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Pacific Northwest National Laboratory
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Technical Support Document: Development of the *Advanced Energy Design Guide for Small Office Buildings*

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November 2006

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

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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 Office Buildings* (AEDG-SO), a design guidance document intended to provide recommendations for achieving 30% energy savings in small office buildings over levels contained in ANSI/ASHRAE/IESNA Standard 90.1-1999, *Energy Standard for Buildings Except Low-Rise Residential Buildings*. The AEDG-SO is the first 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 New Buildings Institute (NBI), and the U.S. Department of Energy (DOE).

Each of the guides in the AEDG series will provide 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 will 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-SO was developed by an ASHRAE Special Project committee (SP-102) 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 office guide and outlines the schedule of the development effort. The project committee developed two prototype office buildings (5,000 ft^2 frame building and 20,000 ft^2 two-story mass building) to represent the class of small office 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. 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 38%.

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Nomenclature

AEDG-SO	Advanced Energy Design Guide for Small Office 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
Ec	combustion efficiency
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
NBI	New Buildings Institute
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

1.0 Introduction

The *Advanced Energy Design Guide for Small Office Buildings* (AEDG-SO) (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 New Buildings Institute (NBI), 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). The selection of Standard 90.1-1999 for the baseline was also based on the fact that the standard was the most recent one for which DOE had issued a formal determination of energy savings at the time of preparation of the Guide. ASHRAE and its partners are engaged in the development of a series of guides for small commercial buildings, with the AEDG-SO being the first in the series.

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 office 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.

Office buildings were chosen for the first 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, office buildings account for 1,134 trillion Btu of energy use, or approximately 19.5% of the energy use of all commercial buildings (CBECS 2003). The size of the office buildings covered by this Guide was selected as buildings up to 20,000 ft^2. According to CBECS 2003, offices up to 20,000 ft^2 represent over 75% of the office building stock. Limiting the building size helped in bounding the scope of the effort necessary for development of the Guide, and allowed the Guide to focus on energy measures that were deemed appropriate for the target market.

1.1 Charge to the Committee

A steering committee (known as the Cognizant Committee) made up of representatives of the partner organizations issued a charge to the project committee selected to develop the Guide. The charge included a timeline for the task, an energy savings goal, an intended target audience, and desired design assistance characteristics. These elements of the charge to the committee are contained below:

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
- Address tenant improvements
- Provide case studies where appropriate.

1.2 Scope of Document

The scope of the document is limited to office buildings that meet the following criteria:

- Does not exceed 20,000 gross square feet
- Provide for new buildings, complete renovations to existing buildings, systems within an existing building under renovation
- Has heating and cooling provided by unitary heating, ventilation and air conditioning (HVAC) equipment (packaged or split systems).

Exclusions

- Built-up systems using chillers and boilers
- Has heating or cooling provided by a hydronic heating or cooing system

Recommendations contained in the AEDG-SO 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 day lighting 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-SO project committee was designated as ASHRAE Special Project 102 (SP-102), and included membership from each of the partner organizations.

Table 1-1 lists the project committee members and the organizations that they represent.

Table 1-1. SP-102 Project Committee Organization Chart

Ron Jarnagin – *Chairman*	
Merle McBride	Hayden McKay
ASHRAE At-Large Representative	*IESNA Representative*
Don Colliver	Michael Lane
Steering Committee Ex Officio	*IESNA Representative*
Jay Enck	Harry Misuriello
ASHRAE TC 2.8 Representative	*ASHRAE TC 7.6 Representative*
Jim Edelson	Dan Nall
NBI Representative	*AIA Representative*
Donna Leban	Joe Deringer
AIA Representative	*AIA Representative*
Don Steiner	Bruce Hunn
ASHRAE SSPC 90.1 Representative	*ASHRAE Staff Liaison*

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 and TC 7.6 is the systems energy utilization technical committee. Each of the represented organizations was given the chance to provide peer review input on the various review drafts produced by the project committee. In effect, these representatives served as the interface to their respective organizations to ensure a large body of input into the development of the document

2.0 SP-102 Development Schedule and Milestone

Following the guidance from the steering committee, the SP-102 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. The SP-102 committee planned for three peer review periods that corresponded with a 50% completion draft (conceptual review), an 80% completion draft (technical refinement review) and a 100% 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. Table 2-1 outlines key dates in the development of the AEDG-SO.

Table 2-1. AEDG-SO Key Development Dates

Date	Event	Comment
10/1-2/2003	SP-102 Meeting #1	Initial organizational meeting
10/29-30/2003	SP-102 Meeting #2	Scoping results, climate locations selected
12/18-19/2003	SP-102 Meeting #3	Discussions on format and outline, initiate writing
1/10-11/2004	SP-102 Meeting #4	Review with Cognizant Committee, focus on format and content
1/21-22/2004	SP-102 Meeting #5	Complete 50% draft
1/23-2/6/2004	50% Conceptual Draft Peer Review Period	Milestone #1
2/10/2004	Meeting #6-Conference call	Discuss input on 50% draft
3/1/2004	Meeting #7-Conference call	Respond to input on 50% draft
3/25-26/2004	SP-102 Meeting #8	Completed 80% Draft
3/29-4/9/2004	80% Technical Refinement Draft Review Period	Milestone #2
4/23-24/2004	SP-102 Meeting #9	Review peer review input and prepare 100% Final Draft
5/3/2004	Meeting #10-Conference call	Final preparation of 100% Final Draft
5/7/2004	Meeting #11-Conference call	Approval of 100% Final Draft
5/10-17/2004	100% Final Draft Review Period	Milestone #3
6/7/2004	Meeting#12-Conference call	SP-102 final approval
6/15/2006	Transfer final draft to steering committee	Milestone #4
6/21/2004	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 was to conduct an initial scoping study. The scoping study evaluated the possible energy savings from the energy efficiency measures selected by the SP-102 committee for a set of four climate locations chosen to demonstrate some of the extremes of energy performance. Section 4 in this report describes the scoping study in details. A 5,000-ft^2 single story office prototype with frame wall construction and a 20,000-ft^2 two-story office prototype with mass wall construction were selected as the building prototypes to represent both the smaller end as well as the larger end of the office buildings within the chosen size range. Section 4 of this report describes the basis for the decisions on the small office prototypes.

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 office building prototypes for all 15 representative locations. Fifteen climate locations were selected to adequately represent the eight climate zones (and sub zones) in the United States. Characteristics of the 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 of energy savings analysis involved summarizing the energy simulation results for all locations and presenting the final energy saving recommendations by climate zones, as described in Section 10.

3.2 Simulation Tool Description

The AEDG project committee used eQUEST (Hirsch 2005) as the primary energy simulation tool for the energy analysis in the scoping study due to its ease of use and familiarity to a number of the project committee members. The simulation engine within eQUEST is a private-sector version of DOE-2 (LBNL 2004), 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

The project committee decided to perform 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 office buildings can vary from the simple single story frame construction that often looks like residential construction (for offices like real estate, insurance, doctor's office) up to multiple story mass wall construction, the committee decided to establish two distinct prototypes that represented each end of the spectrum of building types.

The committee felt that having a prototype building with a lightweight frame wall and a pitched roof with attic would represent a building that might more easily comply with the advanced recommendations since the building envelope assemblies provided an easy allowance for additional insulation. Conversely, the mass wall prototype building with a concrete masonry wall would represent a building that might have more difficulty complying with the advanced recommendations due to the difficulty of adding wall insulation to mass walls as well as the fact that this building might be more internally load dominated.

After significant debate, the project committee settled on a 5,000 ft^2 frame wall single story prototype and a 20,000 ft^2 mass wall two-story prototype. The 5,000 ft^2 size was chosen for the smaller building prototype since it approximated the size of a large single family residence. The 20,000 ft^2 size was chosen for the larger building since it represented the upper end of the range of building sizes covered by the charge to the committee.

Each of the prototype buildings had a square floor plan to avoid impacts on energy use due to orientation of the building. This resulted in the simulations being orientation independent. Both buildings used slab-on-grade construction and were heated and cooled with unitary packaged equipment. The smaller prototype utilized punched windows typical of residential construction with a window-wall ratio (WWR) of 20%. On the other end, the larger prototype utilized ribbon windows more typical of commercial construction with a 30% of WWR. The smaller prototype had a single tenant, and the larger prototype had 3 tenants.

For the smaller prototype the unitary equipment served a single zone, while in the larger building prototype the unitary equipment served five zones. Each building was served by packaged rooftop unitary constant volume equipment with electric direct expansion (DX) cooling and gas heating. The two prototypes were served by a single air conditioner sized to meet the building's load. The air conditioning units were operated with setback and setup control strategies, and ventilation air was supplied as required by ASHRAE Standard 62-2001 (ANSI/ASHRAE 2001). The HVAC system used a ducted supply and return system.

Occupancy hours for each prototype were assumed to be the same as the office occupancy schedules developed for DOE's commercial unitary air conditioner rulemaking (PNNL 2004). These schedules are similar to schedules published in ASHRAE Standard 90.1-1989 (ANSI/ASHRAE/IESNA 1989). Peak occupancy values were developed from values of peak occupancy from ASHRAE Standard 62-2001 (ANSI/ASHRAE 2001). Schedules for the HVAC system were matched to the occupancy schedules, and allowed for earlier startup times to bring the space to the desired temperature.

The 5000-ft^2 smaller office exterior envelope consisted of 2x4 wood stud construction 16 in. on center with sheathing and external stucco covering. Glazing was limited to 20% of the exterior wall area, and was distributed equally in all orientations. Each window contained a 5-ft overhang for shading and weather protection for the advanced case. The floor to ceiling height was 9 ft with an attic roof construction of 3 in 12 pitch and 2 ft overhangs.

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 New Building Institute's *Advanced Buildings E-Benchmark* (NBI 2003) for the advanced case. These values are found in Appendix A. *The Advanced Building Guidelines* measures were "borrowed" for the scoping study since these measures had been simulated by NBI and had been shown to reach the 30% savings levels. The scoping study was designed only to get a quick estimate of the committee's ability to meet the energy savings target, and the committee understood that they would have to independently develop a set of recommendations for all of the energy savings measures for the Guide.

Lighting levels in the office prototypes were selected from the whole building values contained in ASHRAE Standard 90.1-1999. The standard allows a maximum lighting power density of 1.3 W/ft^2, which was used for the baseline value in both the scoping study and the full simulation study.

The 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.

Illustrative three-dimensional models of both the 5,000 ft^2 prototype office (Figure 4-1) and the 20,000 ft^2 prototype office (Figure 4-2) are for reference on the following page.

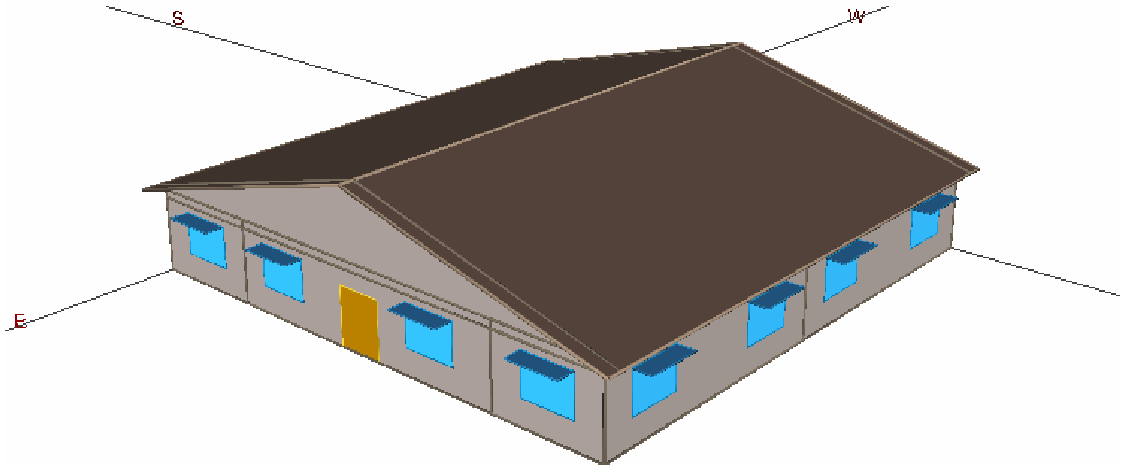


Figure 4-1. Three-Dimensional Model of the 5,000 ft^2 Prototype

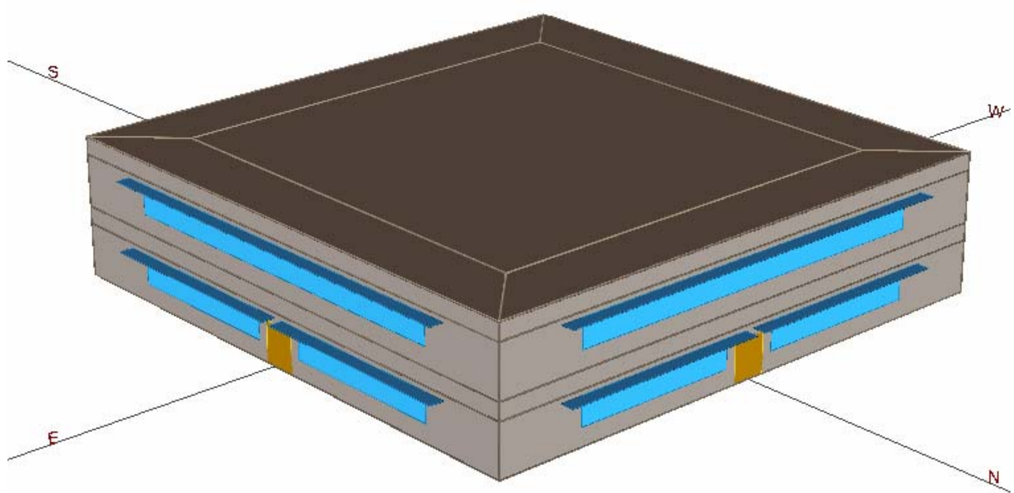


Figure 4-2. Three-Dimensional Model of the 20,000 ft^2 Prototype

Results of the simulation indicated the potential for reaching the energy savings goal in each of the climate extremes. The simulation results indicated that colder climates might easily meet the target, while the warmer or milder climates might require additional attention. 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 Small Office Prototype

Climate Location	Whole Building Savings with Plugs in denominator, %	Whole Building Savings without Plugs in denominator, %
Miami	30.0	35.7
Phoenix	31.0	36.6
Seattle	30.0	36.4
Duluth	46.0	50.4

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 regardless of the method chosen for displaying the results. However, because plug loads are only addressed in the Guide's recommendations as "bonus savings", 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 by about 5% to 6% when plugs are not included in the denominator, indicating that plug loads in offices are a significant energy user.

Based on the initial results of the scoping study on the small office prototype, the committee made the decision to forego a scoping study on the large office prototype. The reason for this was that the preliminary scoping results indicated that achieving the desired savings results might be met in the small office prototype once the committee formulated their own recommendations for the energy savings measures, particularly in the colder climate locations. Even though the large office prototype was not fully 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 for the smaller prototype, as a part of the initial scoping study.

5.0 Selection of Climate Locations for Final Guide

The project committee for the *Advanced Energy Design Guide* decided to standardize on 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 as well as above code documents like the AEDG series. 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.

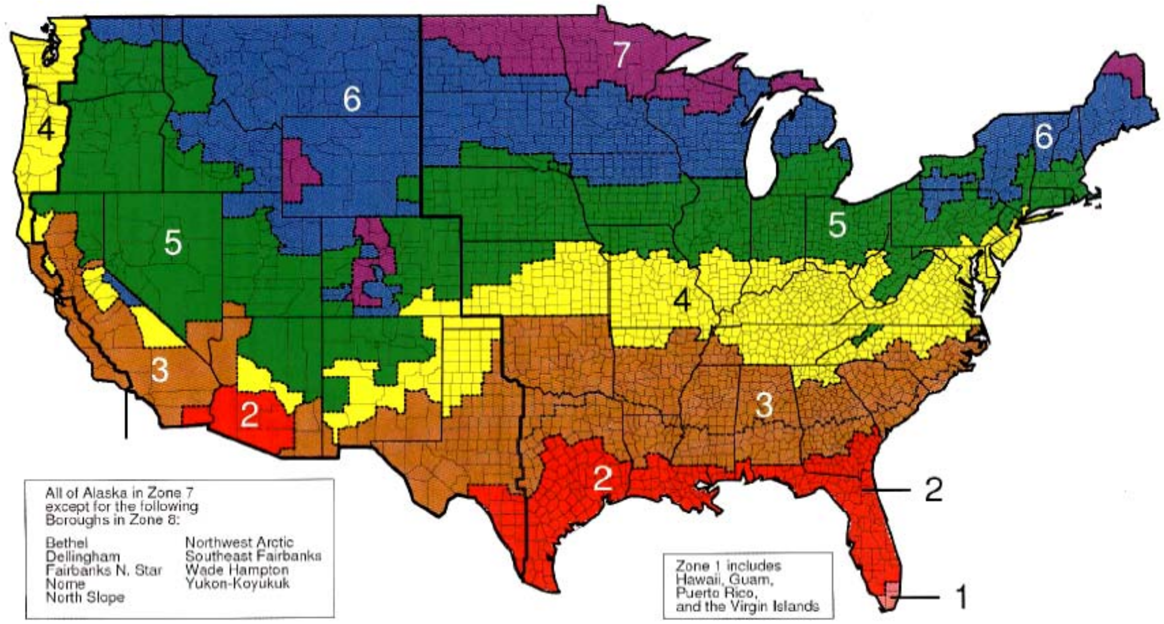


Figure 5-1. U.S. Department of Energy Developed Climate Zone Map

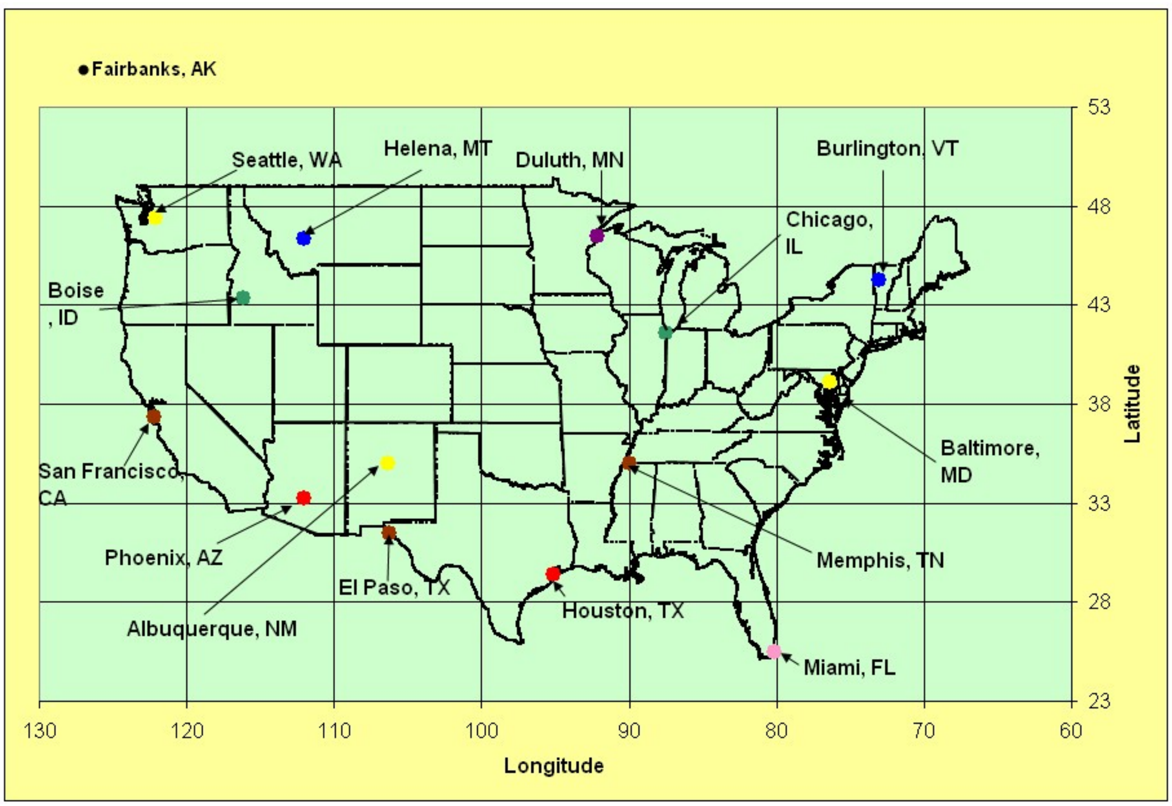


Figure 5-2. Representative Climate Locations in U.S.

