Technical Support Document: Development of the Advanced Energy Design Guide for Large Hospitals – 50% Energy Savings

E. Bonnema, M. Leach, and S. Pless
National Renewable Energy Laboratory

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The authors extend their thanks to their NREL colleague Daniel Studer and Paul Holliday of Holliday Electrical Mechanical Engineering for peer reviews, and to Stefanie Woodward for editorial assistance.

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Executive Summary

Background

This *Technical Support Document* (TSD) describes the process and methodology for the development of the *Advanced Energy Design Guide for Large Hospitals: Achieving 50% Energy Savings Toward a Net Zero Energy Buildings* (AEDG-LH) (ASHRAE et al. 2012). The AEDG-LH provides recommendations for achieving 50% whole-building energy savings in large hospital buildings over levels achieved by following *ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings* (Standard 90.1-2004) (ASHRAE 2004b). The AEDG-LH was developed in collaboration with ASHRAE, AIA, IES, USGBC, ASHE, and DOE.

The AEDG-LH is the second AEDG for healthcare facilities; the first was part of a series of six AEDGs targeting 30% energy savings over levels achieved by following *ANSI/ASHRAE/IESNA Standard 90.1-1999* (ASHRAE 1999). The guides in the 30% energy savings series are:

- The *Advanced Energy Design Guide for Small Office Buildings: Achieving 30% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2004)
- The *Advanced Energy Design Guide for Small Retail Buildings: Achieving 30% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2006)
- The *Advanced Energy Design Guide for K-12 School Buildings: Achieving 30% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2008a)
- The *Advanced Energy Design Guide for Small Warehouses and Self-Storage Buildings: Achieving 30% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2008b)
- The *Advanced Energy Design Guide for Highway Lodging: Achieving 30% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2009a)
- The *Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities: Achieving 30% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2009b).

The AEDG-LH is part of a series of AEDGs targeting 50% energy savings over levels achieved by following *ANSI/ASHRAE/IESNA Standard 90.1-2004*. The other guides in the 50% energy savings series are:

- The *Advanced Energy Design Guide for Small to Medium Office Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2011c)
- The *Advanced Energy Design Guide for K-12 School Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2011a).
- The *Advanced Energy Design Guide for Medium to Big Box Retail Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2011b).

Each guide provides user-friendly design assistance and recommendations to design, architectural, and engineering firms to achieve energy savings. The AEDG-LH includes prescriptive recommendations by climate zone for the building envelope; fenestration; lighting systems (including interior and exterior electric lights and daylighting); plug, process, and phantom loads; commercial kitchen equipment; service water heating (SWH); HVAC systems; building automation and controls; and measurement and verification. Additional savings recommendations are also included, but are not necessary to achieve the 50% savings goal. These recommendations are provided for renewable energy systems, alternative HVAC systems, and electricity distribution systems.

The objectives in developing this TSD were to:

- Document the development of the baseline and low-energy hospital energy models.
- Document the modeling assumptions needed to verify 50% energy savings.
- Present the recommendations for achieving at least 50% savings over Standard 90.1-2004.
- Demonstrate through whole-building annual energy modeling that the recommendations result in 50% or greater energy savings by climate zone.
- Document the process used to develop the AEDG-LH.

AEDG-LH Development Process

The AEDG-LH was developed by a project committee (PC) representing a diverse group of professionals. Guidance and support were provided through a collaboration of ASHRAE, AIA, IES, USGBC, and DOE. Publication of the AEDG-LH was accomplished by two separate committees: a steering committee that provided high-level guidance and a PC that developed the guide.

AEDG-LH Scope

The AEDG-LH was created for a "standard" mid- to large-size hospital, typically at least 100,000 ft^2, but the strategies apply to all sizes and classifications of new construction hospital buildings. Its primary focus is new construction, but recommendations may be applicable to facilities undergoing total renovation, and in part to many other hospital renovation, addition, remodeling, and modernization projects (including changes to one or more systems in existing buildings).

The AEDG-LH does not address all the components covered in Standard 90.1-2004. It focuses only on a building's primary energy systems, so the underlying energy analysis presumes that at a minimum all the other components conform to the requirements of Standard 90.1-2004.

Certain aspects of hospital design, including campus utilities and sewage disposal, were excluded from the AEDG-LH. They were too complex to include given the scope of the project.

The AEDG-LH is not intended to substitute for rating systems or references that address the full range of sustainable issues in hospital design, such as acoustics, productivity, indoor air quality, water efficiency, landscaping, and transportation, except as they relate to operational energy use. The AEDG-LH contains recommendations only and is not a code or standard.

Evaluation Approach and Results

The purpose of the building energy simulation analysis presented in this TSD is to assess and quantify the energy savings potential of the set of climate-specific energy efficiency recommendations in the AEDG-LH. The following steps describe how the energy savings potential of the AEDG-LH's recommendations was determined:

1. Develop a "typical" hospital facility prototype

Building characteristics that are not specified by Standard 90.1-2004, but that are needed to develop a code-compliant baseline model, were taken from the hospital model defined in

Bonnema et al. (2010b). A "typical" hospital facility prototype is an energy model that is a representative example of a large hospital. The high-level building characteristics for the prototype model are shown in Table ES–1.

Table ES–1 AEDG-LH Prototype Model Characteristics

Characteristic	Value
Size	427,173 ft²
Floor-to-ceiling height	9 ft
Floor-to-floor height	14 ft in diagnostic and treatment areas (floor 2) 13 ft in all other areas (floors 1, 3–7)
Ceiling plenum depth	5 ft in diagnostic and treatment areas (floor 2) 4 ft in all other areas (floors 1, 3–7)
Number of floors	7
Window-to-wall ratio	40% (floor-to-ceiling) 26% (floor-to-floor in diagnostic and treatment areas [floor 2]) 28% (floor-to-floor in other areas [floors 1, 3–7])
Glazing details	Banded windows 3.7 ft tall with a 3.6 ft sill height,
Wall construction	Mass
Roof construction	Insulation entirely above deck

2. Create baseline models that are minimally code compliant with Standard 90.1-2004

The baseline model for the large hospital was developed by applying the criteria in Standard 90.1-2004 to the prototype model. The baseline hospital energy modeling assumptions and methods were documented, including the building envelope characteristics, building lighting loads, ventilation rates, HVAC equipment efficiency, operation, control and sizing, fan power assumptions, and SWH. The criteria in Standard 90.1-2004 were used as the baselines to calculate energy savings for the AEDG-LH recommendations.

3. Create the low-energy models based on the recommended energy efficiency technologies in the AEDG-LH

To quantify the potential energy savings from the proposed recommended energy efficiency measures in the AEDG-LH, the low-energy building models were developed by implementing the energy efficiency technologies listed here.

- Enhanced building opaque envelope insulation and window glazing
- Reduced interior lighting power density and installation of occupancy sensors
- Daylighting in staff areas (exam rooms, nurse stations, offices, conference rooms, corridors, dining areas,) and public spaces (waiting, reception, lobby, lounge)
- Exterior lighting power density reductions
- Plug and process load reductions and improved controls
- High-performance commercial kitchen equipment and ventilation
- Demand-controlled ventilation and energy recovery ventilators
- Dedicated outdoor air systems (DOAS)
- Three types of high-efficiency HVAC systems
- High-efficiency SWH equipment.

4. Verify the recommendations meet or exceed the 50% energy savings goal of the AEDG-LH

The final recommendations included in the AEDG-LH were determined based on an iterative process using the PC's expertise and results from modeling proposed recommendations. Energy savings associated with the final recommendations in the AEDG-LH are documented in this TSD. Low-energy versions of the hospital with three types of low-energy HVAC systems were modeled to verify savings over the range of design options: a water source heat pump (WSHP) system with a DOAS, a fan coil unit system with a DOAS (FCU DOAS), and an advanced variable air volume air handling system with separate outdoor air treatment (Advanced VAV). The recommendations in the AEDG-LH resulted in more than 50% savings in all climate zones for all HVAC system types. Table ES–2 summarizes the percent savings for each prototype model in each climate zone. Figure ES–1 illustrates the process used to determine energy savings.

Table ES–2 Percent Savings Over Standard 90.1-2004

Climate Zone	Representative City	WSHP DOAS	FCU DOAS	Advanced VAV
1A	Miami, Florida	52.3%	53.3%	50.4%
2A	Houston, Texas	54.5%	54.9%	52.1%
2B	Phoenix, Arizona	55.9%	56.5%	53.3%
3A	Atlanta, Georgia	53.7%	54.0%	52.5%
3B:CA	Los Angeles, California	55.9%	55.4%	52.4%
3B	Las Vegas, Nevada	53.8%	54.2%	52.2%
3C	San Francisco, California	57.5%	56.5%	54.4%
4A	Baltimore, Maryland	55.1%	55.1%	55.0%
4B	Albuquerque, New Mexico	53.1%	54.6%	52.1%
4C	Seattle, Washington	56.8%	55.9%	53.9%
5A	Chicago, Illinois	55.4%	55.4%	53.9%
5B	Denver, Colorado	53.7%	54.7%	52.4%
6A	Minneapolis, Minnesota	56.1%	55.9%	54.8%
6B	Helena, Montana	55.5%	55.5%	54.1%
7	Duluth, Minnesota	56.8%	56.4%	55.7%
8	Fairbanks, Alaska	59.2%	57.8%	58.3%

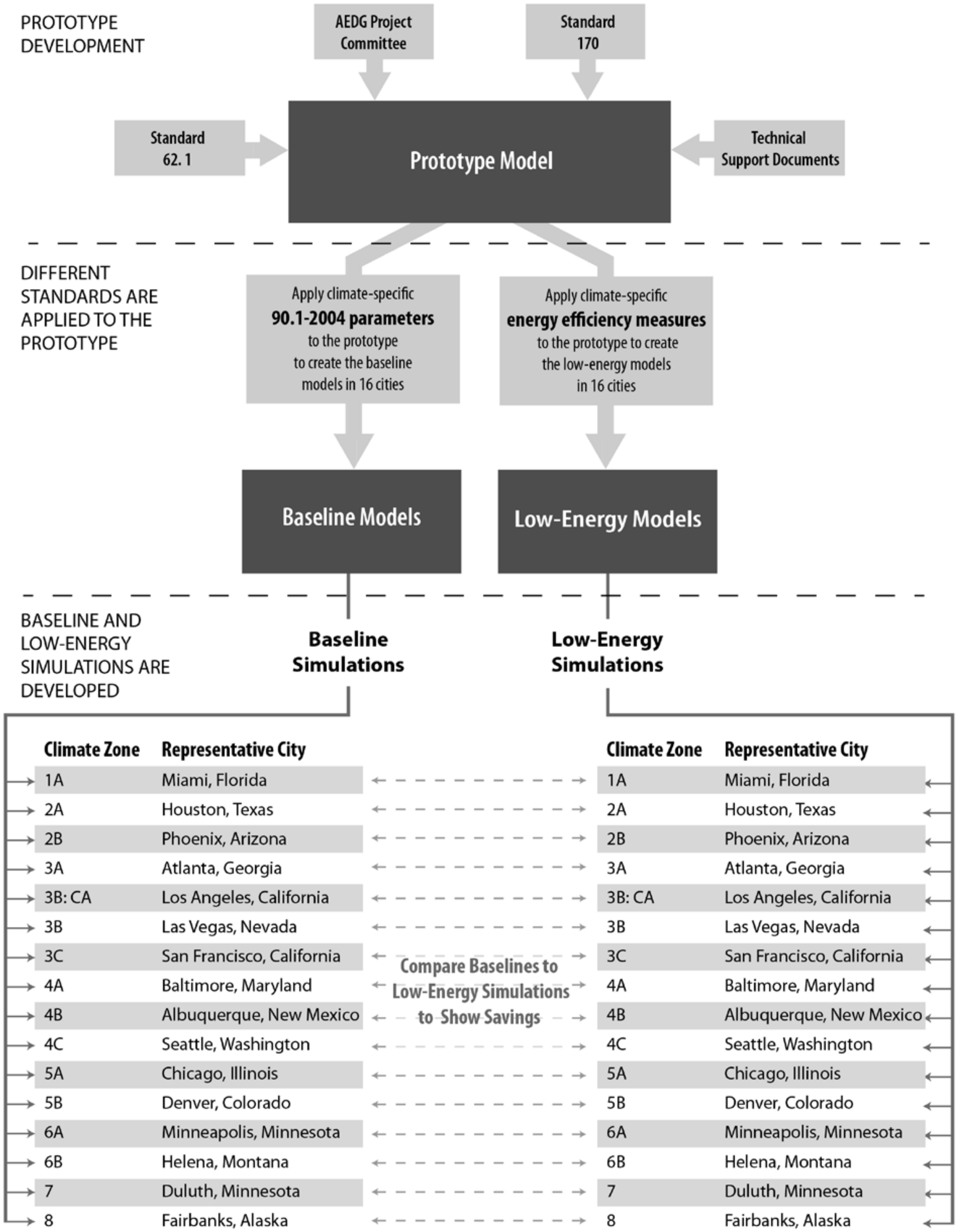

Figure ES–1 Flow diagram of modeling process
(Credit: Marjorie Schott/NREL)

Nomenclature

AEDG	Advanced Energy Design Guide
AEDG-LH	Advanced Energy Design Guide for Large Hospitals: Achieving 50% Energy Savings Toward a Net Zero Energy Building
AHU	air handling unit
AIA	American Institute of Architects
ANSI	American National Standards Institute
ASHE	American Society for Healthcare Engineering
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
bhp	brake horsepower
Btu	British thermal unit
C	Celsius, centigrade
CCU	critical care unit
cfm	cubic feet per minute
c.i.	continuous insulation
COB	close of business
COP	coefficient of performance
d	diameter
DCV	demand-controlled ventilation
DOAS	dedicated outdoor air system
DOE	U.S. Department of Energy
EF	energy factor
ERV	energy recovery ventilator
Ec	combustion efficiency
Et	thermal efficiency
EUI	energy use intensity
F	Fahrenheit
fc	footcandle
FCU	fan coil unit
ft	foot
ft^2	square foot
gal	gallon
GGHC	Green Guide for Health Care: Best Practices for Creating High Performance Healing Environments, Version 2.2
h	hour
HC	heat capacity
HID	high-intensity discharge
HVAC	heating, ventilation, and air conditioning
ICU	intensive care unit
IEQ	indoor environmental quality
IES, IESNA	Illuminating Engineering Society of North America
in.	inch
IT	information technology
LED	light-emitting diode

LPD	lighting power density
m	meter
min	minute
NEMA	National Electrical Manufacturers Association
NFRC	National Fenestration Rating Council
NREL	National Renewable Energy Laboratory
NR	no requirement (insulation)
OA	outdoor air
Pa	Pascal
PACU	post-anesthesia care unit
PC	project committee
PF	projection factor
PLR	part-load ratio
PPL	plug and process load
RH	relative humidity
SC	steering committee
SHGC	solar heat gain coefficient
SWH	service water heating
TBD	to be determined
TSD	Technical Support Document
USGBC	U.S. Green Building Council
V	volt
VAV	variable air volume
VFD	variable frequency drive
VLT	visible light transmittance
WSHP	water source heat pump
W	watt
w.c.	water column

Contents

Figures and Tables

Figures

All figures credit Eric Bonnema/NREL unless otherwise noted.

Tables

All tables credit Eric Bonnema/NREL unless otherwise noted.

1. Introduction

The *Advanced Energy Design Guide for Large Hospitals: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (AEDG-LH) (ASHRAE et al. 2012) was written to help owners and designers of large hospitals achieve 50% whole-building energy savings compared to the minimum requirements of *ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings* (Standard 90.1-2004) (ASHRAE 2004b). Included in the AEDG-LH are prescriptive recommendations by climate zone for the design of the building envelope, fenestration, lighting systems (including electric lights and daylighting); heating, ventilating, and air-conditioning (HVAC) systems; building automation and controls; and service water heating (SWH). Additional savings recommendations are also included, but are not necessary for the 50% savings goal. These recommendations are provided for additional HVAC strategies and renewable energy systems.

The AEDG-LH shows that the 50% target is not only achievable, but surpassable. Case studies profile hospitals around the country that have achieved and surpassed the 50% energy savings target. Best practices and cautions are also provided to demonstrate how to implement the recommendations. The recommendation tables in the AEDG-LH do not include all the components listed in Standard 90.1-2004, and instead focus only on the primary energy systems. The underlying energy analysis presumes that all other components comply with the criteria in Standard 90.1-2004.

By specifying a goal and identifying paths to achieve it in each climate zone, the AEDG-LH illustrates ways to meet the 50% target and build energy-efficient hospitals that use substantially less energy than those built to the minimum requirements of Standard 90.1-2004. There may be other means of achieving the target goal, and it is hoped that the guide helps to generate ideas for continued innovation.

The AEDG-LH was developed by a project committee (PC) representing a diverse group of experienced professionals. Guidance and support were provided through a collaboration of ASHRAE, the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IES), the U.S. Green Building Council (USGBC), the American Society for Healthcare Engineering (ASHE), and the U.S. Department of Energy (DOE).

The AEDG-LH is part of a series of AEDGs targeting 50% energy savings over levels achieved by following Standard 90.1-2004. The other guides in the 50% energy savings series are:

- The *Advanced Energy Design Guide for Small to Medium Office Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2011c)
- The *Advanced Energy Design Guide for K-12 School Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2011a)
- The *Advanced Energy Design Guide for Medium to Big Box Retail Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2011b).

1.1 Technical Support Document Organization

This report is presented in five sections: Section 1 introduces the AEDG-LH and the supporting background information; Section 2 outlines the development process of the AEDG-LH; Section 3 provides the evaluation approach, including baseline and low-energy modeling methods and assumptions; Section 4 discusses the energy target section of the AEDG-LH; and Section 5 documents the final recommendations and predicted energy savings.

The AEDG-LH scoping document can be found in Appendix A. Additional information on the PC development process is included in Appendix B. Appendix C contains tabular data of the schedules used in the energy models and Appendix D contains EnergyPlus refrigeration objects.

