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Technical Support Document: The Development of the *Advanced Energy Design Guide for Small Warehouse and Self-Storage Buildings*

B. Liu
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K. Gowri

December 2007

Prepared for
U.S. Department of Energy
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The authors would like to thank all the members of the project committee for their tremendous volunteering efforts and significant inputs to our energy analysis work during the development of the *Advanced Energy Design Guide for Small Warehouse and Self Storage Buildings*. Without the committee members' expertise in producing the energy efficiency recommendations covering envelop, lighting, daylighting, and HAVC systems, this document would not have been successful.

Last, but not least, the authors would like to specially recognize Andrew Nicholls, the program manager overseeing the Commercial Building Integration Program at PNNL, for providing the thorough review of this document and for his support of this particular project. Finally, the authors greatly appreciate the assistance of Todd Taylor at PNNL. Todd constructed the cluster simulation structure in EnergyPlus, which allowed us to evaluate the many variations of energy efficiency technologies in a timely fashion to meet the project compressed schedule.

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Executive Summary

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

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

The AEDG-WH was developed in seven months by an ASHRAE special project committee (SP-114) made up of representatives of each of the partner organizations. This TSD describes the charge given to the committee in developing the warehouse guide and outlines the schedule of the development effort. The project committee developed two prototype warehouses (non-refrigerated warehouse and self-storage warehouse) to represent the class of small warehouses and performed an energy simulation scoping study to determine the preliminary levels of efficiency necessary to meet the energy savings target. The simulation approach used by the project committee is documented in this TSD, along with the characteristics of the prototype buildings (which were based on data from F.W. Dodge and the Energy Information Administration). 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 daylighting technologies, infiltration reduction, and heating, ventilation and air-conditioning (HVAC) and service water heating (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 42% over the Standard 90.1-1999. If using Standard 90.1-2004 as the basis, this Guide would produce 33% energy savings.

Nomenclature

AEDG-SO	Advanced Energy Design Guide for Small Office Buildings
AEDG-SR	Advanced Energy Design Guide for Small Retail Buildings
AEDG-WH	Advanced Energy Design Guide for Warehouses
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
CDD	Cooling degree day
cfm	cubic feet per minute
COP	coefficient of performance
CUAC	Commercial unitary air conditioners
DCV	demand-controlled ventilation
DOE	U.S. Department of Energy
DX	direct expansion
Ec	combustion efficiency
EER	energy efficiency ratio
EF	energy factors
EIA	Energy Information Administration
EPDM	ethylene-propylenediene-terpolymer membrane
Et	thermal efficiency
EUI	energy use index
GAMA	Gas Appliance Manufactures Association
HDD	heating degree day
HIR	heat input ratio
HSPF	heating season performance factors
HVAC	heating, ventilation and air conditioning
IECC	International Energy Conservation Code
IESNA	Illuminating Engineering Society of North America
in.	inch
IPLV	integrated part load values
IR	infrared
LBNL	Lawrence Berkeley National Laboratory
LCC	life-cycle cost
LEED®	Leadership in Energy and Environment Design
LPD	lighting power densities
MBMA	Metal Building Manufacturers Association

NAECA	National Appliance Energy Conservation Act
NC3	National Commercial Construction Characteristics Database
NOS	net occupied space
o.c.	on center
PG&E	Pacific Gas and Electric Company
PNNL	Pacific Northwest National Laboratory
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
SRI	solar reflectance index
SWH	service water heating
TMY	typical meteorological year
Tdb	dry-bulb temperature
Twb	wet-bulb temperature
TSD	technical support document
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
WD	weekdays
WEH	weekends and holidays
WHAM	Water Heater Analysis Model
WWR	window-to-wall ratio

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1.0 Introduction

The *Advanced Energy Design Guide for Small Warehouses and Self-Storage Buildings* (AEDG-WH) (referred to as the "Guide" in this report) was developed by a partnership of organizations, including the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IESNA), the United States Green Buildings Council (USGBC), and the Department of Energy (DOE). The Guide is intended to offer recommendations to achieve 30% energy savings and thus to encourage steady progress toward net-zero energy buildings. The baseline level energy use was set as buildings built at the turn of the millennium, which are assumed to be based on ANSI/ASHRAE/IESNA Standard 90.1-1999 (ANSI/ASHRAE/IESNA 1999), *Energy Standard for Buildings Except Low-Rise Residential Buildings (*referred to as the "Standard" in this report). ASHRAE and its partners are engaged in development of a series of guides for small commercial buildings, with the AEDG-WH being the fourth in the series. Previously the partnership developed advanced energy design guides for small offices, small retail and K-12 schools.

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 to medium warehouse 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.

Warehouses were chosen for the fourth 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, warehouses account for 456 trillion Btu of energy use[a], or approximately 7% of the energy use of all commercial buildings (CBECS 2003). Non-refrigerated warehouses were singled out for the Guide to help in bounding the scope of the effort necessary for development of the Guide. Refrigeration equipment is not part of the scope of Standard 90.1, which forms the baseline for the Guide, so refrigerated warehouses were eliminated from the Guide's scope. A warehouse within the scope of this Guide is defined as a non-refrigerated facility that is heated, cooled, or heated and cooled (i.e., conditioned space).

The Guide focuses on the following warehouse applications, which are representative of the broad category of warehouses:

- Distribution/shipping centers
- Non-refrigerated warehouses
- Self-storage warehouses.

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[a] Of the the total amount of 456 trillion Btu, 404 trillion Btu are contributed from the non-refrigerated warehouses (i.e., about 89% of energy use of all warehouses) and the remaining 52 trillion Btu are used by the refrigerated warehouses (i.e., about 11% of energy use of all warehouses),

These warehouses are <u>excluded</u> from this Guide:

- Refrigerated units or systems
- Unheated warehouses

Warehouses are understood to pose particular challenges in several areas. The first is *lighting*, to illuminate the rack areas where products are stored. These lighting levels are relatively low, thereby presenting a challenge to reaching energy savings targets. Daylighting is likely to be an effective strategy to address this challenge. The second area is the *low level of heating and cooling* energy used in warehouses, again resulting in lower potential for energy savings. A final area is *infiltration*, which arises from loading docks and loading dock doors.

1.1 Charge to the Committee

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

Timeline

- Complete document in 9 months

Goals

- 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 U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED®) rating system
- Attain energy savings through packages of design measures

Target Audience

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

Desired Design Assistance

- Provide practical, prescriptive recommendations
- Format for ease of use
- Simplify recommendation tables
- Avoid code language
- Provide "how to" guidance to enhance recommendations

- Allow some flexibility for those accustomed to performance-based documents
- Provide case studies where appropriate.

1.2 Scope of the Document

The scope of the Guide is limited to non-refrigerated warehouses that are heated, cooled, or heated and cooled that meet the following criteria:

- Do not exceed 50,000 gross square feet
- Heating and cooling provided by unitary HVAC equipment (packaged or split systems).

Exclusions

- Refrigerated warehouses with refrigeration units or systems
- Unheated warehouses
- Built-up systems using chillers and boilers.

Recommendations contained in the AEDG-WH will apply primarily to new buildings, but may also be applied in their entirety to existing buildings undergoing major renovations. They may be applied in part as recommendations for changes to one or more systems in existing buildings. Covered building components and systems include the building envelope; lighting and daylighting systems; unitary packaged and split mechanical equipment for heating, ventilating and cooling; building automation and control systems; ventilation systems; infiltration control systems; service water heating for bathrooms and sinks; plug loads for charging 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-WH project committee was designated as ASHRAE Special Project 114 (SP-114), and included membership from each of the partner organizations. The following table indicates the project committee members and the organizations that they represent.

Table 1.1. AEDG-WH Project Committee Organization Chart

Ron Jarnagin – *Chairman*

Merle McBride *Vice Chairman*	**Don Colliver** *Steering Committee Ex Officio*
Dan Nall *AIA Representative*	**Michael Lane** *IESNA Representative*
Dan Walker *MBMA Representative*	**Jay Enck** *USGBC Representative*
James McClendon *Wal-Mart, Consultant*	**Lilas Pratt** *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. As a result of the rather specific nature of the warehouse building type, a representative of the Metal Building Manufacturers Association (MBMA) was added to the committee to provide expertise in construction issues related to warehouses. In addition, a member of the Wal-Mart corporate staff provided input as a consultant to the committee. Each of the representative organizations were given the chance to provide peer review input on the various review drafts produced by the project committee. In effect, these representatives were intended to be the interface to their respective organizations to ensure a large body of input into development of the document.

2.0 AEDG-WH Development Schedule and Milestones

Following the guidance from the steering committee, the AEDG-WH project committee developed a 7-month plan for completing the document. Key milestones in the development schedule center around the review periods for the various completion stages for the draft document. Utilizing a similar schedule to what was developed for the most recent guide for retail, the project committee planned for two peer review periods that corresponded with a 65% completion draft (technical refinement review) and a 90% completion draft (final review for errors). During development of the initial guide for small offices, an earlier 35% review period was held to gain input on the conceptual approach for the guides. Since then, two guides have been published following a consistent format, and the steering committee felt that a conceptual review was no longer needed.

Because the document was developed under the ASHRAE Special Project procedures, and not the standards development procedures, the reviews were not considered true "public" reviews. However, review copies were made available to all of the partner organizations, as well as the various bodies within ASHRAE represented by the membership on the project committee. In addition, interested members could download review copies from the ASHRAE web site. The following schedule outlines key dates in the development of the AEDG-WH.

Table 2.1. AEDG-WH Key Development Dates

Date	Event	Comment
3/22 – 3/23/2007	Project Committee Meeting #1	Initial organizational meeting
4/15 – 4/16/2007	Project Committee Meeting #2	Prepare 65% draft
5/7 – 5/18/2007	65% Draft Review Period	Milestone #1
5/31 – 6/2/2007	Project Committee Meeting #3	Address peer review remarks on 65% draft, work on 90% draft
8/17 – 8/18/2007	Project Committee Meeting #4	Review simulation results and complete 90% review draft
Late Aug 2007	90% Draft Review Period	Milestone #3
Early Sep 2007	Conference call	Address peer review remarks on 90% draft
Mid Sep 2007	Conference call	Approval final draft for steering committee
Late Sep 2007	Transfer final draft to steering committee	Milestone #4
Late Sep 2007	Conference call	Steering committee approval of final draft

3.0 Simulation Approach and Analytical Tools

This section describes the energy 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 analytic approach was similar to the one used for previous guides, where several prototype buildings were devised, and then simulated in 15 climate locations covering the eight climate zones contained in ASHRAE Standard 90.1 and the International Energy Conservation Code (IECC). The analysis results established that the packages in the Guide meet the energy savings target.

The purpose of this building energy simulation analysis is to assess and quantify the energy savings potential of the Guide's final 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 AEDG-WH project committee for a limited set (four) climate locations. Following a consistent practice for the two previous guides, the project committee defined two prototypical warehouse buildings that span the range of building sizes, each of which demonstrates varying construction techniques (i.e., mass wall, metal building wall). The prototypes were also of varying sizes within the size range category of small- to medium-size non-refrigerated warehouse buildings. Technologies were selected from a list generated for the first AEDG (i.e., AEDG for small office buildings), and generally reflected technologies in fairly common use. Sensitivities to the use of these technologies were addressed during the scoping study phase, where various technologies are considered in combination to assess the ease with which the energy savings target might be reached. Further sensitivity analyses may be performed as part of the envelope analysis, which is designed to have various envelope assemblies achieve similar economic performance.

During the scoping study phase, two warehouse buildings were defined as the building prototypes, i.e., an 8,000-ft^2 (743.2 m^2) conditioned self-storage building and a 50,000-ft^2 (4645.2 m^2) large warehouse building. The self-storage prototype and the large warehouse prototype represent the smaller end and the higher end building sizes in the category of the non-refrigerated warehouses, respectively. Section 4 in this report describes the scoping study in detail.

After the selected energy-efficient technologies were demonstrated to achieve the 30% energy saving goal in the scoping study, the energy simulations were expanded to the full study, including the above two warehouse building prototypes for all 15 representative locations. Fifteen climate locations were selected to adequately represent the eight climate zones in the United States. Baseline model prototypes were developed in compliance with the prescriptive design options defined in ASHRAE Standard 90.1-1999. The advanced models were established based on the recommended energy-efficient technologies by the Guide. Sections 7 and 8 document the modeling input assumptions for the baseline models and the advanced models, respectively.

The last stage involves summarizing the energy simulation results for all locations and presenting the final energy saving recommendations by climate zones, as described in Section 10.

Finally, the energy savings of the prescriptive recommendations were also examined relative to ASHRAE Standard 90.1-2004 (ANSI/ASHRAE/IESNA 2004) and the saving results were also documented in Section 10 in this report.

3.2 Simulation Tool Description

Unlike the earlier guides using *DOE-2* as the simulation engine, this Guide switched the computer simulation program to *EnergyPlus*. *EnergyPlus* is a new building-energy-simulation program under development by the Department of Energy (DOE) since 1996 (Crawley et al. 2004). It is a complex building energy simulation program for modeling building heating, cooling, lighting, ventilating, and other energy flows. While it is based on the most popular features and capabilities of *BLAST* and *DOE-2*, *EnergyPlus* includes many innovative simulation capabilities such as time steps of less than one hour, modular systems and plant integrated with heat balance-based zone simulation, multi-zone air flow, thermal comfort, and photovoltaic systems. *EnergyPlus* Version 2.0 (released on April 2007) was used to assess the energy savings potential of recommended energy measures, and to perform analysis of the final recommendations in the Guide.

4.0 Initial Scoping Study

Following the proven model used in the development of the *Advanced Energy Design Guide for Small Office Buildings* (AEDG-SO 2004) and *Advanced Energy Design Guide for Small Retail Buildings* (AEDG-SR 2006), the project committee performed an initial scoping study to test the efficiency levels of the various building systems that would be necessary to reach the energy savings targets. By being able to develop an early assessment of the baseline and advanced energy use potential, the committee was then able to prioritize its activities for development of the Guide.

Much of the initial debate by the committee focused on the building configuration to be used for the simulation model. Building size and construction method were discussed at length. Because many small warehouses are used for self-storage applications, the committee initially decided that a self-storage warehouse would be modeled, as well as a larger non-refrigerated warehouse. To span the range of construction types, the self-storage warehouse was assumed to be constructed as a metal building and the warehouse was assumed to be constructed as a tilt-up concrete structure with built-up roof.

The 2003 CBECS dataset has been used to characterize the "typical" warehouse building parameters. Appendix D in the report documents the findings by analyzing of the 493 surveyed warehouse buildings. The floor plan of the self-storage model was estimated by the committee based on typical storage bay sizes as well as typical configurations for enclosed self-storage. This yielded a prototype design that was approximately 8,000 ft^2 in size. This size is also consistent with the weighted-average floor area of self storage surveyed by 2003 CBECS, i.e., 6,358 ft^2. For the warehouse, the committee debated the size building to use. Data from both CBECS and F.W. Dodge were reviewed for typical sizes. A close look at F.W. Dodge data suggested a 50,000 ft^2 size non-refrigerated warehouse would cover about 80% of the most recent new construction in warehouses (see Figure 4.1).

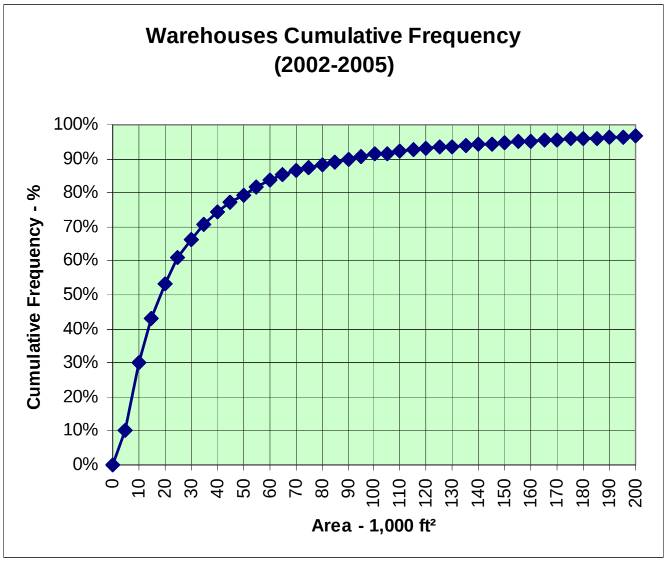

Figure 4.1. Warehouses Cumulative Frequency from F.W. Dodge

Occupancy hours for each warehouse were based on normal business operating schedules derived from 2003 CBECS data set, with the self-storage areas having extended hours in the evenings and weekends. Heating and cooling equipment and lighting operational schedules were developed based on occupancy hours. In addition, for the warehouse, four of the seven loading dock doors were assumed to be occupied by trucks either loading or unloading, and dock doors were assumed to be closed when trucks were not being loaded or unloaded. This assumption was developed based on the consultations with the industrial experts.

Zoning for the HVAC systems was broken down into three zones for the 50,000-ft^2 warehouse: office space, fine storage space and bulky storage space. For the self-storage warehouse there were two zones: office space and self-storage space. Each zone requiring cooling (office, fine storage, self-storage) was served by a single packaged rooftop unitary equipment with electric direct expansion (DX) cooling and gas heating, sized to meet the space'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). Heating and cooling set points in the both the fine storage area of the non-refrigerated warehouse and the self-storage area of the self-storage warehouse were 80°F for cooling and 60°F for heating. The bulky storage area of the non-refrigerated warehouse was defined as a semi-heated zone with heating setpoint of 45°F.

The self-storage exterior envelope consisted of metal building wall construction, while the non-refrigerated warehouse exterior envelope was tilt-up concrete wall. Glazing was limited to the entrance wall of the small office spaces, with less than 5% of gross floor area. Each window contained a 5-ft overhang for shading and weather protection for the advanced case. The floor-to-ceiling height was 12 ft for the self-storage and 24 ft for the warehouse. The roofing construction was a steel deck with rigid insulation, protected by a membrane exterior surface. Each warehouse had a slab-on-grade floor.

Values for the thermal and solar performance of the envelope measures, mechanical equipment efficiencies, and mechanical system requirements came from Standard 90.1-1999 for the baseline, and from the AEDG-SO for the advanced case. These values can be found in Appendix A and Appendix B. The AEDG-SO measures were used for the scoping study because both the warehouses had small office spaces and the envelope measures for this part of the building were carried over into the conditioned storage areas, and the scoping study was designed only to get a quick estimate of the committee's ability to meet the energy savings target.

The self-storage and warehouse 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 the warehouse and the self-storage warehouse are shown in Figure 4.2 and **Error! Reference source not found.**, respectively, for reference below. Each building was oriented with the entrance facing due south in each location to present a worst case energy use scenario resulting from solar loading.

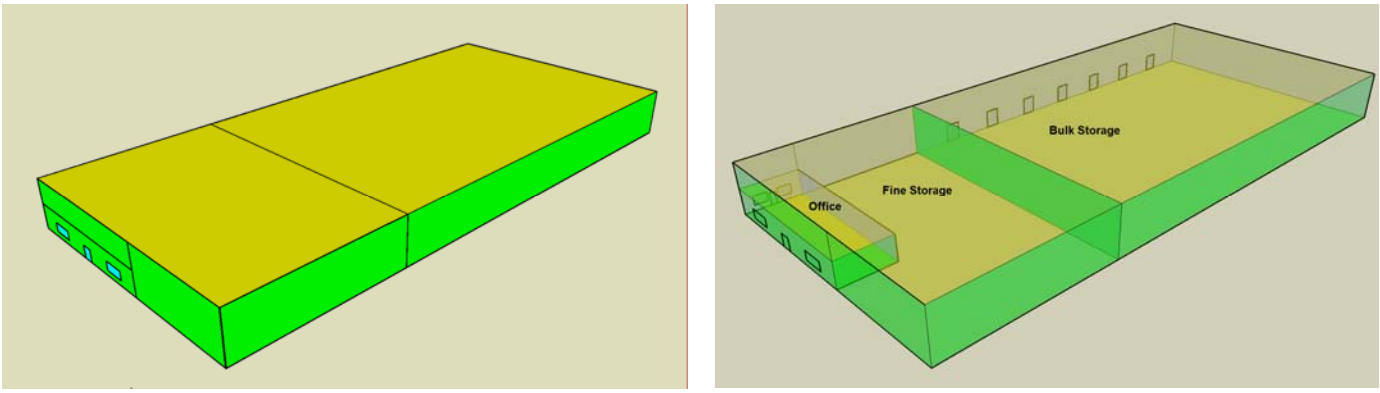

Figure 4.2. Three-Dimensional Computer Model of the 50,000-ft² Warehouse Prototype

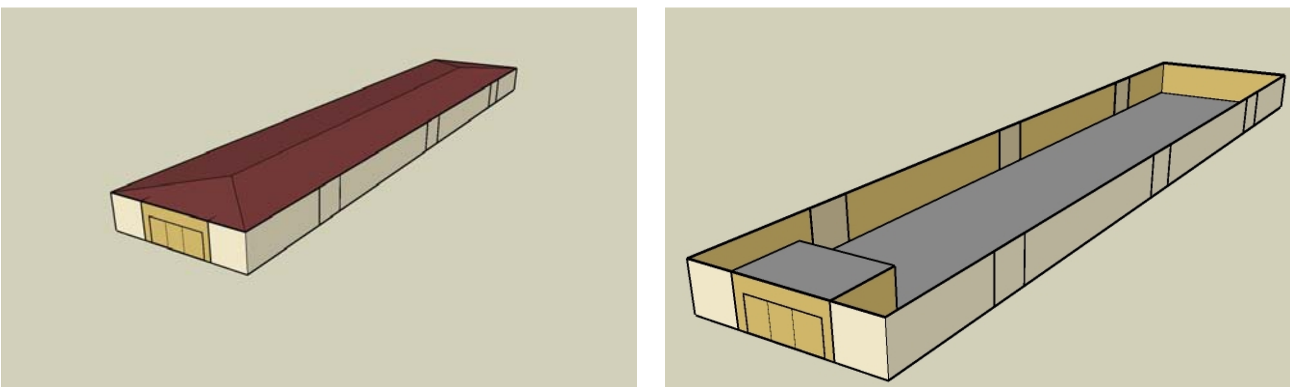

Figure 4.3. Three-Dimensional Computer Model of the 8,000-ft² Self-Storage Prototype

Results of the initial simulation for the 50,000-ft² warehouse indicated the potential for reaching the energy savings goal in each of the climate extremes. Duluth, a very cold climate, proved to be the climate that showed the lowest savings. The results for each of the climate locations are shown in Table 4.1. Table 4.2 summarizes the simulation results for the 8,000-ft² self-storage building. The scoping study observed the challenges inherent in attaining the energy savings targets in some climate locations for the self-storage warehouse. After thoroughly investigating the energy models, we believed the challenge was caused by the relative humidity control requirement for the self-storage building. We conducted further energy analysis and explored additional energy efficiency measures during the full study phase of this project to meet the energy savings targets.

