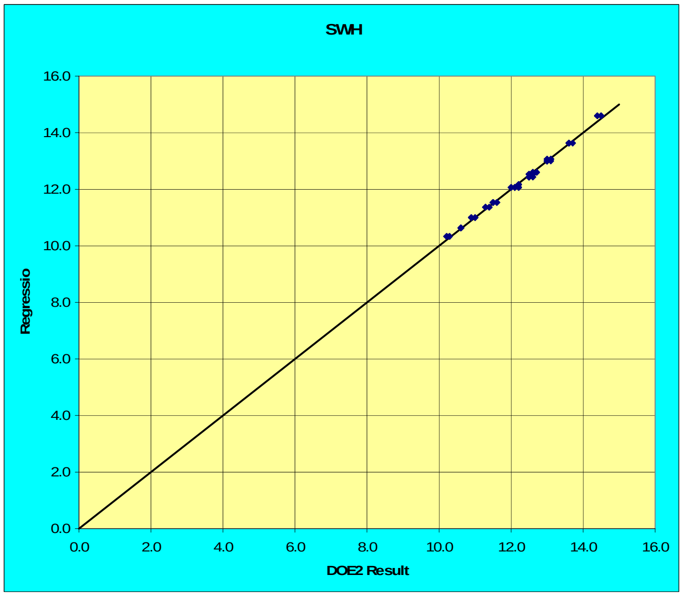

Figure C-3 Service Water Heating Regression

C.4 Fan Energy

Energy for HVAC fans is required year round to provide ventilation, as well as to distribute heated or cooled air. The model for fan energy took the form:

$$Fans = C_0 + C_1 \times (HDD_{65} + CDD_{65}) + C_2 \times U_o A_o \times (HDD_{65} + CDD_{65}) \qquad \text{(C.16)}$$

The standard error for the resulting regression was 1.8 MBtu/yr and the coefficients were listed in Table C-4.

Table C-4 Fan Energy Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	44.56791347	0.386295962	115.372455	4.3463E-146
Vent	-0.000309524	0.000103557	-2.988916124	0.003282527
Heat & Cool	9.28617E-07	6.85478E-08	13.54700175	1.20133E-27

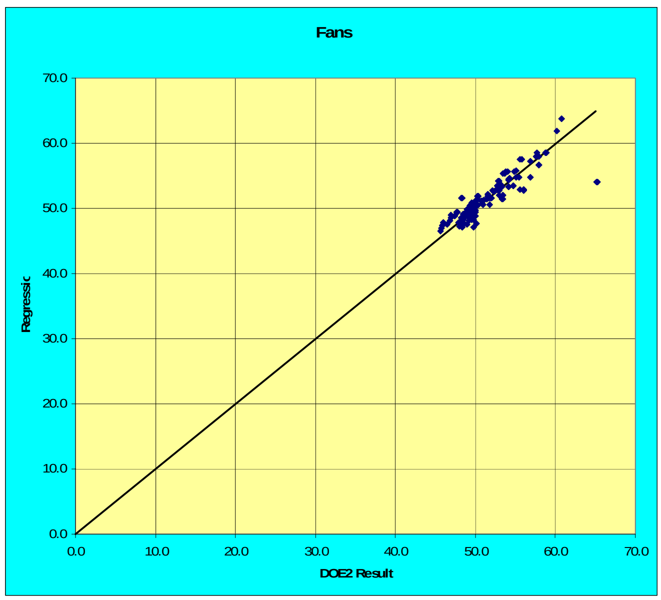

Figure C-4 Fan Regression

C.5 Auxiliary Energy

Auxiliary energy usage (controls) was a small portion of the total energy usage of these buildings. Examination of the data indicated that a simple regression model using heating-degree-days as the variable would adequately represent the auxiliary energy usage.

$$Aux = C_0 + C_1 \times HDD_{65} \qquad \text{(C.17)}$$

The standard error for the resulting regression was 0.3 MBtu/yr and the coefficients were shown in Table C-5.

Table C-5 Auxiliary Energy Coefficients

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.490658897	0.046904041	10.46090891	1.61628E-19
HDD_{65}	0.00024593	7.39303E-06	33.26513926	1.42464E-70

Figure C-5 plots the regression result versus the corresponding DOE-2 result.

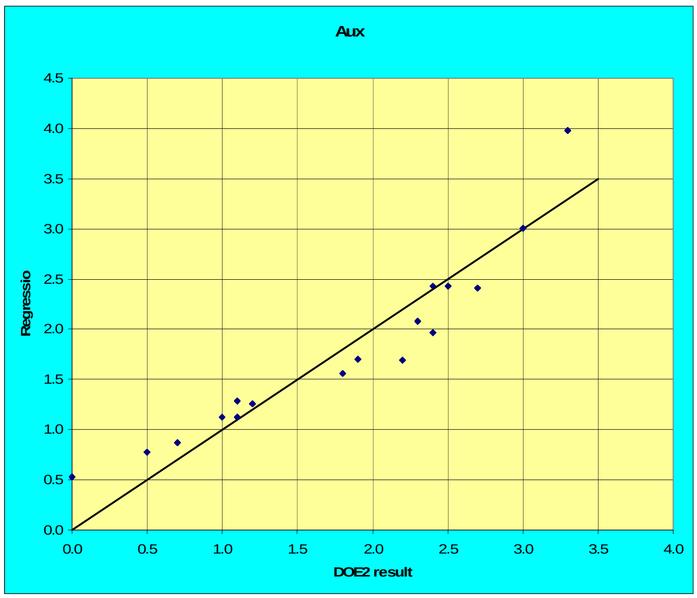

Figure C-5 Auxiliary Energy Regression

C.6 Other Components of Energy Usage

Additional components of energy usage included the interior lighting, exterior lighting, and plug loads. These components were not modeled explicitly because they are considered input to the model. These known values are simply added to the results of the regression models to predict the overall energy usage of the building.

C.7 Overall Results

Figure C-6 gives the results of the regression model compared to the corresponding DOE-2 result. Figure C-7 is a plot of the residuals (DOE-2 result – regression result).