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 typical offices. The committee first went through a brainstorming exercise to list all of the technologies that might be used to achieve higher energy efficiency. Then the committee went back through this list and selected those technologies that would most likely be used at the desired savings level for the Guide. Such technologies as photovoltaics were eliminated since the committee felt these would not be used at the level of efficiency. As a starting point, the project committee used the recommendations from the *Advanced Buildings E-Benchmark* (NBI 2003) for performing its early rounds of scoping study analysis for the reasons explained in Section 4.0. Subsequently the committee developed its own recommendations for all of the technologies when the final recommendations for the guide were developed. The following sections briefly describe the process the committee used to choose the technologies for the final recommendations.

6.1 Envelope Technologies

In general, the committee chose the next assembly insulation level that was more stringent than the base standard, and then the buildings were simulated to assess the impact of that choice. Stringency levels were varied to ensure the envelope contributed proportionately to the savings of the overall building.

The AEDG-SO provides 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. The AEDG-SO also contains a window orientation recommendation that attempted to influence the placement of glazing on orientations to reduce solar loading. This recommendation is, in effect, a recommended solar aperture that limits glazing on east and west orientations.

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%. The upper limit of 40% WWR was based on a desire to limit fenestration to limit thermal penalties since even very good fenestration does not perform as well as good opaque wall assemblies from a thermal standpoint.

6.2 Lighting and Daylighting Technologies

The area of lighting and daylighting are areas where substantial energy savings can occur. 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.

In addition to the lighting levels, the committee addressed light source efficiencies by establishing a minimum mean lumens/watt for fluorescent lamps and provided a recommendation for high performance ballasts, which drives the design towards efficient components.

Lighting control recommendations include a provision for occupancy sensors to turn off lights during unoccupied hours. Daylighting controls recommend fixtures within 12 ft of north or south window walls and within 8 ft of skylight edges. To enhance the performance of daylighting the AEDG-SO recommends values for interior room surface reflectance for ceilings, walls, and vertical partitions when daylighting is used.

6.3 HVAC and Service Water Heating (SWH) Technologies

In general, the HVAC and SWH technologies were increased over the base standard in order to meet the energy savings targets. The AEDG-SO provides an 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. In addition, the AEDG-SO also contains 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 (DCV) were both technologies that are recommended in the Guide. Each of these technologies has been demonstrated through simulation to achieve significant energy savings 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 office 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 small office (4,900 ft^2) was constructed with wood-framed exterior walls, an attic and slab-on-grade floors. For the large office prototype (20,000 ft^2), it was assumed that the exterior walls were concrete masonry units, the roof was built up with insulation above the deck and slab–on-grade floors. These envelope structures represent common construction practice for small office buildings in U.S. based on information from the 2003 CBECS (CBECS 2003).

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 *Prescriptive Building Envelope Option*. 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., wood-framed walls in the smaller office building and mass walls in the larger office building. Wood-framed exterior walls were assumed to have a standard framing configuration, i.e., 2x4 wood stud framing at 16 -in. on center with cavities filled with 14.5- in. wide insulation for 3.5-in. deep wall cavities. The overall U-factor was calculated based on the weighting factor of 75% insulated cavity, 21% of wood studs, plates, and sills, and 4% of wood headers, in accordance with A3.4 (a) in the Standard. The wood-framed wall includes the following layers:

- Exterior air film (R-0.17)
- 1-in. thick stucco (R-0.08)
- 0.625-in. thick gypsum board (R-0.56)
- Cavity insulation (various by climate)
- Wood studs or wood headers (R-4.38)
- 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).

Insulation 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

An attic roof was used for the smaller office building and a built-up roof was used in the larger office building prototype. The attic roof was assumed as the roof with a standard wood framing. In accordance with A2.4 (a) in the Standard, the base attic roof assembly was a roof with a normal 4-in. deep wood as the lower chord of a roof truss or ceiling joist. The ceiling was attached directly to the lower chord of the truss and attic space above was ventilated. Insulation was located directly on top of the ceiling, first filling the cavities between the wood and then later covering both the wood and cavity areas. Insulation was tapered around the perimeter with resultant decrease in thermal resistance. The overall U-factor was determined by the weighting factor of 85% full-depth insulation, 5% half-depth insulation, and 10% of wood joists, in accordance with A2.4 (a) in the Standard. For the wood joists, it was assumed that there was a one inch air space above the top of wood joist until the insulation expands to the full cavity width, based on the inputs from the project committee. The attic roof includes the following layers:

- Semi-exterior air film (R-0.46)
- Full-depth cavity insulation (various by climate)
- Half-depth cavity insulation (various by climate)
- 1-in. air space above wood joists (R-0.9)
- Wood joists (R-4.38)
- 0.625-in. thick gypsum board (R-0.56)
- Interior air film heat flow up (R-0.61).

The built-up roof has rigid insulation over a structural metal deck. The minimum U-factor for the built-up roof 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 was continuous and uninterrupted by framing. Roof insulation R-values for both the attic and built-up roofs 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 (ft^2).

7.2.4 Fenestration

Small office buildings generally have moderate window-to-wall areas, usually in the 20%-30% range according to CBECS database (CBECS 2003). The overall WWR of the entire building used in the modeling was chosen as 20% for the smaller office prototype and 30% for the larger office prototype, 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:

$$SC = \frac{SHGC}{0.86} \tag{7.2}$$

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, for some climates, no actual windows exist to match some of the fenestration requirements in the Standard.

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/ft² of gross exterior wall, per the U.S. Department of Energy's *Code of Federal Regulations* 10 CFR Section 434.516. (10 CFR 434, 2002).

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 and two-story office models 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. In the baseline prototypes, the roof exterior finish was chosen as medium brown asphalt shingles for the attic roof, and a single-ply roof membrane with grey EPDM (ethylene-propylenediene-terpolymer membrane) for the built-up roof, respectively. From a cool roofing materials database by the Lawrence Berkeley National Laboratory (COOL ROOFING 2004), the solar reflectance of the medium brown asphalt shingles was 0.12, and the corresponding emittance was 0.91. The solar reflectance of a grey EPDM 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.

Internal load schedules were developed from schedules previously used in work for the Department of Energy on the Commercial Equipment Standards program. Additional data on occupancy was derived from ASHRAE Standard 62-2001 (ANSI/ASHRAE 2001). Appendix A in this report contains a table of the schedule profiles for each of the three internal load categories (plugs, lights and occupancy). Figure 7-1 shows a typical occupancy schedule for an office open Monday through Friday.

7.3.1 Occupancy Densities and Thermal Loads

The value of the peak occupancy for office space, 7 persons per 1000 square foot of net occupied space, was derived from data in the ASHRAE Standard 62-2001. The committee assumed 80% net occupied space for the studied office 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, including 250 Btu/hr sensible heat gain and 200 Btu/hr latent heat gain. These values represent the degree of activity in offices, i.e., standing, light work and walking, and were derived from Table 1 of Chapter 29 in the ASHRAE 2001 Fundamentals Handbook (ASHRAE 2001), assuming that the occupant activity levels did not vary with climate.

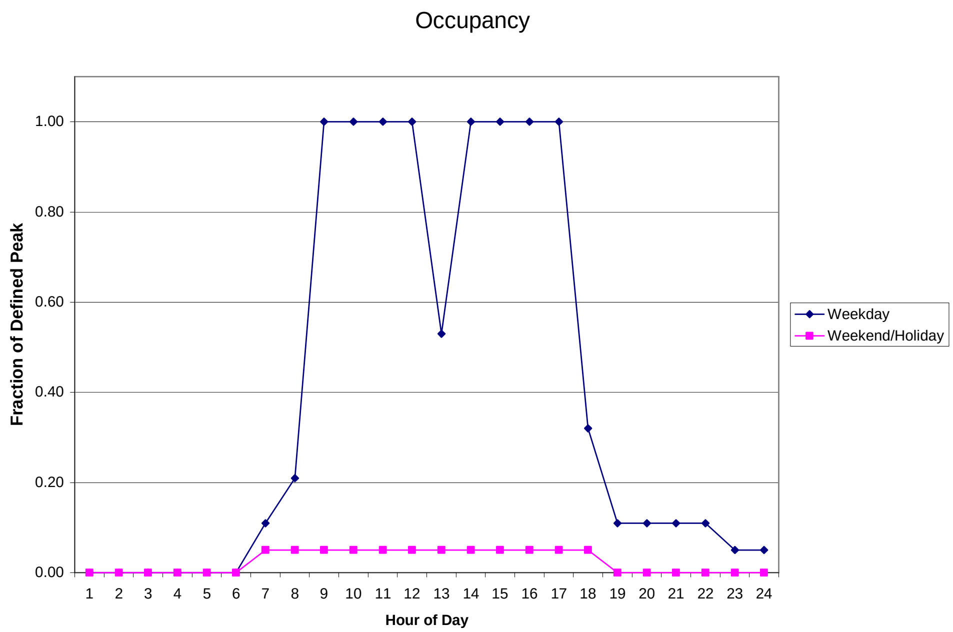


Figure 7-1. Typical Small Office Occupancy Schedules

7.3.2 Lighting Power Densities

Office lighting can vary depending on the nature of the spaces served and the type of lighting fixtures used in the building. However, for typical offices the lighting levels are generally found to be in a somewhat limited range. The baseline lighting levels were drawn from Table 9.3.1.1 in the Standard 90.1-1999, using the building area method. The lighting loads were represented in the simulation models by a peak lighting power density in watts per square foot. The whole building lighting levels from Standard 90.1-1999 allow a lighting power density of 1.3 watts per square foot for office building. This represents a conservative value as use of the space-by-space method could allow higher lighting levels in the baseline building.

7.3.3 Appliance (Plug) Loads

Small offices generally have appliance (plug) loads, normally used for office equipment (computers, monitors, copiers, fax machines and printers etc.), refrigerators, coffee makers, and beverage vending machines. 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 offices range from 0.2 W/ft^2 to 0.8 W/ft^2, with most falling in the range of 0.6 W/ft^2 to 0.8 W/ft^2. Off-hour base-load estimates range from 0.0 W/ft^2 to 0.4 W/ft^2, with many falling near 0.3 W/ft^2. To determine the plug load density, a break-down plug load calculations were developed in accordance with ASHRAE's recommended heat gains from various office equipment and appliances (ASHRAE 2001). As shown in Table 7-1 and the peak and off-hour base loads for the smaller office prototype were 0.62 W/ft^2 and 0.15 W/ft^2, respectively. Table 7-2 summarized the peak and off-hour base loads for the larger office building as 0.62 W/ft^2 and 0.06 W/ft^2, respectively.

The typical office 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. Appendix A in this report contains all the plug load schedules used in the simulations.

Table 7-1 Plug Load Density Calculations for the 5,000 ft² Office Prototype

Occupancy Parameter	Value	Data Source
Gross floor area, ft²	4,900	Prototype specification
Office station space, %	30%	PNNL NC³ Database for less than 5300 ft² office buildings
Floor area per workstation, ft²	100	Note 1
Number of workstations	15	

Office Equipment Inventory	Qty.	Peak Power (watts)	Total (watts)	Weekday (M-F) Diversity	Weekday (M-F) Load (watts)	Weekend Diversity	Weekend Load (watts)	Remarks
Computers - servers	1	65	65	0.75	49	0.75	49	Note 1
Computers - desktop (60% of workstations)	9	65	585	0.75	439	0.00	0	Note 1
Computers - laptop (40% of workstations)	6	19	114	0.75	86	0.00	0	Note 2
Monitors - server -CRT	1	70	70	0.75	53	0.75	53	Note 1
Monitors - CRT (50% monitors)	8	70	560	0.75	420	0.00	0	Note 1
Monitors - LCD (50% monitors)	7	35	245	0.75	184	0.00	0	Note 2
Laser printer - network	1	215	215	0.50	108	0.00	0	Note 1
Copy machine	1	1100	1100	0.50	550	0.00	0	Note 1
Fax machine	1	35	35	0.75	0.26	0.00	0	Note 2
Water cooler	1	350	350	0.50	175	0.50	175	Note 1
Refrigerator	1	76	76	1.00	76	1.00	76	Note 3
Vending machine	1	770	770	0.50	385	0.50	385	Note 1
Coffee maker	1	1050	1050	0.50	525	0.00	0	Note 1
Total Plug Load, W					3,074		738	
Plug Load Density, W/ft²					**0.63**		**0.15**	

Notes:

1. Data derived from 2001 ASHRAE Fundamentals Handbook Chapter 29 (ASHRAE 2001)
2. Data derived from a report by Judy Roberson et al. at LBNL (Roberson et al 2002)
3. The average annual energy consumption is 670 kWh/year for a typical non-Energy Star 18-ft³ side mount freezer with through-the-door ice, based on U.S. Environmental Protection Agency estimates. (http://www.epa.gov/)

Table 7-2 Plug Load Density Calculations for the 20,000 ft² Office Prototype

Occupancy Parameter	Value	Data Source
Gross floor area, ft²	20,000	Prototype specification
Office station space, %	40%	PNNL NC³ Database for less than 24,000 ft² office buildings
Floor area per workstation, ft²	100	Note 1
Number of workstations	80	

Office Equipment Inventory	Qty.	Peak Power (watts)	Total (watts)	Weekday (M-F) Diversity	Weekday (M-F) Load (watts)	Weekend Diversity	Weekend Load (watts)	Remarks
Computers - servers	3	65	195	0.75	146	0.75	146	Note 1
Computers - desktop (60% of workstations)	60	65	3900	0.75	2925	0.00	0	Note 1
Computers - laptop (40% of workstations)	40	19	760	0.75	570	0.00	0	Note 2
Monitors - server -CRT	3	70	210	0.75	158	0.75	158	Note 1
Monitors - CRT (50% monitors)	50	70	3500	0.75	2625	0.00	0	Note 1
Monitors - LCD (50% monitors)	50	35	1750	0.75	1313	0.00	0	Note 2
Laser printer - network	3	215	645	0.50	323	0.00	0	Note 1
Copy machine	3	1100	3300	0.50	1650	0.00	0	Note 1
Fax machine	3	35	105	0.75	79	0.00	0	Note 2
Water cooler	2	350	700	0.50	350	0.50	350	Note 1
Refrigerator	3	76	229	1.00	229	1.00	229	Note 3
Vending machine	1	770	770	0.50	385	0.50	385	Note 1
Coffee maker	3	1050	3150	0.50	1575	0.00	0	Note 1
Total Plug Load, W					**12,327**		**1268**	
Plug Load Density, W/ft²					**0.62**		**0.06**	

Notes:

1. Data derived from 2001 ASHRAE Fundamentals Handbook Chapter 29 (ASHRAE 2001)
2. Data derived from a report by Judy Roberson et al. at LBNL (Roberson et al 2002)
3. The average annual energy consumption is 670 kWh/year for a typical non-Energy Star 18-ft³ side mount freezer with through-the-door ice, based on U.S. Environmental Protection Agency. (http://www.epa.gov/)

7.4 Baseline Building HVAC Systems

The scope of this Guide covers small office 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 office space in the United States (CBECS 2003). Single-zone unitary rooftop equipment is commonly used to provide thermal comfort to small office buildings. 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 building, with less duct work and the flexibility to maintain comfort in the event of partial equipment failure (ASHRAE 2003).

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 large and small office prototypes are less than three stories in height and no more 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 7.3.1. The fan is scheduled "on" 1 hour prior to the staff coming to the office to pre-condition the space, and the fan is scheduled "off" 1 hour after the office closes. For both the large and small office building models, only one fan schedule is used for all the 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, annual-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 from Table 1A (*Heating and Wind Design Conditions)* and Table 1B (*Cooling and Dehumidification Design Conditions)* of Chapter 27 in ASHRAE 2001 Handbook of Fundamentals (ASHRAE 2001). In these tables, the 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 smaller office prototype base case adopts 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 larger office 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. The gas-fired furnace efficiency levels were incorporated as 78% AFUE and 80% E_c into the 5-ton unit and 15-ton unit, respectively, to match the minimum efficiency requirements under the Standard.

7.4.4 Fan Power Assumptions

For both the smaller and larger office prototypes the committee assumed that the HVAC system contains only one supply fan, and there is no return fan or central exhaust fan in the system based on the committee's experience with small office 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.

The DOE-2 program can calculate the fan energy consumptions by taking one parameter as input to the packaged unitary air conditioner model, i.e., design full-load power of the supply fan per unit of supply air flow rate in terms of watts per cfm. To calculate the design full-load power of the supply fan, the external static pressure drops were developed and the design fan power 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 external static pressure for both 5- and 15-ton equipment. An external static pressure of 1.2 in. w.c. was calculated for the 5-ton unit, representing the smaller office baseline prototype. For the larger office baseline prototype with the 15-ton unit, an external static pressure of 1.25 in. w.c. was calculated.

Table 7-3. Baseline Building Calculated Duct External Static Pressure Drops

Component	5,000 ft² Office Prototype 5-ton Packaged Rooftop Unit (@2000 cfm)	20,000 ft² Office Prototype 15-ton Packaged Rooftop Unit (@5300 cfm)
External Static Pressure (ESP), in. w.c.[1]		
Diffuser	0.10	0.10
Supply Ductwork[2]	0.28	0.21
Dirty Portion of Filters	0.25	0.25
Return Ductwork[2]	0.06	0.16
Grille	0.03	0.03
Subtotal	0.72	0.75
10 % Safety Factor	0.07	0.08
Subtotal	0.79	0.83
Fan System Effect	0.40	0.40
Total ESP	**1.20**	**1.25[3]**

Notes:
1. External static pressure was calculated based on the typical duct runs served by the listed cooling capacities. For the 5-ton system, the ESP was calculated assuming only one packaged unit serving the entire 5,000 floor area. For the 15-ton system, the ESP was determined based on one packaged unit per zone and total five thermal zones.
2. Used standard practice of 0.1 inch/100 ft friction rate for the baseline prototypes.
3. Round up number from 1.23 to 1.25 per the design practice.