Table 4.1. Energy Savings from Scoping Study on 50,000-ft^2 Warehouse

Climate City	Whole Building Savings Percentage, Plugs in the denominator	Whole Building Savings Percentage, Plugs not in the denominator
Miami	41.0%	49.2%
Phoenix	43.8%	51.0%
Seattle	35.4%	39.7%
Duluth	35.0%	36.8%

Note: 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.

Table 4.2. Energy Savings from Scoping Study on 8,000-ft2 Self-storage Warehouse

Climate City	Whole Building Savings Percentage, Plugs in the denominator	Whole Building Savings Percentage, Plugs not in the denominator
Miami	27.3%	27.7%
Phoenix	23.2%	23.7%
Seattle	30.5%	30.9%
Duluth	19.6%	19.8%

Note: 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.

5.0 Selection of Climate Locations for Final Guide

The three *Advanced Energy Design Guides* developed to date have standardized climate zones that have been adopted by IECC as well as ASHRAE for both residential and commercial applications. This results in a common set of climate zones for use in codes and standards. The common set of climate zones includes eight zones covering the entire United States as shown in Figure 5.1 (Briggs 2003). 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 (ANSI/ASHRAE/IESNA 2004). 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.

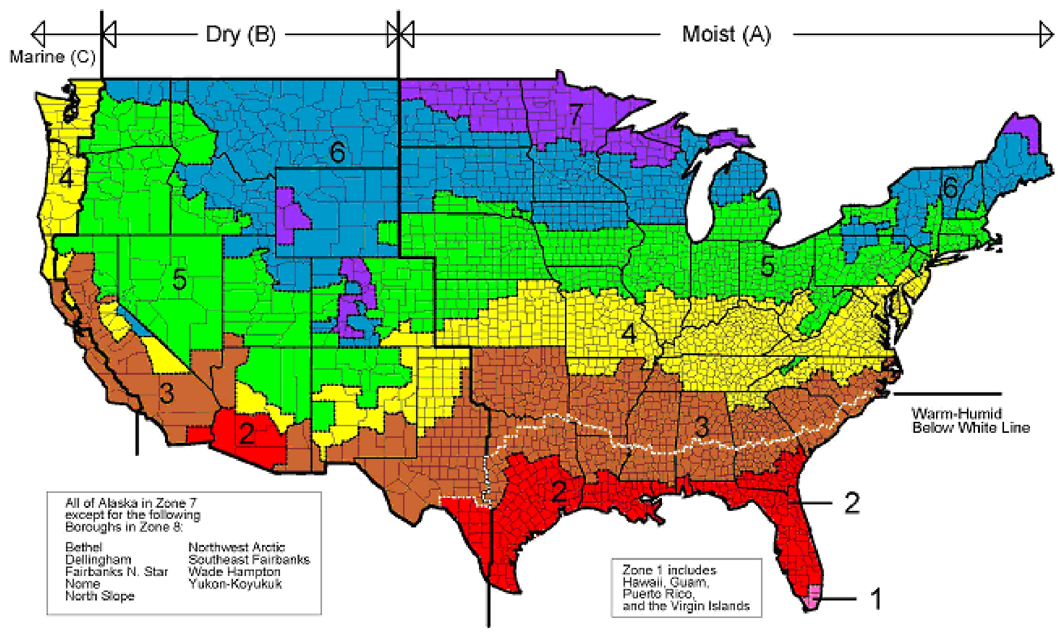

Figure 5.1. U.S. Department of Energy Developed Climate Zone Map

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

The map in Figure 5.2 indicates the 15 climate locations chosen for the analysis of the guides.

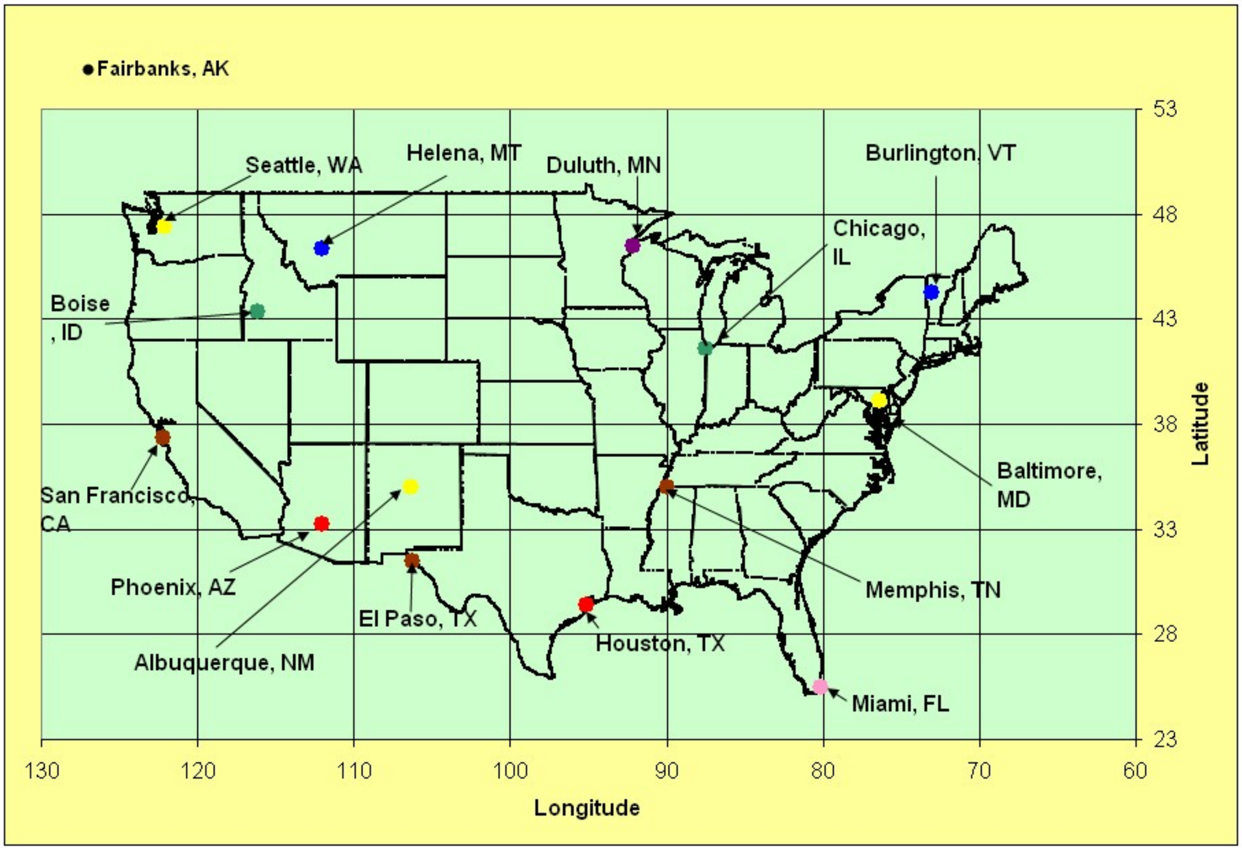

Figure 5.2. Representative Climate Locations in U.S.

6.0 Selection of Energy Saving Technologies

The project committee began the process of selecting energy savings technologies by reviewing the work done in previous AEDG documents for Small Offices and Small Retail. This approach was somewhat relevant since the prototype warehouse buildings contained a small amount of office space (about 5% of the floor area). The project committee decided to utilize the recommendations from the AEDG-SO for the office portion of the prototypes since these were known to produce savings at or above the 30% level. By using these values initially the committee was able to start quickly on the project since the timeline was somewhat compressed. As in the case of the AEDG-SR, using these values initially facilitated the work on the early rounds of scoping study analysis for the reasons explained in Section 4.0. However, since the warehouse represents a significantly different building type in terms of its operation and energy use the committee needed to resort to some exploration of technologies specifically suited to the warehouse application. Some of these technologies included unit heaters, destratification equipment and infiltration reduction measures. The scoping study pointed out some areas in which problems might be encountered in meeting the energy savings targets, and those problems were most prevalent in the Self-storage warehouse where ventilation control and humidity created problems. The following sections briefly describe the process the committee used to choose the technologies for the final recommendations.

6.1 Envelope Technologies

As noted above, the envelope is somewhat less important for warehouses since the heating and cooling loads tend to be lower. This arises from the fact that thermostatic set points are generally relaxed in storage areas, thus reducing the time that the mechanical equipment needs to operate to satisfy the set point conditions. Typically the more critical need for insulation occurs in the colder climates, similar to the other building types in the AEDG series. The committee explored the insulation levels necessary to achieve adequate energy performance during the scoping study runs. Based on these initial runs insulation levels were established early in the process.

Since warehouses commonly have low window to wall ratios the exploration of energy efficient glazing options was somewhat limited due to the low impact on the final energy savings numbers. Only the office segment of the warehouse prototypes had any windows, although the large warehouse prototype did have a fairly significant use of skylights (6% of the roof area in the bulk storage section of the warehouse). Skylights in large warehouses are particularly helpful in reducing the need for electric lighting, especially in the bulk storage area. A fairly significant fraction of the total savings from the warehouse guide came from a reduction in the electric lighting. Skylights can create problems in colder climates, however, where the thermal losses through the skylights increases heating energy use and sometimes offset the lighting energy savings.

In the case of the warehouse guide the committee looked more closely at both mass buildings as well as metal buildings, both of which are common methods of construction for warehouses and storage units. These two construction types offer some unique challenges in terms of how insulation is installed. Fortunately the committee had ready access to professionals from the respective industries to help in addressing these challenges.

6.2 Lighting and Daylighting Technologies

Lighting and daylighting technologies were utilized to produce significant energy savings in the large warehouse and to a somewhat lesser extent in the self-storage warehouse. The primary differences in the lighting energy savings between the two prototypes resulted from the fact that the self-storage warehouse needed much lower lighting levels because of the layout, and because the occupancy patterns were such that occupancy sensors can keep the lighting level low based on the intermittent occupancy of those types of buildings. Lighting systems in larger warehouses must provide sufficient lighting on a vertical plane to allow workers to effectively see the products being stacked on the storage racks. Since their ceilings are fairly high compared to typical self-storage warehouses (e.g 22 ft vs. 12 ft), the light fixtures must produce a fair amount of lighting in order to maintain adequate visibility.

The committee explored different lighting designs and layouts to try and achieve low lighting power while maximizing visibility. Based on some lighting modeling studies performed by the committee it appears that it is possible to fairly easily meet or go below the recommended lighting power density levels contained in the AEDG recommendations. When occupancy sensors are combined with in-fixture daylighting sensors large energy savings may be achieved from lighting. It should be noted that control strategies that interlink the two technologies become significantly more important for these types of applications.

Lighting technologies necessary to meet the recommended lighting power densities are high performance T8 fluorescents with high performance electronic ballasts as well as high output T5 fluorescent lamps. These technologies are readily available from major national suppliers, making it easy for designers and builders to find adequate supplies.

6.3 HVAC and Service Water Heating (SWH) Technologies

In general, the HVAC and SWH technologies were carried forward from the AEDG-SO with the addition of warehouse specific technologies. For example, this AEDG provides recommendations for use of de-stratification fans to maximize the use of heating in high ceiling warehouse applications. Recommendations in the guide continue the approach of varying heating and cooling efficiencies by climate zone where possible, which represents a change from the policy maintained by the Standard, where equipment efficiencies remain constant across climates. The equipment efficiency values used in the AEDG-SO are also used in the AEDG-WH document because they were found to be sufficient to meet the energy savings targets. In addition, the AEDG-WH also continued the recommendations for integrated part load values (IPLV) for commercial cooling equipment because this represents a step forward from the Standard. Another recommendation unique to the warehouse guide is the recommendation for heat pump systems with variable speed fans and compressors to help produce energy savings while simultaneously maintaining humidity control.

Economizer requirements were extended to equipment with capacities as low as 54,000 Btu/hr versus 65,000 Btu/hr as required by the Standard 90.1-1999 , resulting in additional energy savings for smaller capacity equipment in climate zones where the use of economizers is more appropriate. Motorized dampers for outdoor air control in off hours was recommended in the Guide. Each of these technologies has been demonstrated through simulation to achieve energy savings in warehouse 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. In addition, recommendations are provided suggesting that the use of pumped returns for point of use water heaters when loads are light and distributed is discouraged. The reader will also find recommendations that water heaters be sized correctly and provide correct supply temperatures.

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 *EnergyPlus* 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 warehouses were selected by the project committee to meet the prescriptive criteria of ASHRAE Standard 90.1-1999. The Standard provides the fixed reference point based on the Standard 90.1-1999 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 upon which DOE has published its determination in the Federal Register. This determination concluded 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 self-storage prototype (8,000 ft^2) was constructed with steel metal panels as exterior walls, metal building roofs, and slab-on-grade floors. For the larger warehouse prototype (50,000 ft^2), it was assumed that the exterior walls were concrete tilt-up construction, built-up roofs, and slab-on-grade floors. These envelope structures represent common construction practices for small- to medium-size warehouse and self-storage buildings in U.S. The assumptions were derived from the 2003 CBECS database and the F.W. Dodge data set. The development of the building characteristics of these warehouse prototypes is documented in Appendix D.

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

EnergyPlus can calculate the overall 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., metal building walls in the self-storage buildings and mass walls in the warehouse building. The base assembly of the metal building wall is bare galvanized steel metal wall panels. The single-layer or double-layer (varies by climate) mineral fiber insulation was compressed between metal wall panels and the metal structure. The overall U-factor for metal building walls was derived from Table A-9 in the Standard. The U-factor of the metal building wall includes the following layers:

- Outside air film (calculated by EnergyPlus)
- Pre-fabricated metal panels
- First layer of the compressed mineral fiber insulation (R-13 for climate zone 1-6)
- Second layer of the compressed mineral fiber insulation (R13 for zone 7 and 8 only)
- Inside air film (calculated by EnergyPlus).

The concrete tilt-up mass wall was assembled assuming 8-in. medium weight concrete blocks with a density of 115 lb/ft^3 and solid grouted cores (refer to Table A-5 in the Standard). The concrete tilt-up building wall includes the following layers:

- Outside air film (calculated by EnergyPlus)
- 8-in. concrete block, 115 lb/ft^3
- Continuous insulation uninterrupted by framing (R-0 to R-11, varies by climate)
- Inside air film (calculated by EnergyPlus).

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

7.2.2 Roofs

Metal building roofs were used in the self-storage prototype, i.e., standing seam roofs with thermal blocks, as defined in Table A-2 in the Standard. The base assembly contained the insulation draped over the steel structure (purlins) and then compressed when the metal spanning members were attached to the purlins. The minimum U-factor includes R-0.17 for exterior air film, R-0 for metal deck, and R-0.61 for interior air film heat flow up. Compressed insulation could be single layer or double layer, depending on climate. Overall U-factor for assembly of base roof plus compressed insulation was taken from Table A-2 in the Standard.

Built-up roofs were modeled in the 50,000-ft^2 warehouse prototype, i.e., rigid insulation over a structural metal deck. The minimum U-factor includes R-0.17 for exterior air film, R-0 for metal deck, and R-0.61 for interior air film heat flow up. Added insulation is continuous and uninterrupted by framing. Roof insulation R-values were also set to match the minimum roof insulation requirements in Appendix B (*Building Envelope Criteria)* 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. Appendix B also provides the corresponding R-values of the vertical insulation when required by the Standard. This continuous insulation is typically applied directly to the slab exterior, extending downward from the top of the slab for the distance specified.

One of the advanced features in *EnergyPlus* program is that the conduction calculations of the ground heat-transfer through ground-contact surfaces (i.e., slab-on-grade floors) are two- or three-dimensional rather than the simplified one-dimensional in *DOE-2* program. To use this method, the appropriate ground temperature must be specified by using the *Slab* program, a preprocessor as part of the *Auxiliary EnergyPlus* programs. The calculated custom monthly average ground temperatures were manually transferred into the main *EnergyPlus* program as one of the inputs at each of 15 climate locations.

In the *Slab* program, the key inputs to calculate the ground temperatures are described as following:

- Slab material and soil density
- Building height
- Indoor average temperature set point
- R-value and depth of vertical insulation (if presented)
- Thickness of slab-on-grade
- The floor area to perimeter length ratio for this slab
- Distance from edge of slab to domain edge.

7.2.4 Fenestration

Warehouse buildings typically have much smaller areas of window compared with other types of commercial building in U.S. The 2003 CBECS database shows that over 90% of the non-refrigerated warehouse and self-storage buildings have window-to-wall ratio (WWR) less than 10%. In addition, the warehouse construction drawings in the NC3 database[b] indicated that the limited windows are commonly located in the office area as the vision window for the occupants.

Window requirements in the Standard are defined by bulk properties of U-factor and Solar Heat Gain Coefficient (SHGC). *EnergyPlus*, however, requires that the thermal/optical properties be defined for the window assembly layer by layer. Hypothetical window layers were derived by iterative *Window 5* calculations within *EnergyPlus* to produce a match to the specified U-factor and SHGC outlined in Appendix B in the Standard, by climate.

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[b] National Commercial Construction Characteristics Database (NC3), an internal database developed by Pacific Northwest National Laboratory with DOE Building Technologies Program support to represent nationwide commercial construction energy-related characteristics.

For example, to match the U-factor of a double-pane window, the gap thickness was first adjusted, then the inner glazing conductivity, and finally the outer glazing conductivity, as necessary. To match the SHGC, the solar transmittance at normal incidence was adjusted, followed by the front and back solar reflectance at normal incidence, as necessary. The hypothetical component window properties thus created were used in *EnergyPlus* simulation to match the fenestration performance criteria outlined in the Standard.

However, using the window layers method could be problematic in matching the maximum allowable U-factor and SHGC values in accordance with the Standard. The reason is that no actual windows exist to match some of the fenestration requirements in the Standard, for certain climates.

7.2.5 Air Infiltration

Building air infiltration is addressed indirectly in the Standard through the requirements in building envelope sealing, fenestration and doors air leakage, etc. The Standard does not specify the air infiltration rate over the entire building. For this analysis, the project committee evaluated the air infiltration rate in the 50,000-ft² warehouse model by further dividing the infiltration rates into three additive components: 1) general infiltration through the building envelope cracks and air leakage, etc.; 2) air leakage from relief dampers of four central exhaust fans located in the bulky storage area when exhaust fans are off; and 3) infiltration through loading dock doors for truck loading or unloading. General infiltration applies uniformly over the entire building. The infiltration through relief dampers and dock doors (both open and closed) only applies to the bulky storage area. Dock doors are assumed to be open only when a truck is in place. Table 7.1 provides detailed descriptions of the infiltration rate assumptions used in the larger warehouse prototype. Recognizing that infiltration through open load dock doors can result in significant energy use, the committee recommended weatherseals for dock levelers and trailer hinges to restrict infiltration when these doors are open and trailers are in use.

The air filtration rate in the self-storage prototype was set to be 0.038 cfm/ft² of gross exterior wall, consistent with the value of the general infiltration rate used in the larger warehouse prototype per ASHRAE Standard 90.1-1989.

The basic equation used to calculate infiltration in *EnergyPlus* is:

$$\text{Infiltration} = (I_{design})\,(F_{schedule})[A+B|(T_{zone} - T_{odb})| + C(\text{WindSpeed}) + D(\text{Windspeed}^2)]$$

where

I_{design} = maximum infiltration rate at design conditions, cfm

$F_{schedule}$ = infiltration schedule

$T_{zone} - T_{odb}$ = the temperature difference between the outdoor and indoor air dry-bulb temperatures, °F

To determine the coefficients A, B and C in above equation, the air change method was used to maintain consistency with previous AEDGs. Therefore, the air change method defaults in *DOE-2* are (adjusted to SI units) 0, 0, 0.224, and 0 for A, B, C, and D, respectively (EnergyPlus 2007). With these coefficients, the summer conditions above would give an infiltration factor of 0.75, and the winter conditions would give 1.34. A wind speed of 10 mph gives a factor of 1.0 for both summer and winter conditions.

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”.

Table 7.1. Baseline Air Infiltration Rate Assumptions for the 50,000-ft² Warehouse

Infiltration	**Input**	**Data Source**
General infiltration	0.038 cfm/ft² of gross exterior walls, total 1000 cfm over the entire building	Use the value from ASHRAE Standard 90.1-1989 and the same values have been used for the AEDG-SO and AEDG-SR guides to keep consistency.
Air leakage for relief dampers	2000 cfm total (four relief dampers with 500 cfm each)	Infiltration occurs through the relief damper leakage when the exhaust fans are off with the following assumptions: 1. Four of 20,000 cfm fans each with 2-hp motor. The fans would operate under thermostatic control to energize when the indoor temperature in the bulky storage reached 85°F. Relief dampers will need to be provided for makeup air. 2. The air leakage per relief damper is 50 cfm /sf x 10 sf, with a leakage rate at 2.5% of peak flow stated by manufacturers.
Dock doors closed infiltration	0.40 cfm/ft² of door area, 32.0 cfm per door	1. Use the value from ASHRAE Standard 90.1-1999 for dock doors (rollup or overhead) 2. Use the loading dock door size as 8 ft x 10 ft as this appears to be the most common loading dock door size (7 of them)
Dock doors open infiltration	783 cfm per door	Infiltration occurs around the crack between the truck and the door with the following assumptions: 1. Effective crack area: Assume: • crack around two sides and top of truck = 0.5” • hinge gap for each of the two truck doors when open = 2” on each side • gap on 3 sides of standard 6x6 dock leveler = 1.25” • gap on 2 sides at base of truck between dock leveler and side of truck = 0.5” This results in an effective crack area of 6.27 ft². 2. Leakage rate based on the following equation: $Q = C \text{ x } dP \text{ x } n$ where dP = the pressure differential due to wind speed, n = assumed to be 0.5, C = crack thickness, assumed to be 31.5 inches. The leakage rate translates to 125 cfm/sf of effective crack area.