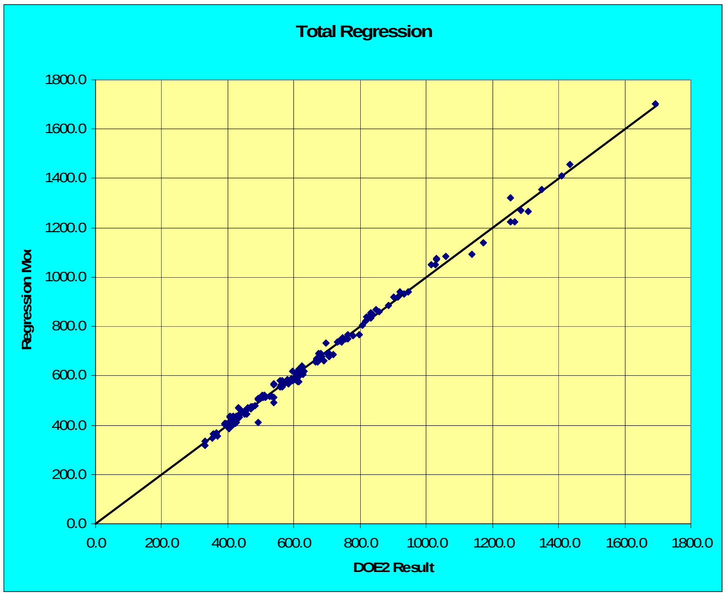

Figure C-6 Overall Regression Results

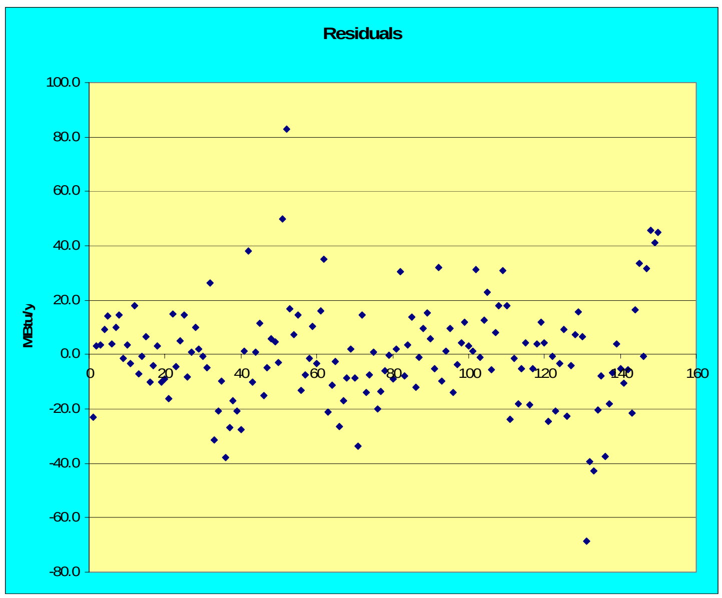

Figure C-7 Residuals

The standard deviation of the residuals for this model is 19.3 MBtu/yr and the coefficient of variation (SD/Mean) was 3.0%. The maximum residual is 83 MBtu/yr and represents one of the baseline cases for San Francisco. The DOE-2 result for this case was 493 MBtu/yr, so the maximum regression error was 17% below the DOE-2 prediction.

APPENDIX D

Data Base of Opaque Constructions

APPENDIX D – Data Base of Opaque Constructions (McBride, 1995)

1 Roof Criteria: Attic and Other

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+ R Post	Actual U-factor	dFC/dU
NR	NR	0	0.6135	0	0	0.6135	0.00
R-13.0	R-2.3	0.23	0.0809	13	0	0.0809	0.43
R-19.0	R-3.3	0.29	0.0528	19	0	0.0528	2.14
R-30.0	R-5.3	0.4	0.0339	30	0	0.0339	5.82
R-38.0	R-6.7	0.5	0.0269	38	0	0.0269	14.29
R-49.0	R-8.6	0.66	0.0210	49	0	0.0210	27.12
R-60.0	R-10.6	0.77	0.0172	60	0	0.0172	28.95
R-71.0	R-12.5	0.9	0.0146	71	0	0.0146	50.00
R-82.0	R-14.4	1.03	0.0126	82	0	0.0126	65.00
R-93.0	R-16.4	1.16	0.0112	93	0	0.0112	92.86
R-104.0	R-18.3	1.29	0.0100	104	0	0.0100	108.33
R-115.0	R-20.3	1.42	0.0090	115	0	0.0090	130.00
R-126.0	R-22.2	1.54	0.0083	126	0	0.0083	171.43
R-137.0	R-24.1	1.67	0.0076	137	0	0.0076	185.71
R-148.0	R-26.1	1.8	0.0070	148	0	0.0070	216.67

2 Roof Criteria: Insulation Entirely Above Deck

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+ R Post	Actual U-factor	dFC/dU
NR	NR	0	1.2821	0	0	1.2821	0.00
R-3.8	R-0.7	0.34	0.2183	3.8	0	0.2183	0.32
R-5.0	R-0.9	0.43	0.1730	5	0	0.1730	1.99
R-7.6	R-1.3	0.66	0.1193	7.6	0	0.1193	4.28
R-10.0	R-1.8	0.8	0.0928	10	0	0.0928	5.28
R-15.0	R-2.6	1.08	0.0634	15	0	0.0634	9.52
R-20	R-3.5	1.36	0.0481	22.4	0	0.0481	18.27
R-25	R-4.4	1.64	0.0388	28	0	0.0388	30.05
R-30	R-5.3	1.92	0.0325	33.6	0	0.0325	44.50
R-39.2	R-6.9	2.62	0.0250	39.2	0	0.0250	93.74
R-44.8	R-7.9	2.93	0.0219	44.8	0	0.0219	100.00
R-50.4	R-8.9	3.23	0.0195	50.4	0	0.0195	125.00
R-56.0	R-9.9	3.53	0.0176	56	0	0.0176	157.89
R-61.6	R-10.8	3.84	0.0160	61.6	0	0.0160	193.75
R-67.2	R-11.8	4.14	0.0147	67.2	0	0.0147	230.77

3 Roof Criteria: Single Rafter Roof

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+R Post	U-factor	dFC/dU
NR	NR	0	0.4171	0	0	0.4171	0
R-13.0	R-2.3	0.29	0.0782	13	0	0.0782	0.86
R-19.0	R-3.3	0.35	0.0554	19	0	0.0554	2.63
R-21.0	R-3.7	0.43	0.0515	21	0	0.0515	20.51
R-30.0	R-5.3	1.01	0.0360	30	0	0.0360	37.42
R-38.0	R-6.7	1.59	0.0282	38	0	0.0282	74.36