In addition, the design full-load powers of supply fans were determined based on manufacturer's product specifications. For the 5-ton unit at 2000 cfm design flow rate, the full-load fan power is 0.9045 W/cfm at 1.20 in.w.c. external static pressure. For the 15-ton unit at 5300 cfm design flow rate, the full-load fan power is 0.5909 W/cfm corresponding to 1.25 in. w.c. external static pressure. These two full-load power values were used as the baseline models fan power 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 (ANSI/ASHRAE 2001). Standard 62-2001 has requirements for offices based on 20 cfm per person. Assuming typical office occupancy rates as described in section 7.3.1, the ventilation rate for the 5,000 ft^2 and 20,000 ft^2 baseline offices are 0.735 air change per hour and 0.746 air change per hour, respectively. 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 smaller office prototype, with cooling capacity normalized at 60,000 Btu/hr, have no economizer. For the larger office baseline building, 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.

7.5 Baseline Service Hot Water System

The committee defined the baseline service hot water system for both the smaller office and the larger office buildings as a gas-fired storage water heater that meets the minimum equipment efficiency requirements under Standard 90.1-1999. The smaller office prototype was served with a residential water heater (with rated input power less than 75,000 Btu/hr) and the larger office model was designed with a commercial water heater (with rated input >75,000 Btu/hr and ≤155,500 Btu/hr). 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 for the smaller office prototype is that the peak hot water load is usually only from the use of a few lavatories in the 5,000 ft^2 offices. 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.

Table 7-4. Baseline Modeling Economizer Requirement (20,000 ft^2 Office 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.

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 (ASHRAE 2003). The committee determined the average 1 gallon hot water storage per person per day for studied office buildings, as shown in Table 6 of Chapter 49 Service Water Heating (ASHRAE 2003), resulting in the possible hot water demand of 27 gal/day for the smaller prototype and 112 gal/day for the larger prototype. Assuming 70% of the hot water in a storage tank is usable from the same source, the storage tank capacity is sized as 40 gallons for the smaller office building and two of 75 gallons for the larger building.

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 14.41 Btu/hr-°F, as one of input variables for the smaller office prototype in DOE-2 program.

For the commercial gas storage water heaters, the minimum performance required is expressed as two values, i.e. the thermal efficiency E_t and the standby loss SL. For a water heater in the size range of 76,000 Btu/hr rated input, the minimum E_t was required as 80%. The maximum standby loss SL was 1047.6 Btu/hr using following equation required in the Standard:

$$SL = \frac{Q}{800} + \frac{110}{\sqrt{V}} \tag{7.5}$$

Where

SL	=	standby heat loss (Btu/hr)
Q	=	rated input power (Btu/hr)
V	=	rated storage tank volume (gallons)

Based on commercial water heater manufacturer's equipment specifications, the most common input rating of a 75-gallon gas water heater is 76,000 Btu/hr, with recovery efficiency of 76%. Furthermore, the standby heat loss coefficient (UA) of the commercial heater was determined using the following equation:

$$UA = \frac{SL \times RE}{70} \tag{7.6}$$

Where

UA	=	standby heat loss efficient (Btu/hr-°F)
SL	=	standby heat loss (Btu/hr)
RE	=	recovery efficiency
70	=	difference in temperature between stored water thermostat set point and ambient air temperature at the test condition (°F)

Plugging in the appropriate values for SL and RE results in a UA of 11.973 Btu/hr-°F, as one of input variables for the larger office prototype 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.

$$E_t = \frac{UA \times 67.5 + P_{on} \times RE}{P_{on}} \tag{7.7}$$

For the commercial water heater, the thermal efficiency E_t was set as 0.80 to match the minimum performance requirement under the Standard, resulting in the heat input ratio HIR of 1.25.

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
- Daylighting controls
- Occupancy lighting controls
- Demand controlled ventilation
- Automatic motorized damper control for outside air intake
- Lower pressure ductwork design
- Higher efficiency HVAC equipment based on climate intensity
- 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 for built-up roofs and metal building roofs in the advanced building prototypes. Therefore, the solar reflectance used in the advanced cases for the 20,000 ft^2 office prototype was 0.65, and the corresponding emittance was 0.86, derived from a study by PG&E (Eilert 2000). The guide recommends cool roof application only in climate zone 1-3. No cool roof is recommended for the attic roofs in this Guide.

- 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 recommendations 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 Level Assumptions

The committee chose to adopt the advanced lighting levels that were slightly lower than those being proposed for Standard 90.1-2004 (ANSI/ASHRAE/IESNA 2004). Whole building lighting levels were set at 0.9 watts per square foot, which is 0.1 watts per square foot lower than being proposed for the standard. Both the smaller and the larger office prototypes utilized the same uniform lighting levels in the advanced case. The committee added example lighting layouts to Section 4 (*How to Implement Recommendations*) of the Guide to assist in meeting these recommendations.

The Guide recommends daylighting controls in all climate zones for buildings with a 25% window-wall ratio or higher. Daylighting controls were incorporated into the advanced building simulation modeling by providing for dimming of electric lighting when daylighting levels are sufficient to provide adequate interior lighting. The Guide does recommend dimming control for daylight harvesting near vertical glazing on north and south orientations as well as under skylights, if skylights are present. For purposes of modeling the advanced case, daylighting was incorporated only in the larger office prototype (with 30% of WWR).

In addition, occupancy controls were also included in the simulations for the advanced building case. The impact of occupancy controls was modeled by modifying the peak lighting levels by a percentage to account for typical office occupancy based on field studies of office occupancy as shown in Figure 8-1.

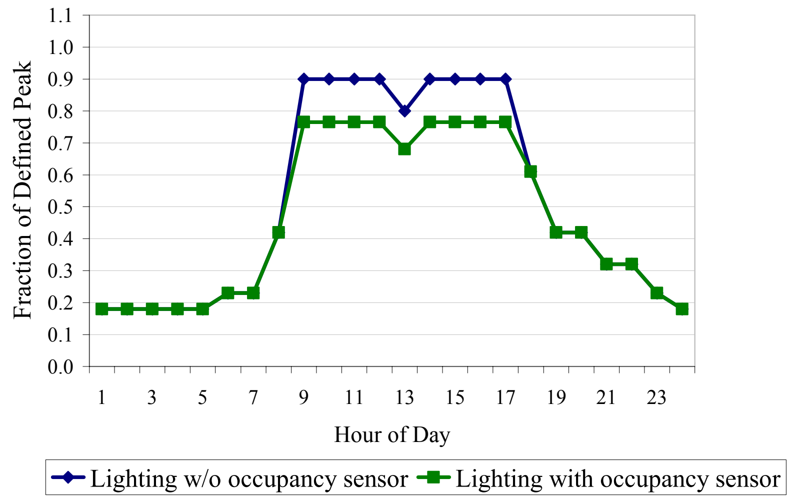


Figure 8-1 Lighting Schedules and Occupancy Sensor

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 for the smaller office prototype. For 15-ton commercial products modeled in the larger office prototype, the equipment efficiency recommendation varies by climate, i.e., 11.0 EER in zones 1 and 2, 10.8 EER in zones 3, 4 and 5; and remains the same level as Standard 90.1-1999 (9.5 EER) in zones 6, 7 and 8.

In addition, the committee recommended the minimum efficiency of 80% AFUE for the smaller gas-fired furnaces (<225,000 Btu/hr) and adopted the same level of 80% combustion efficiency (Ec) for the larger furnaces (≥225,000 Btu/hr).

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 smaller office prototype have economizers implemented in climate zones 3, 4, 5, and 6 only. For the larger office 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 office buildings can be significant. Minimum ventilation air rate is normally designed to satisfy the maximum occupancy in a space. However, there is some percentage of time that an office 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 20,000-ft² office prototype, but not to the smaller 5,000-ft² small office 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 the committee's inputs. The committee chose to adopt the ventilation rate being proposed for Standard 62.1-2004 (ANSI/ASHRAE 2004). The new ventilation rate was calculated based on the minimum rates of office buildings listed in Table 6-1 under Standard 62.1-2004, i.e., 5 cfm per person plus 0.06 cfm per square foot of floor area. The calculation results in a reduced ventilation rate of 1760 cfm, corresponding to a 0.588 air change per hour, a 21% ventilation rate reduction compared to the baseline values. The percentage of ventilation rate reduction was also in line with the field studies and concurred by the experts in the committee. The impact of occupancy controls was modeled by modifying the peak lighting levels by a percentage to account for typical office occupancy based on field studies of office occupancy

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. Table 8-1 summarizes the breakdown calculation of the fan external static pressure for both 5- and 15-ton equipment. The difference compared to the baseline calculation is shaded in Table 8-1, 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 1.20 in. w.c. to 1.10 in. w.c., representing the smaller office advanced prototype. For the larger office advanced prototype with the 15-ton unit, a total fan static pressure of 1.15 in. w.c. was calculated compared to 1.25 in. w.c. in the baseline prototype.

Table 8-1. Advanced Building Calculated Fan External Static Pressure Drops

	5,000 ft² Office Prototype	**20,000 ft² Office Prototype**
Component	5-ton Packaged Rooftop Unit (@2000 cfm)	15-ton Packaged Rooftop Unit (@5300 cfm)
External Static Pressure (ESP), in. w.c.[1]		
Diffuser	0.08	0.08
Supply Ductwork[2]	0.236	0.18
Dirty Portion of Filters	0.25	0.25
Return Ductwork[2]	0.056	0.15
Grille	0.03	0.03
Subtotal	0.65	0.69
10 % Safety Factor	0.06	0.06
Subtotal	0.71	0.75
Fan System Effect	0.40	0.40
Total ESP	**1.10**	**1.15**

Notes:
1. External static pressure was calculated based on the typical duct runs served by the listed cooling capacities. For the 5-ton system, the ESP was calculated assuming only one packaged unit serving the entire 5,000 floor area. For the 15-ton system, the ESP was determined based on one packaged unit per zone and total five thermal zones.
2. Used good practice of 0.08 inch/100 ft friction rate for the baseline prototypes.

8.4 Advanced Service Water Heating

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 gas instantaneous water heaters for both the residential and commercial water heaters as modeled in the smaller and larger office prototypes, respectively. 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 for the residential water heaters. The HIR was then calculated as 1.235, as the inverse of Et. Fro the commercial water heaters, the thermal efficiency Et was slightly increased from 80% as required under the Standard to 81%,as shown in Table 10-3.

In summary, the base and advanced water heater input variables in the DOE-2 program for both the 5,000 ft² and 20,000 ft² office prototypes were:

		Thermal Efficiency (Et)	HIR	Storage Volume (gallons)	Rated Input Power (Btu/hr)	Tank Standby Loss UA (Btu/hr-°F)
5,000 ft² office	Base	0.784	1.276	40	40,000	14.41
	Advanced	0.81	1.235	0.0	40,000	0.0
20,000 ft² office	Base	0.80	1.250	75	76,000	11.97
	Advanced	0.81	1.235	0.0	76,000	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:

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

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 8-2. The manufacture's reported data was derived from the California Energy Commission Appliance Database (CEC 2004). 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:

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

Figure 8-2 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.

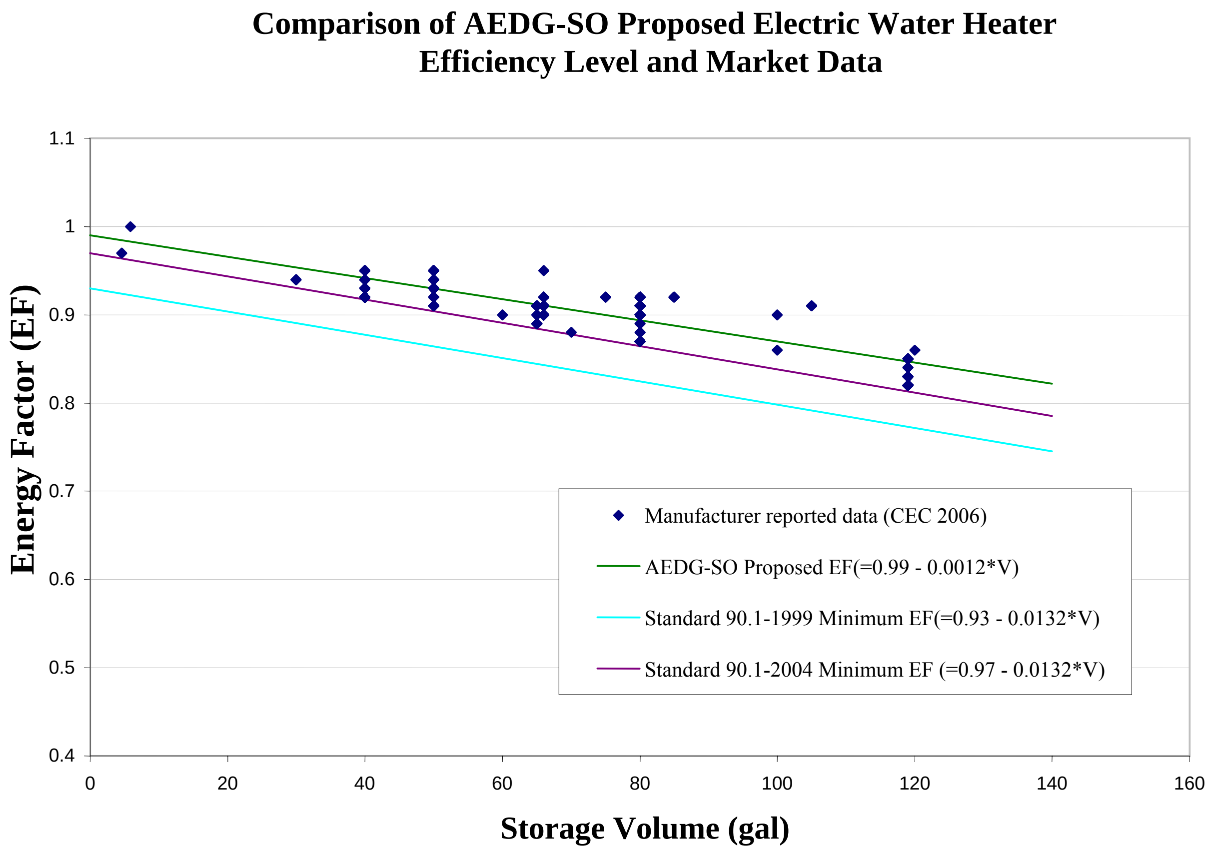


Figure 8-2. Comparison of Efficiency Levels of the Electric Water Heaters

9.0 Development of the Envelope Criteria

The target of achieving a 30% energy savings relative to 90.1-1999 for the envelope criteria is challenging because the envelope measures in 90.1-1999 were developed using 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 number of combinations of all the possible envelope measures is too large to evaluate 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 5,000 ft^2 office was representative of the smaller office building. An 20,000 ft^2 prototype represented the larger office building.

Task 2 – DOE-2 Sensitivity Runs

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

It is critical to note that the sensitivity runs were completed assuming that the outdoor air damper controls allowed the dampers to remain open during unoccupied hours per Standard 90.1-1999. A separate analysis of the energy savings identified that in climates above 4,000 HDD65 a majority or in some locations nearly all of the 30% energy saving targets could be achieved just by implementing outdoor air damper controls that would close the dampers during the unoccupied hours. The decision was made not to implement the outdoor air control strategy in order to develop the recommendations but to allow it as additional energy savings that could be achieved over and above the 30% energy savings target.

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 (LCC) 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 Envelope Criteria Results

The results follow the six steps defined in the Technical Approach.

Task 1 – Define Representative Buildings

There were two size office designs analyzed, a 5,000 ft^2 and a 20,000 ft^2 building. The basic construction of the 5,000 ft^2 building was an attic, metal framed walls and a slab foundation. The 20,000 ft^2 building had a metal roof deck, mass walls and a slab foundation. The fenestration in both buildings was uniformly distributed on the four cardinal orientations.

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 office buildings in each of the 15 cities, see Table 9-1.

Table 9-1. ASHRAE Standard 90.1-1999 Envelope Criteria

		City and Climate Bins									
			Phoenix	Memphis	San	Baltimore		Chicago	Burlington		
		Miami	Houston	El Paso	Francisco	Albuquerque	Seattle	Boise	Helena	Duluth	Fairbanks
Envelope	Metric	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 presented in Table 9-2. The heating and cooling degree days and annual dry-bulb temperatures were extracted from the TMY-2 (Marion and Urban 1995) files while the average daily solar radiation data were taken from ASHRAE Standard 90.1-1989.

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

No.	City	ST	Climate 90.1	Climate Bin	HDD_{65}	CDD_{50}	HDD_{65} + CDD_{50}	%Heat	%Cool	Avg. Solar Radiation - Btu/ft2-day North	East/West	South	Annual DBT-ºF
1	Miami	FL	2	1	140	9462	9602	1.5%	98.5%	527	874	936	75.76
2	Phoenix	AZ	5	2	1153	8222	9375	12.3%	87.7%	488	1116	1310	72.55
3	Houston	TX	5	2	1552	7061	8613	18.0%	82.0%	490	805	883	68.09
4	El Paso	TX	10	3	2597	5430	8027	32.4%	67.6%	503	1133	1306	64.06
5	Memphis	TN	10	3	3106	5323	8429	36.8%	63.2%	460	806	935	62.08
6	San Francisco	CA	12	3	3236	2489	5725	56.5%	43.5%	454	941	1146	55.56
7	Albuquerque	NM	13	4	4362	3884	8246	52.9%	47.1%	469	1105	1361	55.84
8	Seattle	WA	14	4	4867	1957	6824	71.3%	28.7%	350	621	828	51.58
9	Baltimore	MD	13	4	4911	3722	8633	56.9%	43.1%	419	739	932	54.70
10	Boise	ID	17	5	6001	2682	8683	69.1%	30.9%	399	916	1228	50.47
11	Chicago	IL	17	5	6449	2954	9403	68.6%	31.4%	402	729	936	49.55
12	Helena	MT	19	6	7815	1854	9669	80.8%	19.2%	372	771	1098	44.30
13	Burlington	VT	19	6	7902	2215	10117	78.1%	21.9%	382	698	925	44.98
14	Duluth	MN	22	7	10215	1313	11528	88.6%	11.4%	355	633	886	37.74
15	Fairbanks	AK	24	8	14172	876	15048	94.2%	5.8%	241	492	919	26.47

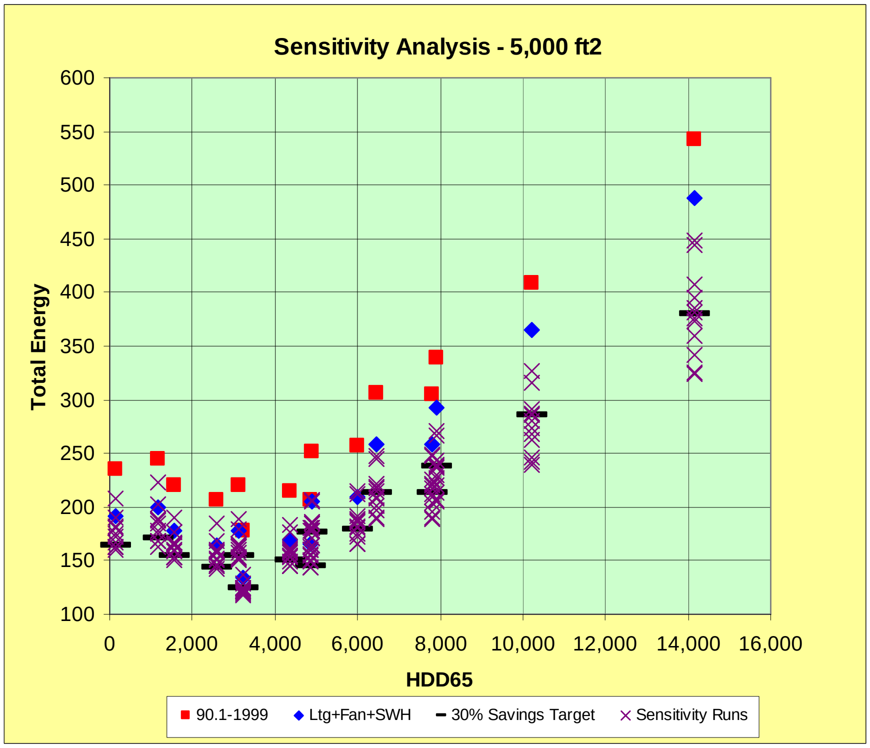
Next, a design of experiment strategy was used to define a range of construction options for the office buildings. Table 9-3 presents the envelope measures that were used.