1.2 Objectives

One of the National Renewable Energy Laboratory's (NREL) tasks in developing the AEDG-LH was to provide the analysis and modeling support to:

- Verify energy savings: These are specific prescriptive recommendations that, in aggregate, yield at least 50% savings beyond a benchmark building built to Standard 90.1-2004 for each climate region. The 50% savings value is measured based on the total energy consumption, not on regulated loads only. It is not an average of the national energy savings; 50% savings were verified for each U.S. climate zone and corresponding subzones.
- Develop recommendations that meet a numeric goal value: The 50% energy savings goal is a hard value, not an approximate target. As in past AEDGs, the AEDG-LH is intended for use as an option in obtaining Energy and Atmosphere credits under the USGBC Leadership in Energy and Environmental Design rating system.

Separate from the AEDG-LH, this Technical Support Document (TSD) was developed to document the process used to develop the AEDG-LH and the analysis and modeling performed to support that development. The specific objectives were to:

- Document the process used for developing the AEDG-LH.
- Document prototypical hospital characteristics.
- Document the EnergyPlus modeling assumptions used to establish 50% energy savings.
- Document the EnergyPlus baseline and low-energy hospital models.
- Demonstrate that the recommendations result in 50% or greater energy savings by climate zone.

1.3 Scopes of the Advanced Energy Design Guide and Technical Support Document

Each guide in the AEDG series provides recommendations and user-friendly design assistance to designers, developers, and owners of commercial buildings to encourage setting and achieving energy savings goals. The AEDGs provide prescriptive packages that enable energy savings targets to be reached for each climate zone.

The AEDG-LH applies to "standard" mid- to large-size hospitals, typically at least 100,000 ft^2, but the strategies apply to all sizes and classifications of new construction hospital buildings. These facilities typically include some or all of the following space types: cafeterias, kitchens, dining facilities, conference rooms, lobbies, lounges, office areas, reception/waiting areas, examination/treatment rooms, clean and soiled workrooms/holding areas, nurse stations, nurseries, patient rooms, hallways, lockers, restrooms, operating suites, procedure rooms, recovery rooms, sterilizer equipment areas, pharmacies, medication rooms, laboratories, triage areas, trauma/emergency rooms, physical therapy spaces, imaging/radiology rooms, storage areas, shipping/receiving, and mechanical/electrical rooms. The AEDG-LH does not consider steam boiler rooms, trash incinerator rooms, or other atypical specialty spaces that generate extraordinary heat or pollution. Certain aspects of hospital design, including campus utilities and sewage disposal, are excluded from the AEDG-LH. They were too complex to include given the scope of the project. Significant energy efficiency opportunities may be available with these aspects, and AEDG-LH users are encouraged to take advantage of these opportunities.

The AEDG-LH is also not intended to substitute for rating systems or references that address the full range of sustainability issues in hospitals, such as acoustics, productivity, indoor air quality, water efficiency, landscaping, and transportation, except as they relate to operational energy consumption. The AEDG-LH contains recommendations only and is not a code or standard.

The guides in the AEDG series also do not provide energy savings details or detailed documentation for developing recommendations. This TSD describes the process and methodology that were used to develop the AEDG-LH, and provides the technical details that were used to determine energy savings, including model inputs and assumptions.

1.4 AEDG-LH Layout and Content

This section comprises a brief overview of how the AEDG-LH is organized and the type of information it contains to familiarize the reader of this TSD with the AEDG-LH.

1.4.1 Chapter 1 – Introduction

This chapter contains a summary of the guide contents, a step-by-step guide for an owner to follow when using the AEDG, information about the project goal and scope, and instructions for use.

1.4.2 Chapter 2 – Integrated Design

This chapter provides resources for those who want to understand and adopt an integrated process for designing, constructing, and operating energy-efficient healthcare facilities. The AEDG-LH presents an integrated process for achieving energy savings in these facilities and is valuable for designers and builders who want to augment and improve their practices to ensure energy efficiency is deliberately considered at each stage of the development process—from project conception through building operation and beyond. Figures and checklists are included to aid in addressing energy goals in each stage of the development process. This chapter addresses the details and best practices of an integrated design process, and discusses the benefits and features of integrated design, including step-by-step details about the phases of the process.

1.4.3 Chapter 3 – Energy Efficiency Strategies for Integrated Design

This chapter presents energy efficiency strategies for integrated design, including performance targets to better define the 50% energy savings goal. These targets are presented as annual absolute whole-building energy use intensity (EUI) values, and owners are encouraged to set their own EUI targets to provide focused and measurable 50% savings goals. These targets allow users to follow the more prescriptive recommendations in the guide, but also take a more performance-based approach so they can compare their projects to the AEDG-LH, even though they may have used different approaches or made different design choices for some aspects. This chapter also provides an overview of design influences, discusses the impact that the site and building configurations have on energy use, and provides a holistic design perspective in energy efficiency integration.

1.4.4 Chapter 4 – Strategies and Recommendations by Climate Zone

This chapter contains the climate-specific recommendation tables, which provide a unique set of energy efficiency recommendations for each DOE climate zone. Recommendations are organized by several categories: envelope, electric lighting, daylighting, plug and process loads (PPLs), commercial kitchen, SWH, HVAC, and measurement and verification (M&V). The recommendations are simply one path to reach the 50% energy savings target. Other approaches may also save energy; however, identifying all possible solutions is not in the scope of the AEDG-LH. To achieve 50% energy savings, the AEDG-LH assumes compliance with the more stringent of either the applicable edition of Standard 90.1 or the local code requirements in all areas not addressed in the climate-specific recommendation tables. Future editions of energy codes may have more stringent values. In these cases, the more stringent values are recommended.

1.4.5 Chapter 5 – How to Implement Recommendations

The final chapter provides guidance and successful practices for implementing the recommendations, as well as cautions to avoid known problems in energy-efficient construction. The chapter includes sections about the building envelope, daylighting, electric lighting, plug loads, kitchen equipment, SWH, HVAC, and quality assurance/commissioning. The chapter concludes with a "bonus savings" section that includes additional items that, if implemented properly, should achieve savings beyond the 50% level. This chapter includes the following how-to sections:

- Envelope: the envelope how-to section contains climate zone-specific design details about explicit types of walls, roofs, floors, doors, insulation, infiltration, and vertical fenestration.
- Daylighting: the daylighting how-to section provides general tips related to basic principles; building shape and orientation with respect to daylighting; window-to-wall ratios; analysis tool information; glare control and direct beam radiation elimination; daylighting space types and layouts, including space type-specific strategies; lighting controls; photosensor specification and photocell placement; and system commissioning.
- Lighting: the lighting how-to section details space type-specific lighting power density (LPD) targets; how to use specific lamp and ballast types (linear fluorescent, compact fluorescent, solid-state, and metal halide) to achieve these LPDs; control strategies (including occupant-based controls and daylight harvesting); lighting layouts for specific space types (including patient rooms, nurses' stations and care area corridors, surgical suites, recovery rooms, nonsurgical procedure rooms, examination rooms, obstetrics suites, radiology and diagnostic imaging rooms, offices and conference rooms, and public spaces), as well as exterior and parking lot; grounds; and parking garage lighting power and control.
- Plug loads: the plug load how-to section provides methods to reduce parasitic loads and discussions on implementing ENERGY STAR® equipment. It also contains detailed information on designing an energy-efficient kitchen, with tips on selecting energy-efficient kitchen equipment; minimizing exhaust/ventilation and hot water energy use; utilizing high-efficiency walk-in refrigeration systems; and operating considerations to save energy. This section also discusses ways to save energy on process loads, including large medical equipment, high-performance laundry equipment, elevators, and escalators.

- SWH: the SWH how-to section discusses the best types of systems for hospitals, proper sizing of the systems, how to choose energy-efficient systems, and the best locations for the system components.
- HVAC: the HVAC section includes best practices for space planning; water source heat pump (WSHP), fan coil unit (FCU), and advanced variable air volume (VAV) HVAC systems; dedicated outdoor air systems (DOAS); demand-controlled ventilation (DCV); indirect evaporative cooling; exhaust air systems and energy recovery; part-load dehumidification; desiccant systems; economizers; system-level control strategies; reducing air handling unit (AHU) face velocity (pressure drop); ductwork design; testing, adjusting, and balancing; filtration and air cleaning; space set points and zone temperature controls; zone airflow control and setbacks; humidification systems; elimination of steam boilers; noise control; chilled water systems including chiller diversity, cooling towers, and condenser water heat recovery; and operating suite setback.
- Commissioning: the quality assurance and commissioning subsection contains specific details about commissioning and its importance in every step of the design process, as well as information on M&V.
- Additional savings: the "bonus savings" section includes good practices for radiant heating and cooling with displacement ventilation, combined heat and power, fan arrays, evaporative condensing, photovoltaic systems, solar hot water systems, wind turbine power systems, power purchase agreements, and electricity distribution systems.

Interspersed throughout the guide are detailed technology and whole-building case studies that illustrate techniques and methods discussed in the AEDG-LH. The technology case studies highlight a particular aspect and expand on that, whereas the whole-building case studies demonstrate energy-efficient hospitals. Technology case study topics include light-emitting diode (LED) surgical task lighting, LED parking garage lighting, computer power management, lake-coupled geothermal systems, and condenser water heat recovery. The whole-building case studies highlight how entire hospitals achieved energy savings levels similar to the AEDG-LH goals. These case studies provide EUI numbers to benchmark future buildings against these buildings. All the case studies use some of the recommendations in the tables, but the case study buildings predate the publication of the AEDG-LH, and were not developed explicitly using those specific recommendations. The case studies are important because they demonstrate real-life energy savings and successful implementation of the AEDG-LH recommendations. Case studies provide the motivation and the examples for others to follow and validate the recommendations in the AEDG-LH.

2. AEDG-LH Development Process

The AEDG-LH was developed by a PC representing a diverse group of professionals. The PC members were nominated by the AEDG-LH partnering organizations (ASHRAE, AIA, IES, USGBC, and ASHE). Guidance and support were provided through collaboration between ASHRAE, AIA, IES, USGBC, ASHE, and DOE. PC members were provided by these partner organizations, ASHRAE Project Committee 90.1 (SSPC 90.1), and the ASHRAE Technical Committee on Healthcare Facilities (TC 9.6). A steering committee (SC) was assembled to oversee the development process, and was composed of representatives of ASHRAE, AIA, IES, USGBC, and DOE. The SC issued a scoping document to the PC, including the timeline for the task, energy savings goal, intended target audience, space types to include, and desired design assistance characteristics.

The PC followed SC guidance to develop a plan for completing the AEDG-LH. The project schedule was modeled after those used for previous guides. Key milestones and their delivery dates were set based on the required final publication date and included two peer reviews, which corresponded to 60% (technical refinement) and 90% (final review) completion drafts. Four PC meetings were held at ASHRAE headquarters and NREL. Many conference calls with the full PC were also held to provide updates on the AEDG-LH's progress toward the peer review and publication milestones.

2.1 Steering Committee

The SC was composed of representatives of the partner organizations and guided the PC in developing the AEDG-LH. The SC was composed of a chair, one representative from each partner organization (ASHRAE, AIA, IES, USGBC, ASHE, and DOE), liaisons from ASHRAE SSPC 90.1 and ASHRAE TC 9.6, and one ASHRAE staff member, for a total of nine people. The guidance provided by the SC to the PC included a timeline for the task, an energy savings goal, an intended target audience, and desired design assistance characteristics. The SC guidance points were to:

- Develop and document a process and recommendations to achieve 50% savings over Standard 90.1-2004 in large hospitals.
- Constrain the scope and duration of the analysis to maintain the project schedule.
- Rely on current knowledge of energy-efficient building design, supplemented with energy design analysis.

Additional priorities identified by the SC were provided in a scoping document (see Appendix A), which includes:

- The baseline for energy use evaluation will be annual site energy consumption.
- Address the practical how-to, user-friendly information needs of the AEDG-LH's intended users (designers in medium to large firms, design/build contractors, and construction firms).
- The AEDG-LH will be formatted for easy use, provide specific procedures, convey best practices, and avoid mandatory language typical of codes and standards. The apparent complexity of a typical standard/guideline layout and format should be avoided to increase usability for the target audience.

- The interactions between building components and systems will need to be considered rather than having all the savings come from individual parts (savings from systems integration is encouraged). Accommodate, to the extent practical, design flexibility through use of packages of energy efficiency measures from which users may choose.
- Adopt a prescriptive recommendation approach with packages of measures. This will include envelope, mechanical, lighting, and water heating measures.
- In addition to prescriptive energy efficiency measures, the AEDG-LH should contain "how to" guidance to help the designer construct an energy-efficient healthcare facility. The guide should be presented in a very user-friendly manner to reduce design time. By focusing on user-friendly layouts and presentation, as well as prescriptive design recommendations, the AEDG-LH should ease the burden for the designers and give hospital decision makers an overview of specific, easy-to-follow recommendations.
- The prescriptive recommendations presented should be sufficient to allow innovative firms to extend the information when designing facilities that might be evaluated using performance-based criteria. That is, some additional allowance or flexibility should be provided for people who are accustomed to performance-based documents.
- Several case studies should be included to illustrate the energy efficiency components identified. These case studies can focus on specific geographic regions or illustrate particular items or recommended techniques.

2.1.1 Inclusion of Economics and Cost

The purpose of the AEDG-LH is to assist designers in the design of energy-efficient hospitals. The guide focuses on the goal of 50% energy savings, rather than on installations that have a payback threshold.

The AEDG-LH does include numerous cost control strategies and best practices; the case studies help to reinforce the claim that high-performance hospitals can be built within typical budgets.

2.2 Approval Authority

The final approval for the AEDG-LH was the responsibility of the SC. Committee members were responsible for reflecting the opinions of the partner organizations that they represented. This included consulting with their organizations, obtaining buy-in during the review process, and providing peer reviews. Efforts were made to agree on the content, as was done during the development of the *ASHRAE Handbook: Fundamentals* (ASHRAE 2009); however, the AEDG-LH was not developed through a consensus-based process.

2.3 Project Committee Organization and Membership

The AEDG-LH was developed by a PC administered under ASHRAE's Special Project procedures. The AEDG-LH PC was designated as ASHRAE Special Project 136 (SP-136), and included membership from each partner organization. Table 2–1 lists the PC members and the organizations they represented. Some members were not affiliated with a partner organization. In these cases, the function of that member is listed instead.

Table 2–1 AEDG-LH PC Membership Chart

Member	Organization/Function
Shanti Pless	Chair
Merle McBride	Vice chair
Mara Baum	AIA representative
Ray Pradinuk	AIA representative
John Gill	IES representative
Joel Loveland	IES representative
John D'Angelo	USGBC representative
Kim Shinn	USGBC representative
Jeff Boldt	ASHRAE representative
Mick Schwedler	ASHRAE representative
Tim Peglow	Member at large
Walt Vernon	ASHE representative
Don Colliver	SC ex officio
Lilas Pratt	ASHRAE staff liaison
Bert Etheredge	ASHRAE staff liaison
Eric Bonnema	Analysis support
Matt Leach	Analysis support

The SC helped to select PC members with energy efficiency experience in large hospitals. Each representative was given the chance to provide peer review input on the various review drafts produced by the PC. In effect, these representatives were intended to be the interfaces to their respective organizations to ensure a large body of input into the AEDG-LH's development.

2.4 Development Schedule and Process

Following SC guidance, the PC developed a one-year plan for completing the AEDG-LH. Key milestones in the development schedule were determined based on the final publication date and time needed for the publication process. The PC planned for two peer review periods that corresponded with a 60% completion draft (technical refinement) and a 90% completion draft (final review). Four PC meetings and many interim conference calls were held.

Further information about each meeting is included in the agendas, which are provided in Appendix B. These agendas were updated after each meeting to reflect the actual discussions and length of time spent on each item. After each meeting, the meeting notes, agenda, action items, future schedules, and other related documents were compiled into a meeting report. These reports were very useful for reference and organizational purposes during the AEDG-LH development.

The iterative development of the prototype, baseline, and low-energy models included discussions of the model inputs and the current model results at every meeting and conference call. Results from the modeling, combined with input from the PC, led to the final AEDG-LH recommendations. The following steps show the modeling process used, from the initial prototype development to the final recommendations:

1. Use the expertise of the PC to help define inputs not governed by applicable standards.
2. Present preliminary results for the prototype models to the PC.
3. Develop a consensus from the PC on the prototype model inputs.

4. Generate baseline models by applying the climate-specific criteria in Standard 90.1-2004.
5. Investigate initial strategies by applying preliminary recommendations to the prototype models.
6. Present the low-energy modeling results to the PC and identify recommendations that do not meaningfully contribute to the 50% energy savings goal.
7. Fine-tune the recommendations to achieve at least 50% whole-building energy savings in all climate zones.
8. Document final recommendations for the AEDG-LH that achieve at least 50% savings.

The following sections of this TSD present the prototype development results from Step 3, the baseline model results from Step 4, and the final recommendations and energy savings results as documented in Step 8.

3. Evaluation Approach

This chapter describes the analysis methods used to support development of the AEDG-LH. It explains how the prototype, baseline, and low-energy models were developed, and how the resultant energy savings were quantified.

3.1 Determining Energy Savings

The purpose of the building energy simulation analysis was to assess and quantify the energy savings potential of the final AEDG-LH recommendations. All AEDGs contain a set of energy efficiency recommendations for all U.S. climate zones (Briggs et al. 2003) and their corresponding subzones (resulting in 16 total climate locations). To provide the prescriptive recommendations necessary to achieve 50% energy savings, a specific, quantitative energy savings goal must be measured against a specific version of Standard 90.1. For the AEDG-LH, this was Standard 90.1-2004.

The following steps were used to determine that the 50% savings goal was met or exceeded:

1. Identify “typical” hospital prototype characteristics.
2. Create Standard 90.1-2004-compliant baseline models from the prototypes.
3. Use energy modeling iteratively to help inform AEDG-LH recommendations and ultimately create complete low-energy models based on the final recommended energy efficiency technologies in the AEDG-LH.
4. Verify 50% energy savings were achieved for each of the three investigated HVAC system types in the AEDG-LH across all U.S. climate zones and corresponding subzones.

These steps are presented in a linear fashion, but there was some iteration. The flowchart in Figure 3–1 presents a visual representation of the evaluation approach.