4 Slab-on-Grade Floor Criteria (Heated)

I-P Description	S-I Description	Cost	Display F-factor	R-value	R-in.	Actual U-facotor	dFC/dU
R-7.5 for 12 in.	R-1.3 for 30.5 cm	0	1.02	7.5	12	0.730	0
R-7.5 for 24 in.	R-1.3 for 61.0 cm	0.3094	0.95	7.5	24	0.710	15.47
R-10.0 for 36 in.	R-1.8 for 91.4 cm	1.0387	0.84	10	36	0.660	14.59
R-10.0 Full Slab	R-1.8	2.52	0.55	10	0	0.540	12.34
R-15.0 Full Slab	R-2.6	2.89	0.44	15	0	0.520	18.50
R-20.0 Full Slab	R-3.5	3.26	0.373	20	0	0.510	36.27
R-25.0 Full Slab	R-4.4	5.78	0.326	25	0	0.450	42.14
R-30.0 Full Slab	R-5.3	6.53	0.296	30	0	0.434	45.45
R-35.0 Full Slab	R-6.2	7.28	0.273	35	0	0.424	78.95
R-40.0 Full Slab	R-7.0	20.19	0.255	40	0	0.300	104.11
R-45.0 Full Slab	R-7.9	25.08	0.239	45	0	0.261	124.74
R-50.0 Full Slab	R-8.8	29.96	0.227	50	0	0.233	177.45
R-55.0 Full Slab	R-9.7	34.85	0.217	55	0	0.213	242.08

5 Slab-on-Grade Floor Criteria (Unheated)

I-P Description	S-I Description	Cost	Display F-factor	R-value	R-in.	Actual U-factor	dFC/dU
NR	NR	0	0.730	0	0	0.730	0
R-10.0 for 24 in.	R-1.8 for 61.0 cm	2.52	0.540	10	24	0.540	13.26
R-15.0 for 24 in.	R-2.6 for 61.0 cm	2.89	0.520	15	24	0.520	18.50
R-20.0 for 24 in.	R-3.5 for 61.0 cm	3.26	0.510	20	24	0.510	36.27
R-15.0 for 48 in.	R-2.6 for 121.9 cm	5.78	0.450	15	48	0.450	42.14
R-20.0 for 48 in.	R-3.5 for 121.9 cm	6.53	0.434	20	48	0.434	45.45
R-25.0 for 48 in.	R-4.4 for 121.9 cm	7.28	0.424	25	48	0.424	78.95
R-15.0 Full Slab	R-2.6	20.19	0.300	15	0	0.300	104.11
R-20.0 Full Slab	R-3.5	25.08	0.261	20	0	0.261	124.74
R-25.0 Full Slab	R-4.4	29.96	0.233	25	0	0.233	177.45
R-30.0 Full Slab	R-5.3	34.85	0.213	30	0	0.213	242.08

6 Floor Over Unconditioned Space Criteria: Mass Floor

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+ R post	Actual U-factor	dFC/dU
NR	NR	0	0.3215	0	0	0.3215	0
R-4.2 ci	R-0.7 ci	0.64	0.1374	0	4.2	0.1374	3.48
R-6.3 ci	R-1.1 ci	0.82	0.1067	0	6.3	0.1067	5.86
R-8.3 ci	R-1.5 ci	0.99	0.0873	0	8.3	0.0873	8.76
R-10.4 ci	R-1.8 ci	1.17	0.0739	0	10.4	0.0739	13.43
R-12.5 ci	R-2.2 ci	1.33	0.0640	0	12.5	0.0640	16.16
R-14.6 ci	R-2.6 ci	1.51	0.0565	0	14.6	0.0565	24.00
R-16.7 ci	R-2.9 ci	1.68	0.0505	0	16.7	0.0505	28.33
R-4.2 + R-30.8 ci	R-0.7 + R-5.4 ci	3.76	0.0263	4.2	30.8	0.0263	85.95
R-4.2 + R-33.6 ci	R-0.7 + R-5.9 ci	3.92	0.0245	4.2	33.6	0.0245	88.89
R-4.2 + R-36.4 ci	R-0.7 + R-6.4 ci	4.08	0.0229	4.2	36.4	0.0229	100.00
R-4.2 + R-37.2 ci	R-0.7 + R-6.6 ci	4.25	0.0215	4.2	37.2	0.0215	121.43
R-4.2 + R-42 ci	R-0.7 + R-7.4 ci	4.41	0.0203	4.2	42	0.0203	133.33
R-4.2 + R-44.8 ci	R-0.7 + R-7.9 ci	4.57	0.0192	4.2	44.8	0.0192	145.45
R-4.2 + R-47.6 ci	R-0.7 + R-8.4 ci	4.74	0.0182	4.2	47.6	0.0182	170.00
R-4.2 + R-50.4 ci	R-0.7 + R-8.9 ci	4.9	0.0173	4.2	50.4	0.0173	177.78
R-4.2 + R-53.2 ci	R-0.7 + R-9.4 ci	5.07	0.0165	4.2	53.2	0.0165	212.50
R-4.2 + R-56 ci	R-0.7 + R-9.9 ci	5.23	0.0158	4.2	56	0.0158	228.57
R-6.3 + R-56 ci	R-1.1 + R-9.9 ci	5.405	0.0153	6.3	56	0.0153	350.00
R-8.3 + R-56 ci	R-1.5 + R-9.9 ci	5.581	0.0148	8.3	56	0.0148	374.47
R-12.5 + R-56 ci	R-2.2 + R-9.9 ci	5.92	0.0140	12.5	56	0.0140	389.66
R-14.6 + R-56 ci	R-2.6 + R-9.9 ci	6.096	0.0136	14.6	56	0.0136	451.28
R-16.7 + R-56 ci	R-2.9 + R-9.9 ci	6.271	0.0132	16.7	56	0.0132	460.53
R-24.0 + R-56 ci	R-4.2 + R-9.9 ci	8.249	0.0120	24	56	0.0120	1705.17