7.2.6 Roof Absorptivities

The Standard does not specify either absorptance or other surface assumptions. The roof exterior finish was defined as a single-ply roof membrane with grey EPDM (ethylene-propylenediene-terpolymer membrane) in the baseline of the warehouse prototype, based on the inputs from the experts in the project committee. According to both Lawrence Berkeley National Laboratory’s Cool Roof Materials Database[c]

[c] To access LBNL’s cool roof materials database, go to http://eetd.lbl.gov/coolroof/.

and a study by Pacific Gas and Electric Company, the solar reflectance was assumed to be 0.23 for this type of roofing (Eilert 2000).

For the metal building roofs in the self-storage prototype, the bare galvanized steel was selected as the exterior finish to capture the typical US metal building conditions. Based on Lawrence Berkeley National Laboratory's Cool Roof Materials Database, the committee set the solar reflectance at 0.61,

7.3 Baseline Building Internal Loads

Internal loads from lighting, people, and miscellaneous sources (plug loads) are generally low in warehouses. Most of load is thermal transmission and infiltration. Warehouses are used to store merchandise, equipment or other massive materials. The stored materials may be massive enough to cause air-conditioning peak load to lag and consequently flatten the load profile. Therefore, the internal mass was considered when defining the baseline internal loads for both the self-storage building and larger warehouse building.

Modeling the energy impacts of the building internal loads using the *EnergyPlus* simulation program requires assumptions about the building internal loads and operation schedules. The loads for people refer to the maximum occupancy at the peak time of a typical day. For lighting and plug loads, these loads are represented by a power design level and the operation schedules.

The warehouse operating schedules were developed based on the weekly operating hours surveyed by 2003 CBECS. Analysis of the CBECS database shows that the average of weekly operating hours are 52 hours for the non-refrigerated warehouse building and 93 hours for the self-storage building. Furthermore, the building operation schedules for the larger warehouse prototype were defined as 8 am to 5 pm from Monday to Saturday, based on the project committee's inputs. Similarly, the operation schedules for the self-storage prototype were defined as 6 am to 8 pm, Monday through Sunday. The business hours of the self-storage buildings were verified through phone interviews with some national chain self-storage warehouses, such as Public Storage. Appendix B in this report contains tables of the schedule profiles for each of the two prototypical buildings. Figure 7.1 shows a typical occupancy schedule for the larger warehouse prototype, open Monday through Saturday.

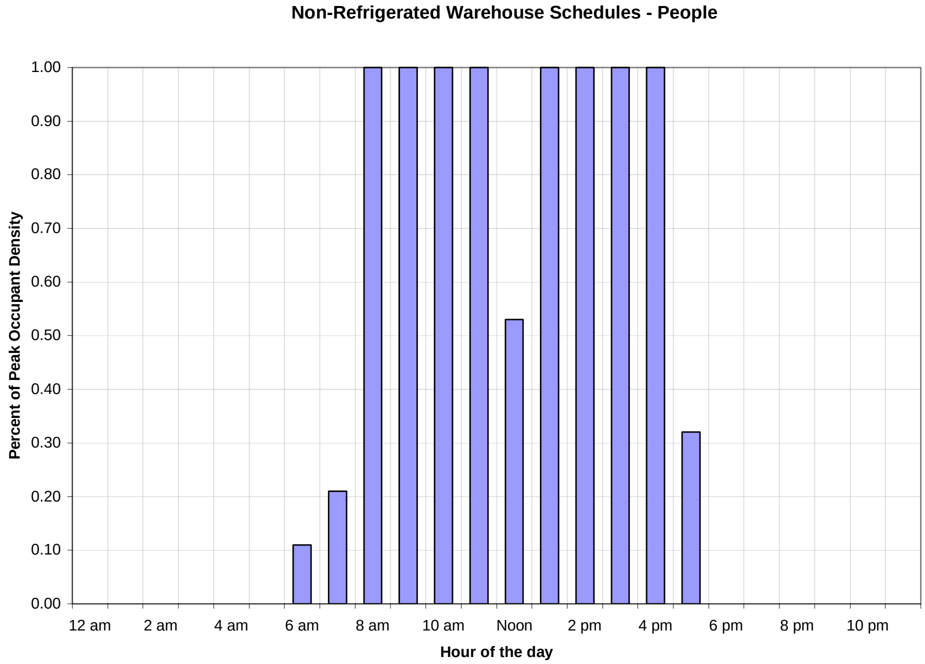

Figure 7.1. Occupancy Schedule in the office are of the 50,000-ft² Warehouse

7.3.1 People

The number of employees during main shift is 5 persons and 1 person for the warehouse and self-storage buildings, respectively, derived from data in the 2003 CBECS.

For the computer simulations, it is assumed that the occupant activity level was 450 Btu/hr per person for all the prototypes, including 250 Btu/hr sensible heat gain and 200 Btu/hr latent heat gain. These values represent the degree of activity in the office areas of the warehouse buildings, i.e., standing, light work, and walking, and were derived from Table 1 of Chapter 30 in the ASHRAE 2005 Fundamentals Handbook, assuming that the occupant activity levels did not vary with climate (ASHRAE 2005).

7.3.2 Interior Lighting

The *EnergyPlus* program allows the user to specify information about a zone's electric lighting system, including design power level and operation schedule, and how the heat from lights is distributed thermally.

The baseline interior lighting power for each specific area is derived using the building area method described in Standard 90.1-1999, as shown in Table 7.2. The interior lighting power design levels in watts in Table 7.2 were used as the *EnergyPlus* inputs for each zone. Table 7.2 also shows the lighing power requirement to meet the Standard 90.1-2004 as baseline. Figure 7.2 illustrates the typical lighting operation schedules for the fine and bulky storage areas in the 50,000-ft² warehouse prototype.

Table 7.2. Baseline Interior Lighting Design Power Levels

Building Type	Building Area	Floor Area (ft^2)	Standard 90.1-1999		Standard 90.1-2004	
			LPD (watts/ft^2)	Lighting Level (watts)	LPD (watts/ft^2)	Lighting Level (watts)
50,000-ft^2 warehouse building	Zone 1 – office	2,550	1.3	3,315	1.0	2,550
	Zone 2 – fine storage	12,450	1.2	14,940	0.8	9,960
	Zone 3 – bulky storage	34,500	1.2	41,400	0.8	27,600
8,000-ft^2 self-storage building	Zone 1 – office	300	1.3	390	1.0	300
	Zone 2 – storage	7,700	1.2	9,240	0.8	6,160

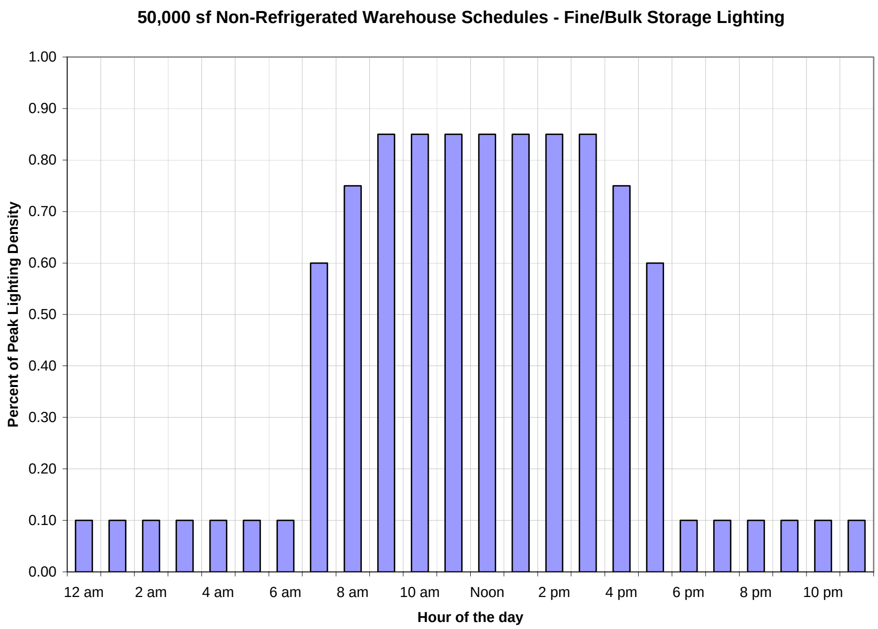

Figure 7.2. Lighting Schedule in the Fine and Bulky Storage for the Baseline 50,000-ft^2 Warehouse

7.3.3 Plug Loads

The project committee assumed that the plug loads in the office would be consistent with those used for the office guide, that plug loads in the fine storage would be essentially zero, and that plug loads for the bulky storage would be due to the charging and discharging of the tow motor fork lifts. The committee assumed the warehouse would have three 4,000-lb capacity tow motors, which would operate for 8 hours a day and be charged for 16 hours at night.

The plug load heat release values are 9,329 Btu/hr for 8 hours and 2,332 Btu/hr for 16 hours. These calculations are based on the assumptions that the tow motor charging efficiency is 75% and thus 25% of the input energy to the charger is lost to the space during charging. The daily charging energy for each tow motor is 32.8 kWh, so three tow motors will use 98.4 kWh. Given the total gross floor area of 35,000 ft² in the bulky storage area, this results in 0.35 w/sf of plug load during occupied hours.

7.3.4 Internal Mass

The internal mass could contribute to the space cooling load because of the time delay effect. Therefore, the project committee considered to evaluate the internal mass in the storage areas. The internal mass for the bulky storage is assumed to be made up of products stored in the racks.

- The bulky storage mass value = 545.14 lb/sf
- Total rack volume = 8-ft wide x 106-ft long x 20-ft high = 16,960 cf
- Usable rack volume = 16,960 ft x 75% = 12,720 cf
- Assumed product density from loaded truck weights = 12.5 lb/cf
- Loaded rack weight = 12,720 cf x 12.5 lbs/cf = 1,590,000 lbs/rack x 12 racks = 19,080,000 lbs
- Internal mass density = 19,080,000 lb/35,000 sf = 545 lb/sf

7.4 Baseline Building HVAC Systems

The scope of this Guide covers small warehouse buildings up to 50,000 ft² that use unitary heating and air-conditioning equipment. Buildings of this size represent over 80 percent of warehouses in the U.S. Some of stored products or materials may not require defined inside conditions, which applied to the bulky storage and loading areas in the 50,000-ft² warehouse building. Consequently, the project committee assumed that the bulky storage area is not air conditioned, but is semi-heated and ventilated. Even though thermal comfort may not be considered for these areas, it is necessary to keep the temperature about 45°F to provide a tolerable working environment and to protect sprinkler piping or stored materials from freezing. If the stored products do require defined controlled conditions, an air-conditioning system must be added. Both the 8,000-ft² self-storage building and the fine storage area in the 50,000-ft² warehouse were designed with air-conditioning systems to provide temperature and humidity control to prevent the stored products from melting or other damages. Associated facilities occupied by office workers, such as self-storage leasing offices and inventory control offices, are generally air conditioned (ASHRAE 2003).

As shown in Table 7.3, single-zone packaged unitary systems were selected to provide conditioned supply air to certain areas in the warehouse and self-storage buildings, where thermal comfort or controlled indoor conditions were required. All the packaged rooftop units are constant air volume systems, equipped with an electric direct expansion (DX) coil for cooling and a gas-fired furnace or heat pump for heating.

There are two single-zone packaged rooftop units in the 50,000-ft² warehouse prototype, one unit serving each zone. For the 8,000-ft² self-storage prototype, it is assumed that one single packaged air conditioner provides certain conditioned supply air to the entire building, with the exception of the leasing office. The 300-ft² leasing office was equipped with a packaged terminal heat pump unit to meet the thermal comfort requirement in the office. The project committee also decided to apply the single packaged heat pump to the self-storage building in climate zones 1 to 5, and to apply the gas-fired furnace to the cold climate zones 6, 7 and 8.

For the semi-heated area, i.e., the bulky storage area in the 50,000-ft² warehouse, unit heaters were used to heat up the space. In addition, 20,000 cfm exhaust fans (4 of them) with 2-hp motor each would be installed in the same area. Relief dampers with 10-ft² face area each were also assumed to provide makeup air when the exhaust fans are on.

Table 7.3. Baseline Building HVAC Systems

Building Type	Building Area	HVAC System Type	Thermostat Setpoints
50,000-ft² warehouse	Office area	Packaged single-zone DX with gas-fired furnace	75°F cooling 70°F heating
	Fine storage	Packaged single-zone DX with gas-fired furnace	80°F cooling 60°F heating
	Bulky storage	Unit heaters and central exhaust fans	45°F heating
8,000-ft² self-storage	Leasing office	Packaged terminal heat pump	75°F cooling 70°F heating
	Storage	• Packaged single-zone heat pump in climate zone 1 to 5 • Packaged single-zone DX with gas-fired furnace in climate zone 6, 7 and 8	80°F cooling 60°F heating

7.4.1 Building HAVC System Operating Schedules

The air conditioning operating schedule is based on the building occupancy schedule, as described in Section 7.3. The fan is scheduled “on” 1 hour prior to the staff coming to the store to pre-condition the space, and the fan is scheduled “off” 1 hour after the store closes. 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.

For the semi-heated bulky storage area, the operation of the unit heaters was controlled by the thermostat. The units only operated to maintain the space temperature above 45°F. The exhaust fans would also operate under thermostatic control to energize when the indoor temperature in the bulky storage reached 85°F.

7.4.2 Heating and Cooling Thermostat Setpoints

As shown in Table 7.3, the offices were designed for 70°F heating setpoint and 75°F cooling thermostat setpoint during occupied hours. During off hours, thermostat setback control strategy is applied in the baseline prototypes, assuming a 5°F temperature setback to 65°F for heating and 80°F for cooling. For the self-storage building and the fine-storage zone in the warehouse building, the heating and cooling thermostat setpoints are 60°F and 80°F to provide defined inside conditions to the stored products. The semi-heated bulky storage zone was maintained at 45°F year around.

7.4.3 Equipment Sizing and Efficiency

Equipment sizing refers to the method used to determine the cooling capacity of the DX cooling coil, the supply air flow rate through the supply fans, or the heating capacity of the furnace in the packaged rooftop unit or other type of heating equipment. Similar to the *DOE-2* program, *EnergyPlus* allows users to use a "design day" simulation method for sizing equipment. When using the design day simulation method, two separate design day inputs should be specified, one for heating and one for cooling. 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 thus 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 equipment oversizing to meet the extreme peak weather conditions occurring for a very short period of time during a year.

The design-day data for all 15 climate locations were developed based on the "weather data" contained in the accompanying CD-ROM of ASHRAE 2005 Handbook of Fundamentals (ASHRAE 2005). In this data set, annual heating design condition is based on annual percentiles of 99.6. 99.6% values of occurrence represent that the dry-bulb temperature occurs or is below the heating design condition for 35 hours per year in cold conditions. Similarly, annual cooling design condition is based on dry-bulb temperature corresponding to 1% annual cumulative frequency of occurrence in warm conditions. Similarly, 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 *EnergyPlus* 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.

For the baseline buildings, equipment efficiencies were taken from the equipment efficiency tables in Standard 90.1-1999, as approved in June 1999. To meet the minimum efficiency requirements in the Standard, the project committee recommended using three levels of cooling capacities (i.e., 5-ton, 10-ton and 15-ton) for single-zone packaged unitary air conditioners or heat pumps. 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-ton level should be rated by the seasonal energy efficiency ratio (SEER). The 10-ton and 15-ton levels should be rated by the energy efficiency ratio (EER). Furthermore, the cooling capacity of the office zone in the 50,000-ft^2 warehouse prototype was normalized to a 5-ton unit, adopting the minimum efficiency requirements of 9.7 SEER as the baseline case. Similarly, for the fine storage zone and the self-storage building baseline models, the minimum efficiency of 9.5 EER and 10.1 EER were set to meet the minimum requirements for the 15-ton and 10-ton size category, respectively.

7.4.4 Fan Power Assumptions

The *EnergyPlus* program calculates the fan power by taking three inputs for a constant air volume fan, i.e., the design pressure drops through the fan, total efficiency, and motor efficiency. For the systems using the packaged unitary equipment, the project committee assumed that the HVAC system contains only a supply fan, and there is no return fan or central exhaust fan in the system based on the committee's experience with warehouse and self-storage buildings and current construction practice. This assumption is consistent with the most likely HVAC system design configurations for single-zone packaged rooftop air conditioners and heat pumps with a constant-air-volume system.

To calculate the total supply fan static pressure drops, two elements have to be considered. These are internal static pressure drops and external static pressure drops. The internal static pressure is the static pressure drop across the packaged unitary equipment while operating, and was estimated based on the manufacturer's product performance data for 5-ton and 15-ton single packaged rooftop units with a gas furnace. The external static pressure calculation was based on the standard HVAC ductwork design method for representative duct runs served by 5- and 15-ton packaged unitary equipment. Table 7.4 summarizes the breakdown calculation of the fan total static pressure for both 5- and 15-ton equipment. A total fan static pressure of 1.11 inch water column (in. w.c.) was calculated for the 5-ton unit, representing the system serving the office zone in the 50,000-ft^2 warehouse prototype. For the fine storage zone with the 15-ton unit, a total fan static pressure of 2.61 in. w.c. was calculated. Similarly, a total fan static pressure of 1.44 in. w.c. was calculated for the self-storage building with 10-ton unit.

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

Table 7.4. Total Fan Static Pressure Drops Calculations for the Baseline Buildings

Component	50,000-ft² Warehouse Prototype: Office Zone: 5-ton Packaged Rooftop Unit (@2000 cfm)	50,000-ft² Warehouse Prototype: Fine Storage: 15-ton Packaged Rooftop Unit (@5250 cfm)	8,000-ft² Self-storage Prototype: Self-Storage: 10-ton Packaged Rooftop Unit (@3500 cfm)
Internal Static Pressure (Inches Water Column)[1]			
Standard DX Coil	0.15	0.79	0.28
Gas Heating Section	0.13	0.51	0.14
2-in. Plated Filters[2]	0.15	0.29	0.18
Economizer[3]	0.00	0.16	0.09
Acoustical Curb	0.04	0.13	0.07
Subtotal	0.47	1.88	0.75
External Static Pressure (Inches Water Column)[4]			
Diffuser	0.10	0.10	0.10
Supply Ductwork[5]	0.20	0.28	0.24
Return Ductwork[5]	0.05	0.06	0.06
Grille	0.03	0.03	0.03
Fan Outlet Transition	0.20	0.20	0.20
Subtotal	0.58	0.67	0.63
10 % Safety Factor	0.06	0.07	0.06
Subtotal	0.64	0.74	0.69
Total Static Pressure Drops	**1.11**	**2.61**	**1.44**

Notes:
1. Internal static pressure drops were derived from AAON product catalog for RK Series, last updated on July 1999.
2. Used average difference between the clean and dirty filters.
3. For system with 15-ton units baseline models, if economizer is not required by the Standard, the total static pressure drops will be 2.45 in. w.c., by deducting the pressure drop of 0.16 in. w.c. from 2.61 in. w.c..
4. External static pressure was calculated based on the typical duct runs served by the listed cooling capacities.
5. Used standard practice of 0.1 inch/100 ft friction rate for the baseline prototypes.

7.4.5 Ventilation Rates and Schedules

Forklifts and trucks powered by gasoline, propane, and other fuels are often used inside warehouses. Proper ventilation is necessary to alleviate the buildup of CO and other noxious fumes. Outdoor air requirement for ventilation was adopted in this Guide to meet ASHRAE Standard 62-2001. The committee believes that designers are more likely to follow the ventilation rates contained in ASHRAE Standard 62, and there are no other readily available, credible data sources to support alternative ventilation rates in commercial buildings. The committee chose to use the 2001 version rather than 2004 version to be consistent with the analysis work from the earlier guides. Standard 62-2001 requires 0.05 cfm/ft² outdoor air ventilation for warehouses, and 20 cfm/person for office area.

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 off 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 with 5-ton units have no economizer. For the 10-ton and 15-ton units, the systems were equipped with an economizer at some climate locations, in compliance with the Standard. Table 7.5 summarizes the requirements of economizers for each representative city.

Table 7.5. Baseline Modeling Economizer Requirement (for 10- and 15-ton Units)

Climate Zone	Representative City	T_{wb}[1] (°F)	No. of Hours Between 8 am and 4 pm with 55°F < T_{db} < 69°F	Economizer Requirement
Zone 1	Miami	77	259	no
Zone 2	Phoenix	70	746	yes
Zone 2	Houston	77	644[2]	no
Zone 3A	Memphis	77	851	yes
Zone 3B	El Paso	64	735	yes
Zone 3C	San Francisco	62	1796	yes
Zone 4	Baltimore	74	785[2]	no
Zone 4	Albuquerque	60	703	yes
Zone 4	Seattle	64	982	yes
Zone 5	Chicago	73	613	yes
Zone 5	Boise	63	647	yes
Zone 6	Helena	59	651	yes
Zone 6	Burlington	69	637	yes
Zone 7	Duluth	67	650	yes
Zone 8	Fairbanks	59	700[2]	yes
Notes:				
1. Twb = 1% cooling design web-bulb temperature, derived from Standard 90.1-1999 Appendix D 2. Data is not available in Appendix D of 90.1-1999 and was created using *BinMaker*, a weather data program.				

7.5 Service Hot Water System

The project committee defined the baseline service hot water system for both the 50,000-ft² warehouse and the 8,000-ft² self-storage prototype buildings as an electric storage water heater that meets the minimum efficiency requirement for residential water heaters (with rated input power less than 12 kW) under Standard 90.1-1999. Electric-resistant water heaters were chosen for the baseline to capture common warehouse and self-storage building conditions (CBECS 2003), where the majority of warehouse buildings used electricity as fuel source rather than natural gas. The reason to choose the residential water heater is that the peak hot water load is usually only from the use of a few lavatories by the office workers. This limited hot-water demand can normally to be met by a residential water heater. The Guide also provides the efficiency recommendation for the gas-fired water heater. The recommended efficiency level for the advanced design guide is described in Section 8.4.

To estimate the energy performance of a service water heater with a storage tank, the *EnergyPlus* 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 (expressed as UA) in Btu/hr-°F
- heat input ratio (HIR) – this is a ratio of gas heat input to heating capacity at full load. HIR is the inverse of the water hear thermal efficiency (E_t).