Table 9-3. Sensitivity Runs

5,000 ft^2	Ceiling	Wall	Door	Slab	Fenestration				
Case No.	R	R	U	F	U	SHGC	WWR	PF	Orientation
1	30	13	0.61	0.73	0.7	0.49	0.2	0	Uniform
2	38	13 + 8 c.i.	0.61	0.45	0.7	0.49	0.2	0	Uniform
3	49	13 + 20 c.i.	0.61	0.16	0.7	0.49	0.2	0	Uniform
4	30	13	0.61	0.73	0.3	0.20	0.2	0	Uniform
5	38	13 + 8 c.i.	0.61	0.45	0.3	0.20	0.2	0	Uniform
6	49	13 + 20 c.i.	0.61	0.16	0.3	0.20	0.2	0	Uniform
7	38	13 + 8 c.i.	0.61	0.45	0.7	0.49	0.2	0.5	Uniform
8	49	13 + 20 c.i.	0.61	0.16	0.3	0.20	0.2	0.5	Uniform
9	38	13 + 8 c.i.	0.61	0.45	0.7	0.49	0.4	0	Uniform
10	49	13 + 20 c.i.	0.61	0.16	0.3	0.20	0.4	0	Uniform
11	38	13 + 8 c.i.	0.61	0.45	0.7	0.49	0.4	0.5	Uniform
12	49	13 + 20 c.i.	0.61	0.16	0.3	0.20	0.4	0.5	Uniform

20,000 ft^2	Roof	Wall	Door	Slab	Fenestration				
Case No.	R	R	U	F	U	SHGC	WWR	PF	Orientation
1	15	0	0.61	0.73	0.67	0.49	0.2	0	Uniform
2	23	7.5	0.61	0.45	0.67	0.49	0.2	0	Uniform
3	45	33.6	0.61	0.16	0.67	0.49	0.2	0	Uniform
4	15	0	0.61	0.73	0.31	0.20	0.2	0	Uniform
5	23	7.5	0.61	0.45	0.31	0.20	0.2	0	Uniform
6	45	33.6	0.61	0.16	0.31	0.20	0.2	0	Uniform
7	23	7.5	0.61	0.45	0.67	0.49	0.2	0.5	Uniform
8	45	33.6	0.61	0.16	0.31	0.20	0.2	0.5	Uniform
9	23	7.5	0.61	0.45	0.67	0.49	0.4	0	Uniform
10	45	33.6	0.61	0.16	0.31	0.20	0.4	0	Uniform
11	23	7.5	0.61	0.45	0.67	0.49	0.4	0.5	Uniform
12	45	33.6	0.61	0.16	0.31	0.20	0.4	0.5	Uniform

The results of all the sensitivity runs are presented in Figure 9-1.



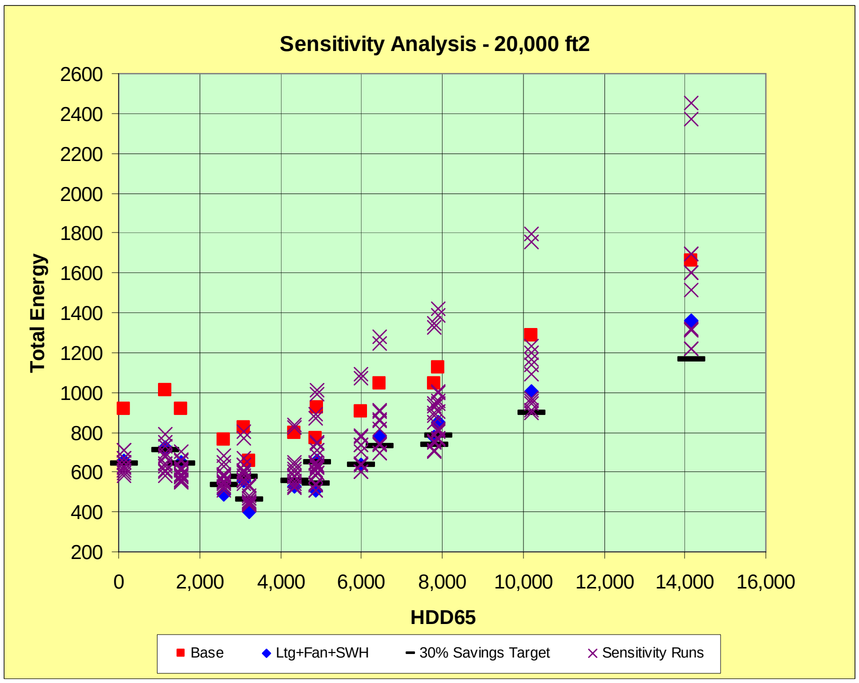


Figure 9-1. Sensitivity Analysis

The baseline energy consumption for each city is presented as a square. The 30% energy savings target is shown as a solid horizontal line. The energy use of the individual components such as lighting, fans, and service water heating are shown as a diamond. The results of the sensitivity analysis are shown as Figure 9-1. 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 in order to provide a uniform and consistent procedure for the 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 are 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:

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

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 which 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 Eq. 9.1 can be divided through by S_2 to yield:

$$\mathrm{FYS_h} \times \mathrm{A} \times \mathrm{P_h} \times \frac{\mathrm{S_h}}{\mathrm{S_2}} + \mathrm{FYS_c} \times \mathrm{A} \times \mathrm{P_c} \times \frac{\mathrm{S_c}}{\mathrm{S_2}} \geq \mathrm{FC} \times \mathrm{A} \quad (9.2)$$

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:

$$\begin{aligned}&(\mathrm{U_1} - \mathrm{U_2}) \times \mathrm{A} \times \mathrm{HCoef} \times \mathrm{HDD_{65}} \times \mathrm{P_h} \times \mathrm{SR} + (\mathrm{U_1} - \mathrm{U_2}) \times \mathrm{A} \\ &\times (\mathrm{Ccoef1} \times \mathrm{CDD_{50}} + \mathrm{Ccoef2}) \times \mathrm{P_c} \times \mathrm{SR} \geq \Delta FC \times A\end{aligned} \quad (9.3)$$

where

U_1 = reference or base case U-factor (Btu/h·ft^2°F)
U_2 = upgraded or improved U-factor (Btu/h·ft^2°F)
Hcoef = heating energy savings regression coefficient (Btu/HDD_{65}·ΔU)
HDD_{65} = heating degree days to base 65°F (°F·days)
SR = scalar ratio (dimensionless)
Ccoef1 = cooling energy savings regression coefficient (kWh/CDD_{50}-ΔU)
Ccoef2 = cooling energy savings regression constant (kWh·ΔU)

CDD_{50} = cooling degree days to base 50°F (°F·days)

Eq. 9.3 can be divided through by the area which produces:

$$(U_1 - U_2) \times \text{HCoef} \times \text{HDD}_{65} \times P_h \times \text{SR} + (U_1 - U_2) \times (\text{Ccoef1} \times \text{CDD50} + \text{Ccoef2}) \times P_c \times \text{SR} \geq \Delta FC \quad (9.4)$$

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 Eq. 9.4 to produce:

$$\text{HCoef} \times \text{HDD}_{65} \times P_h \times \text{SR} + (\text{Ccoef1} \times \text{CDD}_{50} + \text{Ccoef2}) \times P_c \times \text{SR} \geq \frac{\Delta FC}{(U_1 - U_2)} \quad (9.5)$$

The left hand side of the Eq. 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							
			Display			Actual	
I-P Description	S-I Description	Cost-$	U-factor	Rval	c.i.	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

B. Fenestration Components

The LCC for fenestration is:

$$LCC_i = FC_i \times WWR + FYC_h \times P_h \times SR + FYC_c \times P_c \times SR \quad (9.6)$$

where:

LCC_i	= life-cycle-cost (dollars)
FC_i	= first cost of fenestration option (dollars)
WWR	= window-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:

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

where

U_i	= U-factor for the i^{th} fenestration (Btu/h·ft^2·°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:

$$FYC_c = \begin{array}{l} c_0 + c_1 \times HDD_{65} + c_2 \times CDD_{50} + c_3 \times WWR \times HDD_{65} \times SC_i \\ + c_4 \times WWR \times CDD_{50} \times SC_i + kWh_{lght} \end{array} \tag{9.8}$$

where

$c_0, c_1 \ldots c_3$	= 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:

$$kWh_{lght} = \frac{P_L \times H_L \times (1 - K_d)}{1000} \tag{9.9}$$

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 (h·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 ith 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.

C. Overall Analysis

Thus, the overall analysis was to select a SR which 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 5,000 ft^2 total regression equations was 4.4% while the SD for the 20,000 ft2 total regression equations was 2.6%. 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.

Table 9-5 shows all city results for the various SR by climate zone.

Table 9-5. Energy Savings by Scalar Ratio

5,000	SR =	8			10			12			14		
Zone	City	-1 SD	Avg.	+1 SD	-1 SD	Avg.	+1 SD	-1 SD	Avg.	+1 SD	-1 SD	Avg.	+1 SD
1	Miami	25%	30%	34%	25%	30%	35%	25%	30%	35%	28%	33%	38%
2	Phoenix	29%	34%	38%	29%	34%	38%	30%	34%	39%	34%	38%	43%
2	Houston	22%	27%	32%	22%	27%	32%	23%	28%	33%	29%	34%	39%
3	El Paso	15%	21%	26%	15%	20%	26%	16%	21%	26%	24%	29%	34%
3	Memphis	14%	19%	24%	14%	19%	24%	22%	27%	32%	22%	27%	32%
3	San Francisco	25%	31%	37%	25%	31%	38%	25%	31%	38%	26%	32%	38%
4	Albuquerque	10%	15%	20%	11%	16%	21%	11%	16%	21%	19%	24%	29%
4	Seattle	16%	22%	27%	16%	22%	27%	17%	22%	28%	26%	31%	37%
4	Baltimore	12%	17%	21%	13%	17%	22%	23%	27%	32%	22%	26%	30%
5	Boise	9%	14%	18%	10%	15%	19%	21%	26%	30%	23%	27%	31%
5	Chicago	14%	18%	21%	25%	28%	32%	25%	29%	32%	27%	31%	34%
6	Helena	11%	14%	18%	22%	26%	29%	25%	29%	32%	26%	29%	33%
6	Burlington	14%	17%	20%	24%	28%	31%	25%	28%	31%	25%	28%	32%
7	Duluth	21%	23%	26%	24%	26%	29%	24%	27%	30%	28%	30%	33%
8	Fairbanks	18%	20%	22%	19%	21%	23%	21%	23%	25%	21%	23%	25%

5,000	SR =	16			18			20			22		
Zone	City	-1 SD	Avg.	+1 SD	-1 SD	Avg.	+1 SD	-1 SD	Avg.	+1 SD	-1 SD	Avg.	+1 SD
1	Miami	28%	33%	38%	30%	34%	39%	30%	34%	39%	30%	34%	39%
2	Phoenix	34%	38%	43%	35%	39%	44%	35%	39%	44%	35%	39%	44%
2	Houston	27%	32%	37%	27%	32%	37%	30%	35%	40%	30%	35%	40%
3	El Paso	24%	29%	34%	24%	29%	34%	25%	30%	36%	26%	32%	37%
3	Memphis	22%	27%	32%	22%	27%	32%	25%	30%	35%	25%	30%	35%
3	San Francisco	26%	32%	38%	28%	34%	41%	29%	35%	41%	29%	35%	41%
4	Albuquerque	19%	24%	29%	20%	25%	30%	23%	28%	33%	24%	29%	35%
4	Seattle	26%	32%	37%	28%	33%	38%	30%	35%	40%	31%	36%	41%
4	Baltimore	23%	27%	32%	26%	31%	35%	27%	32%	36%	27%	32%	36%
5	Boise	24%	28%	33%	27%	32%	36%	28%	32%	36%	28%	32%	37%
5	Chicago	30%	33%	37%	31%	34%	38%	30%	33%	37%	30%	34%	37%
6	Helena	28%	32%	35%	29%	32%	36%	29%	32%	36%	29%	32%	36%
6	Burlington	29%	32%	35%	29%	32%	35%	29%	32%	35%	29%	32%	35%
7	Duluth	28%	31%	33%	28%	31%	33%	28%	31%	33%	28%	31%	33%
8	Fairbanks	21%	23%	25%	21%	23%	25%	23%	25%	27%	23%	25%	27%

5,000	SR =	24			26			28			30		
Zone	City	-1 SD	Avg.	+1 SD	-1 SD	Avg.	+1 SD	-1 SD	Avg.	+1 SD	-1 SD	Avg.	+1 SD
1	Miami	30%	34%	39%	30%	34%	39%	30%	34%	39%	30%	34%	39%
2	Phoenix	35%	39%	44%	35%	39%	44%	35%	39%	44%	35%	39%	44%
2	Houston	30%	35%	40%	30%	35%	40%	30%	35%	40%	30%	35%	40%
3	El Paso	26%	32%	37%	27%	32%	37%	25%	30%	36%	25%	30%	36%
3	Memphis	26%	31%	35%	26%	31%	35%	26%	31%	35%	25%	30%	35%
3	San Francisco	29%	35%	41%	29%	35%	41%	30%	36%	42%	30%	36%	42%
4	Albuquerque	24%	29%	35%	24%	29%	35%	25%	30%	35%	25%	30%	35%
4	Seattle	33%	38%	44%	33%	38%	44%	33%	38%	44%	33%	38%	44%
4	Baltimore	27%	32%	36%	28%	32%	36%	28%	32%	36%	28%	32%	36%
5	Boise	26%	31%	35%	26%	31%	35%	26%	31%	35%	26%	31%	35%
5	Chicago	30%	34%	37%	30%	34%	37%	30%	34%	37%	30%	34%	37%
6	Helena	29%	32%	36%	26%	29%	33%	26%	30%	33%	26%	30%	33%
6	Burlington	29%	32%	35%	29%	32%	35%	29%	32%	35%	29%	33%	36%
7	Duluth	29%	31%	34%	29%	32%	35%	30%	33%	35%	30%	33%	35%
8	Fairbanks	23%	25%	27%	24%	26%	28%	24%	26%	28%	24%	26%	28%

20,000	SR =	8			10			12			14		
Zone	City	-1 SD	Avg	+1 SD	-1 SD	Avg	+1 SD	-1 SD	Avg	+1 SD	-1 SD	Avg	+1 SD
1	Miami	29%	32%	36%	29%	32%	36%	28%	32%	36%	31%	34%	38%
2	Phoenix	36%	39%	42%	36%	40%	43%	37%	40%	43%	39%	43%	46%
2	Houston	32%	36%	39%	32%	36%	40%	33%	36%	40%	36%	40%	43%
3	El Paso	19%	23%	28%	19%	24%	28%	20%	24%	28%	25%	29%	34%
3	Memphis	20%	24%	28%	20%	24%	28%	26%	30%	34%	26%	30%	34%
3	San Francisco	24%	29%	34%	25%	30%	35%	25%	30%	35%	26%	31%	36%
4	Albuquerque	17%	21%	25%	17%	21%	25%	23%	27%	31%	23%	27%	31%
4	Seattle	22%	27%	31%	20%	25%	29%	21%	25%	30%	29%	33%	37%
4	Baltimore	21%	25%	28%	22%	25%	29%	28%	31%	35%	28%	31%	35%
5	Boise	17%	21%	24%	18%	21%	25%	26%	29%	33%	28%	31%	35%
5	Chicago	21%	24%	27%	29%	32%	36%	29%	32%	36%	31%	34%	37%
6	Helena	18%	22%	25%	25%	28%	31%	28%	31%	34%	29%	32%	35%
6	Burlington	19%	21%	24%	27%	30%	33%	30%	33%	36%	31%	34%	36%
7	Duluth	26%	28%	31%	29%	31%	34%	30%	32%	35%	33%	35%	38%
8	Fairbanks	26%	28%	30%	28%	30%	32%	30%	32%	34%	30%	32%	34%

20,000	SR =	16			18			20			22		
Zone	City	-1 SD	Avg	+1 SD	-1 SD	Avg	+1 SD	-1 SD	Avg	+1 SD	-1 SD	Avg	+1 SD
1	Miami	31%	34%	38%	32%	36%	39%	32%	36%	39%	32%	36%	39%
2	Phoenix	39%	43%	46%	40%	44%	47%	41%	44%	47%	41%	44%	47%
2	Houston	36%	40%	43%	36%	40%	43%	38%	41%	45%	38%	42%	45%
3	El Paso	25%	29%	34%	25%	29%	34%	26%	30%	34%	27%	31%	36%
3	Memphis	26%	30%	34%	28%	32%	35%	28%	32%	36%	28%	32%	36%
3	San Francisco	26%	31%	36%	31%	36%	41%	31%	36%	41%	31%	36%	41%
4	Albuquerque	23%	27%	31%	26%	30%	34%	27%	31%	35%	29%	33%	37%
4	Seattle	29%	33%	37%	31%	35%	39%	32%	36%	40%	35%	39%	43%
4	Baltimore	29%	33%	36%	32%	35%	39%	33%	37%	40%	33%	37%	40%
5	Boise	27%	31%	35%	30%	34%	38%	31%	34%	38%	31%	34%	38%
5	Chicago	33%	36%	39%	34%	37%	40%	34%	37%	41%	34%	38%	41%
6	Helena	32%	35%	38%	32%	35%	38%	32%	35%	38%	32%	35%	38%
6	Burlington	33%	36%	39%	33%	36%	39%	34%	37%	39%	33%	36%	39%
7	Duluth	33%	36%	38%	33%	36%	38%	33%	36%	38%	31%	34%	36%
8	Fairbanks	30%	32%	34%	30%	32%	34%	32%	34%	36%	32%	34%	36%

20,000	SR =	24			26			28			30		
Zone	City	-1 SD	Avg	+1 SD	-1 SD	Avg	+1 SD	-1 SD	Avg	+1 SD	-1 SD	Avg	+1 SD
1	Miami	32%	36%	39%	32%	36%	39%	32%	36%	39%	32%	36%	39%
2	Phoenix	41%	44%	47%	41%	44%	47%	41%	44%	47%	41%	44%	47%
2	Houston	38%	42%	45%	39%	42%	46%	39%	42%	46%	39%	42%	46%
3	El Paso	27%	31%	36%	28%	32%	36%	28%	32%	36%	28%	32%	36%
3	Memphis	29%	33%	37%	29%	33%	37%	29%	33%	37%	30%	34%	38%
3	San Francisco	31%	36%	41%	31%	36%	41%	31%	36%	41%	31%	36%	41%
4	Albuquerque	29%	33%	37%	29%	33%	37%	29%	33%	37%	29%	33%	37%
4	Seattle	35%	39%	43%	34%	38%	42%	34%	38%	42%	34%	38%	42%
4	Baltimore	33%	37%	40%	33%	37%	40%	33%	37%	40%	33%	37%	40%
5	Boise	31%	35%	38%	31%	35%	38%	31%	35%	38%	31%	35%	38%
5	Chicago	34%	38%	41%	34%	38%	41%	34%	38%	41%	35%	38%	41%
6	Helena	32%	35%	38%	32%	35%	38%	32%	36%	39%	31%	35%	38%
6	Burlington	33%	36%	39%	33%	36%	39%	33%	36%	39%	33%	36%	39%
7	Duluth	32%	35%	37%	33%	35%	38%	33%	36%	39%	34%	36%	39%
8	Fairbanks	32%	34%	36%	33%	35%	37%	33%	35%	37%	33%	35%	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 multiple cities in five of the climate zones further added to the difficulty in selecting a single SR that would achieve the 30% energy savings.