7 Floor Over Unconditioned Space Criteria: Wood Joists

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+R post	Actual U-factor	dFC/dU
NR	NR	0	0.2817	0	0	0.2817	
R-13.0	R-2.3	0.34	0.0663	13	0	0.0663	1.58
R-19.0	R-3.3	0.4	0.0508	19	0	0.0508	3.87
R-30.0	R-5.3	0.55	0.0331	30	0	0.0331	8.47
R-30.0 + R-7.5 ci	R-5.3 + R-1.3 ci	1.11	0.0261	30	7.5	0.0261	80.00
R-38.0 + R-7.5 ci	R-6.7 + R-1.3 ci	1.66	0.0221	38	7.5	0.0221	137.50
R-38.0 + R-10 ci	R-6.7 + R-1.8 ci	1.9	0.0209	38	10	0.0209	200.00
R-38.0 + R-11.2 ci	R-6.7 + R-2.0 ci	2.02	0.0204	38	11.2	0.0204	240.00
R-38.0 + R-11.2 ci	R-6.7 + R-2.0 ci	2.08	0.0201	38	11.2	0.0201	200.00

8 Wall Criteria: Metal Frame

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+ R post	Actual U-factor	dFC/dU
NR	NR	0	0.3519	0	0	0.3519	
R-13.0	R-2.3	0.33	0.1242	13	0	0.1242	1.45
R-13.0 + R-3.8 ci	R-2.3 + R-0.7 ci	0.67	0.0844	13	3.8	0.0844	8.54
R-13.0 + R-7.5 ci	R-2.3 + R-1.3 ci	0.89	0.0643	13	7.5	0.0643	10.95
R-13.0 + R-10 ci	R-2.3 + R-1.8 ci	1.12	0.0554	13	10	0.0554	25.84
R-13.0 + R-18 ci	R-2.3 + R-3.2 ci	1.4	0.0454	13	18	0.0454	28.00
R-13.0 + R-21.6 ci	R-2.3 + R-3.8 ci	1.57	0.0402	13	21.6	0.0402	32.69
R-13.0 + R-25.2 ci	R-2.3 + R-4.4 ci	1.73	0.0362	13	25.2	0.0362	40.00
R-13.0 + R-28.8 ci	R-2.3 + R-5.1 ci	1.9	0.0328	13	28.8	0.0328	50.00
R-13.0 + R-32.4 ci	R-2.3 + R-5.7 ci	2.06	0.0301	13	32.4	0.0301	59.26
R-13.0 + R-36 ci	R-2.3 + R-6.3 ci	2.22	0.0277	13	36	0.0277	66.67
R-13.0 + R-39.6 ci	R-2.3 + R-7.0 ci	2.39	0.0257	13	39.6	0.0257	85.00
R-13.0 + R-43.2 ci	R-2.3 + R-7.6 ci	2.55	0.0240	13	43.2	0.0240	94.12
R-13.0 + R-46.8 ci	R-2.3 + R-8.2 ci	2.71	0.0225	13	46.8	0.0225	106.67

9 Wall Criteria: Wood Frame

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+ R post	Actual U-factor	dFC/dU
NR	NR	0	0.2923	0	0	0.2923	0
R-13.0	R-2.3	0.25	0.0887	13	13	0.0887	1.23
R-13.0 + R-3.8 ci	R-2.3 + R-0.7 ci	0.59	0.0642	13	16.8	0.0642	13.88
R-13.0 + R-7.5 ci	R-2.3 + R-1.3 ci	0.81	0.0512	13	20.5	0.0512	16.92
R-13.0 + R-10 ci	R-2.3 + R-1.8 ci	1.04	0.0452	13	23	0.0452	38.33
R-13.0 + R-18 ci	R-2.3 + R-3.2 ci	1.32	0.0381	13	31	0.0381	39.44
R-13.0 + R-21.6 ci	R-2.3 + R-3.8 ci	1.49	0.0343	13	34.6	0.0343	44.74
R-13.0 + R-25.2 ci	R-2.3 + R-4.4 ci	1.65	0.0312	13	38.2	0.0312	51.61
R-13.0 + R-28.8 ci	R-2.3 + R-5.1 ci	1.81	0.0287	13	41.8	0.0287	64.00
R-13.0 + R-32.4 ci	R-2.3 + R-5.7 ci	1.98	0.0265	13	45.4	0.0265	77.27
R-13.0 + R-36 ci	R-2.3 + R-6.3 ci	2.14	0.0247	13	49	0.0247	88.89
R-13.0 + R-39.6 ci	R-2.3 + R-7.0 ci	2.3	0.0231	13	52.6	0.0231	100.00
R-13.0 + R-43.2 ci	R-2.3 + R-7.6 ci	2.47	0.0217	13	56.2	0.0217	121.43
R-13.0 + R-46.8 ci	R-2.3 + R-8.2 ci	2.63	0.0204	13	59.8	0.0204	123.08

10 Floor over Unconditioned Space Criteria: Metal Joists

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+R post	Actual U-value	dFC/dU
NR	NR	0	0.3497	0	0	0.3788	0
R-13.0	R-2.3	0.33	0.0687	13	0	0.0697	1.07
R-19.0	R-3.3	0.39	0.0521	19	0	0.0527	3.53
R-30.0	R-5.3	0.55	0.0377	30	0	0.0380	10.88
R-38.0	R-6.7	0.67	0.0323	38	0	0.0325	21.82
R-38.0 + R-11.2 ci	R-6.7 + R-2.0 ci	2.63	0.0237	38	11.2	0.0325	#DIV/0!

11 Wall Criteria: Mass Walls

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+R post	Actual U-value	dFC/dU
NR	NR	0	0.5800	0	0	0.5800	0
R-5.7 ci	R-1.0 ci	1.81	0.1510	5.7	0	0.1510	4.22
R-7.6 ci	R-1.3 ci	1.99	0.1234	7.6	0	0.1234	6.52
R-9.5 ci	R-1.7 ci	2.16	0.1043	9.5	0	0.1043	8.90
R-11.4 ci	R-2.0 ci	2.32	0.0903	11.4	0	0.0903	11.43
R-13.3 ci	R-2.3 ci	2.492	0.0797	13.3	0	0.0797	16.23
R-15.2 ci	R-2.7 ci	2.65	0.0712	15.2	0	0.0712	18.59
R-28.0 ci	R-4.9 ci	4.04	0.0455	28	0	0.0455	54.09
R-33.6 ci	R-5.9 ci	4.55	0.0386	33.6	0	0.0386	73.91
R-39.2 ci	R-6.9 ci	5.06	0.0335	39.2	0	0.0335	100.00
R-44.8 ci	R-7.9 ci	5.57	0.0295	44.8	0	0.0295	127.50
R-50.4 ci	R-8.9 ci	6.08	0.0265	50.4	0	0.0265	170.00
R-56.0 ci	R-9.9 ci	6.59	0.0239	56	0	0.0239	196.15
R-61.6 ci	R-10.8 ci	7.1	0.0219	61.6	0	0.0219	255.00