7.5.1 Storage Tank Size

The water heater storage tank volume was sized based on the methodology described in the 2003 ASHRAE Applications Handbook. The committee determined the maximum of four lavatories and one kitchen sink will satisfy the needs for studied warehouse buildings. Possible maximum hot water demand is determined by multiplying the number of fixtures with the hot-water demand per fixture in Table 8 of Chapter 49 *Service Water Heating (*ASHRAE 2003). Warehouse is not listed as one of the building types in Table 8, and the closest building type with similar demand is an office building. The hot-water demand for an office building is 2 gal/h per private lavatory and 20 gal/h per kitchen sink, resulting in the possible maximum demand of 28 gal/h. Plugging in the demand factor of 0.30 and the storage capacity factor of 2.0 from the same table, the storage tank capacity is calculated as 16.8 gallons. Therefore, a storage tank with rated capacity of 20 gallons is chosen as one of the baseline input variables.

7.5.2 Standby Heat Loss Coefficient and Heat Input Ratio

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. The Energy Factor of a water heater was 0.90 using the following equation required in the Standard:

$$EF = 0.93 - 0.00132 \times Rated\ Storage\ Tank\ Volume$$

Based on one manufacturer's electric water heater specification, the corresponding input rate of a 20-gallon electric water heater is 20,480 Btu/h[d], with recovery efficiency (RE) of 98%[e]. Furthermore, the Water Heater Analysis Model used in DOE's Appliance Standard Rulemaking for Residential Water Heater (DOE 2000) estimated the heater standby heat loss coefficient (UA) from the following equation:

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

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[d] Refer to A.O. Smith water heater catalog, Model DEL-20 Electric Water Heater with 20 gallons rated tank size and maximum 6 kW input. http://www.hotwater.com/lit/catalogs.html

[e] Gas Appliance Manufacturers Association (GAMA) reports that electric water heaters have recovery efficiency of 98% (GAMA 2006).

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 2.393 Btu/hr-°F, as one of the input variables in the *EnergyPlus* program.

The electric-resistance water heater has thermal efficiency E_t of 100%, resulting in the heat input ratio (HIR) of 1.0.

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 *EnergyPlus* modeling. The energy-efficiency measures include:

- Enhanced building opaque envelope insulation
- High performance window glazing
- Reduced air infiltration for loading dock doors
- Reduced air leakage through the relief dampers
- Reduced lighting power density
- Skylights and daylighting controls
- 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
- Lower friction rate ductwork design
- Instantaneous service water heater.

8.1 Advanced Building Envelope Assumptions

The advanced building prototypes were modeled with the same number of floors, identical conditioned floor area, identical opaque envelope types and areas, and identical fenestration locations and areas. The Guide recommends the following energy-efficiency measures in the envelope section. All these measures have been incorporated into the *EnergyPlus* models for the advanced case to estimate the potential energy savings.

- Opaque assemblies – Opaque assemblies such as roof, walls, floors and doors were modeled as having the same opaque types and heat capacity as the baseline buildings, but with the enhanced insulation R-values required in the Guide, as described in Section 10.0 of 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 case. Therefore, the solar reflectance used in the advanced cases for the 50,000-ft^2 warehouse 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 zones 1 through 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 recommendations for the climate, and the solar heat gain coefficient was set to the maximum allowed for the climate, as shown in Section 10 in this report.
- Infiltration – The project committee recommends the use of weatherseals for dock levelers and trailer hinges to reduce the air infiltration through the dock doors when they are open and the trailers are in place. In addition, reduction of air leakage through the relief dampers of the exhaust fans can be achieved by using the dampers with less leakage rate. See Table 8.1 for detailed assumptions.

Table 8.1. Baseline and Advanced Case Air Infiltration Rate Assumptions for the 50,000-ft² Warehouse

Infiltration	**Baseline (ASHRAE Standard 90.1-1999)**	**Advanced Case**
General infiltration	0.038 cfm/ft² of gross exterior walls, total 1000 cfm over the entire building	Same as baseline
Air leakage from relief dampers	2000 cfm	1400 cfm (=35 cfm/sf x 10 sf x 4 dampers)
Dock doors closed infiltration	0.40 cfm/ft² of door area, 32.0 cfm per door	0.28 cfm/ft² of door area, 22.4 cfm per door
Dock doors open infiltration	783 cfm per door	203 cfm per door (Reduce the effective crack area from 6.27 sf to 1.65 sf using weatherseals when doors open)

8.2 Advanced Building Lighting Levels Assumptions

The committee chose to adopt the advanced lighting levels that were lower than those being required by Standard 90.1-2004 (ANSI/ASHRAE/IESNA 2004). The lighting levels for the office areas were set at 0.9 w/ft², consistent with the recommendations from the AEDG-SO and 0.1 w/ft² lower than that required by Standard 90.1-2004. The lighting level for the fine storage area was reduced from 1.2 w/ft² (as required by Standard 90.1-1999) to 0.85 w/ft², recommended by the project committee. Similarly, the lighting levels for the bulky storage area and self-storage prototype were set at 0.6 w/ft² in the advanced case. Table 8.2 summarizes the advanced lighting levels incorporated into the *EnergyPlus* models for both prototypes. As shown in Table 8.2, the average lighting levels reductions were 44% relative to the 1999 baseline and 16% relative to the 2004 baseline for the 50,000-ft² prototype, and 49% and 24%, respectively, for the self-storage prototype.

Table 8.2. Interior Lighting Power Density Comparison

Building Prototype	Building Area	Floor Area (ft²)	Lighting Power Densities (W/ft²)		
			Baseline (Standard 90.1-1999)	Standard 90.1-2004	AEDG-WH
50,000-ft² Warehouse	Zone 1 – office	2,550	1.30	1.00	0.90
	Zone 2 – fine storage	12,450	1.20	0.80	0.85
	Zone 3 – bulky storage	34,500	1.20	0.80	0.60
	Total	49,500	1.21	0.81	0.68
8,000-ft² Self-Storage	Zone 1 – office	300	1.30	1.00	0.90
	Zone 2 – storage	7,700	1.20	0.80	0.60
	Total	8,000	1.20	0.81	0.61

The Guide requires 6% prismatic diffusing skylights in the warehouse area with exception of the self-storage building. Furthermore, the Guide recommends automatic dimming control in daylit warehouse areas. No skylights were recommended in climate zone 8 because the energy saving analysis indicated that the winter heat loss from the skylights exceeds the potential energy savings from daylighting in this very cold climate. Daylight dimming 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. No recommendations were provided for daylighting from vertical glazing because this was deemed to be an inappropriate application. For purposes of modeling the advanced case, daylighting was incorporated only in the bulky storage area of the larger warehouse prototype.

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..

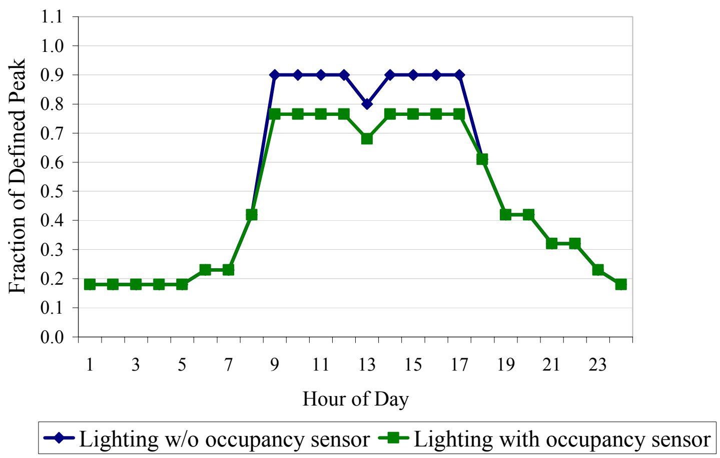

Figure 8.1. Lighting Schedules and Occupancy Sensor

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
- Lower friction rate ductwork design.

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

8.3.1 Higher HVAC Equipment Efficiency

The committee recommended the minimum cooling equipment efficiency of 13 SEER for 5-ton residential products normalized in the office area of the 50,000-ft² warehouse prototype. This recommendation is consistent with the requirements in the AEDG-SO. For 15-ton commercial products modeled serving the fine-storage area in the same 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, 5 and 6, and remains the same level as Standard 90.1-1999 (9.5 EER) in zones 7 and 8. Similarly, for the 10-ton equipment in the self-storage prototype, the equipment efficiency recommends 11.3 EER in zones 1 and 2, 11.0 EER in zones 3, 4, 5 and 6, and remains the same level as Standard 90.1-1999 (10.1 EER) in zones 7 and 8.

8.3.2 Air Economizer

Following the recommendation in the AEDG-SO, the committee recommended lowering the capacity threshold for air economizers from 65,000 Btu/hr to 54,000 Btu/hr for climate zones 3 through 6. Accordingly, the advanced systems with unitary packaged equipment have economizers implemented in climate zones 3, 4, 5, and 6 only. 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 Lower Static Pressure Ductwork

To quantify the potential energy savings from the recommended improved ductwork design (low friction rate) in the simulation analysis, the supply fan external static pressure drops were re-calculated, based on a maximum ductwork friction rate no greater than 0.08 in. per 100 liner feet of duct run, as recommended by the Guide. The internal static pressure remained the same as the baseline calculation shown in Table 7.4. Table 8.3 summarizes the breakdown calculation of the fan total static pressure for 5-, 10- and 15-ton equipment. The difference compared to the baseline calculation is shaded in Table 8.2, including static pressure drops through diffusers, registers, and supply and return ductwork. In summary, total fan static pressure of the 5-ton unit was reduced from 1.11 in. w.c. to 1.05 in. w.c., representing the office area in the larger warehouse advanced prototype. For the fine storage area advanced prototype with the 15-ton unit, a total fan static pressure of 2.48 in. w.c. was calculated compared to 2.61 in. w.c. in the baseline prototype. Similarly, the 10-ton unit serving the self-storage advanced prototype was set to 1.32 in. w.c. rather than 1.44 in. w.c. in the baseline case.

Table 8.3. Advanced Building Calculated Total Fan Static Pressure Drops

Component	50,000-ft² Warehouse Prototype		8,000-ft² Self-storage Prototype
	Office Zone: 5-ton Packaged Rooftop Unit (@2000 cfm)	**Fine Storage: 15-ton Packaged Rooftop Unit (@5250 cfm)**	**Self-Storage: 10-ton Packaged Rooftop Unit (@3500 cfm)**
Internal Static Pressure (Inches Water Column)[1]			
Standard DX Coil	0.15	0.79	0.28
Gas Heating Section	0.13	0.51	0.14
2-in. Plated Filters[2]	0.15	0.29	0.18
Economizer[3]	0.05	0.16	0.09
Acoustical Curb	0.04	0.13	0.07
Subtotal of internal SP	0.52	1.87	0.75
External Static Pressure (Inches Water Column)[4]			
Diffuser	0.05	0.05	0.05
Supply Ductwork[5]	0.16	0.22	0.19
Return Ductwork[5]	0.04	0.05	0.05
Grille	0.03	0.03	0.03
Fan Outlet Transition	0.20	0.20	0.20
Subtotal	0.48	0.55	0.52
10 % Safety Factor	0.05	0.06	0.05
Subtotal of external SP	0.53	0.61	0.57
Total Static Pressure Drops	**1.05**	**2.48**	**1.32**

Notes:
1. Internal static pressure drops were derived from AAON product catalog for RK Series, last updated on July 1999.
2. Used average difference between the clean and dirty filters.
3. For system with 15-ton units baseline models, if economizer is not required by the Standard, the total static pressure drops will be 2.45 in. w.c., by deducting the pressure drop of 0.16 in. w.c. from 2.61 in. w.c..
4. External static pressure was calculated based on the typical duct runs served by the listed cooling capacities.
5. Used standard practice of 0.1 inch/100 ft friction rate for the baseline prototypes.

8.4 Service Water Heating

Following the recommendations in the AEDG-SO, this Guide provides higher efficiency requirement for electric water heater, i.e., energy factor (EF) of 0.97 using Equation 8.1 recommended by the Guide. Additional recommendations are provided in the Guide for gas-fired water heaters. 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. Gas-fired water heaters were not modeled as part of this exercise.

$$EF = 0.99 - 0.0012 \times Rated\ Storage\ Tank\ Volume \tag{8.1}$$

Plugging in the new EF and the same values for RE and P_{on} using equation 7.4, the standby loss UA was reduced from 2.393 Btu/hr-°F (in the base case) to 0.410 Btu/hr-°F (in the advanced case).

In summary, the base and advanced electric water heater input variables in the *EnergyPlus* program for both the smaller and larger warehouse prototypes were:

	Heat Input Ratio	Storage Volume (gallons)	Rated Input Power (Btu/hr)	Tank Standby Loss UA (Btu/hr-°F)
Base	1.0	20	20,478	2.393
Advanced	1.0	20	20,478	0.410

9.0 Development of Cost Effectiveness Data

The electric charge given to the AEDG-WH Project Committee clearly delineated that the objective function of the work was to maximize energy savings. Cost effectiveness was not specified as one of the key variables to consider by the Steering Committee. An additional concern about cost effectiveness was the potential effort necessary to collect large amounts of cost data on various measures as well as the challenges in establishing agreement on parameters such as measure life, installation costs and the economic parameters such as discount rates and fuel escalation rates. For these reasons the guides have not contained information on cost effectiveness. This was deemed acceptable by the Steering Committee since the guides are voluntary recommendations rather than mandatory requirements like those contained in building codes.

Based on feedback received from DOE, as well as users and promoters of the guides, there is a strong interest in having some sense of the additional costs necessary to meet the recommended energy performance levels in the guides. Most of the input was focused on having a feel for the additional costs rather than the cost effectiveness. The cost data provided in this report is intended to represent a reasonable estimate of the incremental costs for energy efficient warehouses based on the large prototype building (50,000 sf) used for performing energy simulations. Using incremental costs helps to offset some of the biases in cost data when the cost data is deemed to be either routinely high or routinely low. For example, cost data from R.S. Means is generally considered to be a bit high in absolute, but using differences between the baseline and energy savings costs may be more representative of incremental costs seen in the industry.

9.1 Basis for Incremental Energy Savings Measure Costs

The costs for various energy savings measures are developed as incremental costs based on the difference between the costs for the baseline measure and the costs for the energy savings measure. The incremental costs may be based on a per unit cost, such as costs per square foot of wall area, or a per building cost, such as the cost of an economizer for a single air conditioning unit that serves an entire building or section of a building. This approach requires that for each measure both baseline cost and energy savings cost must be developed.

The 50,000-ft^2 warehouse prototype building described in Section 4 was used to develop the cost data. Costs were developed for each of the efficiency measures used in the building, and then the measure costs will be summed to get the overall cost premium for the building prototype. Table 9.1 summarizes the basis for estimating both the baseline and energy savings costs for each of the critical measures for the prototype building. The results are shown in Table 9.2.

Table 9.1. Baseline and Energy Saving Costs Summary for the 50,000-ft² Warehouse

Component	Cost Equation	Source
Roof insulation	Cost = Area of roof x incremental cost/ft^2 of higher insulation value	SSPC 90.1 Cost Database
Exterior wall insulation	Cost = Net area of exterior wall x incremental cost/ft^2 of higher insulation value	SSPC 90.1 Cost Database
Interior wall insulation	Cost = Net area of interior wall x incremental cost/ft^2 of higher insulation value	SSPC 90.1 Cost Database
Slab-on-grade insulation	Cost = Perimeter of slab x incremental cost/ft of higher insulation value	SSPC 90.1 Cost Database
Doors - swinging	Cost = Area of door x incremental cost/ft^2 of lower U-factor	SSPC 90.1 Cost Database
Vehicular/Dock doors	Cost = Area of door x incremental cost/ft^2 of lower U-factor	SSPC 90.1 Cost Database
	Cost = Perimeter of door x incremental cost of sealing material	Industry quotations
	Cost = Perimeter of door hinge area x incremental cost of sealing material	Industry quotations
	Cost = Perimeter of dock leveler x incremental cost of sealing material	Industry quotations
Fenestration - Windows	Cost = Area of windows x incremental cost of window type	SSPC 90.1 Cost Database
Fenestration – Skylights	Cost = Area of skylights x incremental cost of skylights	SSPC 90.1 Cost Database
Interior lighting - LPD	Cost = Incremental cost of bulbs x number of bulbs used	Grainger catalog
	Cost = Incremental cost of ballasts x number of ballasts used	Grainger catalog
Daylighting controls	Cost = Additional costs of daylighting controls	Estimates provided by Seattle Lighting Laboratory
Occupancy sensors	Cost = Additional costs of occupancy sensors	Estimates provided by Seattle Lighting Laboratory
Cooling – Air conditioner efficiency	Cost = Incremental cost/ton for higher EER x total tonnage	DOE Technical Support Document for CUAC Rulemaking
Heating – Furnace Efficiency	Cost = Incremental cost/furnace for higher thermal efficiency x number of furnaces	Industry quotations
Heating – Heat Pump	Cost = Incremental cost/ton for higher EER x total tonnage	Industry quotations

Table 9.1 (Cont.)

Component	Cost Equation	Source
Heating – Destratification	Cost = Additional cost of destratification fans	Industry quotations
Economizer – Cooling for Office and Fine Storage	Cost = Additional cost of economizer	Industry quotations
Economizer – Cooling for Bulk Storage	Cost = Additional cost of controls for exhaust fans x number of fans used	Industry quotations
Ventilation – Outside Air Damper	Cost = Additional cost for motorized damper x number of dampers used	Industry quotations
Ventilation – Demand Controlled	Cost = Additional costs for CO_2 sensors x number of sensors used	Industry quotations
Ducts	Cost = Additional cost of sealing material	Contractor estimate
	Cost = Additional cost of insulation material	Industrial quotations
Service Water Heating	Cost = Additional cost of higher efficiency water heater	Contractor estimate

Table 9.2. Incremental Costs per Building for Energy Measures in 50,000-ft^2 Warehouse

Item	Component	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7	Zone 8
Opaque Elements	Roof Insulation	$11,026.20	$4,200.00	$7,118.70	$7,118.70	$11,658.90	$16,199.10	$16,199.10	$17,480.40
	Exterior Wall Insulation	$0.00	$0.00	$1,598.94	$3,109.05	$32,718.56	$32,096.75	$37,102.10	$8,691.34
	Interior Wall Insulation	$1,452.50	$1,452.50	$1,452.50	$1,452.50	$1,452.50	$1,452.50	$1,452.50	$1,452.50
	Slab Insulation	$0.00	$0.00	$0.00	$0.00	$0.00	$882.00	$1,011.50	$1,141.00
	Doors – Swinging	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	Vehicular/Dock Doors	$15,562.40	$15,562.40	$15,562.40	$15,562.40	$15,562.40	$15,562.40	$15,562.40	$15,562.40
Fenestration	Windows	$3,898.44	$1,865.92	$1,132.88	$649.74	$649.74	$649.74	$6,905.57	$3,406.97
	Skylights	$39,102.30	$39,102.30	$39,102.30	$39,102.30	$39,102.30	$39,102.30	$39,102.30	$0.00
Interior Lighting	Lighting	$1,982.50	$1,982.50	$1,982.50	$1,982.50	$1,982.50	$1,982.50	$1,982.50	$1,982.50
	Daylighting Controls	$19,000.00	$19,000.00	$19,000.00	$19,000.00	$19,000.00	$19,000.00	$19,000.00	$0.00
	Occupancy Sensors	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00	$600.00
Cooling	Cooling Efficiency	$9,000.00	$9,000.00	$7,800.00	$7,800.00	$7,800.00	$3,000.00	$0.00	$0.00
Heating	Furnace Efficiency	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
	De-stratification	$0.00	$0.00	$0.00	$0.00	$44,000.00	$44,000.00	$44,000.00	$44,000.00
Economizer	Economizer-Office	$0.00	$0.00	$2,000.00	$2,000.00	$2,000.00	$2,000.00	$0.00	$0.00
	Economizer-Storage	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Ventilation	Outside Air Damper	$200.00	$200.00	$200.00	$200.00	$200.00	$200.00	$200.00	$200.00
	Exhaust Fan Damper	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00	$20.00
Ducts	Insulation	$363.00	$363.00	$363.00	$363.00	$363.00	$363.00	$363.00	$363.00
Pipes	Insulation	$324.00	$324.00	$324.00	$324.00	$324.00	$324.00	$324.00	$324.00
SWH	Efficiency factor	$472.00	$472.00	$472.00	$472.00	$472.00	$472.00	$472.00	$472.00
TOTAL		$103,003.34	$94,144.62	$98,729.22	$99,756.19	$177,905.90	$177,906.29	$184,296.97	$95,696.11

9.2 Comparison of Incremental Costs to Baseline Costs for Construction

Another item that needs to be addressed is the baseline costs for construction of typical warehouses. Armed with this information, designers and owners can quickly evaluate the estimated cost premiums for meeting the recommendations for the guides. Within the design and construction community the quick evaluation of cost premiums versus the expected cost per square foot estimates seemingly serves as the surrogate for cost effectiveness.

For example, the 2007 version of R.S. Means Construction Cost Database indicates that for warehouses and storage buildings the median unit construction cost is $54.00/ft^2 with a lower quartile value of $37.50/ft^2 and an upper quartile value of $77.00/ft^2. For warehouse and office “hybrids” the median unit construction cost is $59.00/ft^2 with a lower quartile value of $44.00/ft^2 and an upper quartile value of $79.50/ft^2. For purposes of this analysis the unit cost values for the warehouse and offices combination buildings will be used. Presumably cost premiums of a few percent of the average construction costs might be deemed in the cost effective range, while those in higher ranges of percentage might not.

To address the needs of this segment of the industry the total incremental costs developed in Section 9.1 will be compared to the median baseline construction costs to help evaluate the surrogate cost effectiveness of the guide for each of the climate zones. **Error! Reference source not found.** Table 9.3 indicates the comparison by climate zones. Note that in this table the median baseline construction cost estimates for each zone are adjusted by the cost multipliers for the climate cities modeled as part of the energy savings analysis.