Table 9-6. Summary of SR and Final Value

Zone	City	5,000 ft2	20,000 ft2	Final
1	Miami	10	8	10
2	Houston	12	8	12
3	Memphis	12 - 20 - 22	12-18-22	14
4	Albuquerque	10	14-18	14
5	Boise	10 - 14	8	14
6	Helena	12 - 16	8	12
7	Duluth	14	10	14
8	Fairbanks	12-20-26	10	20

Task 6 – Final Verification of the Envelope Measures

Once the final SR values were identified for each climate zone all of the 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 of this report.

10.0 Final Recommendations and Energy Savings Results

This section contains the final recommendations approved by the project committee for AEDG-SO, 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 office 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-SO. The recommendations are grouped into envelope measures, lighting and day lighting 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.

In several additional cases, the recommendations are constant across all climate zones, which suggest 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. In addition, the Guide recommends reducing the solar aperture (the product of the glazing area and the SHGC) on the east and west orientations of glazing to help control unnecessary solar loads in warmer climates.

Table 10-1. AEDG-SO 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-20 c.i.	R-30 c.i.
	Metal building	R-19	R-19	R-13 + R-13	R-13 + R-19	R-13 + R-19	R-13 + R-19	R-13 + R-19	R-19 + 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-38	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/ emittance	0.65 initial /0.86	0.65 initial /0.86	0.65 initial /0.86	NR	NR	NR	NR	NR
Walls	Mass (HC > 7 Btu/ft2)	NR	R-7.6 c.i.	R-9.5 c.i.	R-11.4 c.i.	R-11.4 c.i.	R-11.4 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-16
	Steel framed	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.	R-13 +R-21.6 c.i.
	Wood framed and other	R-13	R-13	R-13	R-13	R-13 + R-3.8 c.i.	R-13 + R-3.8 c.i.	R-13 + R-7.5 c.i.	R-13 + R-10 c.i.
	Below-grade walls	NR	NR	NR	NR	R-7.5 c.i.	R-7.5 c.i.	R-7.5 c.i.	R-15 c.i.
Floors	Mass	R-4.2 c.i.	R-6.3 c.i.	R-8.3 c.i.	R-8.3 c.i.	R-10.4 c.i.	R-10.4 c.i.	R-12.5 c.i.	R-16.7 c.i.
	Steel framed	R-19	R-19	R-19	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	NR	R-10 for 24 in.	R-15 for 24 in.	R-20 for 24 in.
	Heated	NR	NR	NR	R-7.5 for 24 in.	R-10 for 36 in.	R-10 for 36 in.	R-15 Full slab	R-20 Full slab
Doors Opaque	Swinging	U-0.70	U-0.70	U-0.70	U-0.70	U-0.70	U-0.70	U-0.50	U-0.50
	Non-swinging	U-1.45	U-1.45	U-1.45	U-0.50	U-0.50	U-0.50	U-0.50	U-0.50
Vertical glazing including doors	Area (percent of gross wall)	20% min to 40% max	20% min to 40% max	20% min to 40% max	20% min to 40% max	20% min to 40% max	20% min to 40% max	20% min to 40% max	20% min to 40% max
	Thermal transmittance	U-0.56	U-0.45	U-0.45	U-0.42	U-0.42	U-0.42	U-0.33	U-0.33
	Solar heat gain coefficient (SHGC)	N,S,E,W 0.35 N only 0.49	N,S,E,W 0.31 N only 0.44	N,S,E,W 0.31 N only 0.46	N,S,E,W 0.46 N only 0.46	N,S,E,W 0.46 N only 0.46	N,S,E,W 0.46 N only 0.46	NR	NR
	Window orientation	$(A_N * SHGC_N + A_S * SHGC_S) > (A_E * SHGC_E + A_W * SHGC_W)$						NR	NR
	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	NR	NR
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	0.19	0.34	0.39	0.49	0.64	NR

10.1.2 Lighting and Daylighting Measures

For lighting and day lighting, 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 day lighting) in Table 10-2

Table 10-2. AEDG-SO Final Energy Savings Recommendations – Lighting

Item	Component	Zones 1-8
Interior Lighting	Lighting power density (LPD)	0.9 W/ft^2
	Linear fluorescent	90 mean lumens/watt
	Ballast	High performance electronic ballast
	Dimming controls for daylight harvesting for WWR 25% or higher	Dim fixtures within 12 ft of N/S window wall or within 8 ft of skylight edge
	Occupancy controls	Auto-off all unoccupied rooms
	Interior room surface reflectances	80%+ on ceilings, 70%+ on walls and vertical partitions

Interior lighting recommendations include a maximum lighting power density for general lighting. Additional recommendations cover the minimum performance of the light sources and ballasts (minimum mean lumens/watt and high performance ballasts). Occupancy and day lighting control recommendations are provided, as well as recommendations for horizontal and vertical surface reflectance values to enhance the value of day lighting.

Exterior lighting recommendations are included in the “how to” section of the Guide (Chapter 4) as “bonus savings” and include a maximum LPD for parking lot and grounds lighting (0.10 W/ft^2) as well recommendations for light sources and decorative façade lighting. The “bonus savings” recommendations are not accounted for in the energy savings estimates for implementing the Guide.

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 office 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.

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. Economizers are not recommended in the hotter humid climates (zones 1 and 2) since they can adversely affect energy usage by introducing excess moisture due to ambient humid conditions. In addition, economizers are not recommended in the coldest climate (zones 7 and 8) since without additional heat they may tend to freeze during certain times of the year.

Table 10-3.lists the final HVAC and SWH recommendations for the AEDG-SO.

Table 10-3. AEDG-SO 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.

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 office 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 Figure 10-1 and Figure 10-2 for the 5,000 ft^2 prototype and in Figure 10-3 and Figure 10-4 for the 20,000 ft^2 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). Both building prototypes met the 30% savings goal in each climate for the case without plug loads included in the denominator.

Both the small office prototype and the large office prototype perform about the same on average, even though one or the other performs better depending on the climate. The large office tends not to perform as well in colder climates where higher insulation levels are needed due to its mass wall construction. In addition, the large office uses larger unitary equipment that benefits less from the energy efficiency improvements for cooling since the recommendations in the guide are somewhat less aggressive for these categories of equipment. The economizer recommendations in the Guide impacted the small office more than the large office in certain climates because the large office already had economizer requirements from the Standard as a result of the larger cooling equipment in that building.

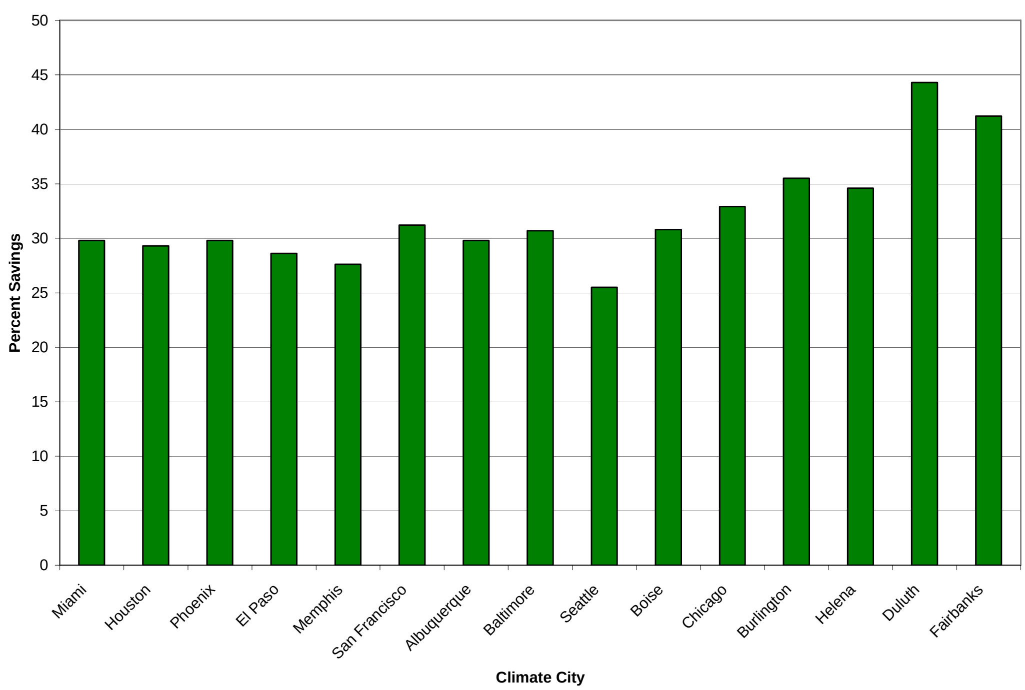


Figure 10-1. 5,000 ft^2 Prototype Energy Savings (plugs in denominator)

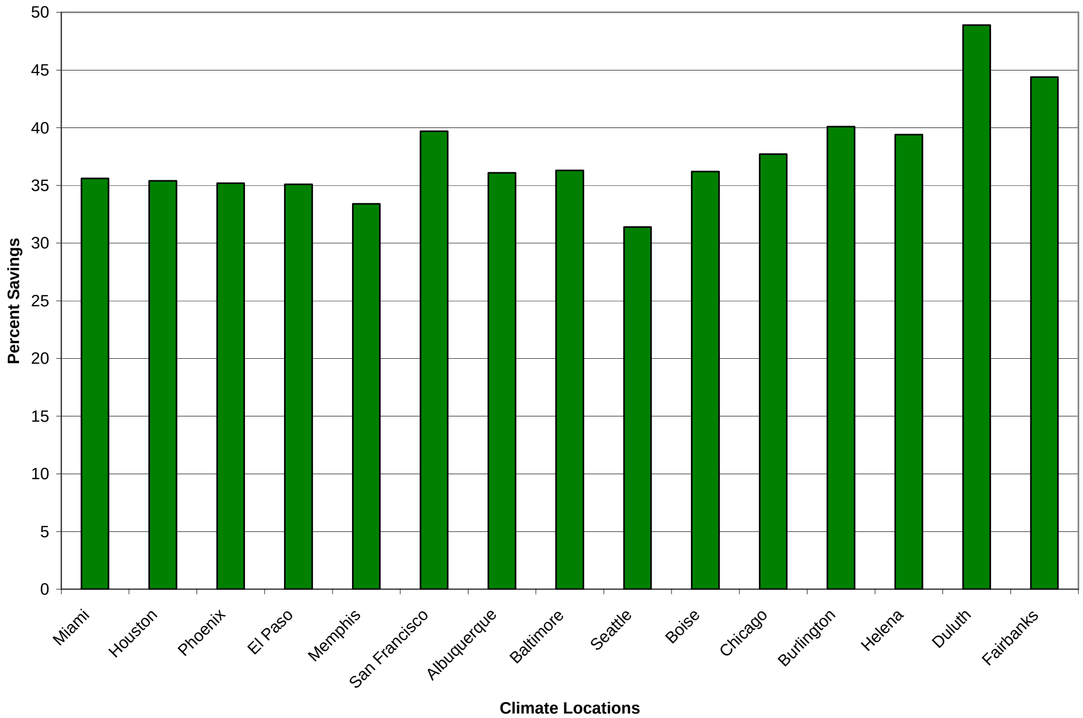


Figure 10-2. 5,000 ft^2 Prototype Energy Savings (plugs not in denominator)

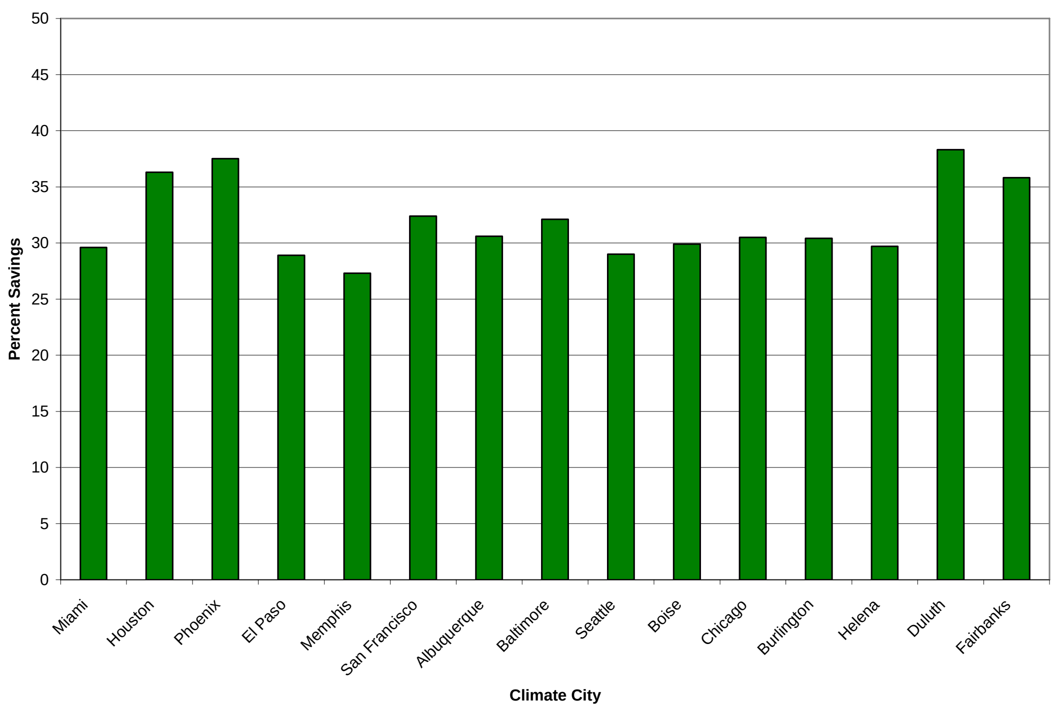


Figure 10-3. 20,000 ft^2 Prototype Energy Savings (plugs in denominator)

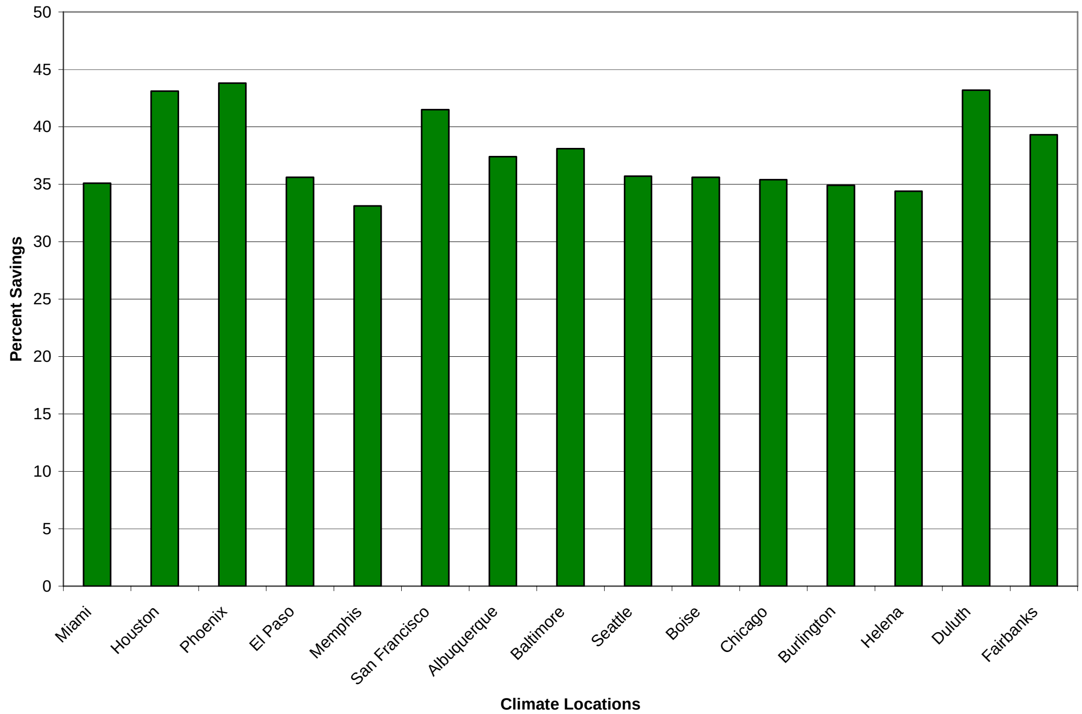


Figure 10-4. 20,000 ft^2 Prototype Energy Savings (plugs not in denominator)

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Appendix A

Simulation Input Assumptions for Scoping Study

Appendix A

Simulation Input Assumptions for Scoping Study

Table A.1. 5,000 ft² Office Prototype Energy Modeling Assumptions – Key Inputs Consistent across Climate

Characteristic	Baseline Model	AEDG Model	Data Source/Remarks
General			
Building Type	Office	Same	
Gross Floor Area	4,900 sq. ft. total (70 ft x 70 ft)	Same	Committee inputs
Operation Hours	8:00 am – 5:00 pm M-F	Same	Typical office occupancy assumed
Architectural Features			
Configuration/Shape			
Aspect Ratio	Overall building 1 to 1	Same	Chosen to make simulations orientation independent
Zoning	1 zone	Same	
Number of Floors	1	Same	Appropriate for building size
Window-to-Wall Ratio	20% uniformly distributed by orientation	Same	Committee assumption based on professional judgment
Floor-to-Ceiling Height:	9 ft	Same	General practice
Infiltration Rate	- 0.038 cfm/sf of the gross exterior walls - -0.145 air change per hour for entire building	Same	ASHRAE 90.1-1989 (ASHRAE/IESNA 1989) Section 13.7.3.2 -10 ft. high exterior wall
Infiltration Schedule	OFF_M_F_INFIL	Same	Off when the HVAC fan is on
Exterior Walls			
Structure	2x4 wood 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: *NBI EBenchmark (NBI 2003)*