12 Wall Criteria: Below-Grade Walls

I-P Description	S-I Description	Cost	Display C-Factor	R Rval	+R post	Actual U-facotr	dFC/dU
NR	NR	0	1.1400	0	0	0.1284	0.00
R-7.5 ci	R-1.3 ci	0.71	0.1194	7.5	0	0.0654	11.27
R-10.0 ci	R-1.8 ci	0.95	0.0919	10	0	0.0562	26.09
R-12.5 ci	R-2.2 ci	1.15	0.0748	12.5	0	0.0493	28.99
R-15.0 ci	R-2.6 ci	1.35	0.0630	15	0	0.0439	37.04
R-17.5 ci	R-3.1 ci	1.55	0.0544	17.5	0	0.0395	45.45
R-20.0 ci	R-3.5 ci	1.75	0.0479	20	0	0.0360	57.14
R-25.0 ci	R-4.4 ci	2.15	0.0386	25	0	0.0305	72.73
R-30.0 ci	R-5.3 ci	2.55	0.0324	30	0	0.0265	100.00
R-35.0 ci	R-6.2 ci	2.95	0.0279	35	0	0.0234	129.03
R-40.0 ci	R-7.0 ci	3.35	0.0245	40	0	0.0209	160.00
R-45.0 ci	R-7.9 ci	3.75	0.0218	45	0	0.0190	210.53
R-50.0 ci	R-8.8 ci	4.15	0.0197	50	0	0.0173	235.29

13 Wall Criteria: Mass Walls -- Perlite Overlay

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+R post	Actual U-factor	dFC/dU
0	0	0	0.4800	0	0	0.4800	0
0	0	0.45	0.3500	0	0	0.3500	3.46
0	0	1.81	0.1432	5.7	0	0.1432	6.58
0	0	1.99	0.1181	7.6	0	0.1181	7.17

14 Roof Criteria: Metal Building

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+R post	Actual U-factor	dFC/dU
NR	NR	0	1.2800	0	0	1.2800	
R-6.0	R-1.1	0.37	0.1670	6	0	0.1670	0.33
R-10.0	R-1.8	0.44	0.0970	10	0	0.0970	1.00
R-13.0	R-2.3	0.5	0.0830	13	0	0.0830	4.29
R-16.0	R-2.8	0.56	0.0720	16	0	0.0720	5.45
R-19.0	R-3.3	0.62	0.0650	19	0	0.0650	8.57
R-13.0 + R-13.0	R-2.3 + R-2.3	0.8	0.0550	26	13	0.0550	18.00
R-13.0 + R-19.0	R-2.3 + R-3.3	0.92	0.0490	32	19	0.0490	20.00
R-16.0 + R-19.0	R-2.8 + R-3.3	0.98	0.0470	35	19	0.0470	30.00
R-19.0 + R-19.0	R-3.3 + R-3.3	1.04	0.0460	38	19	0.0460	60.00
R4/R19/R10	R0.7/R3.3/R1.8	2	0.0330	NA	NA	0.0330	73.85
R5.6/R19/R10	R1/R3.3/R1.8	2.21	0.0310	NA	NA	0.0209	17.36

15 Wall Criteria: Metal Building

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+R post	Actual U-factor	dFC/dU
NR	NR	0	1.1800	0	0	1.1800	
R-6.0	R-1.1	0.33	0.1840	6	0	0.1840	0.33
R-10.0	R-1.8	0.41	0.1340	10	0	0.1340	1.60
R-11.0	R-1.9	0.43	0.1230	11	0	0.1230	1.82
R-13.0	R-2.3	0.46	0.1130	13	0	0.1130	3.00
R-13.0 + R-13.0	R-2.3 + R-2.3	1.13	0.0570	26	13	0.0570	11.96
R-13.0 + R-16.0	R-2.3 + R-2.8	1.19	0.0550	29	16	0.0550	30.00
R-13.0 + R-25.0	R-2.3 + R-4.4	1.38	0.0520	38	25	0.0520	63.33
R-13.0 + R-25.2 ci	R-2.3 + R-4.4 ci	2.92	0.0294	38.2	25.2	0.0294	68.14
R-13.0 + R-28.0 ci	R-2.3 + R-4.9 ci	3.09	0.0271	41	28	0.0271	73.91
R-13.0 + R-30.8 ci	R-2.3 + R-5.4 ci	3.25	0.0252	43.8	30.8	0.0252	84.21
R-13.0 + R-33.6 ci	R-2.3 + R-5.9 ci	3.41	0.0236	46.6	33.6	0.0236	100.00

16 Opaque Door Criteria: Swinging

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+R post	Actual U-factor	dFC/dU
uninsulated	Uninsulated	0	0.7	1.43	0	0.7	0
insulated	Insulated	3.25	0.5	2	0	0.5	16.25

17 Opaque Door Criteria: Roll-Up

I-P Description	S-I Description	Cost	Display U-factor	R Rval	+R post	Actual U-factor	dFC/dU
uninsulated	Uninsulated	0	1.45	0.69	0	1.45	0
insulated	Insulated	9.29	0.5	2	0	0.5	9.78