Table 9.3. Percentage Cost Increases for Meeting the Recommendations of the Guide - 50,000 ft^2 Warehouse

Climate Zone	Incremental Cost	Unit Cost Increase Over Median Baseline	Adjusted Unit Median Baseline Construction Cost	Percentage of Cost Increase Over Median Baseline
1	$103,003.34	$2.06/ft^2	$51.09/ft^2	4.0%
2	$94,144.62	$1.88/ft^2	$52.45/ft^2	3.6%
3	$98,729.22	$1.97/ft^2	$56.05/ft^2	3.5%
4	$99,756.19	$2.00/ft^2	$56.29/ft^2	3.5%
5	$177,905.90	$3.56/ft^2	$60.06/ft^2	5.9%
6	$177,906.29	$3.56/ft^2	$51.04/ft^2	7.0%
7	$184,296.97	$3.69/ft^2	$61.77/ft^2	6.0%
8	$95,696.11	$1.91/ft^2	$73.10/ft^2	2.6%

9.3 Cost Effectiveness Calculations

Cost effectiveness can be shown most directly by looking at the simple payback for the energy savings measures recommended in the guide. The simple payback is calculated for the energy savings measures in aggregate by dividing the total incremental cost of the measures by the energy savings in dollars. Energy savings in dollars is calculated by using the EIA national average natural gas rate of $1.16/therm and the national average electric rate of $0.0939/kWh.[f] These rates are the same ones being used by the SSPC 90.1 committee in developing the 2010 version of Standard 90.1. See Table 9.4 for a tabulation of the simple paybacks for each climate location simulated for the energy savings analysis.

The reader will note the significant increase in the incremental costs for climate zones 5-7 in the following tables. This is attributable to two main driving functions: (1) recommendations call for de-

[f] National average natural gas rate and electric rate are derived from the report *Annual Energy Review 2006* by EIA. Last accessed at http://www.eia.doe.gov/emeu/aer/pdf/aer.pdf in October 2007.

stratification fans to circulate heated air in the bulk storage area which adds a fairly large first cost to the project, and (2) the exterior wall insulation goes up substantially in these climate zones and the baseline mass wall assemblies have no insulation to begin with. This second factor results in a fairly large increase in costs for exterior wall insulation that drives the total project cost up a bit disproportionately. The values for climate zone 8 drop due to the elimination of the skylights and day lighting controls in that climate.

Table 9.4. Simple Payback Period for Meeting the Recommendations of the Guide – 50,000 ft² Warehouse

Climate Zone	Climate City	Incremental First Cost	Energy Cost Savings			Simple Payback (Years)
			Electricity	Natural Gas	Total	
1A	Miami	$103,003.34	$13,627.37	$0.12	$13,627.49	7.6
2A	Houston	$94,144.62	$13,986.91	$349.67	$14,336.58	6.6
2B	Phoenix	$94,144.62	$15,710.09	$110.57	$15,820.66	6.0
3A	Memphis	$98,729.22	$13,047.62	-$115.60	$12,932.03	7.6
3B	El Paso	$98,729.22	$13,124.08	-$118.06	$13,006.02	7.6
3C	San Francisco	$98,729.22	$11,903.82	$17.99	$11,921.81	8.3
4A	Albuquerque	$99,756.19	$12,528.20	$175.19	$12,703.39	7.9
4B	Baltimore	$99,756.19	$12,400.09	$474.80	$12,874.88	7.7
4C	Seattle	$99,756.19	$11,760.74	$226.82	$11,987.56	8.3
5A	Boise	$177,905.90	$12,043.00	$1,162.19	$13,205.18	13.5
5B	Chicago	$177,905.90	$12,161.70	$2,230.19	$14,391.89	12.4
6A	Burlington	$177,906.29	$12,023.46	$3,965.87	$15,989.34	11.1
6B	Helena	$177,906.29	$11,975.20	$3,149.39	$15,124.58	11.8
7A	Duluth	$184,296.97	$12,033.93	$7,205.60	$19,239.53	9.6
8A	Fairbanks	$95,696.11	$9,090.49	$4,685.00	$13,775.49	6.9

10.0 Final Recommendations and Energy Savings Results

This section contains the final recommendations approved by the project committee for AEDG-WH, 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 warehouse 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-WH. The recommendations are grouped into envelope measures, lighting and daylighting measures, and HVAC and SWH measures.

10.1.1 Envelope Measures

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

Recommendations for each envelope component are contained in Table 10.1 for the semi-heated areas in the warehouses, and in Table 10.2 for the conditioned areas in the warehouse buildings. These tables 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 important 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. Warehouses typically have very low glazing areas, thus this is not a critical parameter in the design. The reader should note that the AEDG-WH repeats most of the recommendations from the AEDG-SO for the conditioned office portion of the warehouse with some updated changes, especially for the metal buildings.

In several additional cases, the recommendations are constant across all climate zones, which suggests an insensitivity to climate. The recommendation for the maximum (and minimum) skylight areas demonstrate this. These areas are limited to reduce overall energy use while maximizing the daylighting potential regardless of the climate.

Table 10.1. Final Energy Savings Recommendations for Semi-Heated Warehouse – 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-3.8 ci	R-3.8 ci	R-5.0 ci	R-5.0 ci	R-7.6 ci	R-10.0 ci	R-10.0 ci	R-15.0 ci
	Metal building	R-6.0	R-10.0	R-10.0	R-10.0	R-13.0	R-16.0	R-16.0	R-19.0
	Single rafter	R-21.0	R-21.0	R-21.0	R-30.0	R-30.0	R-38.0	R-38.0	R-38.0
	Solar reflectance index	78	78	78	NR	NR	NR	NR	NR
Walls-Exterior	Mass (HC > 7 Btu/ft^2)	NR	NR	NR	NR	R-5.7 ci	R-5.7 ci	R-7.6 ci	R-9.5 ci
	Metal building	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0
	Steel framed	NR	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0 + R-3.8 ci
	Wood framed and other	NR	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0
Walls-Interior	Partition Walls	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0
Slabs	Unheated	NR	NR	NR	NR	NR	NR	NR	NR
Doors Opaque	Swinging	U-0.700	U-0.700	U-0.700	U-0.700	U-0.700	U-0.700	U-0.700	U-0.700
	Vehicular/Dock Thermal Transmittance	U-0.500	U-0.500	U-0.500	U-0.500	U-0.500	U-0.500	U-0.500	U-0.500
	Vehicular/Dock infiltration-door closed	0.28 cfm/ft^2 of door area	0.28 cfm/ft^2 of door area	0.28 cfm/ft^2 of door area	0.28 cfm/ft^2 of door area	0.28 cfm/ft^2 of door area	0.28 cfm/ft^2 of door area	0.28 cfm/ft^2 of door area	0.28 cfm/ft^2 of door area
	Vehicular/Dock infiltration-door open with truck in place	NR	NR	NR	Weatherseals for dock levelers and trailer hinges	Weatherseals for dock levelers and trailer hinges	Weatherseals for dock levelers and trailer hinges	Weatherseals for dock levelers and trailer hinges	Weatherseals for dock levelers and trailer hinges
Vertical glazing including doors	Thermal transmittance	U-1.20	U-1.20	U-1.20	U-1.20	U-1.20	U-0.60	U-0.60	U-0.60
	Solar heat gain coefficient (SHGC)	NR	NR	NR	NR	NR	NR	NR	NR
	Exterior sun control (S, E, W only)	NR	NR	NR	NR	NR	NR	NR	NR
Skylights	Area (percent of gross roof)	5-7% prismatic diffusing skylights required in warehouse areas (except in self-storage warehouse)							No Skylights
	Thermal transmittance	U-1.36	U-1.36	U-1.36	U-1.36	U-1.36	U-1.36	U-1.36	NR
	Solar heat gain coefficient (SHGC)	NR	NR	NR	NR	NR	NR	NR	NR
	Visible light transmittance (VLT)	0.45	0.59	0.59	0.59	0.59	0.59	0.59	NR

Table 10.2. Final Energy Savings Recommendations for Conditioned Warehouse – 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 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-20.0 ci	R-30.0 ci
	Metal building	R-19.0	R-13.0 + R-13.0	R-13.0 + R-13.0	R-13.0 + R-19.0	R-13.0 + R-19.0	R-13.0 + R-19.0	R-13.0 + R-19.0	R-11.0 + R-30.0 ls
	Single rafter	R-30.0	R-38.0	R-38.0	R-38.0	R-38.0 + R-5.0 ci	R-38.0 + R-5.0 ci	R-38.0 + R-10.0 ci	R-38.0 + R-10.0 ci
	Solar reflectance index	78	78	78	78	NR	NR	NR	NR
Walls-Exterior	Mass (HC > 7 Btu/ft^2)	NR	R-5.7 ci	R-7.6 ci	R-9.5 ci	R-11.4 ci	R-13.3 ci	R-15.2 ci	R-15.2 ci
	Metal building	R-16.0	R-16.0	R-19.0	R-19.0	R-19.0+ R-5.6 ci	R-19.0+ R-5.6 ci	R-19.0+ R-11.2 ci	R-19.0+ R-11.2 ci
	Steel framed	R-13.0	R-13.0	R-13.0+ R-3.8 ci	R-13.0+ R-7.5 ci	R-13.0+ R-7.5 ci	R-13.0+ R-7.5 ci	R-13.0+ R-7.5 ci	R-13.0+ R-7.5 ci
	Wood framed and other	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0+ R-3.8 ci	R-13.0+ R-7.5 ci	R-13.0+ R-7.5 ci	R-13.0+ R-15.6 ci
Walls-Interior	Partition Walls	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0	R-13.0
Slabs	Unheated	NR	NR	NR	NR	NR	R-10.0 for 24 in.	R-15.0 for 24 in.	R-20.0 for 24 in.
Doors Opaque	Swinging	U-0.700	U-0.700	U-0.700	U-0.700	U-0.700	U-0.700	U-0.500	U-0.500
	Vehicular/Dock Thermal Transmittance	U-0.500	U-0.500	U-0.500	U-0.500	U-0.500	U-0.500	U-0.500	U-0.500
	Vehicular/Dock infiltration-door closed	0.28 cfm/ft^2 of door area							
	Vehicular/Dock infiltration-door open with truck in place	Weatherseals for dock levelers and trailer hinges							
Vertical glazing including doors	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-0.25	N,S,E,W-0.25	N,S,E,W-0.25	N,S,E,W-0.40	N,S,E,W-0.40	N,S,E,W-0.40	N,S,E,W-0.45	N,S,E,W-0.45
	Exterior sun control (S, E, W only)	PF>0.5	PF>0.5	PF>0.5	PF>0.5	PF>0.5	PF>0.5	PF>0.5	PF>0.5
Skylights	Area (percent of gross roof)	5-7% prismatic diffusing skylights required in warehouse areas (except in self-storage warehouse)							No Skylights
	Thermal transmittance	U-1.36	U-1.36	U-0.69	U-0.69	U-0.69	U-0.69	U-0.69	NR
	Solar heat gain coefficient (SHGC)	0.19	0.19	0.19	0.32	0.36	0.46	0.64	NR
	Visible light transmittance (VLT)	0.45	0.59	0.59	0.59	0.59	0.59	0.59	NR

10.1.2 Lighting and Daylighting Measures

For lighting and daylighting, the measures are not climate dependent except for daylighting via skylights in very cold climates such as Zone 8. As such, the same recommendation is provided for each of the climate zones with the exception of Zone 8 where no skylights are recommended. The reason that skylights are not recommended is that the thermal losses during the winter when temperatures are low and sunlight is rarely available offset the electric light savings due to daylighting. Recommendations are provided for interior lighting (including additional light power allowances and daylighting), as well as exterior lighting, in Table 10.3.

Table 10.3. AEDG-WH Final Energy Savings Recommendations – Lighting

Item	Component	Zones 1-8
Interior Lighting	Lighting power density (LPD)	Warehouse (bulky & Self-Storage) = 0.60 W/ft^2 Warehouse (fine storage) = 0.85 W/ft^2 Office area = 0.90 W/ ft^2
	Linear fluorescent lamps	T5HO or T-8 high-performance electronic ballast
	Controls for daylight harvesting	Automatic dimming or switching of all luminaires in daylit areas
	Occupancy controls	Auto-on/off for all luminaires in the warehouse and self-storage areas, manual-on/off for all office areas
	Ceiling surface reflectance	80%
Exterior Lighting	Canopied Areas	0.50 W/ft^2

Interior lighting recommendations include a maximum lighting power density for the different types of warehouse storage spaces as well as office spaces. Additional recommendations cover the minimum performance of the light sources and ballasts (minimum mean lumens/watt). Occupancy and daylighting control recommendations are provided, as well as recommendations for surface reflectance values to enhance daylighting.

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

10.1.3 HVAC and SWH Measures

HVAC measures include recommendations for minimum heating and cooling equipment efficiencies for both residential and commercial products because both of these types of products are used in warehouse 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.

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. Table 10.4 provides the recommendations for HVAC and SWH measures.

Table 10.4. AEDG-WH 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	Cooling System (Conditioned Storage all)	Heat Pump packaged systems for low sensible load spaces, Variable speed supply fan; inverter compressor					NR		
	Air conditioner (0-65 KBtuh)	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	11.0 EER 11.4 IPLV	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	10.8 EER 11.2 IPLV	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	10.0 EER 10.4 IPLV	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 81% Et	80% AFUE or 81% Et	80% AFUE or 81% Et	80% AFUE or 81% 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	82% Ec or 81% Et	82% Ec or 81% Et	82% Ec or 81% Et	82% Ec or 81% Et
	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
	Destratification	NR				Destratification fans for high bay spaces			
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							
	Air leakage through relief dampers	20 cfm/ft² of damper area							
Ducts	Friction rate	0.08 in. w.c./100 feet							
	Sealing	Seal class B							
	Location	Interior only							
	Insulation level	R-6							R-8
Service Water Heating	Gas Water Heater Efficiency	Storage - 90% Et Instantaneous - 0.81 EF or 81% Et							
	Electric storage (≤12 kW and > 20 gal)	EF > 0.99 – 0.0012xVolume							
	Point of Use Heater Selection	Avoid pumped return for distributed light loads							
	Water Heater Sizing	Avoid oversizing and excessive supply temperatures							
	Pipe insulation (d<1½ in./ d≥1½ in.)	1 in./ 1½ in.							

10.2 Energy Savings Results

Once the project committee determined the final recommendations, the prototype large warehouses and self-storage buildings were simulated in each of the 15 climate locations to determine if the 30% energy savings goal was achieved. The whole building energy savings results for the recommendations are summarized in Table 10.5 for both the 8,000-ft² self-storage and the 50,000-ft² warehouse prototype. In addition, the energy savings in percentage are also provided in Figure 10.1 for the self-storage warehouse prototype and in Figure 10.2 for the 50,000 sf warehouse prototype, respectively. In all cases the energy 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). The 50,000-ft² warehouse building prototype met the 30% savings goal in all climates for the case without plug loads included in the denominator. The self storage building met or exceeded the 30% savings in climate zone 1 though 5 and fell short from 1% to 3% in meeting the 30% goal in a few cities of the colder climate zones. The average whole building energy savings including the plug load in denominator are 42% for the self-storage and 42% for the large warehouse buildings, respectively.

Table 10.5. Energy Saving Results: ASHRAE 90.1-1999 Baseline

Climate Zone	Climate City	8,000 ft² Self-Storage		50,000 ft² Warehouse	
		Plug load in denominator	Plug load not in denominator	Plug load in denominator	Plug load not in denominator
1	Miami	63%	67%	51%	59%
2A	Houston	58%	61%	54%	63%
2B	Phoenix	59%	63%	53%	60%
3A	Memphis	46%	49%	43%	49%
3B	El Paso	49%	52%	47%	54%
3C	San Francisco	52%	56%	46%	53%
4A	Albuquerque	39%	41%	40%	45%
4B	Baltimore	35%	36%	37%	41%
4C	Seattle	43%	45%	36%	40%
5A	Boise	37%	38%	37%	41%
5B	Chicago	33%	34%	39%	43%
6A	Burlington	31%	31%	42%	45%
6B	Helena	29%	29%	39%	42%
7	Duluth	28%	28%	43%	45%
8	Fairbanks	27%	27%	29%	30%
Average		42%	44%	42%	47%

On average, the 50,000 sf warehouse prototype performs slightly better than the self-storage building prototype for several reasons. First, the large warehouse is able to make maximum use of daylighting to reduce the energy use of electric light and thus save additional energy. The larger warehouse also benefits from occupancy controls and infiltration control measures not necessarily available in the self-storage building. The self storage building tends not to perform as well in colder climates where higher insulation levels are needed due to its metal wall construction. In addition, the self storage uses the packaged unitary equipment with gas furnace that benefits less from the energy efficiency improvements for heating since the recommendations in the guide are somewhat less aggressive for these categories of equipment.

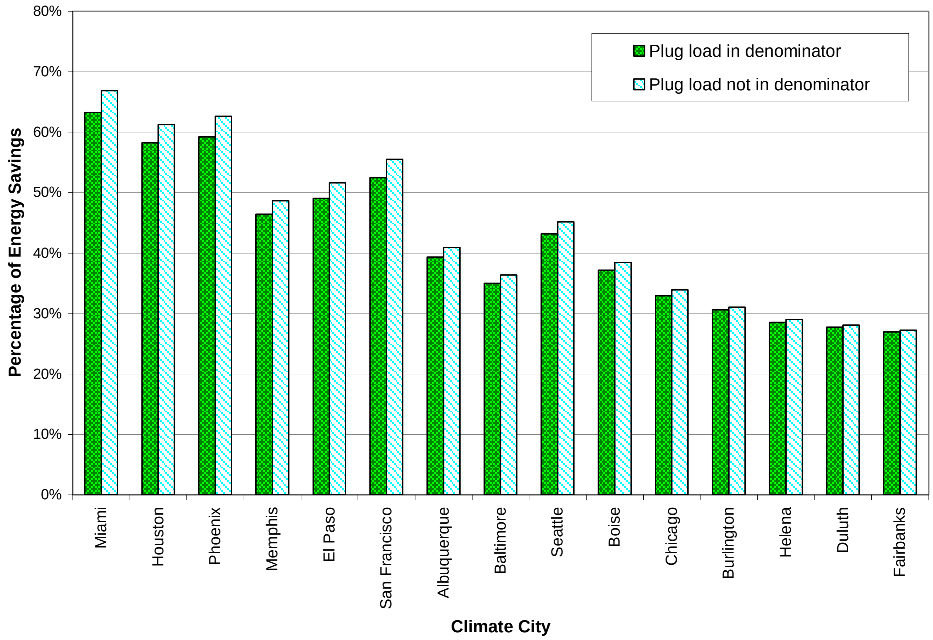

Figure 10.1. 8,000-ft² Self-Storage Energy Savings (ASHRAE 90.1-1999 as baseline)

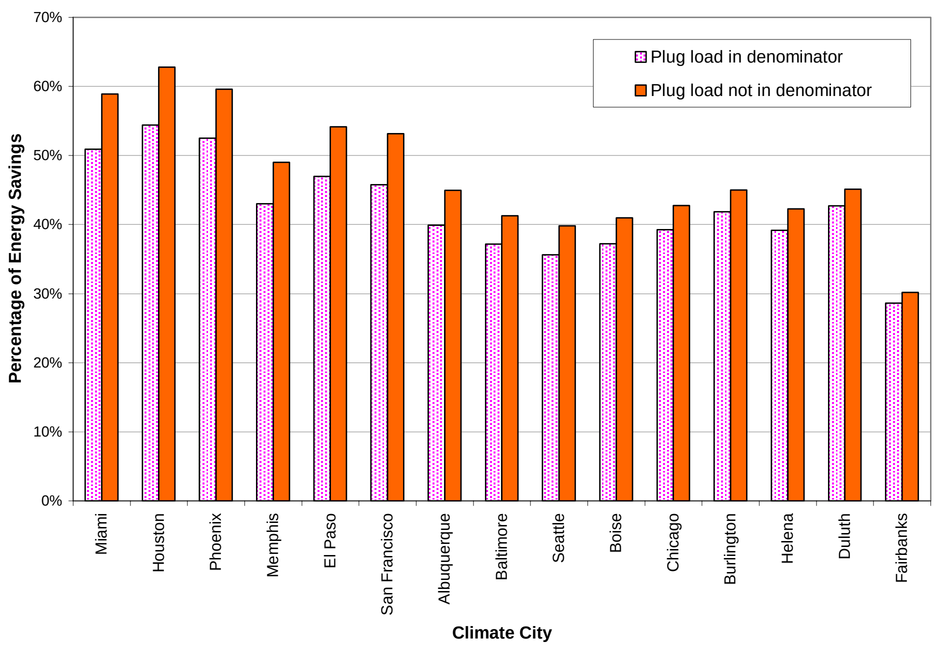

Figure 10.2. 50,000-ft² Warehouse Energy Savings (ASHRAE 90.1-1999 as baseline)

The energy savings results for the recommendations in the Warehouse AEDG, relative to ASHRAE 90.1-2004, are shown in Table 10.6 for both the self-storage and large warehouse prototype buildings. The recommendations in the Warehouse AEDG result in 30% or greater energy savings over ASHRAE 90.1-2004 in most of the climate cities, with a few percentage of short in a couple of cities. The average whole building energy savings including the plug load in denominator are 33% for the self-storage and 33% for the large warehouse buildings, respectively.

Table 10.6. Energy Saving Results: ASHRAE 90.1-2004 Baseline

Climate Zone	Climate City	8,000 ft² Self-Storage		50,000 ft² Warehouse	
		Plug load in denominator	Plug load not in denominator	Plug load in denominator	Plug load not in denominator
1	Miami	48%	52%	36%	44%
2A	Houston	44%	47%	42%	50%
2B	Phoenix	44%	48%	41%	48%
3A	Memphis	34%	36%	30%	35%
3B	El Paso	36%	38%	38%	45%
3C	San Francisco	39%	42%	30%	37%
4A	Albuquerque	29%	31%	28%	33%
4B	Baltimore	25%	26%	27%	31%
4C	Seattle	32%	34%	25%	28%
5A	Boise	28%	30%	29%	32%
5B	Chicago	26%	27%	32%	36%
6A	Burlington	29%	30%	37%	40%
6B	Helena	27%	28%	34%	36%
7	Duluth	26%	26%	40%	42%
8	Fairbanks	25%	25%	25%	27%
Average		33%	35%	33%	38%

The energy end uses for each ASHRAE 90.1-1999 baseline and the advanced model are illustrated in Figure 10.3 and Figure 10.4 for both the self-storage and warehouse prototype buildings, respectively. Similarly, the energy end uses for each ASHRAE 90.1-2004 baseline and the advanced model are shown in Figure 10.5 and Figure 10.6 for both the self-storage and warehouse prototype buildings, respectively. In addition, the end use data and percent savings in tabular format are shown in Appendix C.