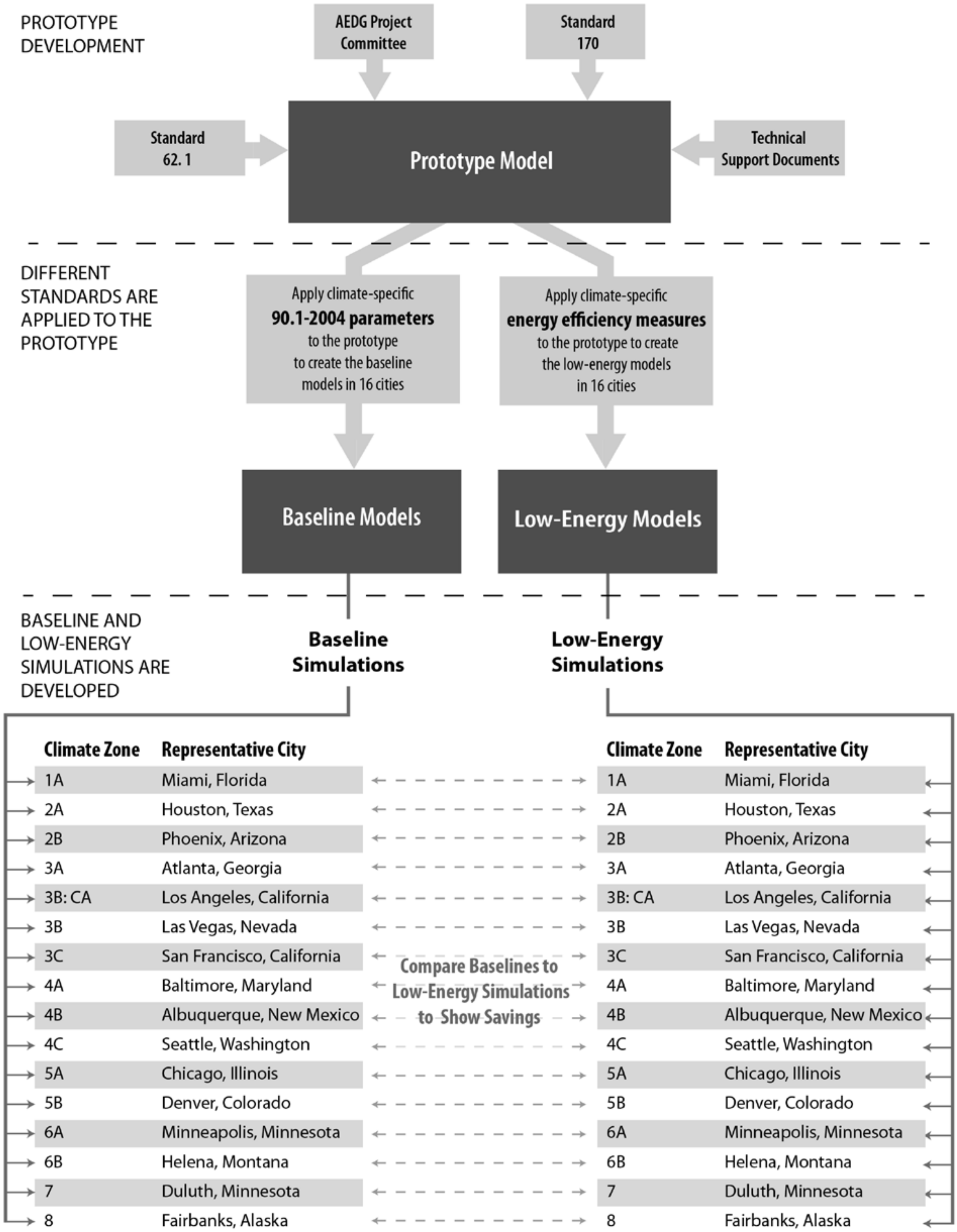

Figure 3–1 Flow diagram of modeling process
(Credit: Marjorie Schott/NREL)

3.1.1 Site Energy Use

The 50% energy savings goal of the AEDG series is based on site energy savings between a minimally code-compliant building and a low-energy building that uses the AEDG recommendations. Other metrics, such as energy cost savings, source energy savings, and carbon savings, could be used to determine energy savings. Each metric has advantages and disadvantages from an implementation and a calculation perspective, and each can favor different technologies and fuel types. The AEDG-LH uses site energy savings, as directed by the SC, to retain consistency with previous AEDGs.

3.1.2 Whole-Building Energy Savings

Historically, energy savings have been expressed in two ways: those associated with regulated loads and those associated with the whole building. The "regulated loads" energy savings indicate the savings when only the code-regulated loads are included in the total building energy use. Unregulated loads typically include plug and some process loads, such as office equipment (computers, copiers, fax machines, etc.), small appliances (coffee makers, water coolers, etc.) and medical equipment (scopes, monitors, etc.) The "whole-building" energy savings indicate the savings when all the loads (regulated and unregulated) are included in the calculations. In general, for the same level of percent savings, whole-building savings are more challenging to attain than regulated loads savings. The AEDG-LH uses the "whole-building" method for determining energy savings.

3.1.3 Modeling Methods

EnergyPlus version 7.0 (DOE 2011) was used to complete the energy simulations for the AEDG-LH, because it accounts for the complicated interactions between climate, internal gains, building form and fabric, HVAC systems, and renewable energy systems. EnergyPlus is a heavily tested program with formal BESTEST validation efforts repeated for every release (Judkoff et al. 1995). All simulations were completed with an NREL analysis platform called Opt-E-Plus (NREL 2010) that manages inputs and outputs of the EnergyPlus simulations. Opt-E-Plus' core functionality is the user's ability to pass high-level parameters of the building (building area, internal gains per zone, HVAC system configuration, etc.) to generate a fully parameterized EnergyPlus input file. Such files are generated rapidly and can be easily changed to accommodate the evolution of the model. The high-level parameter file is a structured text file written in Extensible Markup Language. Modifying the high-level parameters is preferred over modifying the EnergyPlus input file, because it greatly simplifies the modeling input development process. Modifying EnergyPlus input files can be time intensive when the high-level parameters have a one-to-many relationship with the corresponding objects in the low-level input file.

The AEDG-LH simulations were used to evaluate and vet guide recommendations and to verify that the final set met the savings goal. There were one baseline and three low-energy models (one for each of the three HVAC system types), for a total of four separate seed (starting point) energy models. The Opt-E-Plus software then took these four seed models and "swept" them across the 16 cities representing the U.S. climate zones and corresponding subzones. The Opt-E-Plus "sweep" took the seed energy model files and created 16 separate energy models and applied climate zone-specific details such as weather data, economizer requirements, and building envelope specifications from Standard 90.1-2004 (for the baseline model) or the AEDG-LH (for the low-energy models). This resulted in 64 (16 baseline and 48 low-energy) energy models.

3.1.3.1 Climate Zones

The AEDGs contain a unique set of energy efficiency recommendations for each U.S. climate zone and corresponding subzone (see Figure 3–2). The zones are defined primarily by heating degree days and cooling degree days (Briggs et al. 2003), and range from very hot (Zone 1A) to very cold (Zone 8). Some are divided into subzones based on humidity levels. Humid subzones are "A" zones, dry subzones are "B" zones, and marine subzones are "C" zones. These climate zones may be mapped to other climate locations for international use.

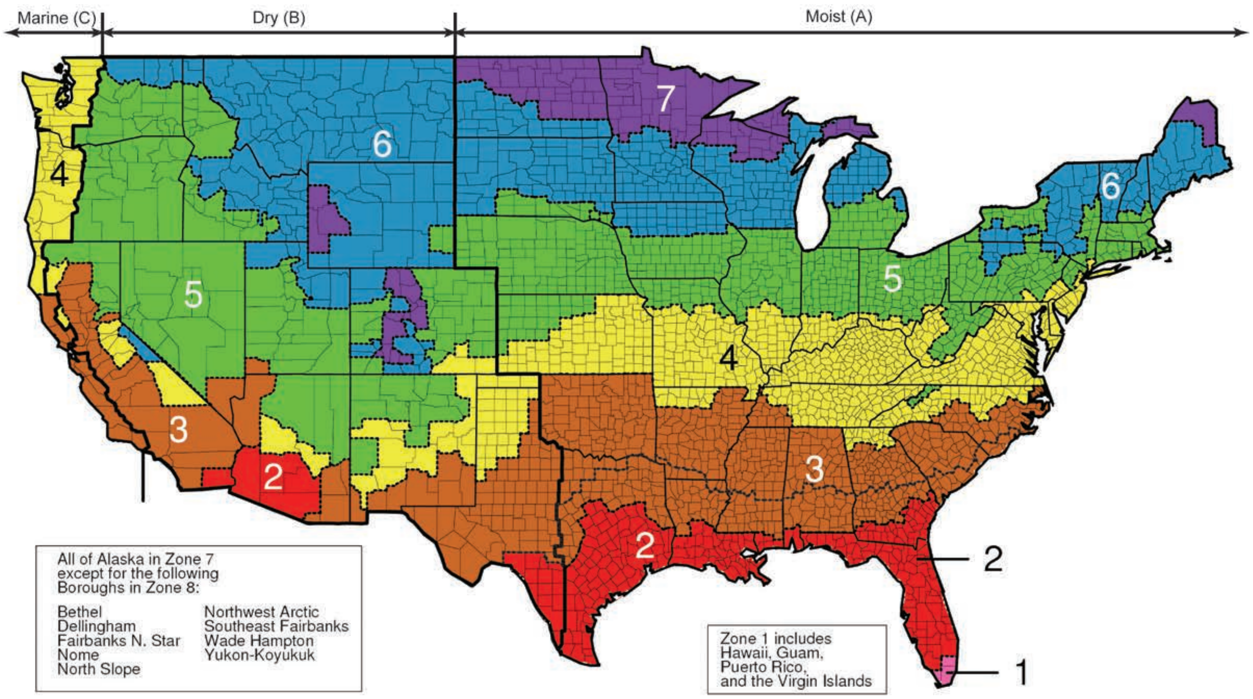

Figure 3–2 DOE climate zones and representative cities
(Credit: DOE 2003)

The 16 specific locations for which analyses were performed are listed below and are designated as being representative of their climate zones. Large cities were chosen, as their weather data directly apply to a large fraction of the total U.S. building floor area. Energy savings were determined by running baseline and low-energy model simulations with the same Typical Meteorological Year 3 weather file (one set of simulations for each city).

- Zone 1A: Miami, Florida (very hot, humid)
- Zone 2A: Houston, Texas (hot, humid)
- Zone 2B: Phoenix, Arizona (hot, dry)
- Zone 3A: Atlanta, Georgia (hot, humid)
- Zone 3B: Las Vegas, Nevada (hot, dry) and Los Angeles, California (warm, dry)
- Zone 3C: San Francisco, California (marine)
- Zone 4A: Baltimore, Maryland (mixed, humid)
- Zone 4B: Albuquerque, New Mexico (mixed, dry)

- Zone 4C: Seattle, Washington (marine)
- Zone 5A: Chicago, Illinois (cold, humid)
- Zone 5B: Denver, Colorado (cold, dry)
- Zone 6A: Minneapolis, Minnesota (cold, humid)
- Zone 6B: Helena, Montana (cold, dry)
- Zone 7: Duluth, Minnesota (very cold)
- Zone 8: Fairbanks, Alaska (extremely cold)

3.2 Prototype Model Overview

For the AEDG-LH, the model from Bonnema et al. (2010b) was used as a starting point to help define certain building characteristics that were not code regulated. The space types represented in this model are listed here. The prototype model characteristics remained consistent between the baseline and low-energy models.

- Anesthesia gas storage
- Cafeteria
- Clean workroom/holding
- Conference room
- Corridor/transition
- Dining room
- Examination/treatment room
- Food preparation center
- Laboratory
- Lobby area
- Locker
- Lounge
- Mechanical/electrical room
- Medical supply/medication room
- Nurse station
- Nursery
- Office
- Operating suite
- Patient room
- Pharmacy
- Physical therapy
- Procedure room
- Radiology/imaging
- Reception/waiting
- Recovery room
- Restroom
- Soiled workroom/holding
- Sterilizer equipment room
- Storage/receiving
- Trauma/emergency room
- Triage.

Table 3–1 presents a summary of the prototype model and Figure 3–3 shows a rendering of the large hospital prototype model.

Table 3–1 Prototype Model Summary

Characteristic	Value
Size	427,173 ft²
Floor-to-ceiling height	9 ft
Floor-to-floor height	14 ft in diagnostic and treatment areas (floor 2) 13 ft in all other areas (floors 1, 3–7)
Ceiling plenum depth	5 ft in diagnostic and treatment areas (floor 2) 4 ft in all other areas (floors 1, 3–7)
Number of floors	7
Window-to-wall ratio	40% (floor-to-ceiling) 26% (floor-to-floor in diagnostic and treatment areas [floor 2]) 28% (floor-to-floor in other areas [floors 1, 3–7])
Glazing details	Banded windows 3.7 ft tall with a 3.6 ft sill height
Wall construction	Mass
Roof construction	Insulation entirely above deck

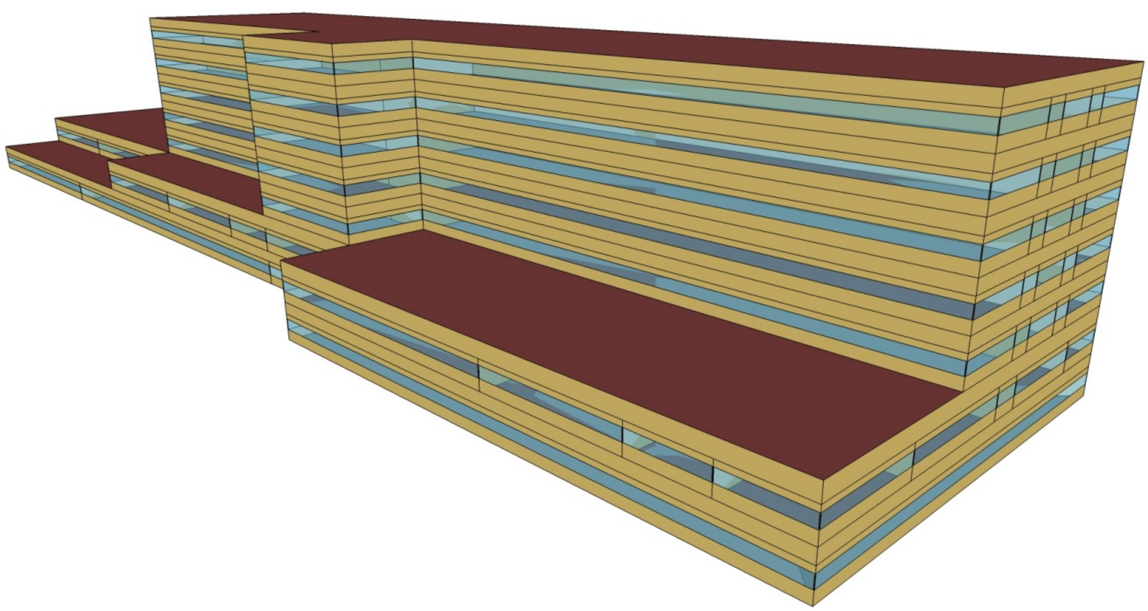

Figure 3–3 Large hospital baseline model rendering, view from southeast

3.2.1 Geometry

Table 3–2 though Table 3–5 show a breakdown by space type of each zone of the prototype model; Figure 3–4 through Figure 3–7 show the zone layout for the model. The numbers in Figure 3–4 through Figure 3–7 map to the first column of the corresponding table (e.g., the numbers in Figure 3–4 map to the first column of Table 3–2). Table 3–2 through Table 3–5 also show a mapping of each zone to a space type. These space types are referenced throughout this TSD when describing other model inputs (lighting, plug loads, etc.).

Table 3–2 **Large Hospital Zone Breakdown – Floor 1**

No.	Zone Name	Space Type	Dimensions (ft × ft)	Area (ft²)
1	Floor 1 Cafeteria	Cafeteria	49.0 × 82.0	4,018.0
2	Floor 1 Clean	Clean workroom/holding	24.0 × 20.0	480.0
3	Floor 1 Conference	Conference room	205.0 × 30.0	6,150.0
4	Floor 1 Dining	Dining room	60.0 × 82.0	4,920.0
5	Floor 1 Elevator	Reception/waiting	60.0 × 30.0	1,800.0
6	Floor 1 Exam	Examination/treatment room	66.0 × 40.0	2,640.0
7	Floor 1 Food Storage	Food preparation center	49.0 × 41.0	2,009.0
8	Floor 1 Gas Storage	Anesthesia gas storage	12.0 × 52.0	624.0
9	Floor 1 Imaging	Radiology/imaging	76.0 × 20.0	1,520.0
10	Floor 1 Kitchen	Food preparation center	49.0 × 41.0	2,009.0
11	Floor 1 Lab 1	Laboratory	50.0 × 40.0	2,000.0
12	Floor 1 Lab 2	Laboratory	98.0 × 50.0	4,900.0
13	Floor 1 Laundry	Storage/receiving	86.0 × 26.0	2,236.0
14	Floor 1 Lobby	Lobby area	125.0 × 30.0	3,750.0
15	Floor 1 Lounge	Lounge	32.0 × 40.0	1,280.0
16	Floor 1 Mechanical 1	Mechanical/electrical room	90.0 × 90.0	8,100.0
17	Floor 1 Mechanical 2	Mechanical/electrical room	60.0 × 180.0	10,800.0
18	Floor 1 Office 1	Office	82.0 × 90.0	7,380.0
19	Floor 1 Office 2	Office	98.0 × 58.0	5,684.0
20	Floor 1 Office 3	Office	185.0 × 107.0	19,795.0
21	Floor 1 Office 3 Perimeter 1	Office	192.5* × 15.0	2,887.5
22	Floor 1 Office 3 Perimeter 2	Office	15.0 × 122.0*	1,830.0
23	Floor 1 Office 3 Perimeter 3	Office	192.5* × 15.0	2,887.5
24	Floor 1 Patient	Patient room	90.0 × 20.0	1,800.0
25	Floor 1 Pharmacy	Pharmacy	60.0 × 100.0	6,000.0
26	Floor 1 Physical Therapy	Physical therapy	82.0 × 60.0	4,920.0
27	Floor 1 Receiving	Storage/receiving	86.0 × 26.0	2,236.0
28	Floor 1 Reception	Reception/waiting	14.0 × 40.0	560.0
29	Floor 1 Soil	Soiled workroom/holding	24.0 × 20.0	480.0
30	Floor 1 Storage	Storage/receiving	60.0 × 90.0	5,400.0
31	Floor 1 Waiting	Reception/waiting	76.0 × 20.0	1,520.0

*This length is the average between the long and short leg of the trapezoid shaped zone.