Table A.1. (contd)

Characteristic	Baseline Model	AEDG Model	Data Source/Remarks
Overall U-factor	Varies by climate locations. See Appendix A Table A-2		ASHRAE 90.1-1999 Table A-10
Roof			
Structure	Attic roof with wood joists, 3 in 12 pitch, 2 ft overhang	Same	Committee inputs
Insulation	Varies by climate locations. See Appendix A Table A-2		Base: ASHRAE 90.1-1999 AEDG: *NBI EBenchmark*
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		ASHRAE 2001 Fundamentals, Chapter 38 Asphalt shingle properties from http://eetd.lbl.gov/coolroof/asshingl.htm
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: *NBI EBenchmark*
Floor F-factor	Varies by climate locations. See Appendix A Table A-2		ASHRAE 90.1-1999 Table B-22
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: *NBI EBenchmark*
SHGC	Varies by climate locations. See Appendix A Table A-2		
Actual DOE-2 Glazing Input	Varies by climate locations. See Appendix A Table A-2		
Window Shading/Overhangs	None	PF = 0.50	
Opaque Doors			
Total U-factor	Varies by climate locations. See Appendix A Table A-2		Base: ASHRAE 90.1-1999 Table B-2 AEDG: *NBI EBenchmark*

Table A.1. (contd)

Characteristic	Baseline Model	AEDG Model	Data Source/Remarks
Building Internal Loads			
Occupancy			
Number of Occupancy	27 peak occupants (7 person/1000 sf at 80% net usable floor area	Same	Committee Inputs ASHRAE Standard 62-2001 (ANSI/ASHRAE 2001)
Occupancy Schedule	8 am – 5 pm M-F	Same	OFF_M_F_OCCUP (EPAct Standards)
People Sensible Heat Gain	250 Btu/hr-person	Same	ASHRAE 2001 Fundamentals, Chapter 29.4
People Latent Heat Gain	200 Btu/hr-person	Same	ASHRAE 2001 Fundamentals, Chapter 29.4
Lighting			
Light Source	T-8 with electronic ballasts	High performance T-8s w/ 2^{nd} generation electronic ballast	Base: General practice AEDG: Committee inputs
Peak Lighting Power, w/sf	1.3 W/sf	0.9 W/sf	Base: ASHRAE 90.1-1999 AEDG: Committee inputs
Lighting Schedule	8am – 5 pm, M-F, assumes 0.9 diversity factor applied during peak hours	Same	Base: AEDG: - Based on committee input, lighting schedule is modified to match the average energy savings
Occupancy Sensors	No	Yes	
Daylighting Responsive Lighting Control	No	Same	AEDG: Committee inputs
Skylights	No	Same	
Office Equipment			
Equipment Schedule	8 am – 5 pm	Same	
Peak Load, w/sf	0.92 W/sf of gross floor area	Same	From the previous energy analysis work for the *Commercial Unitary Air Conditioners Appliance Standard Rulemaking*
HVAC System			

Table A.1. (contd)

Characteristic		Baseline Model	AEDG Model	Data Source/Remarks
	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	1	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: Highest value where product was available
	Heating Equip Efficiency	E_t = 74%	E_t = 80%	Base: ASHRAE 90.1-1999 Table 6.2.1E AEDG: Highest value where product was available
	Outside Air Supply	- 20 cfm/person @ 27 person - 0.11 cfm/sf of gross floor area (0.735 air changes per hour for entire building)	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: *Committee decision*
	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: *Committee decision*
	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	
	Fan Static Pressure	1.20 in. w.c.		Committee inputs
	Fan Schedule	7am 0 6pm, M_F	Same	OFF_M-F-FAN (EPAct Standard)
Service Water Heating				

Table A.1. (contd)

	Characteristic	Baseline Model	AEDG Model	Data Source/Remarks
	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	OFF_M-F_SWH	Same	EPAct Standard

Table A.2. 5,000 ft² Office 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

Table A.2. (contd)

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
	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								
	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 Office Energy Modeling Internal Load Schedules

		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**	0.18	0.18	0.18	0.18	0.23	0.23	0.42	0.90	0.90	0.90	0.90	0.80	0.90	0.90	0.90	0.90	0.61	0.42	0.42	0.32	0.32	0.23	0.18
	S-SU	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Plugs	**M-F**	0.47	0.47	0.47	0.47	0.50	0.50	0.63	1.00	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	0.75	0.63	0.63	0.56	0.56	0.50	0.47
	S-Su	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47	0.47
Occ	**M-F**	0.00	0.00	0.00	0.00	0.00	0.11	0.21	1.00	1.00	1.00	1.00	0.53	1.00	1.00	1.00	1.00	0.32	0.11	0.11	0.11	0.11	0.05	0.05
	S-Su	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	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. 20,000 ft² Office Building Simulation Input Assumptions for Final Guide

								90.1 & AEDG Glazing		DOE-2 Glazing Inputs								
Case	Location	Wall R-value	Roof R-value	Roof Solar Reflectance	Floor F-factor	Opaque Door U-value	WWR	U-Value	SHGC	Code	U-value	SHGC	Min OA Damper Control	econ_control	Cooling EER	Furnace Eff.	SWH UA	SWH Eff.
LO_Base_Miami	Miami	R-0	R-15 ci	0.23	F-0.73	0.70	30%	1.22	0.25	1401	0.90	0.25	no	no	9.5	0.80	11.973	0.784
LO_Adva_Miami	Miami	R-0	R-15 ci	0.65	F-0.73	0.70	30%	0.56	0.35	2666	0.42	0.31	yes	no	11.0	0.80	0.000	0.810
LO_Base_Phoenix	Phoenix	R-0	R-15 ci	0.23	F-0.73	0.70	30%	1.22	0.25	1401	0.90	0.25	no	yes	9.5	0.80	11.973	0.784
LO_Adva_Phoenix	Phoenix	R-7.6 ci	R-15 ci	0.65	F-0.73	0.70	30%	0.45	0.31	2666	0.42	0.31	yes	yes	11.0	0.80	0.000	0.810
LO_Base_Houston	Houston	R-0	R-15 ci	0.23	F-0.73	0.70	30%	1.22	0.25	1401	0.90	0.25	no	no	9.5	0.80	11.973	0.784
LO_Adva_Houston	Houston	R-7.6 ci	R-15 ci	0.65	F-0.73	0.70	30%	0.45	0.31	2666	0.42	0.31	yes	no	11.0	0.80	0.000	0.810
LO_Base_Memphis	Memphis	R-5.7 ci	R-15 ci	0.23	F-0.73	0.70	30%	0.57	0.25	2436	0.53	0.25	no	yes	9.5	0.80	11.973	0.784
LO_Adva_Memphis	Memphis	R-9.5 ci	R-20 ci	0.65	F-0.73	0.70	30%	0.45	0.31	2666	0.42	0.31	yes	yes	10.8	0.80	0.000	0.810
LO_Base_El-Paso	El Paso	R-5.7 ci	R-15 ci	0.23	F-0.73	0.70	30%	0.57	0.25	2436	0.53	0.25	no	yes	9.5	0.80	11.973	0.784
LO_Adva_El-Paso	El Paso	R-9.5 ci	R-20 ci	0.65	F-0.73	0.70	30%	0.45	0.31	2666	0.42	0.31	yes	yes	10.8	0.80	0.000	0.810
LO_Base_San-Francisco	San Francisco	R-5.7 ci	R-10 ci	0.23	F-0.73	0.70	30%	1.22	0.61	1203	1.09	0.61	no	yes	9.5	0.80	11.973	0.784
LO_Adva_San-Francisco	San Francisco	R-9.5 ci	R-20 ci	0.65	F-0.73	0.70	30%	0.45	0.31	2666	0.42	0.31	yes	yes	10.8	0.80	0.000	0.810
LO_Base_Baltimore	Baltimore	R-5.7 ci	R-15 ci	0.23	F-0.73	0.70	30%	0.57	0.39	2470	0.56	0.35	no	no	9.5	0.80	11.973	0.784
LO_Adva_Baltimore	Baltimore	R-11.4 ci	R-20 ci	0.23	F-0.73	0.50	30%	0.42	0.46	2860	0.41	0.46	yes	yes	10.8	0.80	0.000	0.810
LO_Base_Albuquerque	Albuquerque	R-5.7 ci	R-15 ci	0.23	F-0.73	0.70	30%	0.57	0.39	2470	0.56	0.35	no	yes	9.5	0.80	11.973	0.784
LO_Adva_Albuquerque	Albuquerque	R-11.4 ci	R-20 ci	0.23	F-0.73	0.50	30%	0.42	0.46	2860	0.41	0.46	yes	yes	10.8	0.80	0.000	0.810
LO_Base_Seattle	Seattle	R-5.7 ci	R-15 ci	0.23	F-0.73	0.70	30%	0.57	0.39	2470	0.56	0.35	no	yes	9.5	0.80	11.973	0.784
LO_Adva_Seattle	Seattle	R-11.4 ci	R-20 ci	0.23	F-0.73	0.50	30%	0.42	0.46	2860	0.41	0.46	yes	yes	10.8	0.80	0.000	0.810
LO_Base_Chicago	Chicago	R-7.6 ci	R-15 ci	0.23	F-0.73	0.70	30%	0.57	0.39	2470	0.56	0.35	no	yes	9.5	0.80	11.973	0.784
LO_Adva_Chicago	Chicago	R-11.4 ci	R-20 ci	0.23	F-0.73	0.50	30%	0.42	0.46	2860	0.41	0.46	yes	yes	10.8	0.80	0.000	0.810
LO_Base_Boise	Boise	R-7.6 ci	R-15 ci	0.23	F-0.73	0.70	30%	0.57	0.39	2470	0.56	0.35	no	yes	9.5	0.80	11.973	0.784
LO_Adva_Boise	Boise	R-11.4 ci	R-20 ci	0.23	F-0.73	0.50	30%	0.42	0.46	2860	0.41	0.46	yes	yes	10.8	0.80	0.000	0.810
LO_Base_Helena	Helena	R-9.5 ci	R-15 ci	0.23	F-0.73	0.70	30%	0.57	0.39	2470	0.56	0.35	no	yes	9.5	0.80	11.973	0.784
LO_Adva_Helena	Helena	R-11.4 ci	R-20 ci	0.23	F-0.54	0.50	30%	0.42	0.46	2860	0.41	0.46	yes	yes	9.5	0.80	0.000	0.810
LO_Base_Burlington	Burlington	R-9.5 ci	R-15 ci	0.23	F-0.73	0.70	30%	0.57	0.39	2470	0.56	0.35	no	yes	9.5	0.80	11.973	0.784
LO_Adva_Burlington	Burlington	R-11.4 ci	R-20 ci	0.23	F-0.54	0.50	30%	0.42	0.46	2860	0.41	0.46	yes	yes	9.5	0.80	0.000	0.810
LO_Base_Duluth	Duluth	R-11.4 ci	R-15 ci	0.23	F-0.73	0.70	30%	0.57	0.49	2218	0.56	0.49	no	yes	9.5	0.80	11.973	0.784
LO_Adva_Duluth	Duluth	R-15.2 ci	R-20 ci	0.23	F-0.52	0.50	30%	0.33	NR	2631	0.32	0.60	yes	yes	9.5	0.80	0.000	0.810
LO_Base_Fairbanks	Fairbanks	R-13.3 ci	R-15 ci	0.23	F-0.54	0.50	30%	0.46	NR	2002	0.46	0.76	no	yes	9.5	0.80	11.973	0.784
LO_Adva_Fairbanks	Fairbanks	R-15.2 ci	R-30 ci	0.23	F-0.51	0.50	30%	0.33	NR	2631	0.32	0.60	yes	yes	9.5	0.80	0.000	0.810

Table B.2. 5,000 ft² Office Building Simulation Input Assumptions for Final Guide

								90.1 & AEDG Glazing		DOE-2 Glazing Inputs								
Case	Location	Wall R-value	Roof R-value	Roof Solar Reflectance	Floor F-factor	Opaque Door U-value	WWR	U-Value	SHGC	Code	U-value	SHGC	Min OA Damper Control	econ_control	SWH UA	SWH Eff.	Cooling EER	Furnace Eff.
SO_Base_Miami	Miami	R-13	R-30	0.12	F-0.73	0.70	20%	1.22	0.25	1401	0.90	0.29	no	no	14.41	0.784	8.7	0.74
SO_Adva_Miami	Miami	R-13	R-30	0.65	F-0.73	0.70	20%	0.56	0.35	2666	0.42	0.31	yes	no	0	0.81	11.3	0.78
SO_Base_Phoenix	Phoenix	R-13	R-30	0.12	F-0.73	0.70	20%	1.22	0.25	1401	0.90	0.29	no	no	14.41	0.784	8.7	0.74
SO_Adva_Phoenix	Phoenix	R-13	R-38	0.65	F-0.73	0.70	20%	0.45	0.31	2666	0.42	0.31	yes	no	0	0.81	11.3	0.78
SO_Base_Houston	Houston	R-13	R-30	0.12	F-0.73	0.70	20%	1.22	0.25	1401	0.90	0.29	no	no	14.41	0.784	8.7	0.74
SO_Adva_Houston	Houston	R-13	R-38	0.65	F-0.73	0.70	20%	0.45	0.31	2666	0.42	0.31	yes	no	0	0.81	11.3	0.78
SO_Base_Memphis	Memphis	R-13	R-30	0.12	F-0.73	0.70	20%	0.57	0.25	2436	0.53	0.25	no	no	14.41	0.784	8.7	0.74
SO_Adva_Memphis	Memphis	R-13	R-38	0.65	F-0.73	0.70	20%	0.45	0.31	2666	0.42	0.31	yes	yes	0	0.81	11.3	0.78
SO_Base_El-Paso	El Paso	R-13	R-30	0.12	F-0.73	0.70	20%	0.57	0.25	2436	0.53	0.25	no	no	14.41	0.784	8.7	0.74
SO_Adva_El-Paso	El Paso	R-13	R-38	0.65	F-0.73	0.70	20%	0.45	0.31	2666	0.42	0.31	yes	yes	0	0.81	11.3	0.78
SO_Base_San-Francisco	San Francisco	R-13	R-30	0.12	F-0.73	0.70	20%	1.22	0.61	1203	1.09	0.61	no	no	14.41	0.784	8.7	0.74
SO_Adva_San-Francisco	San Francisco	R-13	R-38	0.65	F-0.73	0.70	20%	0.45	0.31	2666	0.42	0.31	yes	yes	0	0.81	11.3	0.78
SO_Base_Baltimore	Baltimore	R-13	R-30	0.12	F-0.73	0.70	20%	0.57	0.39	2470	0.56	0.35	no	no	14.41	0.784	8.7	0.74
SO_Adva_Baltimore	Baltimore	R-13	R-38	0.12	F-0.73	0.70	20%	0.42	0.46	2860	0.41	0.46	yes	yes	0	0.81	11.3	0.78
SO_Base_Albuquerque	Albuquerque	R-13	R-30	0.12	F-0.73	0.70	20%	0.57	0.39	2470	0.56	0.35	no	no	14.41	0.784	8.7	0.74
SO_Adva_Albuquerque	Albuquerque	R-13	R-38	0.12	F-0.73	0.70	20%	0.42	0.46	2860	0.41	0.46	yes	yes	0	0.81	11.3	0.78
SO_Base_Seattle	Seattle	R-13	R-30	0.12	F-0.73	0.70	20%	0.57	0.39	2470	0.56	0.35	no	no	14.41	0.784	8.7	0.74
SO_Adva_Seattle	Seattle	R-13	R-38	0.12	F-0.73	0.70	20%	0.42	0.46	2860	0.41	0.46	yes	yes	0	0.81	11.3	0.78
SO_Base_Chicago	Chicago	R-13	R-30	0.12	F-0.73	0.70	20%	0.57	0.39	2470	0.56	0.35	no	no	14.41	0.784	8.7	0.74
SO_Adva_Chicago	Chicago	R-13 +R-3.8 ci	R-38	0.12	F-0.73	0.70	20%	0.42	0.46	2860	0.41	0.46	yes	yes	0	0.81	11.3	0.78
SO_Base_Boise	Boise	R-13	R-30	0.12	F-0.73	0.70	20%	0.57	0.39	2470	0.56	0.35	no	no	14.41	0.784	8.7	0.74
SO_Adva_Boise	Boise	R-13 +R-3.8 ci	R-38	0.12	F-0.73	0.70	20%	0.42	0.46	2860	0.41	0.46	yes	yes	0	0.81	11.3	0.78
SO_Base_Helena	Helena	R-13	R-38	0.12	F-0.73	0.70	20%	0.57	0.39	2470	0.56	0.35	no	no	14.41	0.784	8.7	0.74
SO_Adva_Helena	Helena	R-13 +R-3.8 ci	R-38	0.12	F-0.54	0.70	20%	0.42	0.46	2860	0.41	0.46	yes	yes	0	0.81	11.3	0.78
SO_Base_Burlington	Burlington	R-13	R-38	0.12	F-0.73	0.70	20%	0.57	0.39	2470	0.56	0.35	no	no	14.41	0.784	8.7	0.74
SO_Adva_Burlington	Burlington	R-13 +R-3.8 ci	R-38	0.12	F-0.54	0.70	20%	0.42	0.46	2860	0.41	0.46	yes	yes	0	0.81	11.3	0.78
SO_Base_Duluth	Duluth	R-13	R-38	0.12	F-0.73	0.70	20%	0.57	0.49	2218	0.56	0.49	no	no	14.41	0.784	8.7	0.74
SO_Adva_Duluth	Duluth	R-13 +R-7.5 ci	R-60	0.12	F-0.52	0.50	20%	0.33	NR	2631	0.32	0.60	yes	no	0	0.81	11.3	0.78
SO_Base_Fairbanks	Fairbanks	R-13 + R-7.5 ci	R-38	0.12	F-0.54	0.50	20%	0.46	NR	2002	0.46	0.76	no	no	14.41	0.784	8.7	0.74
SO_Adva_Fairbanks	Fairbanks	R-13 +R-10 ci	R-60	0.12	F-0.51	0.50	20%	0.33	NR	2631	0.32	0.60	yes	no	0	0.81	11.3	0.78

Appendix C

Development of the Linear Regression Equations

Appendix C

Development of the Linear Regression Equations

C.1 Objective

The objective of this task was to develop a linear regression model for annual energy usage in office buildings. The regression model could then 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 calculated annual energy consumption data for two prototype office buildings, a 5,000 ft^2 and a 20,000 ft^2. 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 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 energy results from the DOE-2 simulations included both the envelope losses and the outdoor air. The heating model calculated heating energy by regressing seven variables and took the following form:

$$\textit{Heating Energy} = \begin{array}{l} C0 \\ + C_1 \times \text{Conduction} \\ + C_2 \times \text{Infiltration} \\ + C_3 \times \text{North Solar} \\ + C_4 \times \text{E/W Solar} \\ + C_5 \times \text{South Solar} \\ + C_6 \times \text{Internals} \\ + C_7 \times \text{People} \end{array} \tag{C.1}$$

where

$C_0, C_1 \ldots C_7$ = 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_0– C_7) are dimensionless.