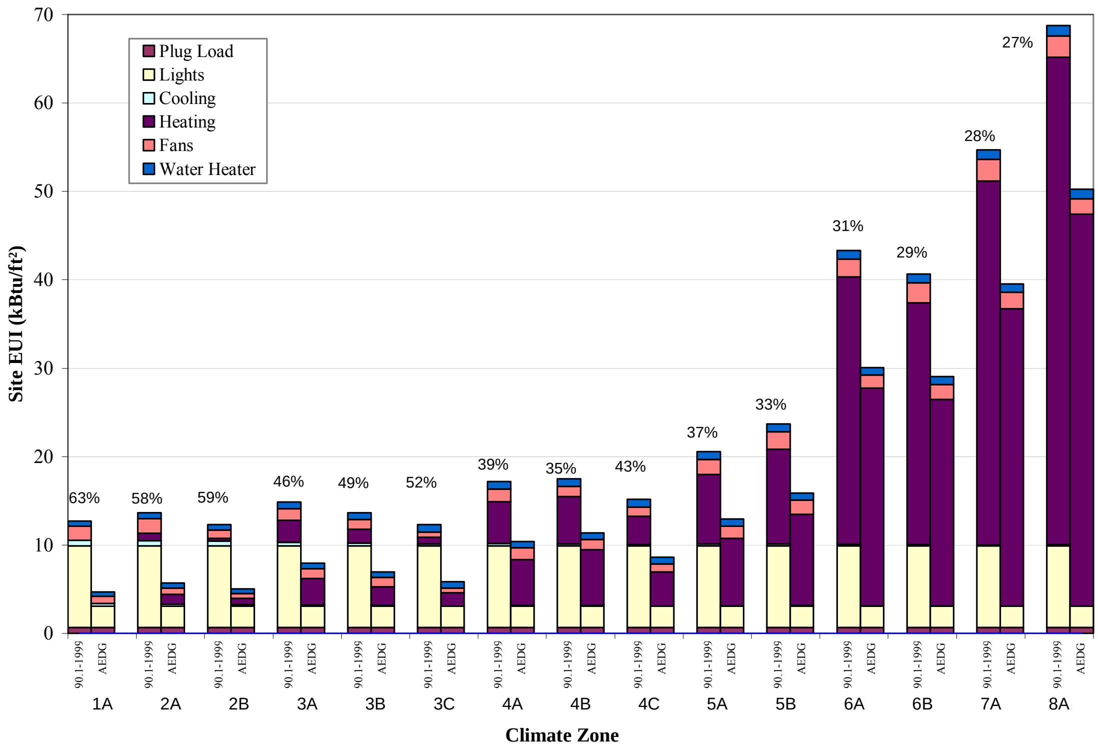

Figure 10.3. 8,000-ft² Self Storage Energy End Use (ASHRAE 90.1-1999 as baseline)

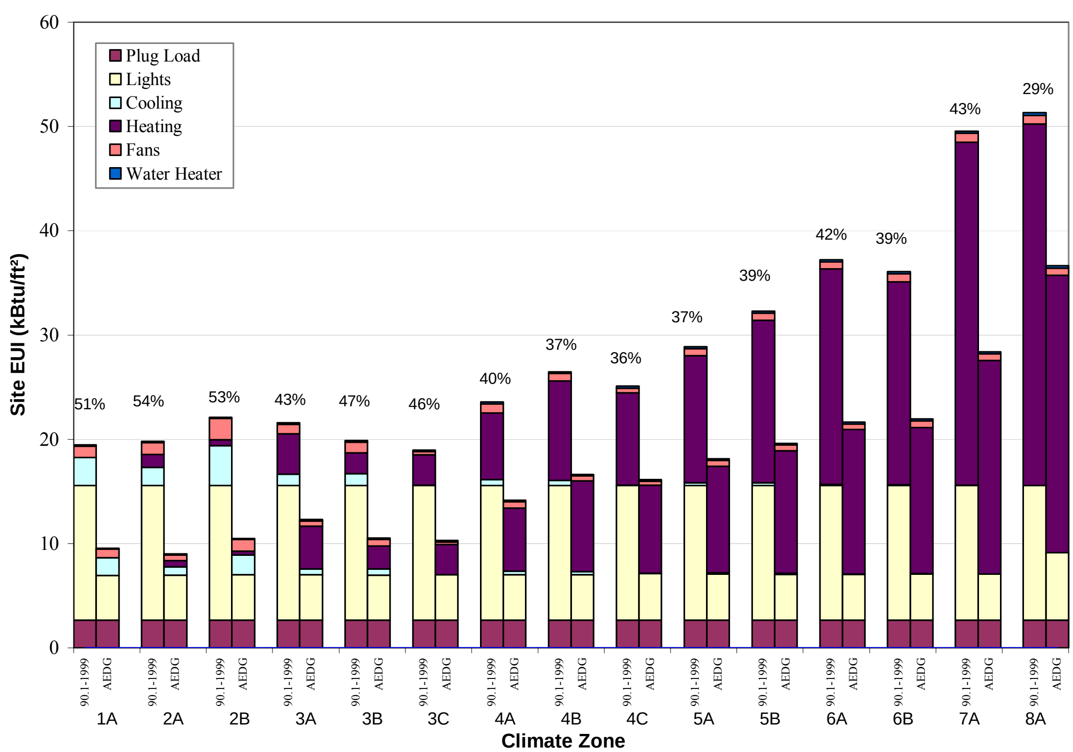

Figure 10.4. 50,000-ft² Warehouse Energy End Use (ASHRAE 90.1-1999 as baseline)

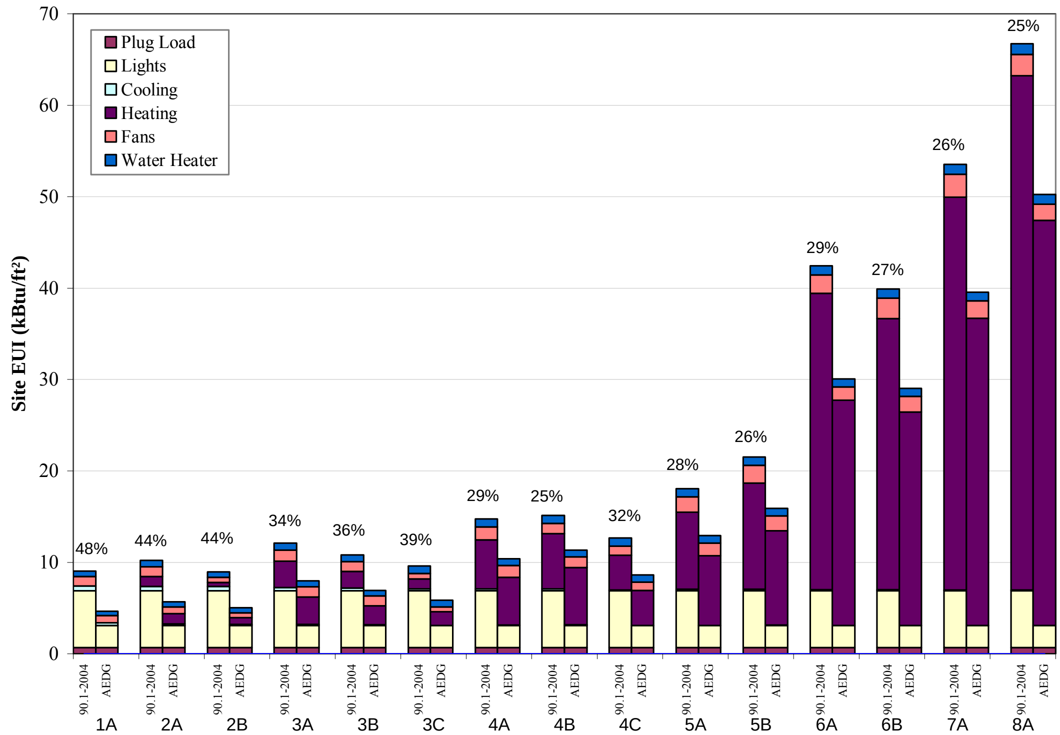

Figure 10.5. 8,000-ft² Self Storage Energy End Use (ASHRAE 90.1-2004 as baseline)

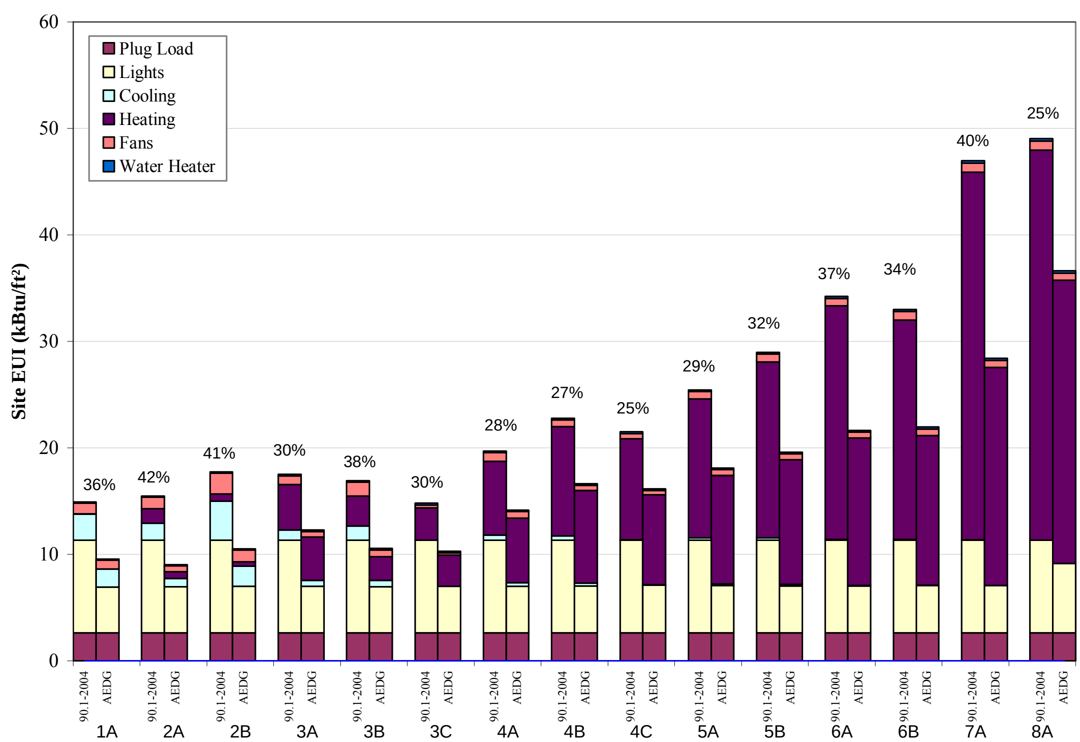

Figure 10.6. 50,000-ft² Warehouse Energy End Use (ASHRAE 90.1-2004 as baseline)

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Appendix A – Prototype Building Descriptions and Assumptions

Appendix A – Prototype Building Baseline Assumptions

Table A.1. Baseline Assumptions for 50,000-ft² Warehouse Prototype

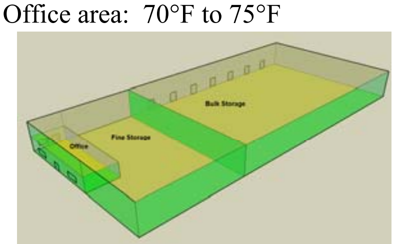
Characteristic	Prototype Building	Data Source/Remarks
GENERAL		
Building Type	Non-refrigerated warehouse	2003 CBECS Database
Gross Floor Area	49,500 ft²	Dodge Data for New Constructions
Operation Hours	Monday-Saturday, 8:00 am – 5:00 pm	2003 CBECS Database
Location	15 climate cities. See Section 5 of the report.	Briggs 2003
ARCHITECTURE		
Configuration/Shape		
Building Shape	Wide rectangle	2003 CBECS Database
Aspect Ratio	2.2 (330 ft x 150 ft)	2003 CBECS Database
Number of Floors	1	2003 CBECS Database
Activity Area (percentage of gross floor area)	• Bulk storage area: 34,500 ft² (70%) • Fine storage area: 12,450 ft² (25%) • Office area: 2,550 ft² (5%)	Committee's inputs
Window to Wall Ratio	• Storage area: no windows • Office area: 12% view windows	Committee's inputs
Floor Height	28 ft	DODGE Database Sample Building Plans
Floor-to-Ceiling Height	14 ft (for the office area only)	Committee's Input
Infiltration Rate	• General: 0.038 cfm/sf of the gross exterior walls over the entire building • Bulk storage: o 2000 cfm total of air leakage through the relief dampers o Dock doors closed: 0.28 cfm/ft² of door area o Dock doors open: 783 cfm per door	ASHRAE 90.1-1989 §13.7.3.2 Committee's inputs
Infiltration Schedule	See Table A.3	
Thermal Zoning	• Bulk storage: 45°F (semi-heated) • Fine storage: 60°F to 80°F • Office area: 70°F to 75°F 	Committee's inputs

Table A.1. Baseline Assumptions for 50,000-ft² Warehouse Prototype (Cont.)

Characteristic		Prototype Building	Data Source/Remarks
	Exterior Walls		
	Structure	Mass wall (8 in. medium weight 115 lb/ft³ concrete tilt-up construction)	Committee's inputs
	Insulation	See Table B.1 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	Roof		
	Structure	Steel deck with rigid insulation	Committee's inputs
	Exterior Finish	Single-ply roof membrane	
	Insulation	See Table B.1 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	Solar Reflectance	See Table B.1 in Appendix B	Base: LBNL's Cool Roof Materials Database (http://eetd.lbl.gov/coolroof/) AEDG: AEDG-WH
	Slab-On-Grade Floor		
	Floor Insulation	See Table B.1 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	Fenestration/Windows (for the office area only)		
	Total U-factor	See Table B.1 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	SHGC	See Table B.1 in Appendix B	
	Window Shading/Overhangs	See Table B.1 in Appendix B	Base: 2003 CBECS Database AEDG: AEDG-WH
	Opaque Doors		
	Door Type	7 of 3' x 7' standard steel doors	DODGE Database Sample Building Plans
	Total U-factor	See Table B.1 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	Overhead Doors		
	Door Type	7 of 8' x 10' roll-up doors	DODGE Database Sample Building Plans
	Total U-factor	See Table B.1 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
INTERNAL LOADS			
	Occupancy		
	Number of People	5 (in the office area)	2003 CBECS Database
	Occupancy Schedule	8:00 am – 5:00 pm (See Table A.3)	DOE Appliance Equipment Standard TSD for CUAC
	People Sensible Heat Gain	250 Btu/h	ASHRAE 2005 Fundamentals Chapter 30.4 Table 1 (for standing light work)
	People Latent Heat Gain	200 Btu/h	
	Lighting		

Table A.1. Baseline Assumptions for 50,000-ft² Warehouse Prototype (Cont.)

Characteristic		Prototype Building	Data Source/Remarks
	Average Power Density	• Bulk storage area: 1.20 w/sf • Fine storage area: 1.20 w/sf • Office area: 1.30 w/sf	Base: ASHRAE 90.1-1999 AEDG: Committee's inputs
	Lighting Schedule	See Table A.3	EPACT Standard (*TSD for Energy Efficiency Program for CUAC*)
	Occupancy Sensors	Baseline: No occupancy sensors AEDG: occupancy sensors in the fine and bulky storage areas	Committee's inputs
	Skylights (Daylighting Responsive Lighting Control)	Baseline: No skylights AEDG: 65 of 4 ft x 8 ft acrylic dome double glazed clear prismatic, 6% of total bulky storage floor area	Base: 2003 CBECS Database AEDG: Committee's inputs
	Plug Load		
	Average Power Density	Office: 0.75 w/sf Bulky storage: 0.24 w/sf	Committee's inputs
	Equipment Schedule	See Table A.3	DOE Appliance Equipment Standard TSD for CUAC
HVAC			
	System Type		
	Heating Type	• Bulky storage area: unit heater • Fine storage area: Gas furnace • Office area: Gas furnace	2003 CBECS Database Committee's inputs
	Cooling Type	• Bulky storage area: no cooling • Fine storage area: Direct expansion • Office area: Direct expansion	
	Fan Control	Constant volume	
	Distribution/Terminal Units	Single zone/Direct air	
	HVAC Efficiency		
	Cooing	• Fine storage: normalized to 15-ton unit • Office area: normalized to 5-ton unit See Table B.1 for EER or SEER	Base: ASHRAE 90.1-1999 Table 6.2.1B AEDG: AEDG-WH
	Heating Efficiency	See Table B.1	Base: ASHRAE 90.1-1999 Table 6.2.1E AEDG: AEDG-WH
	HVAC Control		
	Cooling T-stat	• Fine storage are: 80°F • Office area: 75°F (85°F setup)	Committee's inputs
	Heating T-stat	• Bulky storage area: 45°F • Fine storage area: 60°F • Office area: 70°F (60°F setback)	Committee's inputs
	Outdoor Ventilation Air	• Storage area: 0.05 cfm/ft² • Office area: 20 cfm/person	ASHRAE Standard 62.1-2001 Table 2

Table A.1. Baseline Assumptions for 50,000-ft² Warehouse Prototype (Cont.)

Characteristic		Prototype Building	Data Source/Remarks
	Ventilation Control Mode	Baseline: Outside air damper remains open at minimum position during unoccupied periods AEDG: Outside air damper automatically shut off during unoccupied periods	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	Demanded Control Ventilation	None	Committee's inputs
	Economizer	See Table B.1	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	Fan Loads		
	Supply Fan Efficiency (%)	Fan mechanical efficiency: 60% Fan motor efficiency: 85%	AEDG-Small Retail TSD Manufacturers' Specifications
	Supply Fan Flow Rate (cfm)	Autosized	
	Supply Fan Static Pressure	See Table B.1	
	Supply Fan Schedule	6:00 am – 6:00 pm ON 6:00 pm – 6:00 am CYCLY OFF See Table A.3	
SERVICE WATER HEATER			
	Water Heater Type	Electric storage water heater	
	Tank Capacity, gallon	20	General design practice
	Supply Temperature, °F	120	General design practice
	Energy Factor	Baseline: EF = 0.904 AEGD: EF=0.966	Base: ASHRAE 90.1-1999 Table 7.2.2 AEDG: AEDG-WH
	Recovery Efficiency	98%	
	Tank UA, Btu/h-F	Baseline: UA = 2.393 AEDG: UA = 0.410	
	DHW Schedule	See Table A.3	General design practice

Table A.2. Baseline Assumptions for 8,000-ft² Self-storage

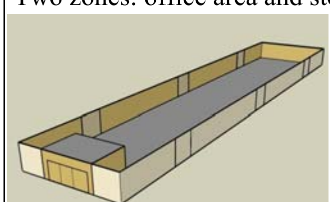
Characteristic	Prototype Building	Data Source/Remarks
GENERAL		
Building Type	Conditioned Self-Storage	2003 CBECS Database
Gross Area	8,000 ft²	2003 CBECS Database
Operation Hours	• Storage area: 6:00 am – 8:00 pm daily • Office: 9:00 am – 5:00 pm daily	2003 CBECS Database
Location	15 climate cities. See Section 5 of the report.	Briggs 2003
ARCHITECTURE		
Configuration/Shape		
Building Shape	Narrow rectangle	2003 CBECS Database
Aspect Ratio	5:1 (200 ft x 40 ft)	2003 CBECS Database
Number of Floors	1	2003 CBECS Database
Activity Area (percentage of gross floor area)	• Storage area: 7,700 ft² (96.2%) • Office area: 300 ft² (3.8%)	Committee's inputs
Windows	• Storage area: no windows • Office area: 6'x7' glass door and two of 5' x 7' view windows	2003 CBECS Database Committee's inputs
Floor Height	10 ft	Committee's inputs
Infiltration Rate	• Base infiltration: 0.038 cfm/sf of the gross exterior walls • Infiltration through the overhead doors: 0.28 cfm/ft² of door area	ASHRAE 90.1-1989 §13.7.3.2
Infiltration Schedule	See Table A.4	
Thermal Zoning	Two zones: office area and storage area 	
Exterior Walls		
Structure	Steel metal panels	2003 CBECS Database
Exterior Finish	Bare galvanized steel	Committee's inputs
Insulation	See Table B.2 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
Roof		
Structure	Metal building roofs (1:12 slope)	2003 CBECS Database
Exterior Finish	Bare galvanized steel	Committee's inputs
Insulation	See Table B.2 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
Solar Reflectance	See Table B.2 in Appendix B	Base: LBNL's Cool Roof Materials Database AEDG: AEDG-WH

Table A.2. Baseline Assumptions for 8,000-ft² Self-storage (Cont.)

Characteristic		Prototype Building	Data Source/Remarks
	Slab-On-Grade Floor		
	Floor Insulation	See Table B.2 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	Windows (Office Area Only)		
	Total U-factor	See Table B.2 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	SHGC	See Table B.2 in Appendix B	
	Window Shading/Overhangs	See Table B.2 in Appendix B	Base: 2003 CBECS Database AEDG: AEDG-WH
	Swinging Doors		
	Door Type		
	Total U-factor		
	Overhead/Roll-up Doors		
	Door Type	10' x 10' (Qty: 6)	Committee's Inputs
	Total U-factor	See Table B.2 in Appendix B	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
INTERNAL LOADS			
	Occupancy		
	Number of People	• Storage area: none • Office area: 1	2003 CBECS Database
	Occupancy Schedule	Office area: 9:00 am – 5:00 pm daily (See Table A.4)	DOE Appliance Equipment Standard TSD for CUAC
	People Heat Gain	250 Btu/h sensible, 200 Btu/h latent	ASHRAE 2005 Fundamentals
	Lighting		
	Average Power Density	• Storage area: 1.20w/sf • Office area: 1.30 w/sf	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	Lighting Schedule	See Table A.4	Committee's inputs
	Occupancy Sensors	Baseline: No occupancy sensors AEDG: occupancy sensors in the storage areas	Committee's inputs
	Skylights (Daylighting Responsive Lighting Control)	None	2003 CBECS Database
	Plug Load		
	Average Power Density	Storage area: 0.0 w/sf Office area: 1.08 w/sf	Committee's inputs
	Equipment Schedule	See under **Schedules**	
HVAC			
	System Type		

Table A.2. Baseline Assumptions for 8,000-ft² Self-storage (Cont.)