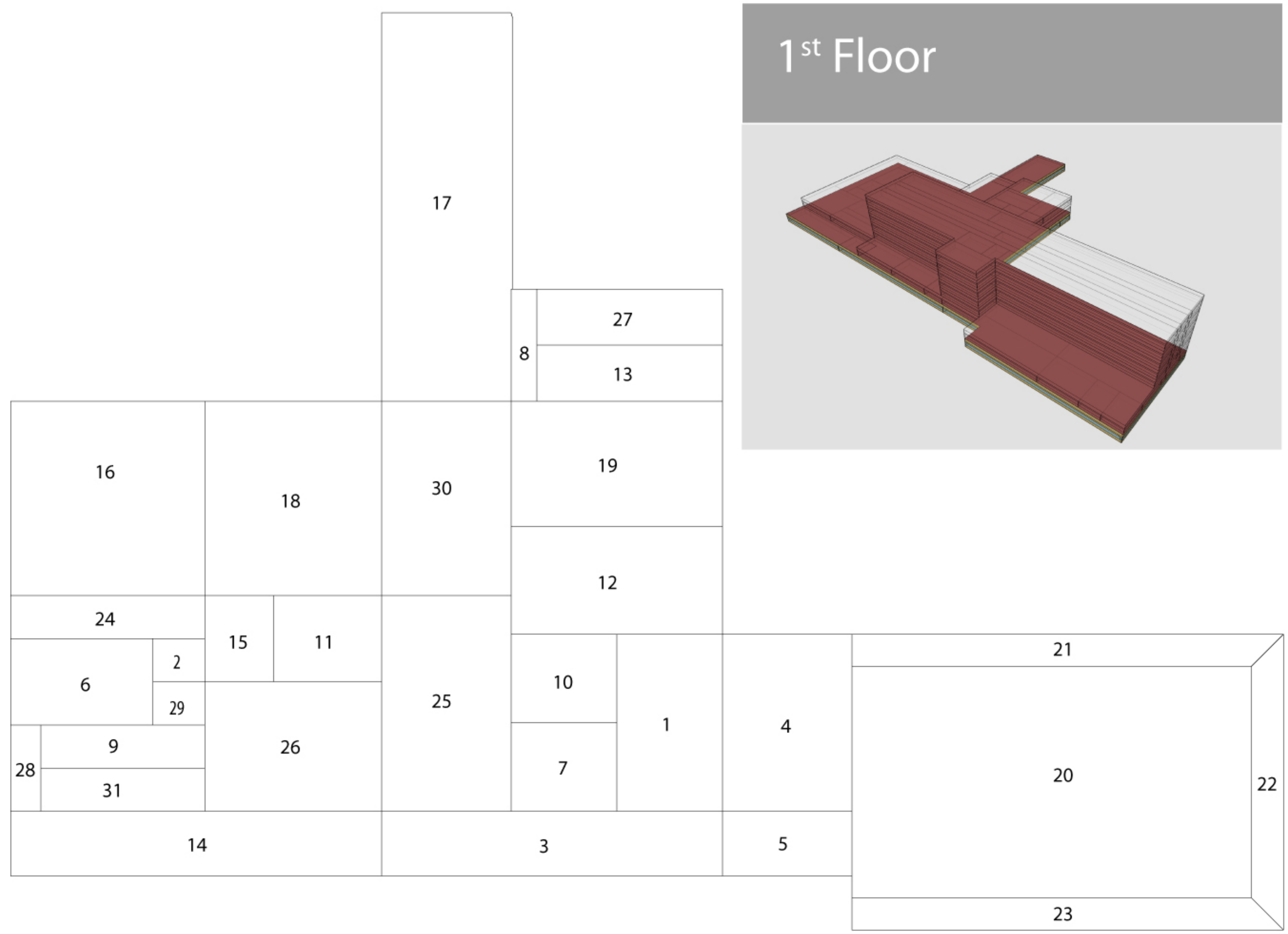

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Figure 3–4 Large hospital zone layout – floor 1
(Credit: Marjorie Schott/NREL)

Table 3–3 Large Hospital Zone Breakdown – Floor 2

No.	Zone Name	Space Type	Dimensions (ft × ft)	Area (ft²)
32	Floor 2 Chapel	Office	60.0 × 30.0	1,800.0
33	Floor 2 Clean 1	Clean workroom/holding	21.0 × 23.0	483.0
34	Floor 2 Clean 2	Clean workroom/holding	20.0 × 16.0	320.0
35	Floor 2 Corridor	Corridor/transition	520.0 × 10.0	5,200.0
36	Floor 2 Elevator	Reception/waiting	60.0 × 30.0	1,800.0
37	Floor 2 Exam 1	Examination/treatment room	70.0 × 60.0	4,200.0
38	Floor 2 Exam 2	Examination/treatment room	45.0 × 30.0	1,350.0
39	Floor 2 Exam 3	Examination/treatment room	90.0 × 45.0	4,050.0
40	Floor 2 Exam 4	Examination/treatment room	100.0 × 40.0	4,000.0
41	Floor 2 Gift Shop	Office	60.0 × 30.0	1,800.0
42	Floor 2 Imaging 1	Radiology/imaging	77.0 × 30.0	2,310.0
43	Floor 2 Imaging 2	Radiology/imaging	170.0 × 20.0	3,400.0
44	Floor 2 Imaging 3	Radiology/imaging	200.0 × 20.0	4,000.0
45	Floor 2 Lab 1	Laboratory	57.0 × 40.0	2,280.0
46	Floor 2 Lab 2	Laboratory	68.0 × 50.0	3,400.0
47	Floor 2 Lockers	Locker	25.0 × 30.0	750.0
48	Floor 2 Lounge 1	Lounge	60.0 × 20.0	1,200.0
49	Floor 2 Lounge 2	Lounge	25.0 × 35.0	875.0
50	Floor 2 Nurse Station 1	Nurse station	15.0 × 86.0	1,290.0
51	Floor 2 Nurse Station 2	Nurse station	100.0 × 40.0	4,000.0
52	Floor 2 Office 1	Office	117.0 × 20.0	2,340.0
53	Floor 2 Office 2	Office	60.0 × 32.0	1,920.0
54	Floor 2 Office 3	Office	150.0 × 20.0	3,000.0
55	Floor 2 Office 4	Office	100.0 × 35.0	3,500.0
56	Floor 2 Operating Suite	Operating room	158.0 × 122.0	19,276.0
57	Floor 2 PACU	Recovery room	90.0 × 45.0	4,050.0
58	Floor 2 Patient 1	Patient room	142.0 × 24.0	3,408.0
59	Floor 2 Patient 2	Patient room	61.0 × 46.0	2,806.0
60	Floor 2 Procedure 1	Procedure room	45.0 × 56.0	2,520.0
61	Floor 2 Procedure 2	Procedure room	60.0 × 20.0	1,200.0
62	Floor 2 Reception	Reception/waiting	50.0 × 35.0	1,750.0
63	Floor 2 Restroom 1	Restroom	20.0 × 32.0	640.0
64	Floor 2 Restroom 2	Restroom	30.0 × 30.0	900.0
65	Floor 2 Soil 1	Soiled workroom/holding	21.0 × 23.0	483.0
66	Floor 2 Soil 2	Soiled workroom/holding	20.0 × 16.0	320.0
67	Floor 2 Sterilizing	Sterilizer equipment room	68.0 × 20.0	1,360.0
68	Floor 2 Storage 1	Storage/receiving	25.0 × 60.0	1,500.0
69	Floor 2 Storage 2	Storage/receiving	20.0 × 32.0	640.0
70	Floor 2 Trauma	Trauma/emergency room	140.0 × 32.0	4,480.0
71	Floor 2 Triage	Triage	25.0 × 35.0	875.0
72	Floor 2 Waiting	Reception/waiting	30.0 × 130.0	3,900.0

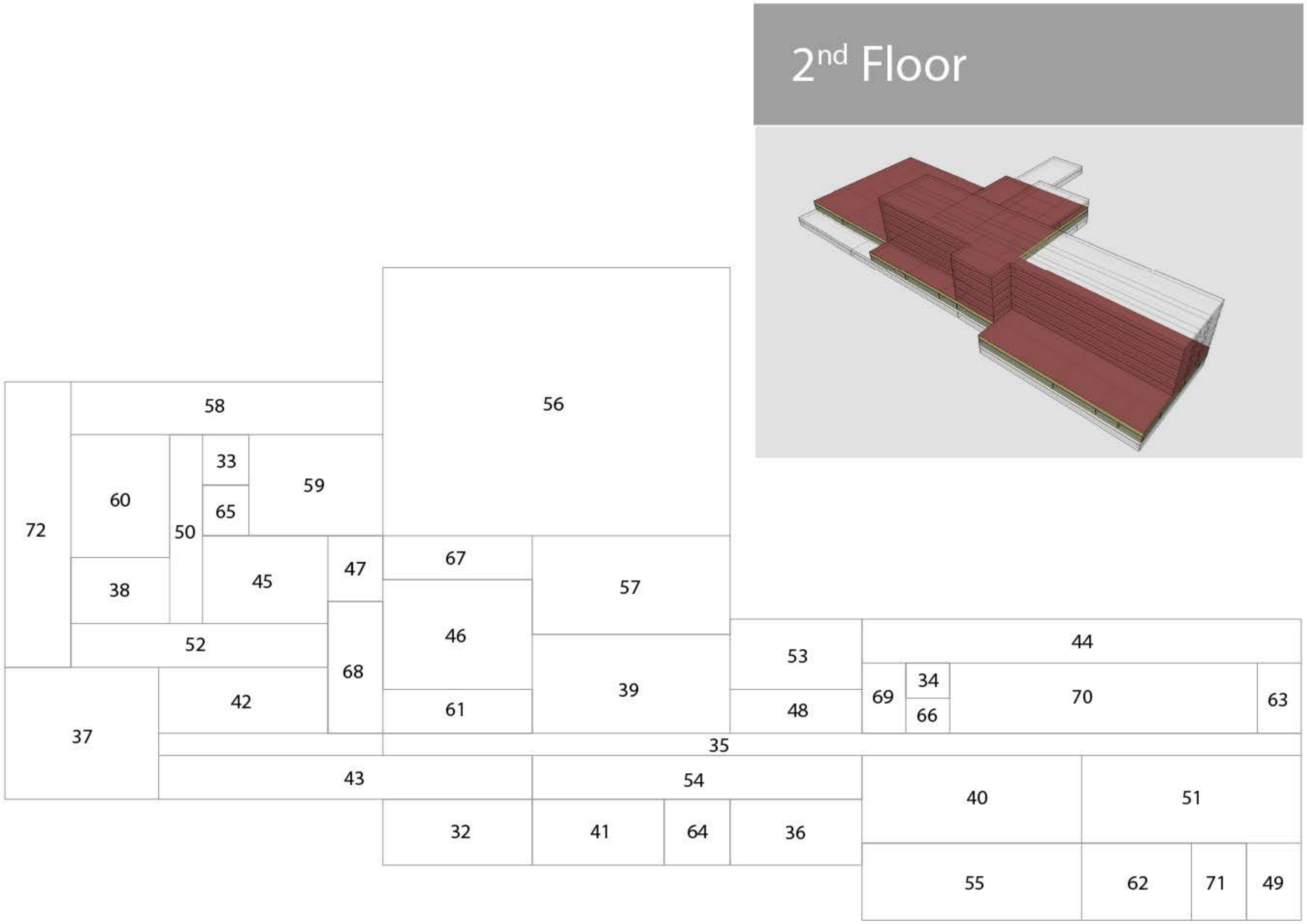

Figure 3–5 Large hospital zone layout – floor 2
(Credit: Marjorie Schott/NREL)

Table 3–4 Large Hospital Zone Breakdown – Floor 3

No.	Zone Name	Space Type	Dimensions (ft × ft)	Area (ft²)
73	Floor 3 Clean	Clean workroom/holding	20.0 × 25.0	500.0
74	Floor 3 Elevator	Reception/waiting	60.0 × 30.0	1,800.0
75	Floor 3 Exam	Examination/treatment room	30.0 × 90.0	2,700.0
76	Floor 3 ICU	Recovery room	30.0 × 70.0	2,700.0
77	Floor 3 Nurse Station 1	Nurse station	188.0 × 16.0	3,008.0
78	Floor 3 Nurse Station 2	Nurse station	60.0 × 40.0	2,400.0
79	Floor 3 Nursery	Nursery	30.0 × 33.0	990.0
80	Floor 3 Office	Office	30.0 × 90.0	2,700.0
81	Floor 3 Operating Suite	Operating room	60.0 × 30.0	1,800.0
82	Floor 3 Patient 1	Patient room	200.0 × 25.0	5,000.0
83	Floor 3 Patient 2	Patient room	200.0 × 25.0	5,000.0
84	Floor 3 Patient 3	Patient room	158.0 × 25.0	3,950.0
85	Floor 3 Patient 4	Patient room	158.0 × 25.0	3,950.0
86	Floor 3 Patient Corridor 1	Corridor/transition	418.0 × 8.0	3,344.0
87	Floor 3 Patient Corridor 2	Corridor/transition	418.0 × 8.0	3,344.0
88	Floor 3 Procedure	Procedure room	30.0 × 24.0	720.0
89	Floor 3 Soil	Soiled workroom/holding	40.0 × 25.0	1,000.0
90	Floor 3 Supply	Medical supply/medication room	230.0 × 16.0	3,680.0
91	Floor 3 Triage	Triage	60.0 × 25.0	1,500.0
92	Floor 3 Waiting	Reception/waiting	30.0 × 33.0	990.0

Table 3–5 Large Hospital Zone Breakdown – Floors 4–7

No.	Zone Name	Space Type	Dimensions (ft × ft)	Area (ft²)
93	Floor 4-7 Clean	Clean workroom/holding	20.0 × 25.0	500.0
94	Floor 4-7 Elevator	Reception/waiting	60.0 × 30.0	1,800.0
95	Floor 4-7 Nurse Station 1	Nurse station	188.0 × 16.0	3,008.0
96	Floor 4-7 Office	Office	60.0 × 25.0	2,700.0
97	Floor 4-7 Patient 1	Patient room	200.0 × 25.0	5,000.0
98	Floor 4-7 Patient 2	Patient room	200.0 × 25.0	5,000.0
99	Floor 4-7 Patient 3	Patient room	158.0 × 25.0	3,950.0
100	Floor 4-7 Patient 4	Patient room	158.0 × 25.0	3,950.0
101	Floor 4-7 Patient Corridor 1	Corridor/transition	418.0 × 8.0	3,344.0
102	Floor 4-7 Patient Corridor 2	Corridor/transition	418.0 × 8.0	3,344.0
103	Floor 4-7 Soil	Soiled workroom/holding	40.0 × 25.0	1,000.0
104	Floor 4-7 Supply	Medical supply/medication room	230.0 × 16.0	3,680.0

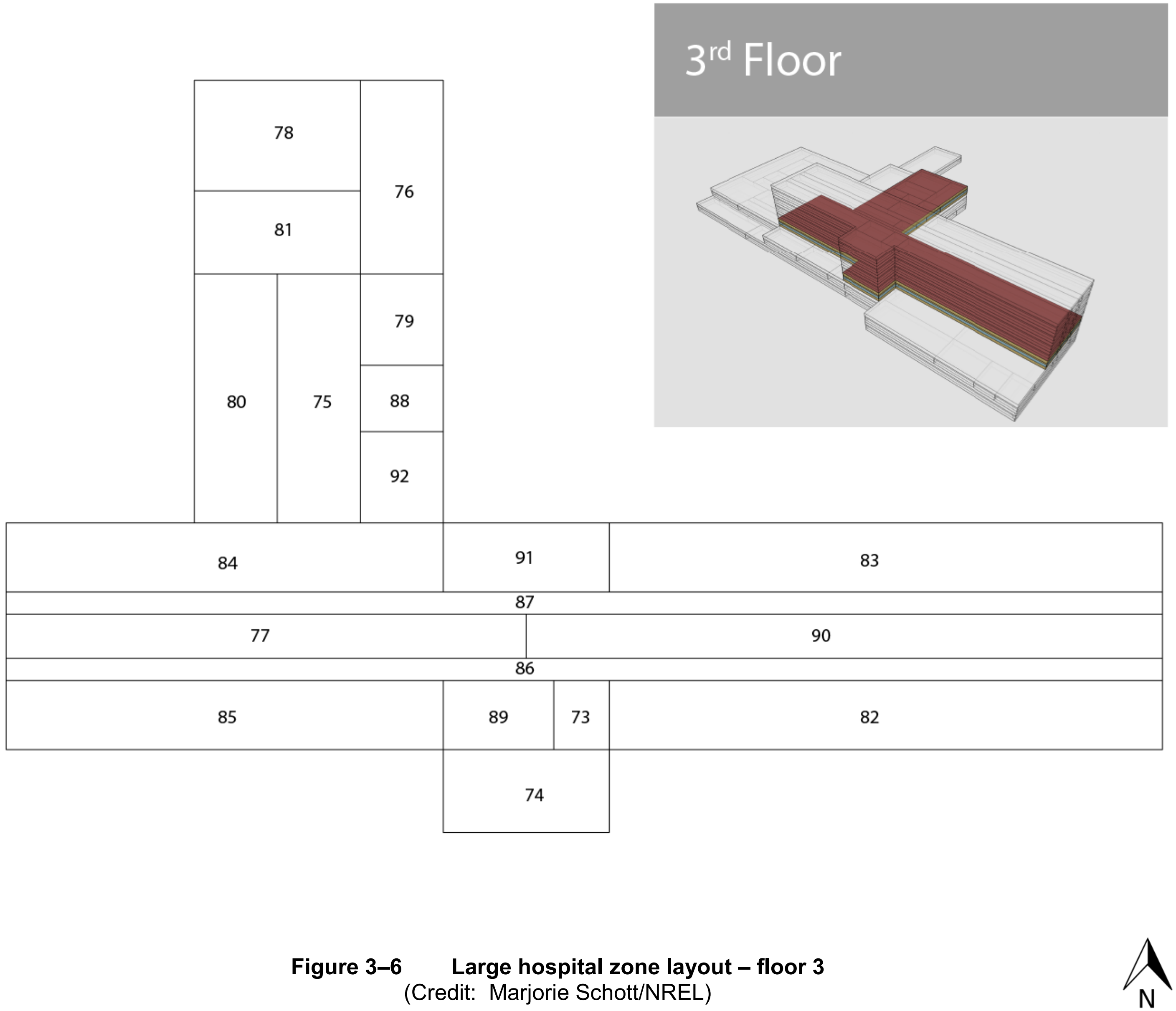

Figure 3–6 Large hospital zone layout – floor 3
(Credit: Marjorie Schott/NREL)