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

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

where

U_oA_o	= overall UA of the building envelope (Btu/hr·ft^2·^{o}F)
HDD_{65}	= heating degree days (base 65^{o}F) per year for the location (^{o}F·days)
AFUE	= annual fuel utilization efficiency of the heating equipment (dimensionless)
CF	= conversion factor (10^6 Btu/MBtu)

The infiltration variable was the second variable and it was intended to account for the energy required to heat infiltration air. On an hourly basis, this would vary strongly with the weather conditions, but on a seasonal basis, it was assumed to be the following:

$$Infiltration = \frac{1.08 \times ACH \times Vol \times 24 \times HDD_{65}}{AFUE \times CF \times 60} \tag{C.3}$$

where

1.08	= density of air x specific heat of air x* 60 min/hr for moist air (Btu·min/ft^3·^{o}F·hr)
ACH	= air changes per hour (1/hr)
Vol	= volume of conditioned space (ft^3)
24	= hours per day (hr/day)
60	= minutes per hour (min/hr)

The solar fenestration variables were intended to account for the solar heat gain to the building through fenestration. The office buildings had a square footprint with each exterior wall facing one of the cardinal orientations. The solar radiation on the north facing fenestration was:

$$North\ Solar = \frac{A_{gw} \times WWR_n \times 0.25 \times SHGC_n \times PF_n \times N_{solar} \times \%Heat \times 365}{CF} \tag{C.4}$$

where

A_{gw}	= area of gross wall (ft^2)
WWR_n	= window to wall ratio on north facing surface (dimensionless)
0.25	= fraction of fenestration area that is north facing (dimensionless)
$SHGC_n$	= solar heat gain factor on north facing surface (dimensionless)
PF_n	= projection factor on north facing fenestration (dimensionless)
N_{solar}	= daily average solar incident on the north fenestration (Btu/day)
% Heat	= fraction of year heating is required (= $\frac{HDD_{65}}{CDD_{50} + HDD_{65}}$) (dimensionless)
365	= days per year (days)

The solar radiation on the east and west facing fenestration was:

$$EW\ Solar = \frac{A_{gw} \times WWR_{ew} \times 0.50 \times SHGC_{ew} \times PF_{ew} \times EW_{solar} \times \%Heat \times 365}{CF} \qquad (C.5)$$

where

WW_{ew}	= window to wall ratio on EW facing surfaces (dimensionless)
0.50	= fraction of fenestration area that is EW facing (dimensionless)
$SHGC_{ew}$	= solar heat gain factor on EW facing surfaces (dimensionless)
PF_{ew}	= projection factor on EW facing surfaces (dimensionless)
EW_{solar}	= daily average solar incident on EW facing surfaces (Btu/day)

The solar radiation on the south facing fenestration was:

$$South\ Solar = \frac{A_{gw} \times WWR_s \times 0.25 \times SHGC_s \times PF_s \times S_{solar} \times \%Heat \times 365}{CF} \qquad (C.6)$$

where

WWR_s	= window to wall ratio on south facing surface (dimensionless)
0.25	= fraction of fenestration area that is south facing (dimensionless)
$SHGC_s$	= solar heat gain factor on south facing surface (dimensionless)
PF_s	= projection factor on south facing fenestration (dimensionless)
S_{solar}	= daily average solar incident on the south fenestration (Btu/day)

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

$$Internals = (\text{Lights} + \text{Plugs} + \text{Fans}) \times \%\text{Heat} \quad \text{(C.7)}$$

where

Lights	= average annual lighting energy (MBtu/yr)
Plugs	= average annual plug energy (MBtu/yr)
Fans	= average annual fan energy (MBtu/yr)

The seventh variable the internal sensible gains due to the building occupants and took the following form:

$$People = \frac{People \times Sensible \times 55 \times 52 \times \%Heat}{CF} \quad \text{(C.8)}$$

where

People	= number of occupants (at design)
Sensible	= sensible heat gain from people (250 Btu/hr/person)
55	= hours of occupancy per week (hr/week)
52	= number of weeks per year (weeks/yr)

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 below:

Table C.1. Heating Model Coefficients

Heating 5,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
C_0 - Intercept	-21.984011	1.920822	-11.445107	0.000000
C_1 - Conduction	0.411124	0.037053	11.095478	0.000000
C_2 - Infiltration	2.867313	0.173736	16.503875	0.000000
C_3 - Nsolar	-0.713480	1.137876	-0.627028	0.531406
C_4 - EWSolar	-0.466609	0.612009	-0.762423	0.446768
C_5 - Ssolar	4.163962	0.976141	4.265737	0.000032
C_6 - Internals	-4.115671	0.812230	-5.067127	0.000001
C_7 - People	29.428598	3.749373	7.848939	0.000000

Heating 20,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
C_0 - Intercept	-55.035558	5.380442	-10.228817	0.000000
C_1 - Conduction	0.607756	0.008318	73.063848	0.000000
C_2 - Infiltration	4.821379	0.236061	20.424334	0.000000
C_3 - Nsolar	-1.024291	0.689002	-1.486631	0.138797
C_4 - EWSolar	1.139170	0.357752	3.184250	0.001700
C_5 - Ssolar	-0.086835	0.471152	-0.184304	0.853974
C_6 - Internals	0.211968	0.166555	1.272667	0.204716
C_7 - People	3.668845	0.719984	5.095728	0.000001

Figure C-1 plots the regression results versus the corresponding DOE-2 results for the two prototypical office buildings. The standard deviation of the residuals of the heating regressions was 10.0 MBtu/yr for the 5,000 ft^2 office and 30.0 MBtu/yr for the 20,000 ft^2 office.

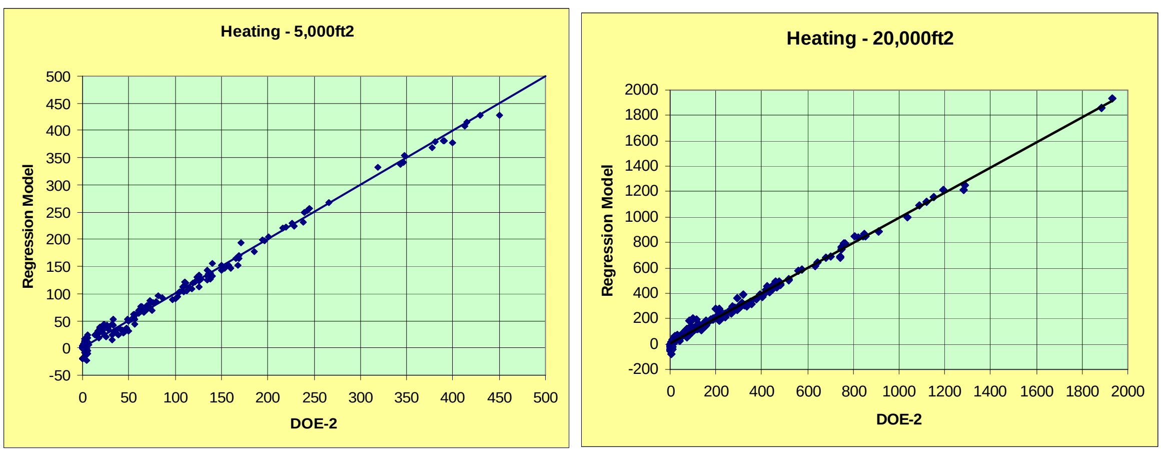


Figure C.1. Heating Regressions

C.4 Cooling Energy

The cooling model calculated cooling energy by regressing seven variables and took the following form:

$$Cooling\ Energy = \begin{aligned} & C0 \\ & + C1 \times \text{Conduction} \\ & + C2 \times \text{Infiltration} \\ & + C3 \times \text{North Solar} \\ & + C4 \times \text{E/W Solar} \\ & + C5 \times \text{South Solar} \\ & + C6 \times \text{Internals} \\ & + C7 \times \text{People} \end{aligned} \qquad (C.9)$$

where

$C_0, C_1 \ldots C_7$ = regression coefficients

The constants are determined by regression. The units for cooling 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_0– C_7) are dimensionless.

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

$$Conduction = \frac{U_o A_o \times 24 \times CDD_{50}}{EFF \times CF} \quad \text{(C.10)}$$

where

U_oA_o = overall UA of the building envelope (Btu/hr·ft^2·°F)
CDD_{50} = cooling degree days (base 50°F) per year for the location
EFF = cooling efficiency (EFF = $\frac{SEER}{3.413}$) (dimensionless)
$SEER$ = seasonal energy efficiency ratio (Btu/W·h)
CF = conversion factor (10^6 Btu/MBtu)

The infiltration variable was the second variable and it was intended to account for the energy required to cool infiltration air. On an hourly basis, this would vary strongly with the weather conditions, but on a seasonal basis, it was assumed to be the following:

$$Infiltration = \frac{1.08 \times ACH \times Vol \times 24 \times CDD_{50}}{EFF \times CF \times 60} \quad \text{(C.11)}$$

The solar fenestration variables were intended to account for the solar heat gain to the building through fenestration. The office buildings had a square footprint with each exterior wall facing one of the cardinal orientations. The solar radiation on the north facing fenestration was:

$$North\ Solar = \frac{A_{gw} \times WWR_n \times 0.25 \times SHGC_n \times PF_n \times N_{solar} \times \%Cool \times 365}{CF} \quad \text{(C.12)}$$

where

WWR_n = window to wall ratio on north facing surface (dimensionless)

$SHGC_n$	= solar heat gain coefficient on north facing fenestration (dimensionless)
PF_n	= projection factor on north facing surfaces (dimensionless)
N_{solar}	= daily average solar radiation on a north facing surface (Btu/h·day)
% Cool	= fraction of year cooling is required (= $\frac{CDD_{50}}{CDD_{50} + HDD_{65}}$)

The solar radiation on the east and west facing fenestration was:

$$EW\ Solar = \frac{A_{gw} \times WWR_{ew} \times 0.50 \times SHGC_{ew} \times PF_{ew} \times EW_{solar} \times \%Cool \times 365}{CF} \quad \text{(C.13)}$$

The solar radiation on the south facing fenestration was:

$$South\ Solar = \frac{A_{gw} \times WWR_s \times 0.25 \times SHGC_s \times PF_s \times S_{solar} \times \%Cool \times 365}{CF} \quad \text{(C.14)}$$

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

$$Internals = (\text{Lights} + \text{Plugs} + \text{Fans}) \times \%\text{Cool} \quad \text{(C.15)}$$

The seventh variable the internal sensible gains due to the building occupants and took the following form:

$$People = \frac{People \times Sensible \times 55 \times 52 \times \%Cool}{CF} \quad \text{(C.16)}$$

The Excel linear regression routine REGRESS was used to calculate the coefficients for these variables. Results, along with the associated statistical measures, are given below:

Table C.2. Cooling Model Coefficients

Cooling 5,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
C_0 - Intercept	-4.306310	0.239156	-18.006277	0.000000
C_1 - Conduction	-0.121467	0.026259	-4.625798	0.000007
C_2 - Infiltration	4.172952	0.140710	29.656466	0.000000
C_3 - Nsolar	0.467569	0.366986	1.274079	0.204216
C_4 - EWSolar	-0.657006	0.378701	-1.734894	0.084407
C_5 - Ssolar	2.572593	0.608785	4.225783	0.000037
C_6 - Internals	1.470300	0.258633	5.684895	0.000000
C_7 - People	-13.424649	1.133346	-11.845144	0.000000

Cooling 20,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
C_0 - Intercept	-14.669194	1.741728	-8.422208	0.000000
C_1 - Conduction	0.097752	0.014562	6.712721	0.000000
C_2 - Infiltration	12.666221	0.534089	23.715545	0.000000
C_3 - Nsolar	-0.277720	0.602289	-0.461107	0.645258
C_4 - EWSolar	0.620543	0.553985	1.120145	0.264089
C_5 - Ssolar	0.512368	0.826549	0.619888	0.536086
C_6 - Internals	0.021759	0.189109	0.115058	0.908523
C_7 - People	-7.310856	1.177780	-6.207317	0.000000

Figure C-2 plots the regression results versus the corresponding DOE-2 results for the two prototypical office buildings. The standard deviation of the residuals of the cooling regressions was 1.2 MBtu/yr for the 5,000 ft^2 office and 9.7 MBtu/yr for the 20,000 ft^2 office.

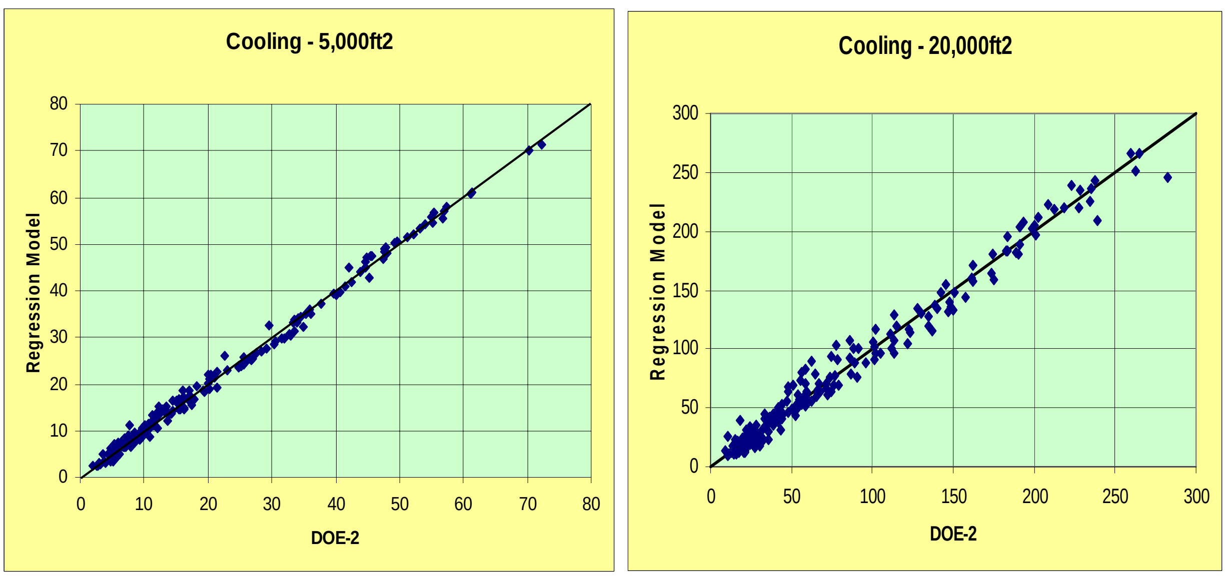


Figure C-2. Cooling Regressions

C.5 Fans

The fan model calculated the fan energy by regressing seven variables and took the following form:

$$
\textit{Fan Energy} = \begin{array}{l} C_0 \\ + C_1 \times (HDD_{65} + CDD_{50}) \\ + C_2 \times WWR \\ + C_3 \times Ufen \\ + C_4 \times PF \\ + C_5 \times Ufen * WWR \\ + C_6 \times Ufen * PF \\ + C_7 \times (HDD_{65} + CDD_{50}) * Ufen * PF * WWR \end{array} \qquad (C.17)
$$

where

$C_0, C_1 \ldots C_7$ = regression coefficients

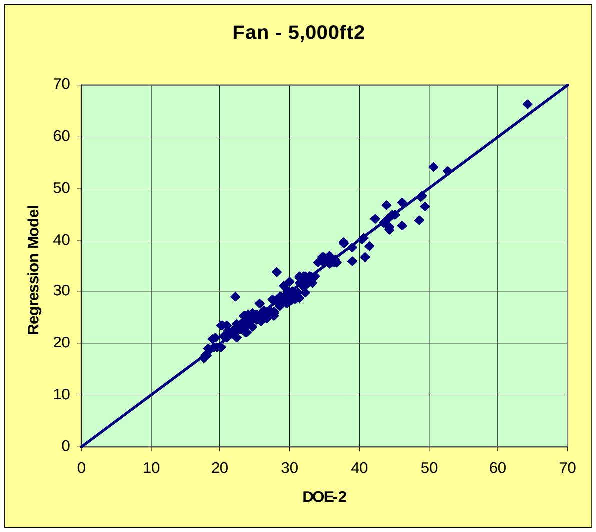
The constants are determined by regression. The units for fan energy for this analysis are millions of Btu per year (MBtu/yr), and the variables are constructed to have units of MBtu/yr so that the regression constants (C_0– C_7) are dimensionless. The Excel linear regression routine REGRESS was used to calculate the coefficients for these variables. Results, along with the associated statistical measures, are given below:

Table C-3. Fan Model Coefficients

Fan - 5,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
C_0 - Intercept	24.070581	5.090499	4.728531	0.000005
C_1 - HDD_{65}+CDD_{50}	0.001129	0.000130	8.675670	0.000000
C_2 - WWR	-61.893277	7.439153	-8.319936	0.000000
C_3 - U_{fen}	-32.772048	10.527348	-3.113039	0.002194
C_4 - PF	-13.996435	4.508577	-3.104402	0.002255
C_5 - U_{fen}*WWR	139.558235	17.552420	7.950940	0.000000
C_6 - U_{fen}*PF	26.096847	9.727560	2.682774	0.008068
C_7 – (HDD_{65}+CDD_{50}*U_{fen}*PF*WWR	0.010906	0.001050	10.387072	0.000000

Fan - 20,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
C_0 - Intercept	149.524510	33.323555	4.487052	0.000013
C_1 - HDD_{65}+CDD_{50}	0.001284	0.001023	1.254651	0.211171
C_2 - WWR	-267.802789	78.376478	-3.416877	0.000777
C_3 - U_{fen}	-236.024892	71.502301	-3.300941	0.001154
C_4 - PF	-54.894910	21.026987	-2.610688	0.009769
C_5 - U_{fen}*WWR	529.573048	173.943260	3.044516	0.002667
C_6 - U_{fen}*PF	148.345149	50.238757	2.952803	0.003553
C_7 – (HDD_{65}+CDD_{50}*U_{fen}*PF*WWR	0.026705	0.007234	3.691546	0.000292

Figure C-3 plots the regression results versus the corresponding DOE-2 results for the two prototypical office buildings. The standard deviation of the residuals of the fan regressions was 1.52 MBtu/yr for the 5,000 ft^2 office and 9.0 MBtu/yr for the 20,000 ft^2 office.