APPENDIX E

Data Base of Fenestration Options

APPENDIX E – Data Base of Fenestration Options

No.	Name	U-Crit	U-Act	SC	SHGC	VLT	Kd	kWh	FC	U-fixed
1	Mtl/Clr	1.27	1.26	0.94	0.82	0.80	0.63	1.21	$0.00	1.22
2	Brk/Clr	1.08	1.15	0.91	0.79	0.80	0.63	1.21	$1.95	1.11
3	Vnl/Clr	0.90	1.02	0.84	0.73	0.77	0.62	1.23	$4.88	0.98
4	Mtl/Clr-Std-Clr	0.81	0.73	0.83	0.72	0.71	0.60	1.29	$3.90	0.72
5	Mtl/ClrSbe-Std-Clr	0.69	0.59	0.51	0.44	0.45	0.48	1.67	$5.27	0.57
6	Brk/Clr-Std-Clr	0.60	0.62	0.78	0.68	0.71	0.60	1.29	$5.85	0.60
7	Brk/ClrSbe-Std-Clr	0.49	0.48	0.46	0.40	0.45	0.48	1.67	$7.22	0.46
8	Brk/Clr-Ins-Clr	0.57	0.59	0.78	0.68	0.71	0.60	1.29	$6.34	0.57
9	Brk/ClrSbe-Ins-Clr	0.46	0.44	0.46	0.40	0.45	0.48	1.67	$7.71	0.43
10	Brk/Clr-Ins-ClrPye	0.48	0.45	0.74	0.64	0.66	0.58	1.34	$7.12	0.46
11	Brk/Clr-Ins-ClrSpe	0.46	0.44	0.64	0.56	0.66	0.58	1.34	$7.12	0.43
12	Brk/Clr-Ins-ClrSue	0.44	0.42	0.53	0.46	0.62	0.57	1.39	$7.12	0.42
13	Vnl/Clr-Std-Clr	0.53	0.51	0.72	0.63	0.68	0.59	1.32	$8.78	0.50
14	Vnl/ClrSbe-Std-Clr	0.42	0.37	0.41	0.36	0.43	0.47	1.71	$10.14	0.37
15	Vnl/Clr-Std-ClrPye	0.44	0.39	0.68	0.59	0.63	0.57	1.38	$9.56	0.40
16	Vnl/Clr-Std-ClrSpe	0.42	0.37	0.59	0.51	0.63	0.57	1.38	$9.56	0.37
17	Vnl/Clr-Std-ClrSue	0.41	0.36	0.47	0.41	0.60	0.56	1.42	$9.56	0.36
18	Vnl/Clr-Ins-Clr	0.50	0.48	0.72	0.63	0.68	0.59	1.32	$9.27	0.47
19	Vnl/ClrSbe-Ins-Clr	0.39	0.34	0.41	0.36	0.43	0.47	1.71	$10.63	0.34
20	Vnl/Clr-Ins-ClrPye	0.41	0.35	0.68	0.59	0.63	0.57	1.38	$10.05	0.37
21	Vnl/Clr-Ins-ClrSpe	0.39	0.33	0.59	0.51	0.63	0.57	1.38	$10.05	0.34
22	Vnl/Clr-Ins-ClrSue	0.38	0.32	0.47	0.41	0.60	0.56	1.42	$10.05	0.33
23	Brk/Clr-Ins-Clr-Ins-Clr	0.43	0.42	0.68	0.59	0.64	0.58	1.37	$10.24	0.42
24	Brk/Clr-Ins-V88-Ins-Clr	0.33	0.35	0.61	0.53	0.63	0.57	1.38	$14.14	0.30
25	Vnl/Clr-Ins-Clr-Ins-Clr	0.37	0.33	0.63	0.55	0.61	0.57	1.41	$13.17	0.33
26	Vnl/Clr-Ins-V88-Ins-Clr	0.28	0.26	0.55	0.48	0.61	0.57	1.41	$17.07	0.22

APPENDIX F

Summary of Peer Review Comments and Responses

APPENDIX F – Summary of Peer Review Comments and Responses

SUMMARY RESPONSE TO PEER REVIEW REMARKS AND RECOMMENDATIONS RECEIVED ON 90% FINAL REVIEW DRAFT OF Advanced Energy Design Guide: Small Retail Buildings

June 14, 2006

On May 8, 2006, the project committee issued a 90% Final Review Draft of the document *Advanced Energy Design Guide: Small Retail Buildings*. Because this draft followed peer review and revision of the 65% Concept Draft, it is essentially complete but it is not final. Following the review period of May 8-17, 2006, the AEDG-SR Project Committee met on May 20-21 to review the recommendations received.

172 remarks and review recommendations were received from 22 reviewers representing ASHRAE SSPC 90.1; TCs 2.8, 7.6, and 9.5; AIA; IESNA; USGBC and the ASHRAE membership at large. The following documents the project committee's summary response to those remarks and review recommendations. Although many of the suggestions dealt with details and wording clarification, this summary includes responses only to significant technical recommendations, in particular those in which there was disagreement with what had been written or omitted. The specific and detailed suggestions and remarks have been, and will continue to be, reviewed and digested by the project committee as it prepares the final version of the Guide. The review remarks fall into the following four categories.

1) General Comments

- Use of "must" in recommendations: this term is used in appropriate contexts to describe how a recommendation or option may be completed to achieve the performance desired, rather than to impose criteria. Final editing will ensure that all figures are referenced in the text. A bibliography or reference listing will be added as Appendix B

- Commissioning: It was suggested that modified wording in ASHRAE Guidelines 0 and 1 (e.g., Pre-Functional Checklist and Functional Performance Testing) be included. Changes will be made to use the Gdl 0 and Gdl 1 terminology.

- The final document will include a percent savings relative to 90.1-2004 that is equivalent to the 30% savings relative to 90.1-1999.

- Durability of window framing materials was raised as a general issue, but especially with respect to EN-22, Table 5-1. Storefront windows are commercially available in vinyl, wood, and aluminum (metal frames with thermal breaks, or isolation, that meet U-factor requirements, are available to achieve as U=0.38). Note that the descriptions are examples only; however, the final document will include several alternatives in Table 5-1 that meet these specifications.

- Concern was expressed that the HVAC equipment and service water heating coverage favors electric resistance over gas and are not fuel neutral. Revisions will be made in the Recommendations Tables and in How-to-Tip HV-2 to clarify these applications. Both gas and electric resistance units may be used in appropriate situations; neither is favored over the other.

- Concern was expressed that the recommendations in this Guide might become law. This is beyond our control but is clearly not our intent. These are recommendations, not requirements.

2) Design Process (Chapter 2)

   a) Design Phase

      - Planning phase is not included: "Planning Phase" will be added to title of section but note that planning phase tasks are included in the table "Energy in the Context of Design Phase Process."

   b) QA: In-House or Third Party?

      - Need clarity on what the overall commissioning cost (time) will be: The number of hours for the Cx work scope is being reviewed. 25-50 hours is estimated for overall project Cx need.

      - Concern that review at 100% CD completion is too late to incorporate changes: text will be added to recommend review at 90% or so completion.

      - Include design and construction team meeting in Design Phase Process: this is adequately covered in the "Energy in the Context of the Design Phase Process" Table in Chapter 2.

   c) Table 2.1 – Energy Goals and Strategies

      - Define control sequences and calibrate site-installed sensors: this information is too detailed for a design strategy table. This should be addressed in Cx work scope.