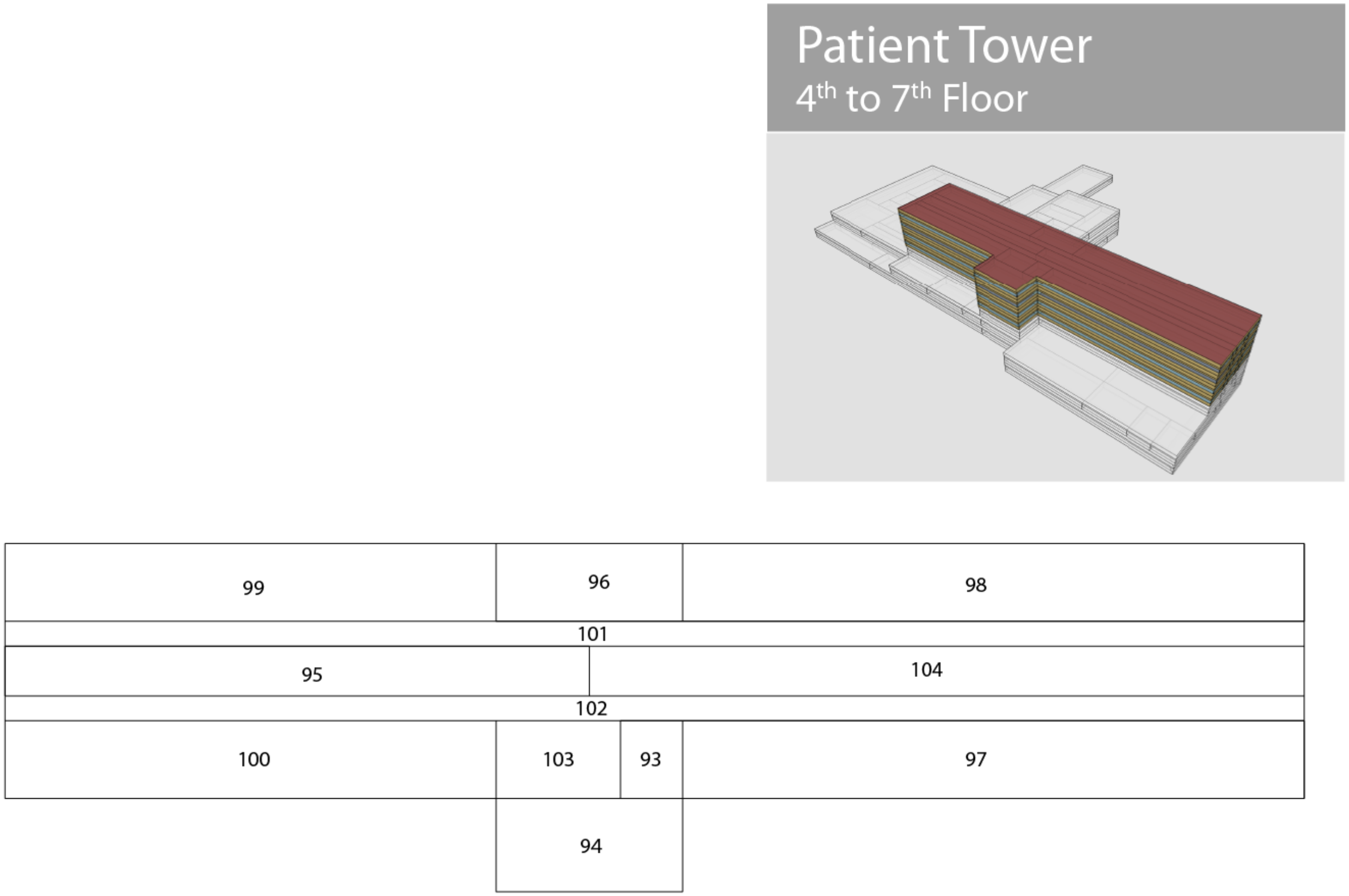

Figure 3–7 Large hospital zone layout – floors 4–7
(Credit: Marjorie Schott/NREL)

Table 3–6 provides a breakdown of the prototype model by space type.

Table 3–6 Prototype Space Type Breakdown

No.	Space Type	Area (ft²)	Percent of Total (%)
1	Anesthesia gas storage	624	0.1
2	Cafeteria	4,018	0.9
3	Clean workroom/holding	3,783	0.9
4	Conference room	6,150	1.4
5	Corridor/transition	38,640	9.0
6	Dining room	4,920	1.2
7	Examination/treatment room	18,940	4.4
8	Food preparation center	4,018	0.9
9	Laboratory	12,580	2.9
10	Lobby area	3,750	0.9
11	Locker	750	0.2
12	Lounge	3,355	0.8
13	Mechanical/electrical room	18,900	4.4
14	Medical supply/medication room	18,400	4.3
15	Nurse station	22,730	5.3
16	Nursery	990	0.2
17	Office	63,765	14.9
18	Operating suite	21,076	4.9
19	Patient room	97,514	22.8
20	Pharmacy	6,000	1.4
21	Physical therapy	4,920	1.2
22	Procedure room	4,600	1.1
23	Radiology/imaging	11,230	2.6
24	Reception/waiting	21,320	5.0
25	Recovery room	6,150	1.4
26	Restroom	1,540	0.4
27	Soiled workroom/holding	6,283	1.5
28	Sterilizer equipment room	1,360	0.3
29	Storage/receiving	12,012	2.8
30	Trauma/emergency room	4,480	1.0
31	Triage	2,375	0.6
Totals		427,173	100

3.2.2 Occupancy

Peak occupant density values by space type were defined according to Table 6-1 in Standard 62.1-2004 (ASHRAE 2004a). The mapping from each space type to the "Occupancy Category" in Standard 62.1-2004 Table 6-1 and the resulting occupant density values are presented in Table 3–7. Values for space types without direct mapping to the standard were estimated (denoted "PC standard practice" in Table 3–7).

Table 3–7 Peak Occupancy by Space Type

Space Type	Occupancy Category (From Table 6-1 in Standard 62.1-2004)	Peak Occupant Density (#/1,000 ft²)
Anesthesia gas storage	General::Storage rooms	0.00
Cafeteria	Food and beverage service:: Cafeteria/fast food dining	100.0
Clean workroom/holding	Office buildings::Office space	5.0
Conference room	General::Conference/meeting	50.0
Corridor/transition	General::Corridors	0.0
Dining room	Food and beverage service:: Restaurant dining rooms	70.0
Examination/treatment room	Office buildings::Office space	5.0
Food preparation center	Kitchen::Commercial	5.0
Laboratory	Office buildings::Office space	5.0
Lobby area	Office buildings::Reception areas	30.0
Locker	Office buildings::Office space	5.0
Lounge	Office buildings::Office space	5.0
Mechanical/electrical room	General::Storage rooms	0.0
Medical supply/medication room	General::Storage rooms	0.0
Nurse station	Office buildings::Office space	5.0
Nursery	Office buildings::Office space	5.0
Office	Office buildings::Office space	5.0
Operating suite	PC standard practice	5.0
Patient room	PC standard practice	5.0
Pharmacy	Miscellaneous spaces::Pharmacy	10.0
Physical therapy	Sports and Entertainment:: Health club/weight rooms	10.0
Procedure room	Office buildings::Office space	5.0
Radiology/imaging	Office buildings::Office space	5.0
Reception/waiting	Office buildings::Reception areas	30.0
Recovery room	Office buildings::Office space	5.0
Restroom	PC standard practice	5.0
Soiled workroom/holding	PC standard practice	5.0
Sterilizer equipment room	PC standard practice	0.0
Storage/receiving	Miscellaneous spaces::Shipping and receiving	0.0
Trauma/emergency room	Office buildings::Office space	5.0
Triage	Office buildings::Office space	5.0

The peak occupant densities in Table 3–7 were modified by schedules in EnergyPlus. Table 3–8 maps each space type in the model to its occupancy schedule. The PC adapted the schedules in the models from those in Bonnema et al. (2010b). The PC modified the schedules reflective of standard practice.

Table 3–8 Occupancy Schedule Matrix

No.	Space Type	Schedule Name	Figure
1	Anesthesia gas storage	24/7 occupancy schedule	Figure 3–9
2	Cafeteria	Dining occupancy schedule	Figure 3–11
3	Clean workroom/holding	24/7 occupancy schedule	Figure 3–9
4	Conference room	Office occupancy schedule	Figure 3–8
5	Corridor/transition	24/7 occupancy schedule	Figure 3–9
6	Dining room	Dining occupancy schedule	Figure 3–11
7	Examination/treatment room	Office occupancy schedule	Figure 3–8
8	Food preparation center	Kitchen occupancy schedule	Figure 3–12
9	Laboratory	24/7 occupancy schedule	Figure 3–9
10	Lobby area	24/7 occupancy schedule	Figure 3–9
11	Locker	24/7 occupancy schedule	Figure 3–9
12	Lounge	24/7 occupancy schedule	Figure 3–9
13	Mechanical/electrical room	Office occupancy schedule	Figure 3–8
14	Medical supply/medication room	24/7 occupancy schedule	Figure 3–9
15	Nurse station	24/7 occupancy schedule	Figure 3–9
16	Nursery	24/7 occupancy schedule	Figure 3–9
17	Office	Office occupancy schedule	Figure 3–8
18	Operating suite	24/7 occupancy schedule	Figure 3–9
19	Patient room	Patient occupancy schedule	Figure 3–10
20	Pharmacy	24/7 occupancy schedule	Figure 3–9
21	Physical therapy	Office occupancy schedule	Figure 3–8
22	Procedure room	Office occupancy schedule	Figure 3–8
23	Radiology/imaging	24/7 occupancy schedule	Figure 3–9
24	Reception/waiting	24/7 occupancy schedule	Figure 3–9
25	Recovery room	24/7 occupancy schedule	Figure 3–9
26	Restroom	24/7 occupancy schedule	Figure 3–9
27	Soiled workroom/holding	24/7 occupancy schedule	Figure 3–9
28	Sterilizer equipment room	24/7 occupancy schedule	Figure 3–9
29	Storage/receiving	Office occupancy schedule	Figure 3–8
30	Trauma/emergency room	24/7 occupancy schedule	Figure 3–9
31	Triage	24/7 occupancy schedule	Figure 3–9