Characteristic		Prototype Building	Data Source/Remarks
	Heating Type	Storage area: • Zone 1-5: Heat pump packaged system • Zone 6-8: Gas furnace Office area: packaged terminal heat pump	AEDG-WH
	Cooling Type	Storage area: • Zone 1-5: Heat pump packaged system • Zone 6-8: Direct expansion Office area: packaged terminal heat pump	AEDG-WH
	Fan Control	Constant volume	
	Distribution/Terminal Units	Single zone/Direct air	
	HVAC Efficiency		
	Cooing	Storage area: normalized to 10-ton unit, See Table B.2 for EER	Base: ASHRAE 90.1-1999 Table 6.2.1B AEDG: AEDG-WH
	Heating Efficiency	See Table B.2 for EER	Base: ASHRAE 90.1-1999 Table 6.2.1E AEDG: AEDG-WH
	HVAC Control		
	Cooling T-stat	Storage area: 80°F Office area: 75°F (85°F setback)	Committee's inputs
	Heating T-stat	Storage area: 60°F Office area: 70°F (60°F setback)	Committee's inputs
	Outdoor Ventilation Air	• Storage area: 0.05 cfm/ft² • Office area: 20 cfm/person	ASHRAE Standard 62.1-2001 Table 2
	Ventilation Control Mode	Baseline: Outside air damper remains open at minimum position during unoccupied periods AEDG: Outside air damper automatically shut off during unoccupied periods	Base: ASHRAE 90.1-1999 (automatic outdoor air damper control is not required for 2-story buildings and below) AEDG: AEDG-WH
	Demand Control Ventilation	None	Committee's inputs
	Economizer	See Table B.2	Base: ASHRAE 90.1-1999 AEDG: AEDG-WH
	Fan Loads		
	Supply Fan Efficiency (%)	Fan mechanical efficiency: 60% Fan motor efficiency: 85%	AEDG-Small Retail TSD Manufacturers' Specifications
	Supply Fan Flow Rate (cfm)	Autosized	
	Supply Fan Static Pressure	See Table B.2	
	Supply Fan Schedule	Storage area: fan runs continuously Office area: fan runs continuously during business hours and cycle on/off during off hours	Note: Supply Fan in the storage areas needs to run continuously to maintain the setting of the space temperature and relative humidity.

Table A.2. Baseline Assumptions for 8,000-ft² Self-storage (Cont.)

Characteristic		Prototype Building	Data Source/Remarks
DOMESTIC HOT WATER			
	Water Heater Type	Electric storage water heater	
	Tank Capacity, gallon	20	General design practice
	Supply Temperature, °F	120	General design practice
	Energy Factor	Baseline: EF = 0.904 AEGD: EF=0.966	Base: ASHRAE 90.1-1999 Table 7.2.2 AEDG: AEDG-WH
	Recovery Efficiency	98%	
	Tank UA, Btu/h-F	Baseline: UA = 2.393 AEDG: UA = 0.410	
	DHW Schedule	See Table A.4	General design practice

Table A.3. Energy Modeling Schedules for the 50,000-ft² Warehouse Prototype

		1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	Noon	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 pm
Office		12-1a	1-2a	2-3a	3-4a	4-5a	5-6a	6-7a	7-8a	8-9a	9-10a	10-11a	11-12p	12-1p	1-2p	2-3p	3-4p	4-5p	5-6p	6-7p	7-8p	8-9p	9-10p	10-11p	11-12a
People	**Mon-Sat**	0.00	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	0.00	0.00	0.00	0.00	0.00	0.00
	Sunday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Light	**Mon-Sat**	0.18	0.18	0.18	0.18	0.18	0.18	0.23	0.42	0.90	0.90	0.90	0.90	0.80	0.90	0.90	0.90	0.90	0.61	0.18	0.18	0.18	0.18	0.18	0.18
(Base)	**Sunday**	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	0.18
Light	**Mon-Sat**	0.18	0.18	0.18	0.18	0.18	0.18	0.23	0.42	0.77	0.77	0.77	0.77	0.68	0.77	0.77	0.77	0.77	0.61	0.18	0.18	0.18	0.18	0.18	0.18
(AEDG)	**Sunday**	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	0.18
Plug	**Mon-Sat**	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.50	1.00	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	0.50	0.30	0.30	0.30	0.30	0.30	0.30
	Sunday	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Infiltration	**Mon-Sat**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.250	1.250	0.500	0.500	0.500	0.500	0.500	0.500	0.500	1.250	1.250	1.000	1.000	1.000	1.000	1.000	1.000
	Sunday	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Heating	**Mon-Sat**	60	60	60	60	60	60	65	70	70	70	70	70	70	70	70	70	70	70	60	60	60	60	60	60
	Sunday	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Cooing	**Mon-Sat**	85	85	85	85	85	85	80	75	75	75	75	75	75	75	75	75	75	75	85	85	85	85	85	85
	Sunday	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85
Fan	**Mon-Sat**	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ventilation	**Mon-Sat**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
(Base)	**Sunday**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ventilation	**Mon-Sat**	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
(AEDG)	**Sunday**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWH	**Mon-Sat**	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.101	0.399	0.501	0.501	0.696	0.900	0.798	0.696	0.798	0.297	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	Sunday	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015

Table A.3. Energy Modeling Schedules for the 50,000-ft² Warehouse Prototype (Cont.)

		1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	Noon	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 pm
Bulk/Fine Storage		12-1a	1-2a	2-3a	3-4a	4-5a	5-6a	6-7a	7-8a	8-9a	9-10a	10-11a	11-12p	12-1p	1-2p	2-3p	3-4p	4-5p	5-6p	6-7p	7-8p	8-9p	9-10p	10-11p	11-12a
Light	**Mon-Sat**	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.60	0.75	0.85	0.85	0.85	0.76	0.85	0.85	0.85	0.75	0.60	0.10	0.10	0.10	0.10	0.10	0.10
(Base)	**Sunday**	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Light	**Mon-Sat**	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.60	0.64	0.72	0.72	0.72	0.64	0.72	0.72	0.72	0.64	0.60	0.10	0.10	0.10	0.10	0.10	0.10
(AEDG)	**Sunday**	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
		1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	Noon	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 pm
Fine Storage		12-1a	1-2a	2-3a	3-4a	4-5a	5-6a	6-7a	7-8a	8-9a	9-10a	10-11a	11-12p	12-1p	1-2p	2-3p	3-4p	4-5p	5-6p	6-7p	7-8p	8-9p	9-10p	10-11p	11-12a
Infiltration	**Mon-Sat**	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.250	1.250	0.500	0.500	0.500	0.500	0.500	0.500	0.500	1.250	1.250	1.000	1.000	1.000	1.000	1.000	1.000
	Sunday	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ventilation	**Mon-Sat**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
(Base)	**Sunday**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ventilation	**Mon-Sat**	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
(AEDG)	**Sunday**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heating	**Mon-Sat**	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	Sunday	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Cooling	**Mon-Sat**	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
	Sunday	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
Fan	**Mon-Sat**	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	Noon	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 pm
Bulk Storage		12-1a	1-2a	2-3a	3-4a	4-5a	5-6a	6-7a	7-8a	8-9a	9-10a	10-11a	11-12p	12-1p	1-2p	2-3p	3-4p	4-5p	5-6p	6-7p	7-8p	8-9p	9-10p	10-11p	11-12a
Plug	**Mon-Sat**	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	1.00	1.00	1.00	1.00	0.25	1.00	1.00	1.00	1.00	0.25	0.25	0.25	0.25	0.25	0.25	0.25
	Sunday	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Infiltration	**Mon-Sat**	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	1.000	1.000	1.000	1.000	0.440	1.000	1.000	1.000	1.000	0.440	0.440	0.440	0.440	0.440	0.440	0.440
(Base)	**Sunday**	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440	0.440
Infiltration	**Mon-Sat**	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	1.000	1.000	1.000	1.000	0.750	1.000	1.000	1.000	1.000	0.750	0.750	0.750	0.750	0.750	0.750	0.750
(AEDG)	**Sunday**	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.750
Heating	**Mon-Sat**	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45
	Sunday	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45	45

Table A.4. Energy Modeling Schedules for the 8,000 ft² Self-storage Prototype

		1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	Noon	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 pm
Storage Area		12-1a	1-2a	2-3a	3-4a	4-5a	5-6a	6-7a	7-8a	8-9a	9-10a	10-11a	11-12p	12-1p	1-2p	2-3p	3-4p	4-5p	5-6p	6-7p	7-8p	8-9p	9-10p	10-11p	11-12a
Light	**WD**	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
(Baseline)	**WEH**	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Light	**WD**	0.0125	0.0125	0.0125	0.0125	0.0125	0.025	0.05	0.075	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.125	0.1	0.0750	0.0125
(AEDG)	**WEH**	0.0125	0.0125	0.0125	0.0125	0.0125	0.025	0.05	0.075	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.1875	0.125	0.1	0.0750	0.0125
Infiltration	**WD**	1.00	1.00	1.00	1.00	1.00	1.00	1.15	1.25	1.25	0.94	0.50	0.50	1.25	1.25	1.25	0.65	1.25	1.25	1.15	1.00	1.00	1.00	1.00	1.00
	WEH	1.00	1.00	1.00	1.00	1.00	1.00	1.15	1.25	1.25	0.94	0.50	0.50	1.25	1.25	1.25	0.65	1.25	1.25	1.15	1.00	1.00	1.00	1.00	1.00
Heating	**WD**	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
	WEH	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
Cooing	**WD**	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
	WEH	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80	80
Fan	**WD**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	WEH	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ventilation	**WD**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
(Base)	**WEH**	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ventilation	**WD**	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
(AEDG)	**WEH**	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0

Table A.4. Energy Modeling Schedules for the 8,000 ft² Self-storage Prototype (Cont.)

		1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	Noon	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 pm
Office Area		12-1a	1-2a	2-3a	3-4a	4-5a	5-6a	6-7a	7-8a	8-9a	9-10a	10-11a	11-12p	12-1p	1-2p	2-3p	3-4p	4-5p	5-6p	6-7p	7-8p	8-9p	9-10p	10-11p	11-12a
People	**WD**	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	WEH	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Light	**WD**	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.90	0.90	0.90	0.80	0.90	0.90	0.90	0.90	0.18	0.18	0.18	0.18	0.18	0.18	0.18
	WEH	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.90	0.90	0.90	0.80	0.90	0.90	0.90	0.90	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Plug	**WD**	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.50	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	0.50	0.33	0.33	0.33	0.33	0.33	0.33
	WEH	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.50	1.00	1.00	1.00	0.94	1.00	1.00	1.00	1.00	0.50	0.33	0.33	0.33	0.33	0.33	0.33
Infiltration	**WD**	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
	WEH	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00
Heating	**WD**	60	60	60	60	60	60	60	60	65	70	70	70	70	70	70	70	70	65	60	60	60	60	60	60
	WEH	60	60	60	60	60	60	60	60	65	70	70	70	70	70	70	70	70	65	60	60	60	60	60	60
Cooing	**WD**	85	85	85	85	85	85	85	85	80	75	75	75	75	75	75	75	75	80	85	85	85	85	85	85
	WEH	85	85	85	85	85	85	85	85	80	75	75	75	75	75	75	75	75	80	85	85	85	85	85	85
Fan	**WD**	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
	WEH	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
SWH	**WD**	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.101	0.399	0.501	0.696	0.900	0.798	0.696	0.798	0.297	0.050	0.050	0.050	0.050	0.050	0.050	0.050
	WEH	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.101	0.399	0.501	0.696	0.900	0.798	0.696	0.798	0.297	0.050	0.050	0.050	0.050	0.050	0.050	0.050

Appendix B – Simulation Input Assumptions for Final Guide

Table B.1. **50,000-ft^2 Warehouse Prototype Energy Simulation Input Assumptions: ASHRAE 90.1-1999 Baseline**

	For conditioned spaces only								**For semi-heated space only**						
	(office area + fine storage)								**(bulk storage)**						
Case	Exterior wall R-value	Roof R-value	Floor F-factor	Glass U-value	Glass SHGC	Overhang Office	Swinging Door U-value	Overhead Door U-value	Exterior wall R-value	Roof R-value	Floor F	Swinging Door U-value	Overhead Door U-value	Skylights	Heating System_bulk
LWH_Base_Miami	R-0	R-15	F-0.73	1.22	0.25	no	0.70	1.45	R-0	R-0	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Miami	R-0	R-15	F-0.73	0.56	0.25	yes	0.70	0.50	R-0	R-3.8	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Phoenix	R-0	R-15	F-0.73	1.22	0.25	no	0.70	1.45	R-0	R-3.8	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Phoenix	R-5	R-20	F-0.73	0.45	0.25	yes	0.70	0.50	R-0	R-3.8	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Houston	R-0	R-15	F-0.73	1.22	0.39	no	0.70	1.45	R-0	R-3.8	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Houston	R-5	R-20	F-0.73	0.45	0.25	yes	0.70	0.50	R-0	R-3.8	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Memphis	R-5	R-15	F-0.73	0.57	0.39	no	0.70	1.45	R-0	R-3.8	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Memphis	R-7	R-20	F-0.73	0.45	0.25	yes	0.70	0.50	R-0	R-5	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_El-Paso	R-5	R-15	F-0.73	0.57	0.39	no	0.70	1.45	R-0	R-3.8	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_El-Paso	R-7	R-20	F-0.73	0.45	0.25	yes	0.70	0.50	R-0	R-5	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_San-Francisco	R-5	R-10	F-0.73	1.22	0.61	no	0.70	1.45	R-0	R-3.8	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_San-Francisco	R-7	R-20	F-0.73	0.45	0.25	yes	0.70	0.50	R-0	R-5	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Baltimore	R-5	R-15	F-0.73	0.57	0.39	no	0.70	1.45	R-0	R-3.8	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Baltimore	R-8	R-20	F-0.73	0.42	0.4	yes	0.70	0.50	R-0	R-5	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Albuquerque	R-5	R-15	F-0.73	0.57	0.39	no	0.70	1.45	R-0	R-3.8	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Albuquerque	R-8	R-20	F-0.73	0.42	0.4	yes	0.70	0.50	R-0	R-5	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Seattle	R-5	R-15	F-0.73	0.57	0.49	no	0.70	1.45	R-0	R-3.8	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Seattle	R-8	R-20	F-0.73	0.42	0.4	yes	0.70	0.50	R-0	R-5	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Chicago	R-7	R-15	F-0.73	0.57	0.49	no	0.70	1.45	R-0	R-5	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Chicago	R-10	R-20	F-0.73	0.42	0.4	yes	0.70	0.50	R-5	R-7.6	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Boise	R-7	R-15	F-0.73	0.57	0.49	no	0.70	1.45	R-0	R-5	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Boise	R-10	R-20	F-0.73	0.42	0.4	yes	0.70	0.50	R-5	R-7.6	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Helena	R-8	R-15	F-0.73	0.57	0.49	no	0.70	1.45	R-0	R-5	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Helena	R-11	R-20	F-0.54	0.42	0.4	yes	0.70	0.50	R-5	R-10	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Burlington	R-8	R-15	F-0.73	0.42	0.4	no	0.70	0.50	R-0	R-5	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Burlington	R-11	R-20	F-0.54	0.42	0.4	yes	0.70	0.50	R-5	R-10	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Duluth	R-10	R-15	F-0.73	0.57	0.49	no	0.70	0.50	R-0	R-5	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Duluth	R-13	R-20	F-0.52	0.33	0.45	yes	0.50	0.50	R-7	R-10	F-0.73	0.70	0.50	yes	UnitHeater
LWH_Base_Fairbanks	R-11	R-20	F-0.54	0.46	NR	no	0.50	0.50	R-5	R-10	F-0.73	0.70	1.45	no	UnitHeater
LWH_Adva_Fairbanks	R-13	R-30	F-0.51	0.33	0.45	yes	0.50	0.50	R-8	R-15	F-0.73	0.70	0.50	no	UnitHeater

Table B.1. **(cont'd)**

	For both conditioned and semi-heated spaces								
Case	Roof Solar Reflectance	Infil-bulk	Infil_schedule_bulk	Damper Leak-bulk	Lighting-office	Lighting-fine storage	Lighting-bulk storage	Occu Sensor-fine storage	Occu Sensor-bulk storage
LWH_Base_Miami	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Miami	0.65	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Phoenix	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Phoenix	0.65	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Houston	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Houston	0.65	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Memphis	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Memphis	0.65	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_El-Paso	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_El-Paso	0.65	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_San-Francisco	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_San-Francisco	0.65	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Baltimore	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Baltimore	0.23	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Albuquerque	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Albuquerque	0.23	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Seattle	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Seattle	0.23	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Chicago	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Chicago	0.23	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Boise	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Boise	0.23	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Helena	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Helena	0.23	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Burlington	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Burlington	0.23	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Duluth	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Duluth	0.23	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes
LWH_Base_Fairbanks	0.23	1999.54	Bulk Storage Infil_Base Schedule	2000	1.30	1.20	1.20	no	no
LWH_Adva_Fairbanks	0.23	1076.74	Bulk Storage Infil_Adva Schedule	800	0.90	0.85	0.60	yes	yes

Table B.1. **(cont'd)**

	For both conditioned and semi-heated spaces										
Case	Min OA Damper Control	economizer-office	economizer-fine storage	Fan TSP-office	Fan TSP-fine storage	Cooling SEER-office	Cooling EER-fine storage	Furnace Eff-office	Furnace Eff-fine storage	Furnace Eff-bulk storage	SWH UA
LWH_Base_Miami	no	no	no	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Miami	yes	no	no	1.05	2.48	13.00	11.00	0.80	0.793	0.793	0.410
LWH_Base_Phoenix	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Phoenix	yes	no	yes	1.05	2.48	13.00	11.00	0.80	0.793	0.793	0.410
LWH_Base_Houston	no	no	no	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Houston	yes	no	no	1.05	2.48	13.00	11.00	0.80	0.793	0.793	0.410
LWH_Base_Memphis	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Memphis	yes	yes	yes	1.05	2.48	13.00	10.80	0.80	0.793	0.793	0.410
LWH_Base_El-Paso	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_El-Paso	yes	yes	yes	1.05	2.48	13.00	10.80	0.80	0.793	0.793	0.410
LWH_Base_San-Francisco	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_San-Francisco	yes	yes	yes	1.05	2.48	13.00	10.80	0.80	0.793	0.793	0.410
LWH_Base_Baltimore	no	no	no	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Baltimore	yes	yes	yes	1.05	2.48	13.00	10.80	0.80	0.793	0.793	0.410
LWH_Base_Albuquerque	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Albuquerque	yes	yes	yes	1.05	2.48	13.00	10.80	0.80	0.793	0.793	0.410
LWH_Base_Seattle	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Seattle	yes	yes	yes	1.05	2.48	13.00	10.80	0.80	0.793	0.793	0.410
LWH_Base_Chicago	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Chicago	yes	yes	yes	1.05	2.48	13.00	10.80	0.81	0.810	0.810	0.410
LWH_Base_Boise	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Boise	yes	yes	yes	1.05	2.48	13.00	10.80	0.81	0.810	0.810	0.410
LWH_Base_Helena	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Helena	yes	yes	yes	1.05	2.48	13.00	10.80	0.81	0.810	0.810	0.410
LWH_Base_Burlington	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Burlington	yes	yes	yes	1.05	2.48	13.00	10.80	0.81	0.810	0.810	0.410
LWH_Base_Duluth	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Duluth	yes	no	yes	1.05	2.48	13.00	9.50	0.81	0.810	0.810	0.410
LWH_Base_Fairbanks	no	no	yes	1.11	2.61	9.70	9.50	0.80	0.793	0.793	2.393
LWH_Adva_Fairbanks	yes	no	yes	1.05	2.48	13.00	9.50	0.81	0.810	0.810	0.410

Table B.2. **8,000-ft^2 Self-Storage Energy Simulation Input Assumptions: ASHRAE 90.1-1999 Baseline**

Case	Meteal Building Wall R	Metal Building Roof R	Roof Solar Reflectance	Floor F	Overhead Door U-value	Glass U-value	Glass SHGC	Overhang Office	Infiltration_storage	Lighting_office	Lighting-storage
SelfStorage_Base_Miami	R-13	R-19	0.61	F-0.73	1.45	1.22	0.25	no	392	1.3	1.2
SelfStorage_Adva_Miami	R-16	R-19	0.67	F-0.73	0.5	0.56	0.25	yes	320	0.9	0.6
SelfStorage_Base_Phoenix	R-13	R-19	0.61	F-0.73	1.45	1.22	0.25	no	392	1.3	1.2
SelfStorage_Adva_Phoenix	R-16	R-13+R-13	0.67	F-0.73	0.5	0.45	0.25	yes	320	0.9	0.6
SelfStorage_Base_Houston	R-13	R-19	0.61	F-0.73	1.45	1.22	0.39	no	392	1.3	1.2
SelfStorage_Adva_Houston	R-16	R-13+R-13	0.67	F-0.73	0.5	0.45	0.25	yes	320	0.9	0.6
SelfStorage_Base_Memphis	R-13	R-19	0.61	F-0.73	1.45	0.57	0.39	no	392	1.3	1.2
SelfStorage_Adva_Memphis	R-19	R-13+R-13	0.67	F-0.73	0.5	0.45	0.25	yes	320	0.9	0.6
SelfStorage_Base_El-Paso	R-13	R-19	0.61	F-0.73	1.45	0.57	0.39	no	392	1.3	1.2
SelfStorage_Adva_El-Paso	R-19	R-13+R-13	0.67	F-0.73	0.5	0.45	0.25	yes	320	0.9	0.6
SelfStorage_Base_San-Francisco	R-13	R-19	0.61	F-0.73	1.45	1.22	0.61	no	392	1.3	1.2
SelfStorage_Adva_San-Francisco	R-19	R-13+R-13	0.67	F-0.73	0.5	0.45	0.25	yes	320	0.9	0.6
SelfStorage_Base_Baltimore	R-13	R-19	0.61	F-0.73	1.45	0.57	0.39	no	392	1.3	1.2
SelfStorage_Adva_Baltimore	R-19	R-13+R-19	0.61	F-0.73	0.5	0.42	0.4	yes	320	0.9	0.6
SelfStorage_Base_Albuquerque	R-13	R-19	0.61	F-0.73	1.45	0.57	0.39	no	392	1.3	1.2
SelfStorage_Adva_Albuquerque	R-19	R-13+R-19	0.61	F-0.73	0.5	0.42	0.4	yes	320	0.9	0.6
SelfStorage_Base_Seattle	R-13	R-19	0.61	F-0.73	1.45	0.57	0.49	no	392	1.3	1.2
SelfStorage_Adva_Seattle	R-19	R-13+R-19	0.61	F-0.73	0.5	0.42	0.4	yes	320	0.9	0.6
SelfStorage_Base_Chicago	R-13	R-19	0.61	F-0.73	1.45	0.57	0.49	no	392	1.3	1.2
SelfStorage_Adva_Chicago	R-19+R-5.6ci	R-13+R-19	0.61	F-0.73	0.5	0.42	0.4	yes	320	0.9	0.6
SelfStorage_Base_Boise	R-13	R-19	0.61	F-0.73	1.45	0.57	0.49	no	392	1.3	1.2
SelfStorage_Adva_Boise	R-19+R-5.6ci	R-13+R-19	0.61	F-0.73	0.5	0.42	0.4	yes	320	0.9	0.6
SelfStorage_Base_Helena	R-13	R-19	0.61	F-0.73	1.45	0.57	0.49	no	392	1.3	1.2
SelfStorage_Adva_Helena	R-19+R-5.6ci	R-13+R-19	0.61	F-0.54	0.5	0.42	0.4	yes	320	0.9	0.6
SelfStorage_Base_Burlington	R-13	R-19	0.61	F-0.73	0.5	0.57	0.49	no	392	1.3	1.2
SelfStorage_Adva_Burlington	R-19+R-5.6ci	R-13+R-19	0.61	F-0.54	0.5	0.42	0.4	yes	320	0.9	0.6
SelfStorage_Base_Duluth	R-13+R-13	R-19	0.61	F-0.73	0.5	0.57	0.49	no	392	1.3	1.2
SelfStorage_Adva_Duluth	R-19+R-11.2ci	R-13+R-19	0.61	F-0.52	0.5	0.33	0.45	yes	320	0.9	0.6
SelfStorage_Base_Fairbanks	R-13+R-13	R-13+R-13	0.61	F-0.54	0.5	0.46	NR	no	392	1.3	1.2
SelfStorage_Adva_Fairbanks	R-19+R-11.2ci	R-11+R-30Ls	0.61	F-0.51	0.5	0.33	0.45	yes	320	0.9	0.6