      - Should note which sides of the building need shading under "Shade building surfaces": shading as a function of wall orientation will be added here.

      - Under "General Strategies" column, "Increase thermal mass", a reference to the How-to-tip on thermal mass will be added. "Say What" was extraneous and has been eliminated. Similarly, under “Operable windows…” a reference to EN-27, which covers operable windows and natural ventilation, will be added.

- Under “More efficient interior lighting” the note will be reworded so as not to categorically eliminate incandescent lighting but to limit its use. The How-to-Tips for interior and exterior lighting will be revised accordingly.

3) Recommendations by Climate (Chapter 3)

- The climate zone map included in the 90% completion draft is the version that will be included in the final document; reference to DOE web sites will be deleted.

- The California county listings in the climate zones (2 through 6) have been reviewed; Humboldt County was missing and will be added in zone 4. Note that 8 zones are used in 90.1 and 90.2, as well as the International Energy Conservation Code.

a) Envelope

- The SRI=78 recommendation is based on formulas in the ASTM E 1980 standard for a reflectance of 0.65 and emittance of 0.86. The SRI=82 value in 90.1-1999 is a trade-off option used to reduce insulation levels below the minimum criteria and thus is not comparable with the SRI=78 in this AEDG.

- Why is the recommended SHGC higher in zone 1 (0.44) than in all other zones (0.41) when zone 1 is the warmest climate? The recommended SHGC/U-factor combinations are derived using the data that is the basis of the 90.1-1999 values. However, the glazing options for this Guide were limited to clear glass because retail stores desire customers to see product displays. The available clear glass products analyzed resulted in a SHGC/U-factor combination meeting the higher heating loads of zone 2, which were not required for zone 1. That combination happened to have a SHGC that is higher in zone 1 than in zone 2. A reflective tint option would have resulted in a lower SHGC in zone 1 as is expected.

- Roof and wall insulation anomaly: The R-60 recommendation for attic insulation in zone 4 will be replaced with R-38. The wood and mass wall recommendation of U=0.090 for zone 3 results from the use of the data base of 90.1; the analysis indicates the same level of insulation for wood and mass walls.

- It was suggested that in zone 5 sections be added to support shading, thermal mass, and natural ventilation tuned to climate and orientation. Because this Guide is not a comprehensive reference for all ways of achieving 30% savings, *a way and not the only way* is presented. Fine tuning to the climate is a complex task beyond the scope of this document.

b) Lighting

- Under "Interior lighting sources" in the Recommendation Tables consideration of LEDs and other sources will be added.

- It was suggested that when using skylights, all ambient fixtures should be dimmed rather than only those within 10 ft. of skylight edge. Clarifying language is being added to address this.

- It was suggested that we develop exterior lighting W/ft^2 for different lighting zones (LZ0 thru LZ4). This is beyond the scope of the Guide.

c) HVAC and SWH

- Concern was expressed that the 90% efficiency recommendation for zones 5 through 8 may be adopted as a code requirement. The committee believes that this is unlikely and notes that the introduction clearly states that the Guide should not be used in this manner. Furthermore, it is only reasonable to recommend higher furnace efficiencies in colder climates.

- It was noted that the majority of SWHs applied to retail stores are of residential size, not commercial. It was suggested that the 90% Et be replaced with the current Federal minimum for residential gas water heaters: EF=0.67-0.0019 x V. In response it is noted that there are <u>commercial gas storage water heaters</u> available at the 90% Et level. If these products are used they should be more efficient than the minimum contained in 90.1. The document will be modified to add the input range for gas storage water heaters to clarify the intent that this recommendation applies only to commercial units and *does not prohibit the use of residential gas storage water heaters*. Because there is no recommendation for residential gas storage water heaters, the default value would come from Standard 90.1, which already contains the Federal minimum level suggested. Wording will be added in the "How-to-Tips" to clarify this.

- It was suggested that a requirement be added for <u>commercial electric storage water heaters</u> because the only recommendation cited is for residential sizes and 90.1 does have a minimum requirement for electric commercial storage type water heaters. The committee considered adding a recommendation for commercial electric storage units, but decided not to because there was insufficient data available to support such a recommendation. Furthermore, most of the water heaters in small retail buildings will be residential sizes. Because hot water loads in small retail buildings are small, the lack of a recommendation on commercial electric water heaters wouldn't result in much of an energy effect anyway.

- It was suggested that a separate provision for <u>residential electric storage water heaters</u> be retained that is consistent with the Federal minimum efficiency levels, and also that the volume adjustment for residential electric storage should read - 0.00132 x V, not -0.0012 x V. It was also suggested that the recommendations address residential units <20 gallons capacity. The Guide generally does not repeat efficiency levels that are already contained as minimums in underlying standards. No correction needs to be made to the volume adjustment because this enhanced recommendation exceeds the current requirement in Standard 90.1 and the equation has different coefficients. It applies to residential electric storage water heaters (but only sizes of 20 gallons or greater), not commercial. Because Standard 90.1 does not contain minimum requirements for electric storage water heaters < 20 gallons, the Guide does not provide a recommendation for them. Furthermore, because this Guide simply provides recommendations and is not a standard, enforcement is not an issue.

- It was suggested that a separate category for electric instantaneous water heaters be added with the Federal minimum energy factor of 0.93-0.00132 x V. Because Standard 90.1 does not contain minimum requirements for electric instantaneous water heaters the Guide has chosen not to provide a recommendation for them. The efficiency of these devices is fairly high already and, as is noted, there is a new Federal minimum requirement.

4) How-to-Tips Implement Recommendations (Chapter 5)

a) Envelope

- EN1 Cool Roofs: The Guide does not limit the slope of cool roofs.

- EN4 Roofs, Attics, and Other Roofs: Ventilation opening requirements are referenced in the International Building Code (IBC) to the floor area, not volume, of the attic. Because the function of the attic ventilation is to relieve heat gain from the roof, and to vent moisture leakage from the occupied space, ventilation opening should be related to these areas rather than to volume. The text will be changed to preclude application of ceiling insulation over lay-in ceiling tiles.

- EN8 Walls, Steel Framed: The sentence related to vapor barrier placement will be deleted because the focus of this Guide is on energy, not moisture control. It will be replaced by a sentence explaining that batt insulation is installed as “full width batts” that are friction fitted.