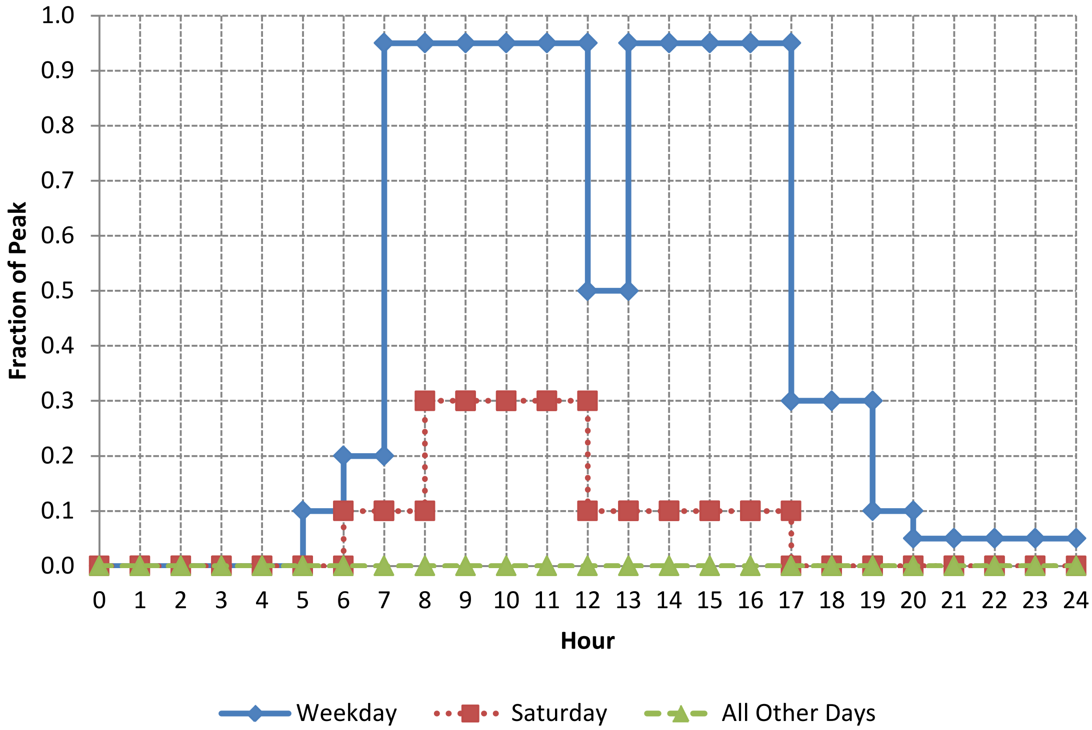

Figure 3–8 Office occupancy schedule

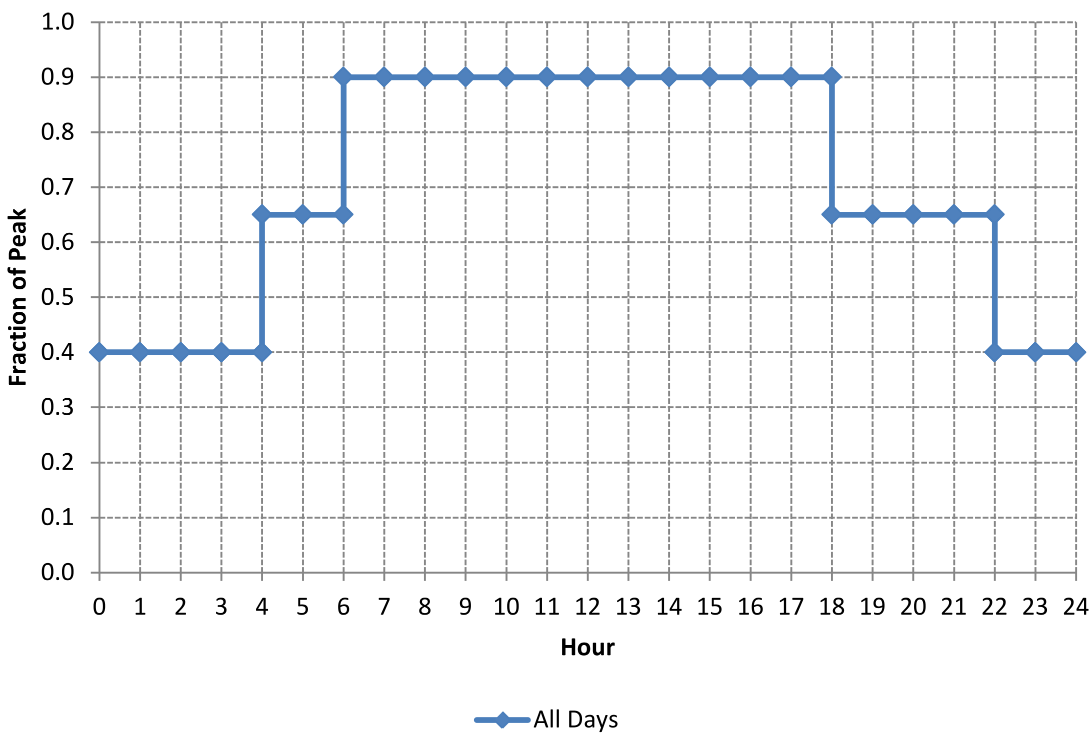

Figure 3–9 24/7 occupancy schedule

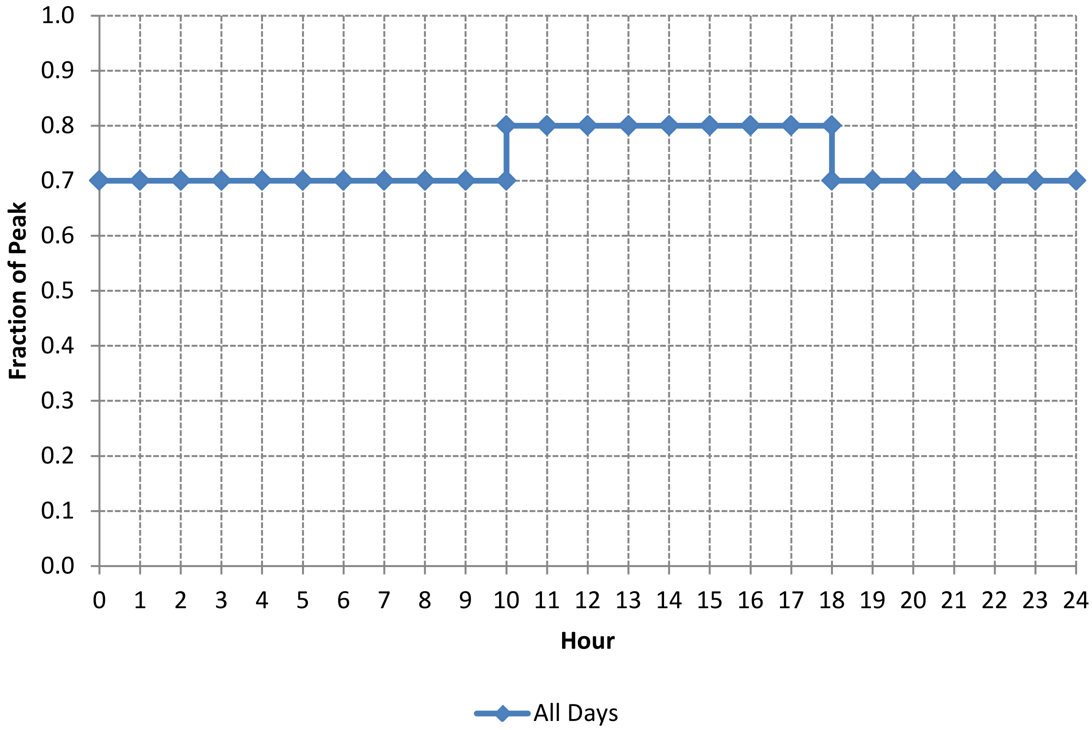

Figure 3–10 Patient occupancy schedule

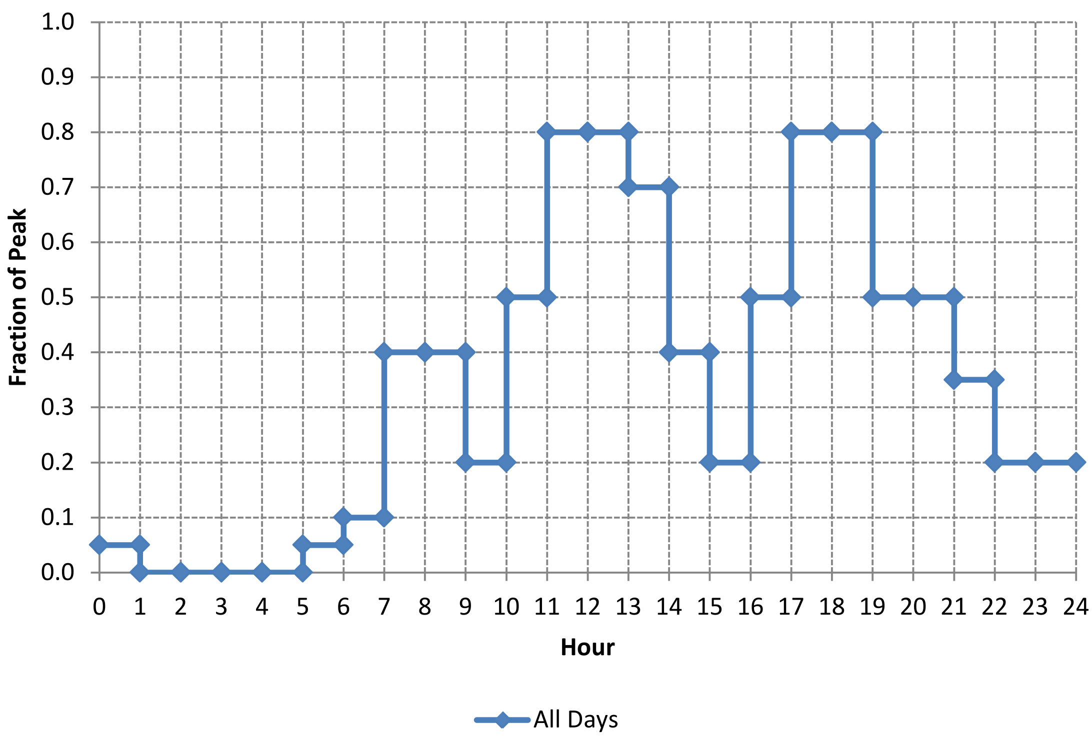

Figure 3–11 Dining occupancy schedule

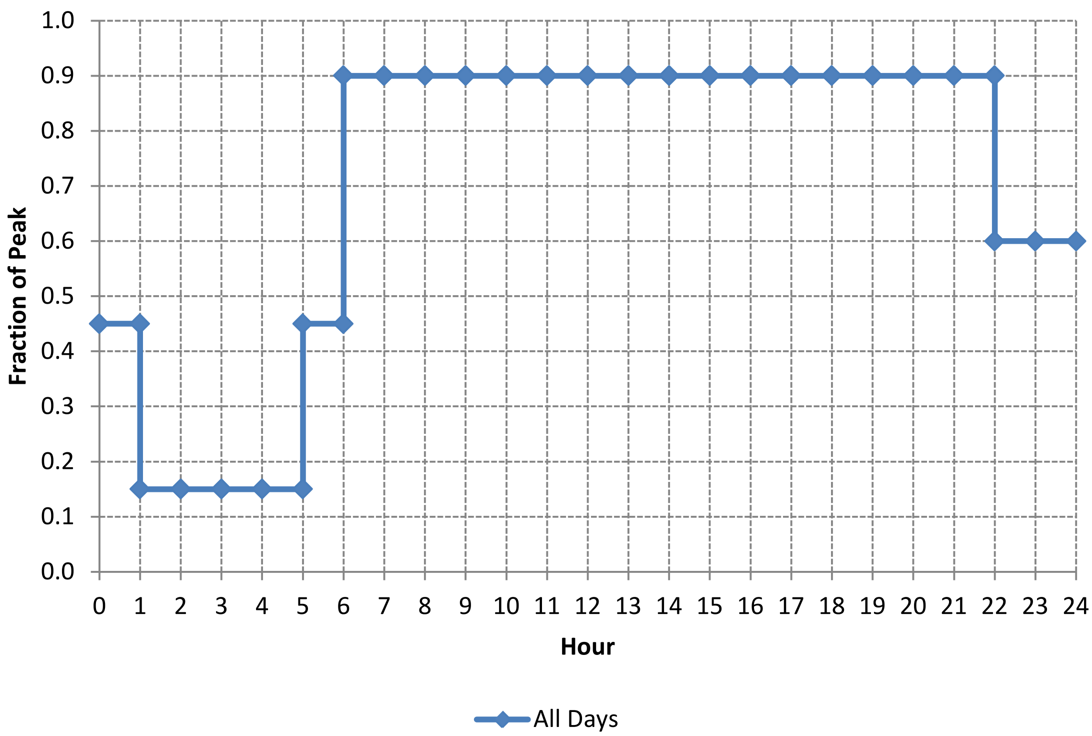

Figure 3–12 Kitchen occupancy schedule

3.2.3 Ventilation and Total Airflow

Ventilation rates by zone were defined in order of priority according to Standard 170-2008 (ASHRAE 2008) and Standard 62.1-2004 (ASHRAE 2004a), depending on space type. Hospitals are unique among commercial buildings in that they have total airflow requirements as well as ventilation airflow requirements. Total airflow requirements are mandated by Standard 170-2008 and apply only to hospital-specific space types. All total air requirements and some ventilation air requirements for the baseline and low-energy model zones were taken from Standard 170-2008. If a zone did not have total air requirements listed in Standard 170-2008, none were set. If a zone did not have ventilation air requirements listed in Standard 170-2008, Standard 62.1-2004 was used.

The mapping from each space type to the respective standard is presented in Table 3–9 and Table 3–10. Spaces with no mapping are shown with a dash. Table 3–10 is very similar to Table 3–7, except Table 3–7 has no estimated values (denoted "PC standard practice"). For these spaces, no value was assumed from Standard 62.1-2004. Table 3–11 presents the minimum ventilation rate for each space type.

Table 3–9 Standard 170-2008 Space Type Mapping

No.	Space Type	Mapping to Standard 170-2008 Table 7-1
1	Anesthesia gas storage	Emergency, surgery, and critical care::Anesthesia gas storage
2	Cafeteria	–
3	Clean workroom/holding	Support areas::Clean workroom or clean holding
4	Conference room	–
5	Corridor/transition	Nursing units::Patient corridor
6	Dining room	–
7	Examination/treatment room	Diagnostic and treatment areas::Examination room
8	Food preparation center	Service areas::Food preparation center
9	Laboratory	Diagnostic and treatment areas::Laboratory::General
10	Lobby area	–
11	Locker	Service areas::Bathroom
12	Lounge	–
13	Mechanical/electrical room	–
14	Medical supply/medication room	Sterilizing and supply::Central medical and surgical supply::Sterile storage
15	Nurse station	–
16	Nursery	Nursing units::Newborn nursery suite
17	Office	–
18	Operating suite	Operating/surgical cytoscopic rooms
19	Patient room	Nursing units::Patient room
20	Pharmacy	Service areas::Pharmacy
21	Physical therapy	Diagnostic and treatment areas::Physical therapy and hydrotherapy
22	Procedure room	Emergency, surgery, and critical care::Procedure room
23	Radiology/imaging	Diagnostic and treatment areas::Imaging::X-ray (diagnostic and treatment)
24	Reception/waiting	–
25	Recovery room	Emergency, surgery, and critical care::Recovery room
26	Restroom	Service areas::Bathroom
27	Soiled workroom/holding	Soiled workroom or soiled holding
28	Sterilizer equipment room	Sterilizing and supply::ETO sterilizer room
29	Storage/receiving	–
30	Trauma/emergency room	Emergency, surgery, and critical care::Trauma room
31	Triage	Emergency, surgical, and critical care::Triage

Table 3–10 Standard 62.1-2004 Space Type Mapping

No.	Space Type	Mapping to Standard 62.1-2004 Table 6-1
1	Anesthesia gas storage	General::Storage rooms
2	Cafeteria	Food and beverage service::Cafeteria/fast food dining
3	Clean workroom/holding	Office buildings::Office space
4	Conference room	General::Conference/meeting
5	Corridor/transition	General::Corridors
6	Dining room	Food and beverage service::Restaurant dining rooms
7	Examination/treatment room	Office buildings::Office space
8	Food preparation center	Kitchen::Commercial*
9	Laboratory	Office buildings::Office space
10	Lobby area	Office buildings::Reception areas
11	Locker	Office buildings::Office space and locker rooms*
12	Lounge	Office buildings::Office space
13	Mechanical/electrical room	General::Storage rooms
14	Medical supply/medication room	General::Storage rooms
15	Nurse station	Office buildings::Office space
16	Nursery	Office buildings::Office space
17	Office	Office buildings::Office space
18	Operating suite	–
19	Patient room	–
20	Pharmacy	Miscellaneous spaces::Pharmacy
21	Physical therapy	Sports and entertainment::Health club/weight rooms
22	Procedure room	Office buildings::Office space
23	Radiology/imaging	Office buildings::Office space
24	Reception/waiting	Office buildings::Reception areas
25	Recovery room	Office buildings::Office space
26	Restroom	Locker/dressing rooms*
27	Soiled workroom/holding	–
28	Sterilizer equipment room	General::Storage rooms
29	Storage/receiving	Miscellaneous spaces::Shipping/receiving
30	Trauma/emergency room	Office buildings::Office space
31	Triage	Office buildings::Office space

*Mapping to Standard 62.1-2004 Table 6-4

Table 3–11 Ventilation and Total Airflow Requirements

No.	Space Type	Per Person Ventilation (cfm/person)	Per Area Ventilation (cfm/ft²)	OA Changes (ACH)	Total Air Changes (ACH)
1	Anesthesia gas storage	–	0.12	–	8
2	Cafeteria	7.5	0.18	–	–
3	Clean workroom/holding	5.0	0.06	–	4
4	Conference room	5.0	0.06	–	–
5	Corridor/transition	–	0.06	–	2
6	Dining room	7.5	0.18	–	–
7	Examination/treatment room	5.0	0.06	–	6
8	Food preparation center	–	0.70	–	10
9	Laboratory	5.0	0.06	–	6
10	Lobby area	5.0	0.06	–	–
11	Locker	–	0.50	–	10
12	Lounge	5.0	0.06	–	–
13	Mechanical/electrical room	–	0.12	–	–
14	Medical supply/medication room	–	0.12	–	4
15	Nurse station	5.0	0.06	–	–
16	Nursery	–	–	2	6
17	Office	5.0	0.06	–	–
18	Operating suite	–	–	4	20
19	Patient room	–	–	2	6*
20	Pharmacy	5.0	0.18	–	4
21	Physical therapy	20.0	0.06	–	6
22	Procedure room	-	-	3	15
23	Radiology/imaging	5.0	0.06	–	6
24	Reception/waiting	5.0	0.06	–	–
25	Recovery room	–	-	2	6
26	Restroom	–	0.25	–	10
27	Soiled workroom/holding	5.0	0.06	–	10
28	Sterilizer equipment room	–	0.12	–	10
29	Storage/receiving	–	0.12	–	–
30	Trauma/emergency room	–	–	3	15
31	Triage	–	–	2	12

* Set to 4 ACH in the low-energy model based on Standard 170-2008 Table 7-1 note s.

3.2.4 Exhaust Fans

Standard 170-2008 requires certain space types to exhaust all room air directly to the outdoors. For this analysis, these requirements applied to the following space types:

- Anesthesia gas storage
- Locker
- Restroom
- Soiled workroom/holding
- Sterilizer equipment room
- Triage.

These space types all have a total air change requirement according to Standard 170-2008 Table 7-1. Because all room air is required to be exhausted directly to the outdoors, the exhaust airflow rate was set to the total air change requirement for that zone (see Table 3–11). The exhaust fans in these space types were modeled as 50% efficient with a 0.75-in. w.c. pressure drop, values the PC felt were appropriate. The exhaust fans in these spaces operated continuously.

Exhaust fans were also modeled in the kitchen. Table 3–12 shows the details on each fan.

Table 3–12 Kitchen Exhaust Fan Details

Fan Efficiency (%)	Pressure Drop (in. w.c.)	Flow Rate (cfm)
55	2.30	10,100
56	1.90	12,500
47	0.75	1,000

The kitchen exhaust fans followed the schedule shown in Figure 3–13.

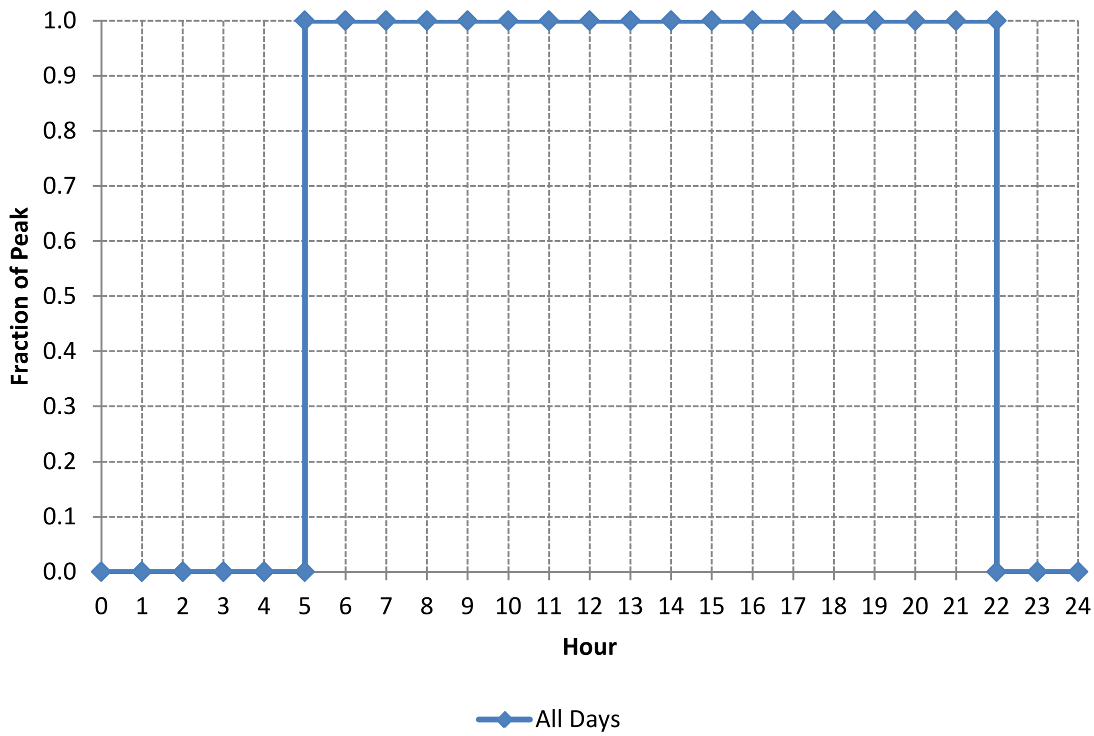

Figure 3–13 Kitchen exhaust fan schedule

3.2.5 Thermostat Set Points

The thermostat set points in the models were derived from those in Bonnema et al. (2010b). The PC modified the set points based on members' experience designing hospitals. Table 3–12 maps each space type in the model to its thermostat schedule. These schedules remain consistent between the baseline and low-energy models.