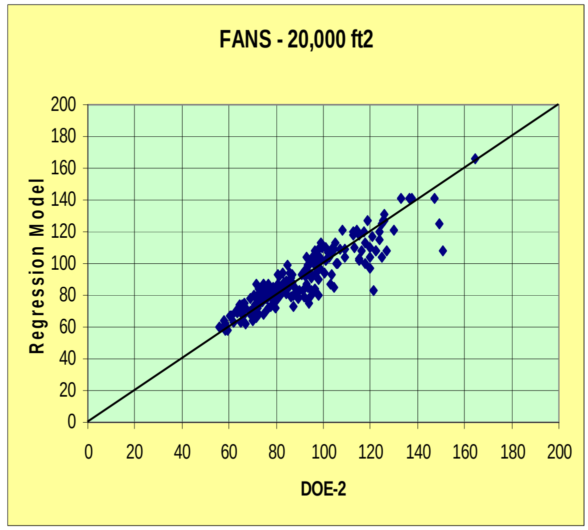


Figure C.3. Fan Regressions

C.6 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 and be approximated by average annual air temperature for a location. Hence the model for service water heating took the simple form:

$$SHW = C_0 + C_1 \times \text{Tannual} \qquad \text{(C.18)}$$

where

T_{annual} = Annual average outdoor dry-bulb 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 below:

Table C.4. Service Water Heating Coefficients

SWH - 5,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
C_0 - Intercept	9.127575	0.027483	332.112246	0.000000
C_1 - T_{annual}	-0.075718	0.000493	-153.504940	0.000000

SWH - 20,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
C_0 - Intercept	31.690585	0.274540	115.431501	0.000000
C_1 - T_{annual}	-0.263304	0.004927	-53.437827	0.000000

Figure C-4 plots the regression result versus the corresponding DOE-2 result. . The standard deviation of the residuals of the service water heater regressions was 0.023 MBtu/yr for the 5,000 ft^2 office and 0.234 MBtu/yr for the 20,000 ft^2 office.

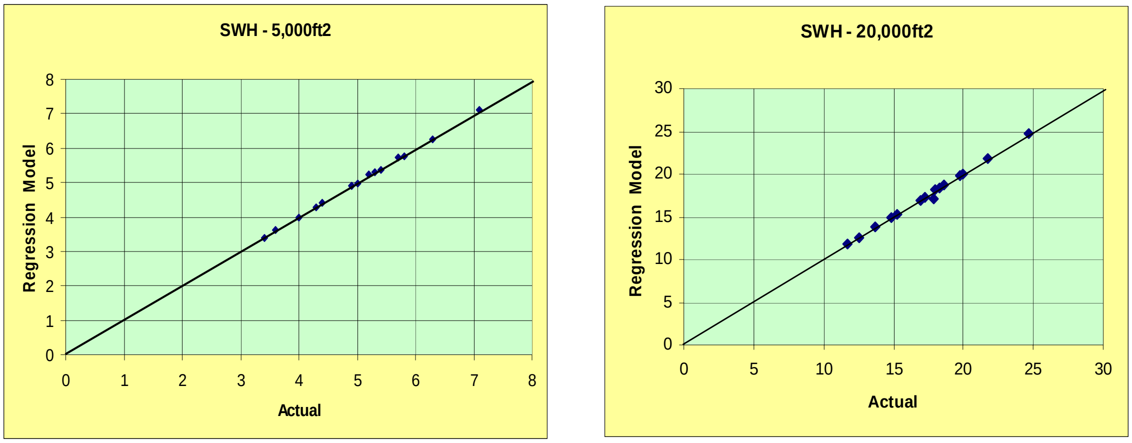


Figure C.4. Service Water Heating Regressions

C.7 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.

$$Aux = C_0 + C_1 \times HDD_{65} \quad (C.19)$$

The Excel linear regression routine REGRESS was used to calculate the coefficients. Results, along with the associated statistical measures, are given below.

Table C.5. Auxiliary Energy Coefficients

AUX – 5,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	1.865658	0.097275	19.179221	0.000000
HDD_{65}	-0.023454	0.001746	-13.433966	0.000000

AUX – 20,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	9.414464	0.514210	18.308612	0.000000
HDD_{65}	-0.118979	0.009229	-12.892210	0.000000

Figure C.5 plots the regression result versus the corresponding DOE-2 result. The standard deviation of the residuals of the auxiliary energy regressions was 0.083 MBtu/yr for the 5,000 ft^2 office and 0.438 MBtu/yr for the 20,000 ft^2 office.

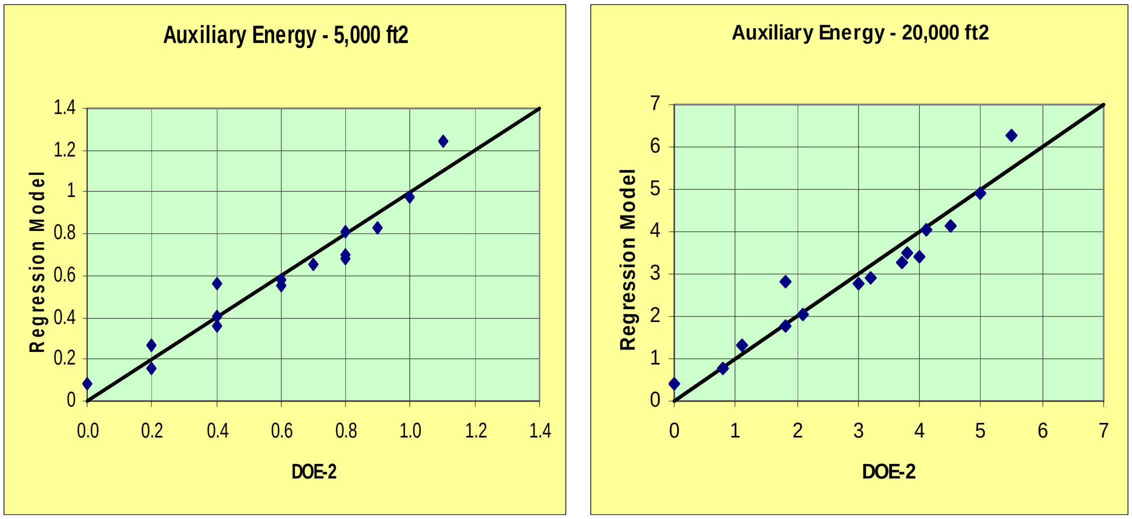


Figure C.5. Auxiliary Energy Regression

C.8 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 since 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.9 Overall Results

The overall results are the sum of the individual regression models. Figure C.6 gives the results of the regression model compared to the corresponding DOE-2 results. The standard deviation of the residuals of the total energy regressions was 10.0 MBtu/yr for the 5,000 ft^2 office and 54.3 MBtu/yr for the 20,000 ft^2 office.

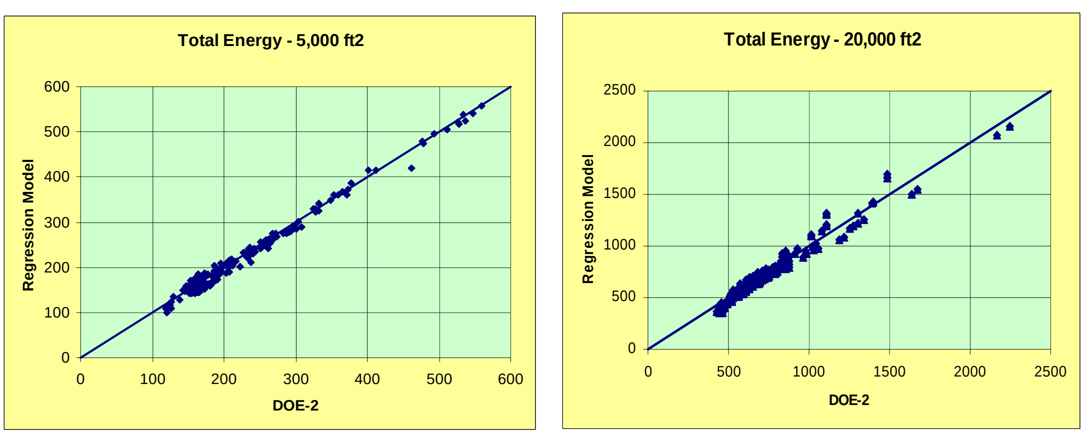


Figure C.6. Overall Regression Results

C.10 Outdoor Air Damper Controls

The impact of the outdoor air damper controls was determined by completing one additional DOE-2 simulation for each of the 15 cities. Examination of the data indicated that a simple regression model using heating degree days as the variable would adequately represent the outdoor air energy usage.

$$\textit{Outdoor Air} = C_0 + C_1 \times HDD_{65} \qquad \text{(C.20)}$$

The Excel linear regression routine REGRESS was used to calculate the coefficients. Results, along with the associated statistical measures, are given below.

Table C.6. Outdoor Air Energy Coefficients

OA – 5,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	-55.453446	7.213501	-7.687453	0.000117
HDD_{65}	0.014556	0.000922	15.789952	0.000001

OA – 20,000 ft^2	*Coefficients*	*Standard Error*	*t Stat*	*P-value*
Intercept	-70.006995	7.324413	-9.558034	0.000029
HDD_{65}	0.019549	0.000936	20.885788	0.000000

Figure C.7 plots the regression result versus the corresponding DOE-2 result. The standard deviation of the residuals of the auxiliary energy regressions was 7.6 MBtu/yr for the 5,000 ft^2 office and 7.7 MBtu/yr for the 20,000 ft^2 office.

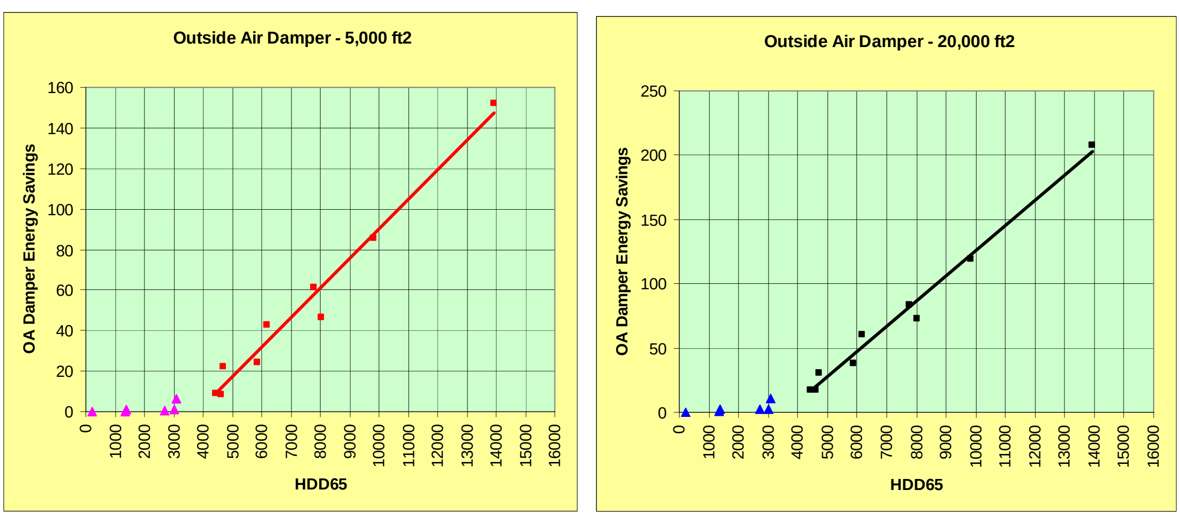


Figure C.7. Outdoor Air Regression Results

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

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ADVANCED ENERGY DESIGN GUIDE: SMALL OFFICE BUILDINGS

On March 27, 2004, the SP 102 Steering Committee issued an 80% Technical Refinement Draft of the document *Advanced Energy Design Guide: Small Office Buildings* for general peer review within ASHRAE and by the collaborating organizations of AIA, IESNA, and NBI. In this second draft review period (the first was for the 50% concept draft) the requested review focused on technical refinement comments and recommendations. Following the review period of March 27 through April 8 the SP 102 Cognizant Committee met by conference call on April 13 to review the recommendations received. Based on these recommendations many significant changes were made to the Guide document.

On May 10 a 100% Final Draft was issued. In this final draft review period of May 10 through May 17 the requested review was focused on factual errors. Following this final review period the SP 102 Cognizant Committee met in Washington, DC, on May 17-18 to review the recommendations received.

Over 400 remarks and review recommendations were received from approximately 40 reviewers for the 80% review and over 440 remarks and recommendations were received from approximately 50 reviewers for the 100% review. These remarks were received from persons involved in ASHRAE SSPC 90.1, TC 2.8, TC 7.6, AIA, IESNA, NBI and from the ASHRAE membership at large. The following summary presents the SP 102 project's summary response to those remarks and review recommendations. Although many of the suggestions dealt with editorial details presented in the drafts, this summary includes responses to the technical content recommendations and in particular those in which there was disagreement with what had been written or omitted. The specific and detailed suggestions and remarks were thoroughly reviewed and digested by the SP 102 committee in preparation of the 110% draft of the guide. Review remarks received fall into the following theme categories.

1. Focus on Target Audience

The Cognizant Committee reaffirmed the target audience as primarily those who construct small office buildings (e.g. contractors), but also including those involved in the design process, particularly in small design firms. Because this is consistent with the committee's charge, both the SP 102 Committee and the Cognizant Committee examined the document closely to ensure that the text and recommendations are consistent with the needs of this audience. Suggestions received that were not appropriate for this target audience were not included in the revised draft.

2. Review Process for Draft Document is Inadequate

Several reviewers questioned the adequacy of the review process for the 80% and 100% drafts, noting that the time periods allotted were very short. It was suggested that because of its importance and impact on the HVAC industry this document should follow the public review procedures for ASHRAE standards. While acknowledging that more review time would have been desirable, the Cognizant Committee was operating under a tight schedule specified by the ASHRAE leadership, which precluded extended review periods. Furthermore, because of its nature this document is intentionally not a standard or a guideline and therefore was developed under modified ASHRAE Special Publications procedures. A thorough and broad peer review was openly conducted both within and outside ASHRAE; all review input was reviewed and incorporated as deemed appropriate by the authors.

3. Combine Sections 1 and 2

A few 80% review comments recommended that there was overlap and redundant coverage in Sections 1 an 2 and that they should be combined. The committee agreed and this has been done.

4. Link to Standards Requirements

Several comments on the 80% draft suggested putting in a number of things that linked the document more closely to Standard 90.1, such as references to test procedures for equipment and to specific sections in the standard. The Cognizant Committee felt that these changes would result in divergence from our mission to develop a guide rather than a standard, and suggested we not make these changes. Thus the text was rewritten to assure that it is clear that the recommendations go beyond the requirements in the standard.

5. Technical Documentation

Several comments on the 80% draft requested detailed technical documentation of energy savings and methods used to develop the recommendations. The Cognizant Committee felt that documentation at some level should be made available at some point once the document is complete, and discussed options for articles, seminars, and perhaps technical papers. A planned schedule for documentation will be developed and communicated to interested parties.

6. Clarifications needed in Design Process Discussion

Many 80% review comments noted that the design section (Section 3) was not clear and was incomplete. In response this entire section was rewritten, expanded, and reformatted to provide clear and useful information.

It was noted that the charts in the pre-design phase discussion regarding prioritizing goals, which presented bar charts depicting end-use load breakdowns for Miami and Duluth, were too small and hard to read. More readable charts will be provided in the final published Guide. Also it was suggested that the assumptions behind these results need to be explained.

The estimated person-hours needed for site visits and acceptance testing listed in the design process discussion were questioned as unrealistically low.

7. Recommendations by Climate Zone

It was noted that the climate zone map is difficult to read and its web reference is inadequate. This will be fixed in the final published Guide, as will the formatting of the recommendations tables.

Several reviewers believed that the recommendations given were too prescriptive and did not afford flexible enough options to achieve the 30% savings goal. We emphasize several places in the Guide that a way, and not the only way is presented here; other options are certainly available and should be used as appropriate.

8. Envelope, Ventilation, and Fenestration

80% reviewers questioned the validity of the R-60 roof insulation in some climate zones and the 1% duct leakage rate. The committee acknowledged that these numbers were preliminary and that further analysis has determined more appropriate values that are included in the 100% draft.

It was recommended that shading be emphasized rather than low SHGC glazing, especially in cold climates. It was suggested that to avoid glare the VLT values should vary with climate for view glass. Numerous clarifications were suggested for the how-to descriptions. These are being addressed in the 110% draft.

Air barrier leakage rate recommendations were deemed too low.

The use of CO2 sensors for demand controlled ventilation was questioned.

9. Heating and Cooling Equipment

Concern continues to be expressed that the heating and cooling equipment efficiencies and other recommended values in the tables vary inconsistently with climate zone. It was suggested by several persons that these efficiencies should be harmonized with those of national voluntary specification programs such as EPA's Energy Star program. The authors took this criticism very seriously and have adjusted the values in the final version (110% draft) to be more consistent with these programs. However, in the warmer (Zones 1 and 2) and colder (Zones 7 and 8) climates the authors believe that cost effective, rational design requires efficiencies appropriate to those climates.

Several recommendations were made to include other types of equipment than those that were initially analyzed, for example economizers, heat recovery, ground-source heat pumps, radiant systems, and dedicated outdoor air systems; some of these have been added. Other equipment and system types have been added to the recommendations, often as alternate strategies that are explained in the "how to" section (now Section 4 in the 100% draft). It is emphasized that because this Guide presents "a way, not the only way" many other equipment types and combinations are possible to achieve the 30% goal. However, the authors focused on selected equipment and systems that they felt confident were practical and which were confirmed to achieve the 30% savings target.

The characterization of heating equipment efficiency (especially <225KBtu/h furnaces) was viewed to be inconsistent and it was suggested that AFUE 92% be extended to Zones 5-6. The use of motorized dampers on furnaces <65KBtu/h was questioned as unrealistic. These are being addressed in the final draft.

10. Water Heating and Duct Leakage Recommendations

Some 80% review commentors raised issues about the efficiency levels for water heaters and expressed concern that instantaneous heaters are rarely used in small buildings. The Cognizant Committee discussed the appropriateness of gas vs. electric and storage vs. instantaneous water heaters for small office applications and agreed that this should be examined more closely. These concerns were addressed in the 100% draft.

However, several 100% draft reviewers believed that other types of water heater options, gas and electric/storage and instantaneous, should be included in the recommendations or how-tos. Heat pump and desuperheating types should be included. Recommended efficiencies should be stated for all types, not just gas instantaneous heaters. Circulating vs. non-circulating systems benefits should be examined. Water heaters are not boilers (or condensing boilers); clarify use of this terminology in water heating section.

The 0.05"/100 ft of duct pressure loss was questioned as unrealistic, as were limits on length of flexible duct. Insulation is recommended on outside ducts but also state that they should not be used. How-tos should be rewritten for clarity and accuracy; some (noise, supply air temperature, zone temperature control, legionellosis) are regarded as unnecessary for this guide.

11. Lighting and Daylighting

It was recommended that practical design information is included in the periodical "Lighting Design and Applications". The SP 102 Committee examined this resource in preparation of the 100% draft.

Most of the numerous recommendations on lighting and daylighting were suggested clarifications in the how-to descriptions. These are being addressed in the 110% draft and copy editing phase.

12. Commissioning

We again received many comments on the commissioning recommendations, suggesting that we still have not yet got it quite right. The Cognizant Committee felt we should pay additional attention to addressing these concerns. A few of the commentors were asked to provide specific language to help address the concerns. Major changes in the text were made to correct this problem and to describe a more flexible approach that emphasizes the importance of quality assurance while suggesting that many options are available to achieve this assurance, particularly at a level lower than commissioning.

Consistent terminology (use of QA, CM, QA/Cx) will be developed in the editing phase. It was suggested that the Commissioning Scope section be made more like a checklist than text, i.e., outline a practical, cost effective approach for small office buildings.