- EN15 Doors – Opaque, Swinging: A line will be added to Table 2.1 promoting use of vestibules. In caption to Fig. 5-14 reference to revolving doors will be deleted.

- EN22: Table 5-1 will be completely revised to provide descriptions of glazing units representative of those typically found in retail buildings. American Architectural Manufacturers Association (AAMA) Standard 507 will be added as reference for site-built products.

- EN29 Glazing: Warm climates will be revised to include only zones 1 through 4. Description of parameters for creating chimney effect is beyond the scope of this Guide.

b) Lighting and Daylighting

- DL3 Control of Direct Sun Penetration: Options for shading are being expanded in the final document to include shades, roll up or horizontal blinds, as well as vertical slat blinds.

- DL6 Expanded Recommendations for Electric Lighting Controls in Daylight Zones: Text will be expanded to include discussion of issues associated with luminance balance. The paragraph relating to specification of luminaries with multiple lamps wired for inboard-outboard or inline switching will be deleted; dimming ballasts should be used. The sentence on photosensor placement will be deleted and incorporated into a revised DL7.

- Accent Lighting: the quantitative aspects of this lighting component are described in EL2, where contrast level categories are listed.

- EL2 Additional Interior Lighting/Accent Lighting: Fig. 5-22 is only a placeholder and will be replaced by an illustration more descriptive of merchandising.

- EL6 Color Rendering Index (CRI): Concern was expressed that CRI is a bad metric. The committee disagrees. While the metric has its limits, it is a valid methodology by which end users may make decisions regarding lamp selection. CRI can be used when a lighting designer is included on the design team; also it is a relatively understandable metric to a retailer or contractor if the design team does not include advanced lighting expertise. The CRI description will be clarified.

- EL8 Fluorescent T5 Sources: It was suggested that more guidance is needed as to when to use different types of lamps. Clarification will be added but there are too many permutations to allow detailed discussion.

- EL11 Halogen IR: The description has been revised to more accurately present the numbers comparing CMH and HIR lamps.

- EL12 Light Emitting Diodes: This section is being rewritten to be less confusing. However, LED binning will not be discussed because it is unnecessarily advanced for the target audience.

- EL 13 Occupancy Sensors: Information on passive infrared (PIR) sensors, ultrasonic and dual technologies will be added to this section.

- EL17 Light Fixture Distribution: Additional information will be added discussing direct, direct/indirect, and indirect lighting strategies.

- Cautions: The cautions here in lines 1835-1839, and in 1526-1530, will be deleted.

- Exterior Lighting: We will change "…at least 50% 2 hours after normal business hours" to "…at least 50% 1 hour after normal business hours." A statement that all lighting should be directed to minimize glare across property lines is already included in the bonus exterior lighting section.

- EL26-EL28 need to be separated from EX1-EX4 because the former are part of the recommendations, whereas the latter are bonus savings not included in the recommendations.

- EL27 Sources: LEDs will be added as a potential exterior lighting source.

c) HVAC and SWH

- HV1 General: Gas furnaces rather than oil furnaces were included because gas is the predominant heating fuel for furnaces, and gas furnaces are common in retail stores. "Integral" will be deleted from the description of the systems covered. The location of equipment is not stipulated; we only recommend a location that minimizes energy use and installation cost.

- HV2 HVAC System Types: Gas-fired heaters are limited to indirect types because direct-fired gas heaters are neither common nor desirable in most small retail store applications. The discussion of the variable-volume systems tips will be rewritten to be more performance oriented. The point of the sentence that mentions reheating is controls, not reheat strategies. But to avoid implying that reheat is desirable, the sentence will be revised for clarification. Discussion of variable speed drives will be modified to be presented as only an option.

- HV3 Cooling and Heating Loads: Truly oversized systems are indeed a significant problem, especially in humid climates. It is appropriate to provide advice on this subject.

- HV4 Humidity Control: The discussion regarding keeping relative humidity below 60% will be clarified to recommend that the number of hours above 60% be minimized.

- HV7 Ventilation Air: Fig. 5-27 is unclear and will be revised and captioned "Example of Ventilation System." While HV7 does not discuss calibration of CO2 sensors, that topic is discussed in HV22. CO2 sensors are a valid option for ventilation control.

- HV9 Ductwork Distribution: The committee believes that ducted systems allow for significantly better control of air flow and ventilation, therefore they should be recommended. The paragraph dealing with duct board will be revised significantly to focus only on low leakage performance. Duct “Seal Class B” has been added as a specification here.

- HV11 Duct Sealing and Leakage: A standard citation for duct sealing will be added per “…Seal Class B from Standard 90.1…”

- HV14 Control Strategies: Revisions will be made to caution that temperature setup during the cooling season may cause a humidity increase and that care should be exercised to avoid this.

- HV16 Filters: Will cite ASHRAE Standard 52.2 as source of MERV 8 recommendation. Filter replacement will be tied to pressure drop across the filter relative to the filter manufacturer’s recommended maximum pressure drop.

- HV18 Return and Relief Air: The return static need for blowers (where duct pressure exceeds 0.5 in. H_2O) is based on engineering judgment. It is not necessary to justify all items of this type in the Guide.

- HV22 Carbon Dioxide Sensors: Linking CO_2 sensors to systems of 500 cfm OA or greater is a rule of thumb. Spaces have widely varying ventilation needs that are not related to floor area and advice such as this is appropriate. Also, the recommendation that the OA ventilation rate should not exceed that required by code, regardless of CO_2 concentration, balances energy use and ventilation requirements.

- HV23 Economizers: Enthalpy economizers should only be *considered* in humid climates, and only to provide protection against high humidity. Yes, economizers are applicable in dry areas of zone 2; however, their use in humid areas of zone 2 is not advisable.

d) Bonus Savings:

- Exterior lighting in this section relates only to parking lots and grounds that are often beyond the control of small retailers. Thus, they are listed as bonus savings. These tips differ from those in the exterior lighting discussion on pp. 71-72.

- EX3 Parking Lighting: The likelihood that a floodlight used in a parking lot will be misaimed is too great and thus, they are discouraged for this application. As for the “dual purpose” aspect, in most cases upward-directed floodlighting increases the probability of light pollution and light trespass onto adjacent properties. However, the text will be revised to allow use of cutoff wall-packs up to 350 W in pulse start lamps.

e) Appendix A, Table A-1: the value for heated slabs with R10/36 in. has been corrected to be 0.84.