Table 3–13 Thermostat Schedule Matrix

No.	Space Type	Schedule Name	Figure
1	Anesthesia gas storage	24/7 thermostat schedule	Figure 3–14
2	Cafeteria	Dining thermostat schedule	Figure 3–15
3	Clean workroom/holding	24/7 thermostat schedule	Figure 3–14
4	Conference room	Office thermostat schedule	Figure 3–13
5	Corridor/transition	24/7 thermostat schedule	Figure 3–14
6	Dining room	Dining thermostat schedule	Figure 3–15
7	Examination/treatment room	Office thermostat schedule	Figure 3–13
8	Food preparation center	Kitchen thermostat schedule	Figure 3–16
9	Laboratory	24/7 thermostat schedule	Figure 3–14
10	Lobby area	24/7 thermostat schedule	Figure 3–14
11	Locker	24/7 thermostat schedule	Figure 3–14
12	Lounge	24/7 thermostat schedule	Figure 3–14
13	Mechanical/electrical room	Office thermostat schedule	Figure 3–13
14	Medical supply/medication room	24/7 thermostat schedule	Figure 3–14
15	Nurse station	24/7 thermostat schedule	Figure 3–14
16	Nursery	24/7 thermostat schedule	Figure 3–14
17	Office	Office thermostat schedule	Figure 3–13
18	Operating suite	Operating thermostat schedule	Figure 3–17
19	Patient room	24/7 thermostat schedule	Figure 3–14
20	Pharmacy	24/7 thermostat schedule	Figure 3–14
21	Physical therapy	Office thermostat schedule	Figure 3–13
22	Procedure room	Office thermostat schedule	Figure 3–13
23	Radiology/imaging	24/7 thermostat schedule	Figure 3–14
24	Reception/waiting	24/7 thermostat schedule	Figure 3–14
25	Recovery room	24/7 thermostat schedule	Figure 3–14
26	Restroom	24/7 thermostat schedule	Figure 3–14
27	Soiled workroom/holding	24/7 thermostat schedule	Figure 3–14
28	Sterilizer equipment room	24/7 thermostat schedule	Figure 3–14
29	Storage/receiving	Office thermostat schedule	Figure 3–13
30	Trauma/emergency room	24/7 thermostat schedule	Figure 3–14
31	Triage	24/7 thermostat schedule	Figure 3–14

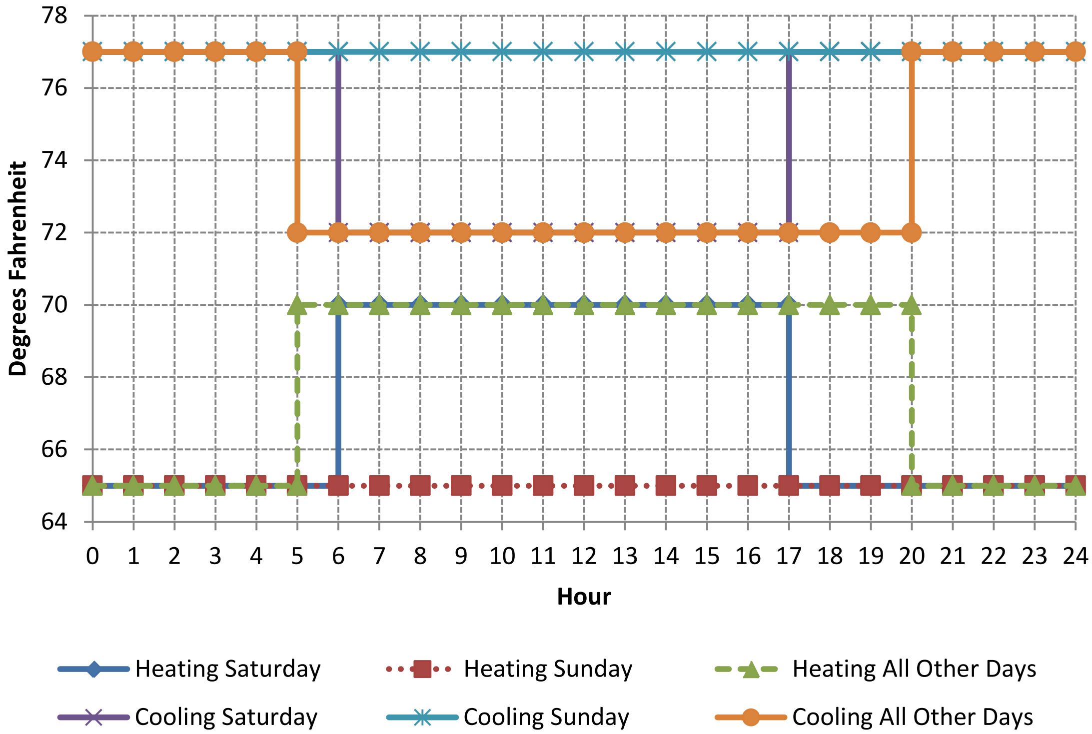

Figure 3–14 Office thermostat schedule

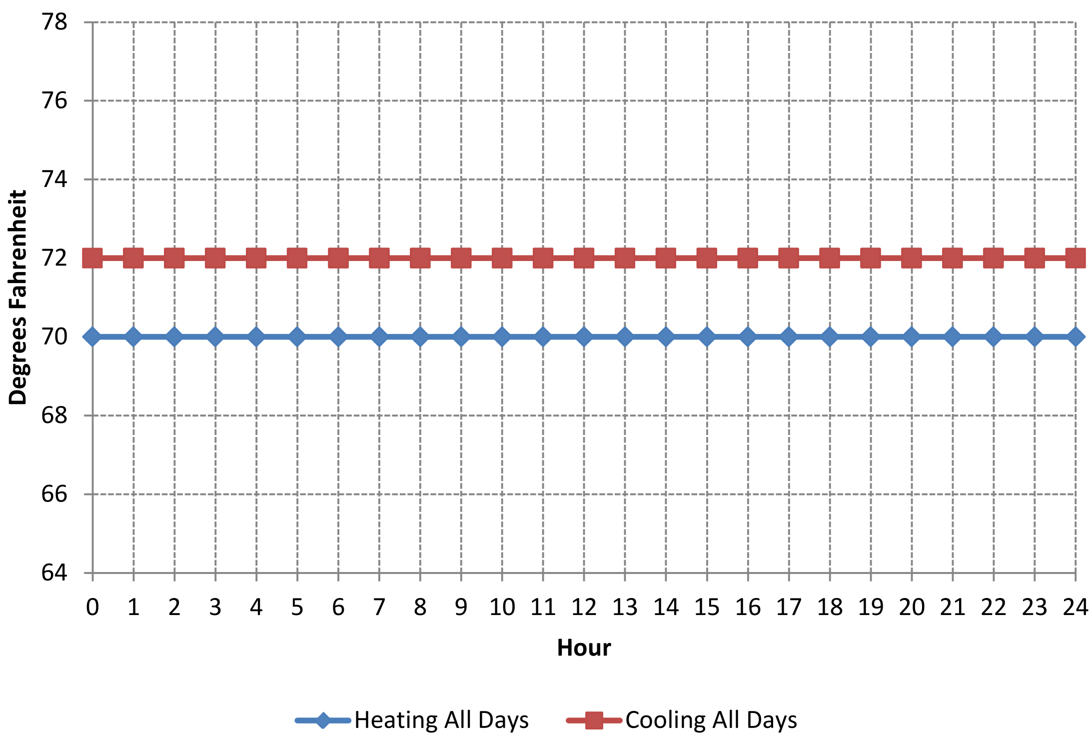

Figure 3–15 24/7 thermostat schedule

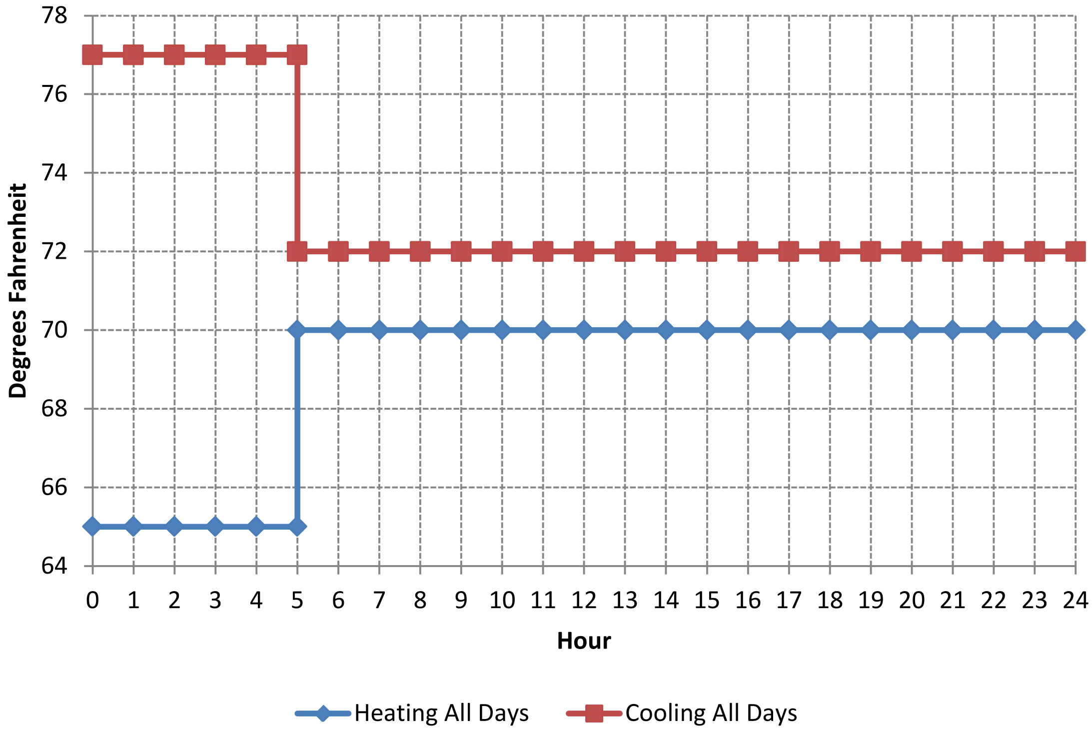

Figure 3–16 Dining thermostat schedule

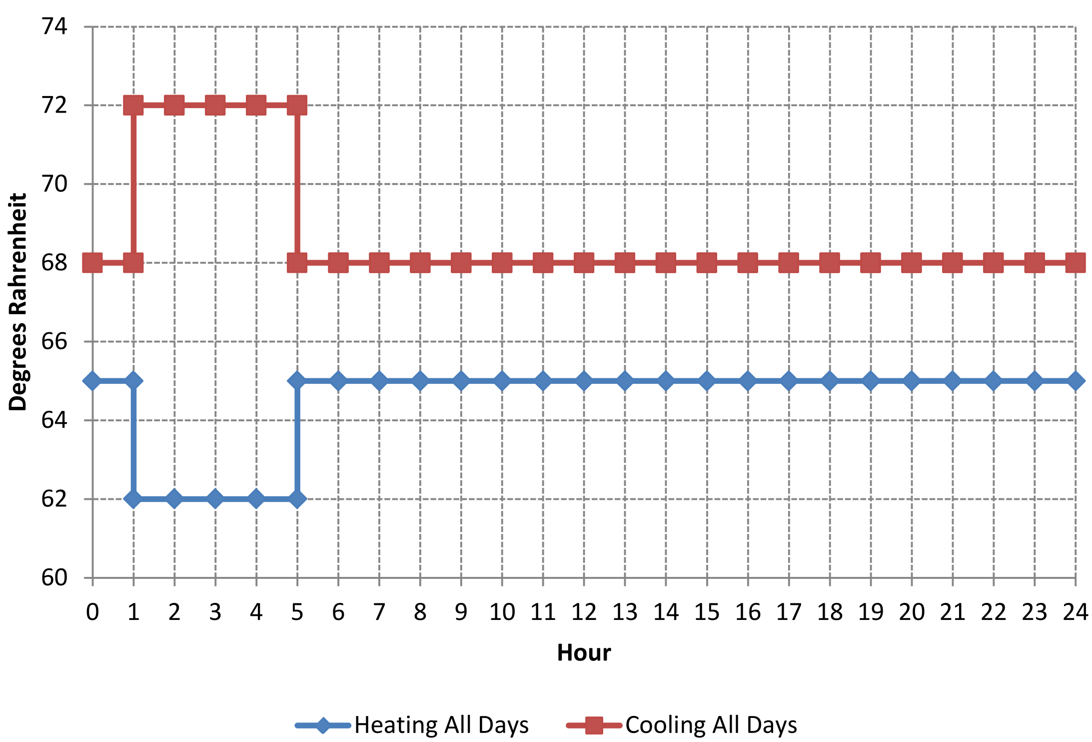

Figure 3–17 Kitchen thermostat schedule

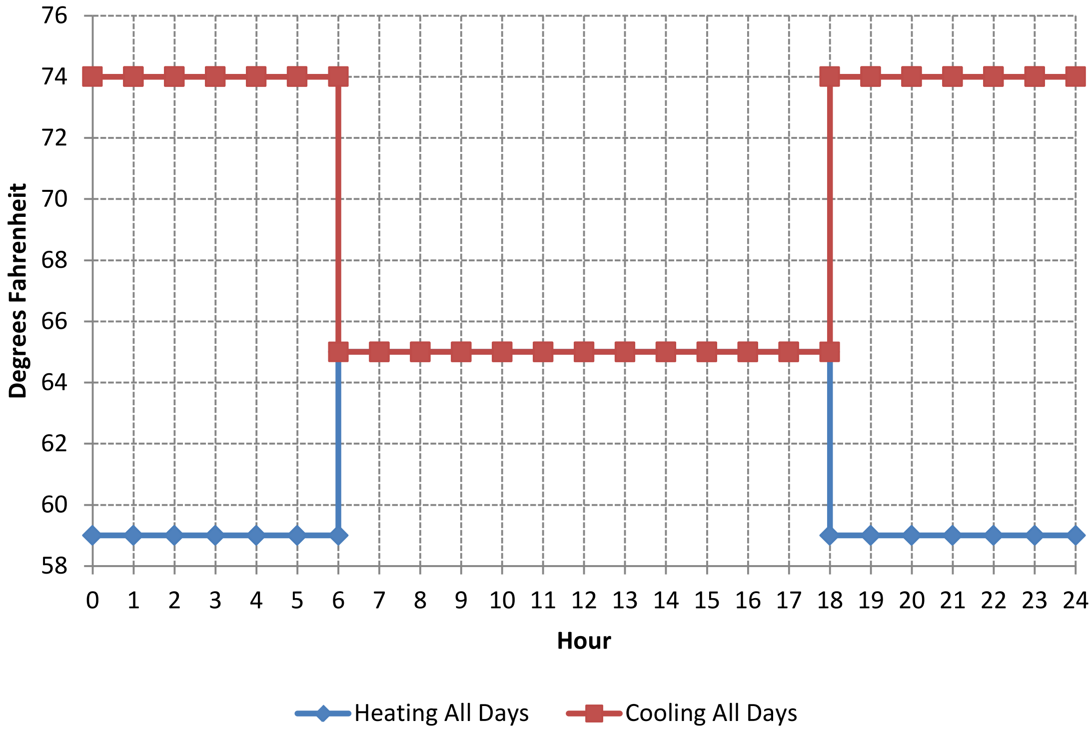

Figure 3–18 Operating thermostat schedule

3.2.6 Economizers

Using economizers for "free cooling" in hospitals is more complex than in other buildings types, because hospitals (unlike most commercial buildings) have minimum humidity requirements. The best economizing climates are often dry, and any energy savings provided by free cooling can be offset (or more than offset) by the additional humidification energy required because of the increased volume of outdoor air (OA). In fact, buildings are exempt from the economizer requirements in Standard 90.1-2004 if they have minimum humidity requirements. To be conservative, no economizers were modeled in either the baseline or the low-energy models.

3.2.7 Refrigeration

The prototype refrigeration system serves the cafeteria and food storage zones and contains two compressor racks: one low-temperature rack (serving a walk-in freezer), and one medium-temperature rack (serving an island, three reach-in coolers, and a walk-in cooler). The heat from the compressor racks is rejected by air-cooled condensers. The refrigeration remained consistent between the baseline and the low-energy models. The types, sizes, and number of cases and walk-in units are listed in Table 3–13. Note the Case IDs in Table 3–13 are referenced in Table 3–14.

Table 3–14 Refrigerated Cases and Walk-In Units by Zone

Zone Name	Case ID	Case/Walk-In Type	Case Length or Walk-In Area
Floor 1 Cafeteria	RC1	Single-deck island	18 ft
Floor 1 Cafeteria	RC2	Single-deck open front reach-in cooler	6 ft
Floor 1 Cafeteria	RC3	Large multideck open front reach-in cooler	24 ft
Floor 1 Cafeteria	RC4	Small multideck open front reach-in cooler	6 ft
Floor 1 Food Storage	WI1	Walk-in freezer	180 ft^2
Floor 1 Food Storage	WI2	Walk-in cooler	480 ft^2

Three types of refrigerated cases are modeled: an island, a single-deck open front reach-in cooler, and a multideck open front reach-in cooler. A typical walk-in cooler and freezer are modeled. The rated performance conditions for all cases/walk-in units are 75°F and 55% relative humidity (RH), per Air Conditioning and Refrigeration Institute Standard 1200-2002 (ARI 2002). Table 3–14 summarizes the performance data of the refrigerated cases.

Table 3–15 Refrigerated Case and Walk-In Unit Characteristics

Characteristic	RC1	RC2	RC3	RC4	WI1	WI2
Rated capacity (Btu/h)	7,094	6,050	38,060	6,787	49,606	38,032
Operating temperature (°F)	34.0	36.0	34.0	34.0	22.0	32.0
Fan power (W)	431.8	213.1	565.8	97.6	335.0	361.0
Lighting power (W)	336.6	425.2	1844.0	147.6	0.0	0.0
Defrost power (W)	0.0	0.0	0.0	0.0	592	7,495

EnergyPlus assumes that compressor racks can always satisfy the case load connected to them. It also models compressor racks and their associated condensers as one unit. Air-cooled condensers are assumed for the models. The fan power for each rack is 12,190 W and the properties from R-404a refrigerant are used. The full set of EnergyPlus refrigeration objects used in the models can be found in Appendix D.

3.3 Baseline Model Development and Assumptions

The baseline models were derived from the prototype models by applying the applicable criteria in Standard 90.1-2004. The PC members used their expertise to help define items (such as PPLs) that are not specified by Standard 90.1-2004.

3.3.1 Envelope

The PC assumed, based on the experience of those in the hospital construction industry, that these facilities are typically constructed with mass exterior walls, built-up roofs, and slab-on-grade floors. There are some regional variations, but the PC felt these constructions represent common practices.

The baseline hospital envelope characteristics were developed to meet the prescriptive design option requirements in accordance with Standard 90.1-2004 Section 5.2. For the baseline model, the prescriptive building envelope option in Section 5.5 was used. Layer-by-layer descriptions of the constructions were used to model the building thermal envelope in EnergyPlus.

3.3.1.1 Exterior Walls

The baseline hospital was modeled with mass wall constructions. The layers consisted of stucco, concrete block, rigid insulation, and gypsum board. Insulation R-values for continuous insulation (c.i.) were selected to meet the minimum wall insulation requirements in Table 5.5-1 through Table 5.5-8 (Building Envelope Requirements) of Standard 90.1-2004, as defined by climate zone. The baseline exterior wall insulation R-values and U-values from Standard 90.1-2004 are listed in Table 3–15.

Table 3–16 Baseline Exterior Wall Constructions

Climate Zone	Assembly U-Factor (Btu/h·ft²·°F)	Insulation R-Value, Nominal (h·ft²·°F/Btu)
1	U-0.580	No insulation requirement (NR)
2	U-0.580	No insulation requirement (NR)
3	U-0.151	R-5.7 c.i.
4	U-0.151	R-5.7 c.i.
5	U-0.123	R-7.6 c.i.
6	U-0.104	R-9.5 c.i.
7	U-0.090	R-11.4 c.i.
8	U-0.080	R-13.3 c.i.

The mass wall construction was assembled assuming 8-in. medium-weight concrete blocks with a density of 140 lb/ft³ and solid grouted cores. The mass wall construction includes the following layers:

- Exterior air film (calculated by EnergyPlus)
- 1-in. exterior stucco
- 8-in. concrete block, 140 lb/ft³
- 1-in. metal clips with rigid insulation (R-value varies by climate)
- 0.5-in. thick gypsum board
- Interior air film (calculated by EnergyPlus).