Table B.2. (cont'd)

Case	Occu Sensor_storage	Min OA Damper Control	Economizer	Supply Fan Total Static Pressure (in.)	HVAC System	HP_Cooling EER	HP_Heating_COP	PSZ_Cooling EER	FurNAce Eff	SWH UA
SelfStorage_Base_Miami	no	no	no	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_Miami	yes	yes	no	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_Phoenix	no	no	no	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_Phoenix	yes	yes	no	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_Houston	no	no	no	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_Houston	yes	yes	no	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_Memphis	no	no	no	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_Memphis	yes	yes	yes	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_El-Paso	no	no	yes	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_El-Paso	yes	yes	yes	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_San-Francisco	no	no	yes	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_San-Francisco	yes	yes	yes	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_Baltimore	no	no	no	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_Baltimore	yes	yes	yes	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_Albuquerque	no	no	yes	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_Albuquerque	yes	yes	yes	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_Seattle	no	no	yes	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_Seattle	yes	yes	yes	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_Chicago	no	no	no	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_Chicago	yes	yes	yes	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_Boise	no	no	yes	1.438	HeatPump	9.9	3.5	NA	NA	2.393
SelfStorage_Adva_Boise	yes	yes	yes	1.317	HeatPump	10.6	3.4	NA	NA	0.41
SelfStorage_Base_Helena	no	no	yes	1.438	PkgSingleZone	NA	NA	10.1	0.7925	2.393
SelfStorage_Adva_Helena	yes	yes	yes	1.317	PkgSingleZone	NA	NA	11	0.81	0.41
SelfStorage_Base_Burlington	no	no	no	1.438	PkgSingleZone	NA	NA	10.1	0.7925	2.393
SelfStorage_Adva_Burlington	yes	yes	yes	1.317	PkgSingleZone	NA	NA	11	0.81	0.41
SelfStorage_Base_Duluth	no	no	yes	1.438	PkgSingleZone	NA	NA	10.1	0.7925	2.393
SelfStorage_Adva_Duluth	yes	yes	yes	1.317	PkgSingleZone	NA	NA	10.1	0.81	0.41
SelfStorage_Base_Fairbanks	no	no	yes	1.438	PkgSingleZone	NA	NA	10.1	0.7925	2.393
SelfStorage_Adva_Fairbanks	yes	yes	yes	1.317	PkgSingleZone	NA	NA	10.1	0.81	0.41

Appendix C – Energy Savings Final Results by End Use

Table C.1. **Energy Savings End Use for the 50,000-ft^2 Warehouse Prototype: ASHRAE 90.1-1999 Baseline**

Case	*Zone*	*Lights [MMBtu]*	*Plug Load [MMBtu]*	*Fans [MMBtu]*	*Cooling [MMBtu]*	*Water Heater [MMBtu]*	*Heating [MMBtu]*	*Total Energy [MMBtu]*	*EUI [kBtu/SF]*	*Savings w/ Plug*	*Savings wo Plug*
LWH_Base_Miami	1A	646	132	55	134	5	0	973	19.5	51%	59%
LWH_Adva_Miami		215	132	42	84	5	0	478	9.6		
LWH_Base_Houston	2A	646	132	56	87	6	61	990	19.8	54%	63%
LWH_Adva_Houston		217	132	26	39	6	31	451	9.0		
LWH_Base_Phoenix	2B	646	132	102	191	6	29	1,106	22.1	53%	60%
LWH_Adva_Phoenix		218	132	55	95	5	19	525	10.5		
LWH_Base_Memphis	3A	646	132	45	54	7	194	1,079	21.6	43%	49%
LWH_Adva_Memphis		217	132	26	29	6	204	615	12.3		
LWH_Base_El-Paso	3B	646	132	53	56	7	100	994	19.9	47%	54%
LWH_Adva_El-Paso		217	132	32	30	6	110	527	10.5		
LWH_Base_San-Francisco	3C	646	132	15	1	8	147	949	19.0	46%	53%
LWH_Adva_San-Francisco		219	132	12	0	7	145	515	10.3		
LWH_Base_Albuquerque	4A	646	132	45	29	8	318	1,179	23.6	40%	45%
LWH_Adva_Albuquerque		218	132	31	17	7	303	708	14.2		
LWH_Base_Baltimore	4B	646	132	36	25	8	476	1,323	26.5	37%	41%
LWH_Adva_Baltimore		219	132	24	14	7	435	832	16.6		
LWH_Base_Seattle	4C	646	132	24	2	9	442	1,254	25.1	36%	40%
LWH_Adva_Seattle		224	132	20	1	8	422	807	16.1		
LWH_Base_Boise	5A	646	132	35	12	9	611	1,444	28.9	37%	41%
LWH_Adva_Boise		222	132	28	6	8	511	906	18.1		
LWH_Base_Chicago	5B	646	132	35	14	9	778	1,614	32.3	39%	43%
LWH_Adva_Chicago		219	132	28	7	8	586	980	19.6		
LWH_Base_Burlington	6A	646	132	35	5	9	1,034	1,861	37.2	42%	45%
LWH_Adva_Burlington		220	132	27	2	9	692	1,082	21.6		
LWH_Base_Helena	6B	646	132	40	4	10	972	1,804	36.1	39%	42%
LWH_Adva_Helena		222	132	32	2	9	700	1,097	21.9		
LWH_Base_Duluth	7A	646	132	44	2	10	1,644	2,479	49.6	43%	45%
LWH_Adva_Duluth		221	132	33	1	10	1,023	1,420	28.4		
LWH_Base_Fairbanks	8A	646	132	42	0	12	1734	2,566	51.3	29%	30%
LWH_Adva_Fairbanks		325	132	34	0	11	1330	1,831	36.6		

Table C.2. **Energy Savings End Use for the 8,000-ft^2 Self Storage Prototype: ASHRAE 90.1-1999 Baseline**

Case	*Zone*	*Lights [MMBtu]*	*Plug Load [MMBtu]*	*Fans [MMBtu]*	*Cooling [MMBtu]*	*Water Heater [MMBtu]*	*Heating [MMBtu]*	*Total Energy [MMBtu]*	*EUI [kBtu/SF]*	*Savings w/ Plug*	*Savings wo Plug*
SelfStorage_Base_Miami	1	74	5	13	5	5	0	102	12.7	63%	67%
SelfStorage_Adva_Miami		19	5	6	3	4	0	37	4.7		
SelfStorage_Base_Houston	2A	74	5	13	5	5	7	109	13.7	58%	61%
SelfStorage_Adva_Houston		19	5	6	2	5	9	46	5.7		
SelfStorage_Base_Phoenix	2B	74	5	8	4	5	2	99	12.3	59%	63%
SelfStorage_Adva_Phoenix		19	5	4	1	4	6	40	5.0		
SelfStorage_Base_Memphis	3A	74	5	11	3	6	20	119	14.9	46%	49%
SelfStorage_Adva_Memphis		19	5	9	1	5	24	64	8.0		
SelfStorage_Base_El-Paso	3B	74	5	9	3	6	12	109	13.6	49%	52%
SelfStorage_Adva_El-Paso		19	5	8	1	5	17	56	6.9		
SelfStorage_Base_San-Francisco	3C	74	5	5	2	7	6	99	12.3	52%	56%
SelfStorage_Adva_San-Francisco		19	5	4	0	6	12	47	5.9		
SelfStorage_Base_Albuquerque	4A	74	5	12	2	7	38	137	17.2	39%	41%
SelfStorage_Adva_Albuquerque		19	5	11	1	6	42	83	10.4		
SelfStorage_Base_Baltimore	4B	74	5	9	2	7	43	140	17.5	35%	36%
SelfStorage_Adva_Baltimore		19	5	9	1	6	50	91	11.4		
SelfStorage_Base_Seattle	4C	74	5	8	1	7	26	122	15.2	43%	45%
SelfStorage_Adva_Seattle		19	5	7	0	6	31	69	8.6		
SelfStorage_Base_Boise	5A	74	5	13	2	7	63	164	20.6	37%	38%
SelfStorage_Adva_Boise		19	5	11	0	6	61	103	12.9		
SelfStorage_Base_Chicago	5B	74	5	16	2	7	86	190	23.7	33%	34%
SelfStorage_Adva_Chicago		19	5	13	1	6	82	127	15.9		
SelfStorage_Base_Burlington	6A	74	5	16	1	8	242	347	43.3	31%	31%
SelfStorage_Adva_Burlington		19	5	12	0	7	197	241	30.1		
SelfStorage_Base_Helena	6B	74	5	18	1	8	219	325	40.6	29%	29%
SelfStorage_Adva_Helena		19	5	14	0	7	187	232	29.0		
SelfStorage_Base_Duluth	7	74	5	20	1	9	329	438	54.7	28%	28%
SelfStorage_Adva_Duluth		19	5	15	0	8	269	316	39.5		
SelfStorage_Base_Fairbanks	8	74	5	19	1	9	441	550	68.8	27%	27%
SelfStorage_Adva_Fairbanks		19	5	14	0	9	355	402	50.2		

Table C.3. **Energy Savings End Use for the 50,000-ft^2 Warehouse Prototype: ASHRAE 90.1-2004 Baseline**

Case	*Zone*	*Lights [MMBtu]*	*Plug Load [MMBtu]*	*Fans [MMBtu]*	*Cooling [MMBtu]*	*Water Heater [MMBtu]*	*Heating [MMBtu]*	*Total Energy [MMBtu]*	*EUI [kBtu/SF]*	*Savings w/ Plug*	*Savings wo Plug*
LWH_Base_Miami	1A	435	132	51	123	5	0	747	14.9	36%	44%
LWH_Adva_Miami		215	132	42	84	5	0	478	9.6		
LWH_Base_Houston	2A	435	132	53	80	6	68	774	15.5	42%	50%
LWH_Adva_Houston		217	132	26	39	6	31	451	9.0		
LWH_Base_Phoenix	2B	435	132	98	183	6	33	887	17.7	41%	48%
LWH_Adva_Phoenix		218	132	55	95	5	19	525	10.5		
LWH_Base_Memphis	3A	435	132	40	47	7	214	876	17.5	30%	35%
LWH_Adva_Memphis		217	132	26	29	6	204	615	12.3		
LWH_Base_El-Paso	3B	435	132	65	67	7	140	846	16.9	38%	45%
LWH_Adva_El-Paso		217	132	32	30	6	110	527	10.5		
LWH_Base_San-Francisco	3C	435	132	14	1	8	150	740	14.8	30%	37%
LWH_Adva_San-Francisco		219	132	12	0	7	145	515	10.3		
LWH_Base_Albuquerque	4A	435	132	40	24	8	347	986	19.7	28%	33%
LWH_Adva_Albuquerque		218	132	31	17	7	303	708	14.2		
LWH_Base_Baltimore	4B	435	132	32	21	8	512	1,139	22.8	27%	31%
LWH_Adva_Baltimore		219	132	24	14	7	435	832	16.6		
LWH_Base_Seattle	4C	435	132	24	1	9	475	1,076	21.5	25%	28%
LWH_Adva_Seattle		224	132	20	1	8	422	807	16.1		
LWH_Base_Boise	5A	435	132	35	10	9	653	1,273	25.5	29%	32%
LWH_Adva_Boise		222	132	28	6	8	511	906	18.1		
LWH_Base_Chicago	5B	435	132	36	11	9	826	1,449	29.0	32%	36%
LWH_Adva_Chicago		219	132	28	7	8	586	980	19.6		
LWH_Base_Burlington	6A	435	132	35	4	9	1,096	1,711	34.2	37%	40%
LWH_Adva_Burlington		220	132	27	2	9	692	1,082	21.6		
LWH_Base_Helena	6B	435	132	41	3	10	1,030	1,651	33.0	34%	36%
LWH_Adva_Helena		222	132	32	2	9	700	1,097	21.9		
LWH_Base_Duluth	7A	435	132	44	1	10	1,725	2,348	47.0	40%	42%
LWH_Adva_Duluth		221	132	33	1	10	1,023	1,420	28.4		
LWH_Base_Fairbanks	8A	435	132	42	0	12	1832	2,452	49.0	25%	27%
LWH_Adva_Fairbanks		325	132	34	0	11	1330	1,831	36.6		

Table C.4. **Energy Savings End Use for the 8,000-ft^2 Self Storage Prototype: ASHRAE 90.1-2004 Baseline**

Case	*Zone*	*Lights [MMBtu]*	*Plug Load [MMBtu]*	*Fans [MMBtu]*	*Cooling [MMBtu]*	*Water Heater [MMBtu]*	*Heating [MMBtu]*	*Total Energy [MMBtu]*	*EUI [kBtu/SF]*	*Savings w/ Plug*	*Savings wo Plug*
SelfStorage_Base_Miami	1A	50	5	8	4	5	0	72	9.0	48%	52%
SelfStorage_Adva_Miami		19	5	6	3	4	0	37	4.7		
SelfStorage_Base_Houston	2A	50	5	9	4	5	9	82	10.2	44%	47%
SelfStorage_Adva_Houston		19	5	6	2	5	9	46	5.7		
SelfStorage_Base_Phoenix	2B	50	5	4	4	5	4	72	9.0	44%	48%
SelfStorage_Adva_Phoenix		19	5	4	1	4	6	40	5.0		
SelfStorage_Base_Memphis	3A	50	5	10	3	6	23	97	12.1	34%	36%
SelfStorage_Adva_Memphis		19	5	9	1	5	24	64	8.0		
SelfStorage_Base_El-Paso	3B	50	5	9	2	6	15	87	10.8	36%	38%
SelfStorage_Adva_El-Paso		19	5	8	1	5	17	56	6.9		
SelfStorage_Base_San-Francisco	3C	50	5	5	2	7	9	77	9.6	39%	42%
SelfStorage_Adva_San-Francisco		19	5	4	0	6	12	47	5.9		
SelfStorage_Base_Albuquerque	4A	50	5	12	2	7	43	118	14.7	29%	31%
SelfStorage_Adva_Albuquerque		19	5	11	1	6	42	83	10.4		
SelfStorage_Base_Baltimore	4B	50	5	9	2	7	48	121	15.1	25%	26%
SelfStorage_Adva_Baltimore		19	5	9	1	6	50	91	11.4		
SelfStorage_Base_Seattle	4C	50	5	8	1	7	30	101	12.7	32%	34%
SelfStorage_Adva_Seattle		19	5	7	0	6	31	69	8.6		
SelfStorage_Base_Boise	5A	50	5	13	1	7	67	144	18.1	28%	30%
SelfStorage_Adva_Boise		19	5	11	0	6	61	103	12.9		
SelfStorage_Base_Chicago	5B	50	5	16	2	7	93	172	21.5	26%	27%
SelfStorage_Adva_Chicago		19	5	13	1	6	82	127	15.9		
SelfStorage_Base_Burlington	6A	50	5	16	1	8	259	339	42.4	29%	30%
SelfStorage_Adva_Burlington		19	5	12	0	7	197	241	30.1		
SelfStorage_Base_Helena	6B	50	5	18	1	8	237	319	39.9	27%	28%
SelfStorage_Adva_Helena		19	5	14	0	7	187	232	29.0		
SelfStorage_Base_Duluth	7A	50	5	20	1	9	344	428	53.5	26%	26%
SelfStorage_Adva_Duluth		19	5	15	0	8	269	316	39.5		
SelfStorage_Base_Fairbanks	8A	50	5	19	1	9	450	534	66.7	25%	25%
SelfStorage_Adva_Fairbanks		19	5	14	0	9	355	402	50.2		

Appendix D – Development of the Prototype Building Characteristics Using 2003 CBECS

Appendix D – Development of the Prototype Building Characteristics Using 2003 CBECS

This appendix summarizes the approach used to develop the warehouse building characteristics by deriving data available in the Energy Information Agency (EIA) 2003 Commercial Building Energy Consumption Survey (2003 CBECS).[g] 2003 CBECS was used to select the representative warehouse building prototypes and develop some building characteristics assumptions for the purpose of energy modeling (i.e., building shape, building construction type, etc.). We supplemented CBECS data with F.W. Dodge Data for new constructions as well as other sources to more accurately foresee the trend in the new construction building stocks.

The CBECS data sets are publicly available and provide statistically valid results from a periodic national survey of commercial buildings and their energy suppliers performed by EIA. While the Guide is used for new constructions, some building characteristics in new constructions are pretty much same as existing constructions.

In the 2003 CBECS survey, 4,859 buildings were surveyed and the sampled buildings were given base weights (CBECS variable “ADJWT8”) to represent the entire stock of commercial buildings in the U.S. 2003 CBECS contains a total of 493 surveyed warehouse buildings, breaking down by four sub-categories: 1) non-refrigerated warehouse, 2) distribution/shipping center, 3) refrigerated warehouse, and 4) self-storage. Based on the scoping document from the steering committee, the project committee decided to evaluate two warehouse prototypes, i.e., the non-refrigerated warehouse and self-storage. Based on the 2003 CBECS dataset, these two types of warehouse represent over 70 percent of warehouses in term of the number of buildings, i.e., 38 percent and 33 percent of warehouses are non-refrigerated warehouse and self-storage, respectively.

The average floor area is 6,358 ft^2 for the self-storage buildings in the 2003 CBECS. The average floor area of non-refrigerated warehouses is 13,296 ft^2. The CBECS data also shows that 84 percent of the self-storage buildings are single-story and 94 percent of non-refrigerated warehouse buildings are single-story.

The CBECS survey asks questions about building shape (square, wide rectangle, other) and 2003 CBECS reported that about 52 percent of self-storage buildings are narrow rectangular shape and 66 percent of non-refrigerated warehouses are wide rectangular shape. Therefore, the committee assumed the prototypical self-storage to be a narrow rectangle and the prototypical non-refrigerated warehouse to be a wide rectangle.

Aspect ratios are important in determining the relative amount of perimeter area (responsive to the outdoor environment and with window daylighting potential) to core area for a given building. Aspect ratio information coupled with orientation and self-shading would also be relevant in determining solar loading in a real building. The aspect ratio is defined as the reported building length divided by the building width:

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[g] The results of the 2003 CBECS surveys are available as downloadable reports and micro-data files from the EIA website (http://www.eia.doe.gov/emeu/cbecs/). The 2003 CBECS is the most recent data set available.

$$Aspect\ Ratio = \frac{Building\ Length}{Building\ Width}$$

Unfortunately, aspect ratio information has not been collected in the CBECS since 1995, so general information on actual aspect ratios has been limited. What information was collected in these early CBECS distributions is building length and width for rectangular and square buildings. The rectangle with courtyard buildings did not have the length and width reported. The committee calculated the actual aspect ratio based on the 1992 CBECS data from the reported length and width of the building. The averages of aspect ratio were calculated to be 5.0 and 2.2 for 1992 CBECS self-storage buildings and non-refrigerated warehouses, respectively. These aspect ratios were used in the prototypical buildings to be simulated.

In the 2003 CBECS data, a "percent exterior glass" variable was reported for each building in one of the five bins (for example, "10 percent or less", "11–25 percent"), and the committee used this data for estimating the window-to-wall ratio (WWR) for the prototypical buildings. The data shows that 82 percent of the non-refrigerated warehouses fall into "10 percent or less" category and all the self-storage buildings are in "10 percent or less" category. The committee assumed the storage areas for both prototypes have no windows.

The description of the wall construction and roof construction variables in 2003 CBECS primarily describes the surface material for these portions of the building envelope and not the actual construction. The most common opaque wall category for self-storage buildings in 2003 CBECS is "sheet metal panel", about 48 percent of self-storage buildings. The most common roof category for self-storage buildings in 2003 CBECS is "metal surfacing", about 66 percent of self-storage buildings. Based on the CBECS data, the committee assumed that the wall construction and roof construction in the simulated self-storage prototypical building are steel metal panel and metal roof, respectively.

The CBECS information with respect to the presence of overhangs and awnings provided virtually no detail on the size or shading capability of overhangs or awnings. Because the 2003 CBECS reported about 77 percent of non-refrigerated warehouses and 80 percent of self-storage buildings that responded to this survey question do not have overhangs or awnings, the committee assumed that both baseline prototypical buildings have no overhangs or awnings.

The CBECS also asks whether the building has skylights and the 2003 CBECS data shows about 93 percent of non-refrigerated warehouses and 100 percent of self-storage buildings that responded to this survey question do not skylight. Therefore, the committee assumed that both baseline prototypical buildings have no skylight.

The CBECS provided information with respect to operating hours and number of employees. The 2003 CBECS reported the average operating hour to be 101 hours per week for self-storage buildings and 41 hours per week for non-refrigerated warehouses. It also showed the average number of employee is 1 for self-storage and 5 for non-refrigerated warehouses. The committee developed the prototypical building internal gain schedules partially based on these data.