To calculate the thermal performance of the interior air films, the EnergyPlus "TARP" algorithm for surface heat transfer film coefficients was used. The EnergyPlus "DOE-2" algorithm for surface heat transfer film coefficients was used to calculate the thermal performance of the exterior air films. This algorithm is based on linearized radiation coefficients that are separate from the convection coefficients, as determined during simulation by surface roughness, wind speed, and terrain. It determines coefficients based on location- and weather-dependent parameters. A set of typical film coefficients was developed to determine standard values. These standardized combined film coefficients were used to target assembly U-factors (see Table 3–16) (DOE 2011).

Table 3–17 Standard Film Coefficients

Surface Class	Interior Film Coefficient (h·ft²·°F/Btu)	Exterior Film Coefficient (h·ft²·°F/Btu)
Wall	0.68	0.17
Floor	0.92	0.46
Ceiling/roof	0.61	0.46

3.3.1.2 Roofs

Built-up, rigid insulation above a structural metal deck roof was used in the baseline model. The layers consisted of the roof membrane, roof insulation, and metal decking. The U-factors varied based on the applicable climate zone. Added insulation was continuous and uninterrupted by framing. Roof insulation R-values were set to match the minimum roof insulation requirements in Table 5.5-1 through Table 5.5-8 of Standard 90.1-2004, by climate. The baseline model roof U-factors and insulation R-values are included in Table 3–17.

Table 3–18 Baseline Roof Constructions

Climate Zone	Assembly U-Factor (Btu/h·ft²·°F)	Insulation R-Value, Nominal (h·ft²·°F/Btu)
1	U-0.063	R-15.0 c.i.
2	U-0.063	R-15.0 c.i.
3	U-0.063	R-15.0 c.i.
4	U-0.063	R-15.0 c.i.
5	U-0.063	R-15.0 c.i.
6	U-0.063	R-15.0 c.i.
7	U-0.063	R-15.0 c.i.
8	U-0.048	R-20.0 c.i.

Standard 90.1-2004 does not specify absorptance or other surface assumptions. The roof exterior finish was assumed to be a single-ply roof membrane with gray ethylene propylene polymer membrane in the baseline models. Therefore, a solar reflectance of 0.3, a thermal absorption of 0.9, and a visible absorption of 0.7 were assumed.

3.3.1.3 Slab-on-Grade Floors

The baseline model was assumed to have slab-on-grade floors, which were composed of a carpet pad layer over an 8-in. thick heavyweight concrete layer.

A slab program that is packaged with EnergyPlus was used to model the ground coupling. It determines the temperature of the ground under the slab based on the area and thickness of the slab, the location of the building, and the type of insulation under or around the slab. For the baseline model, the program was used to run a simple building in each location. The program reported the perimeter ground monthly temperatures, the core ground monthly temperatures, and monthly averages of these temperatures. For this analysis, the average monthly temperatures were used as the input for the ground temperatures under the floor slab in the EnergyPlus input files (see Table 3–18 and Table 3–19).

Table 3–19 Simulated Monthly Ground Temperatures (°F), Climate Zones 1A–4A

Month	1A	2A	2B	3A	3B:CA	3B	3C	4A
January	72.5	69.0	66.7	67.9	68.2	66.0	67.8	67.5
February	72.8	68.6	66.6	67.8	68.2	66.0	67.9	67.4
March	73.0	69.4	68.7	67.9	68.2	66.0	67.8	67.5
April	73.3	71.8	70.5	68.8	68.4	68.6	67.9	67.5
May	73.5	73.0	70.7	71.7	69.0	69.6	67.9	68.9
June	73.5	73.2	70.1	72.6	69.7	69.7	68.1	71.8
July	73.6	73.3	69.9	72.8	72.3	69.4	68.6	72.4
August	73.6	73.3	70.3	73.0	72.9	69.5	68.1	72.6
September	73.6	73.4	70.6	73.1	73.0	69.8	68.8	71.9
October	73.7	73.1	70.9	70.1	71.5	69.6	68.2	69.1
November	73.5	70.9	68.6	68.5	69.1	66.6	68.0	68.1
December	73.2	69.2	66.9	68.1	68.4	66.1	67.9	67.6

Table 3–20 Simulated Monthly Ground Temperatures (°F), Climate Zones 4B–8

Month	4B	4C	5A	5B	6A	6B	7	8
January	66.6	67.5	67.1	66.6	66.8	66.4	66.5	65.2
February	66.6	67.5	67.1	66.5	66.8	66.5	66.5	65.1
March	66.5	67.5	67.2	66.6	66.9	66.5	66.6	65.4
April	66.6	67.6	67.3	66.7	67.1	66.6	66.8	65.7
May	68.8	67.7	68.0	66.9	68.3	66.7	66.9	66.0
June	70.5	68.1	71.0	68.8	70.8	68.1	67.6	66.4
July	70.8	69.3	72.0	70.7	71.8	70.4	69.7	67.3
August	71.1	70.0	72.3	71.2	72.1	69.8	68.8	66.6
September	71.3	68.8	70.6	68.8	69.2	67.7	67.6	66.4
October	67.7	68.0	68.2	67.2	67.8	66.9	67.2	66.1
November	66.9	67.7	67.6	66.8	67.4	66.7	67.0	65.7
December	66.7	67.6	67.3	66.6	67.1	66.5	66.7	65.4

3.3.1.4 Fenestration

Building fenestration includes all envelope penetrations used for ingress and egress or lighting such as windows, doors, and skylights.

Standard 90.1-2004 (ASHRAE 2004b) specifies window properties as window systems and not as window frame and glass separately; thus, window frames were not explicitly modeled and only one window was modeled per exterior surface. This reduced the complexity and increased the speed of the EnergyPlus simulations. The baseline model had an overall fraction of fenestration to gross wall area of 40%; individual fenestration objects were distributed evenly on applicable exterior surfaces.

The U-factors and solar heat gain coefficients (SHGCs) that were applied to the fenestration objects were whole-assembly values and included framing effects. The performance criteria listed in Table 3–20 were set to match the requirements of Table 5.5-1 through Table 5.5-8 in Standard 90.1-2004 (ASHRAE 2004b). One deviation is that all windows were given the same properties, whereas in Standard 90.1-2004 (ASHRAE 2004b) the north-facing windows have a different SHGC. This was done because the AEDG-LH does not differentiate between façade directions. The multipliers from the visible light transmittance (VLT) table, Table C3.5 in

Standard 90.1-2004 Appendix C (ASHRAE 2004b), were used to calculate VLT values for the baseline windows.

Table 3–21 Baseline Window Constructions

Climate Zone	U-Factor (Btu/h·ft²·°F)	SHGC	VLT
1 (A)	1.22	0.25	0.250
2 (A,B)	1.22	0.25	0.250
3 (A,B)	0.57	0.25	0.318
3 (C)	1.22	0.34	0.340
4 (A,B,C)	0.57	0.39	0.495
5 (A,B)	0.57	0.39	0.495
6 (A,B)	0.57	0.39	0.495
7	0.57	0.49	0.490
8	0.46	NR, 0.49 used	NR, 0.490 used

3.3.2 Infiltration

Infiltration (also known as air leakage into a building) is the flow of OA into a building through cracks and other unintentional openings and through the normal use of exterior doors for ingress and egress (ASHRAE 2009).

Infiltration rates were calculated using an infiltration rate factor and total exterior wall areas for each zone. Because the rate is dependent on total exterior wall area, it varies from zone to zone. The calculated infiltration rate factor was assumed to be constant throughout the year. This is a good assumption for annual energy performance, but this method should be used cautiously for evaluating hour-by-hour loads.

To determine the infiltration rate factor, the building was assumed to be constructed such that at a pressure differential of 75 Pa, the infiltration rate was equivalent to 0.4 cfm/ft² of external wall area. Using a flow coefficient of 0.65 and an assumed pressure differential across the envelope of 4 Pa (a pressure likely to be encountered during normal building operation), the final infiltration rate factor of 0.06 cfm/ft² was calculated. For zones with no external wall surfaces, the infiltration rate was set to zero. This methodology is consistent with that used by Deru et al. (2011).

Because a large volume of OA was brought into the building by the HVAC system, the calculated zone infiltration rates were modified via an infiltration schedule that was set to 0.50 during HVAC system operation. The infiltration schedule was a simple multiplier that in this case reduced the total infiltration by half. In many buildings, this schedule would be increased to 1.0 when the HVAC system was shut off for the night, to simulate the greater infiltration rate that would result from the building no longer being pressurized. But because hospitals have unique space requirements, the HVAC system operated 24/7, so the infiltration modification schedule was set to a constant value of 0.50.

3.3.3 Electric Lighting

3.3.3.1 Interior Lighting

The LPDs used in the baseline model are listed in Table 3–21. These values were determined by using the space-by-space method in Standard 90.1-2004, Table 9.6.1 (ASHRAE 2004b). Table 3–21 also lists the mapping from each space type to the standard.

Table 3–22 Baseline Model LPDs

No.	Space Type	Mapping to Standard 90.1-2004 Table 9.6.1	LPD (W/ft²)
1	Anesthesia gas storage	Active storage for hospital	0.90
2	Cafeteria	Dining area	0.90
3	Clean workroom/holding	Office – enclosed	1.10
4	Conference room	Conference/meeting/multipurpose	1.30
5	Corridor/transition	Corridor/transition for hospital	1.00
6	Dining room	Dining area	0.90
7	Examination/treatment room	Hospital exam/treatment	1.50
8	Food preparation center	Food preparation	1.20
9	Laboratory	Laboratory	1.40
10	Lobby area	Lobby	1.30
11	Locker	Dressing/locker/fitting room	0.60
12	Lounge	Lounge/recreation for hospital	0.80
13	Mechanical/electrical room	Electrical/mechanical	1.50
14	Medical supply/medication room	Hospital medical supply	1.40
15	Nurse station	Hospital nurse station	1.00
16	Nursery	Hospital nursery	0.60
17	Office	Office – enclosed	1.10
18	Operating suite	Hospital operating room	2.20
19	Patient room	Hospital patient room	1.70
20	Pharmacy	Hospital pharmacy	1.20
21	Physical therapy	Hospital physical therapy	0.90
22	Procedure room	Hospital emergency room	2.70
23	Radiology/imaging	Hospital radiology	0.40
24	Reception/waiting	Lobby	1.30
25	Recovery room	Hospital recovery	0.80
26	Restroom	Restrooms	0.90
27	Soiled workroom/holding	Office – enclosed	1.10
28	Sterilizer equipment room	Active storage for hospital	0.90
29	Storage/receiving	Active storage for hospital	0.90
30	Trauma/emergency room	Hospital emergency room	2.70
31	Triage	Hospital exam/treatment	2.70
Whole-Building Area Weighted Average			1.35

The peak values in Table 3–21 were modified with hour-by-hour multiplier schedules in EnergyPlus. The lighting schedules were adapted by the PC from those in Bonnema et al. (2010b). The PC modified the schedules reflective of standard practice. Table 3–22 maps each space type in the model to its lighting schedule.

Table 3–23 Lighting Schedule Matrix

No.	Space Type	Schedule Name	Figure
1	Anesthesia gas storage	24/7 Lighting Schedule	Figure 3–19
2	Cafeteria	Dining Lighting Schedule	Figure 3–20
3	Clean workroom/holding	24/7 Lighting Schedule	Figure 3–19
4	Conference room	Office Lighting Schedule	Figure 3–18
5	Corridor/transition	24/7 Lighting Schedule	Figure 3–19
6	Dining room	Dining Lighting Schedule	Figure 3–20
7	Examination/treatment room	Office Lighting Schedule	Figure 3–18
8	Food preparation center	Dining Lighting Schedule	Figure 3–20
9	Laboratory	24/7 Lighting Schedule	Figure 3–19
10	Lobby area	24/7 Lighting Schedule	Figure 3–19
11	Locker	24/7 Lighting Schedule	Figure 3–19
12	Lounge	24/7 Lighting Schedule	Figure 3–19
13	Mechanical/electrical room	Office Lighting Schedule	Figure 3–18
14	Medical supply/medication room	24/7 Lighting Schedule	Figure 3–19
15	Nurse station	24/7 Lighting Schedule	Figure 3–19
16	Nursery	24/7 Lighting Schedule	Figure 3–19
17	Office	Office Lighting Schedule	Figure 3–18
18	Operating suite	24/7 Lighting Schedule	Figure 3–19
19	Patient room	Patient Lighting Schedule	Figure 3–21
20	Pharmacy	24/7 Lighting Schedule	Figure 3–19
21	Physical therapy	Office Lighting Schedule	Figure 3–18
22	Procedure room	Office Lighting Schedule	Figure 3–18
23	Radiology/imaging	24/7 Lighting Schedule	Figure 3–19
24	Reception/waiting	24/7 Lighting Schedule	Figure 3–19
25	Recovery room	24/7 Lighting Schedule	Figure 3–19
26	Restroom	24/7 Lighting Schedule	Figure 3–19
27	Soiled workroom/holding	24/7 Lighting Schedule	Figure 3–19
28	Sterilizer equipment room	24/7 Lighting Schedule	Figure 3–19
29	Storage/receiving	Office Lighting Schedule	Figure 3–18
30	Trauma/emergency room	24/7 Lighting Schedule	Figure 3–19
31	Triage	24/7 Lighting Schedule	Figure 3–19

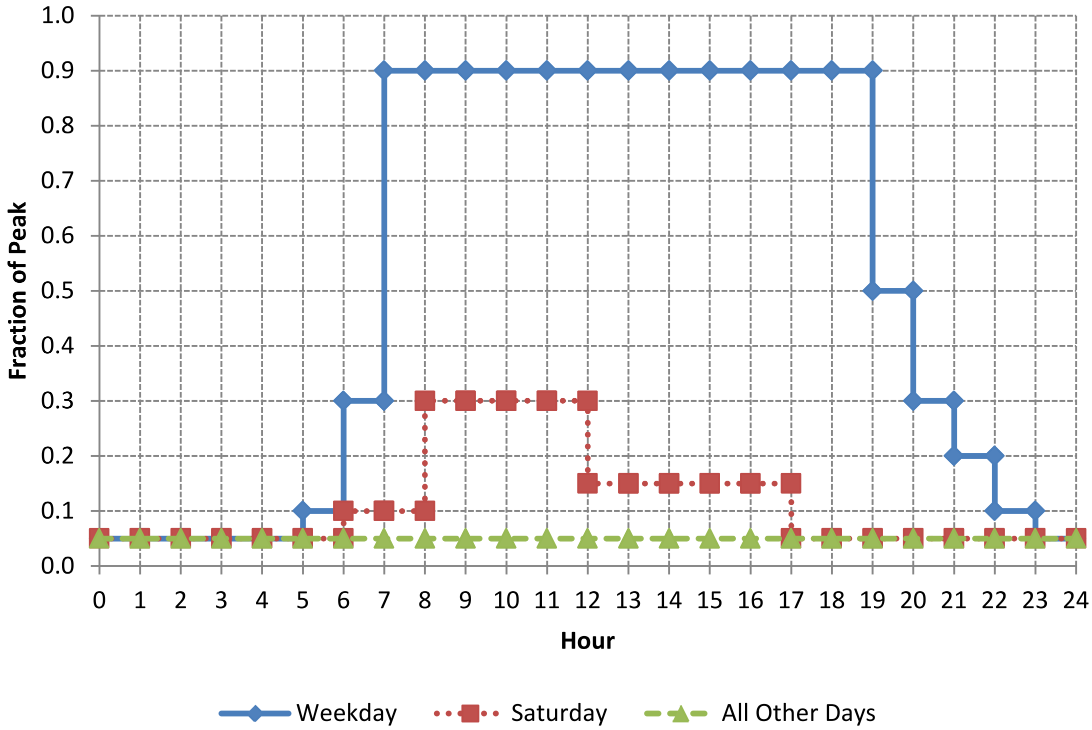

Figure 3–19 Office lighting schedule

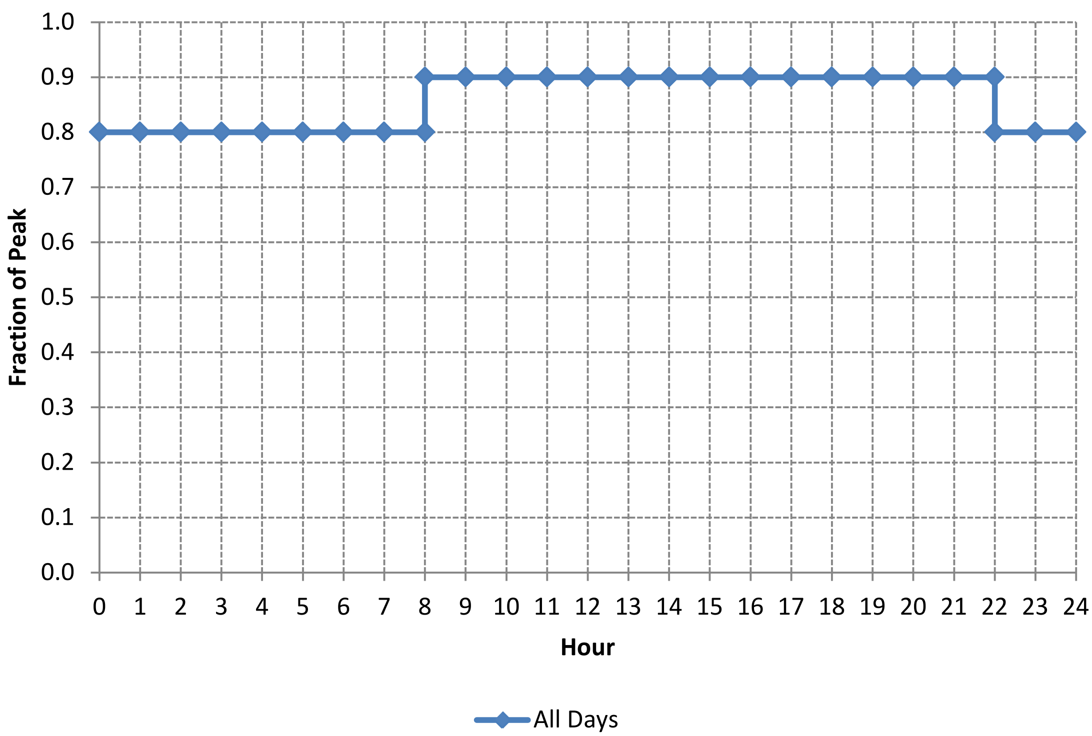

Figure 3–20 24/7 lighting schedule

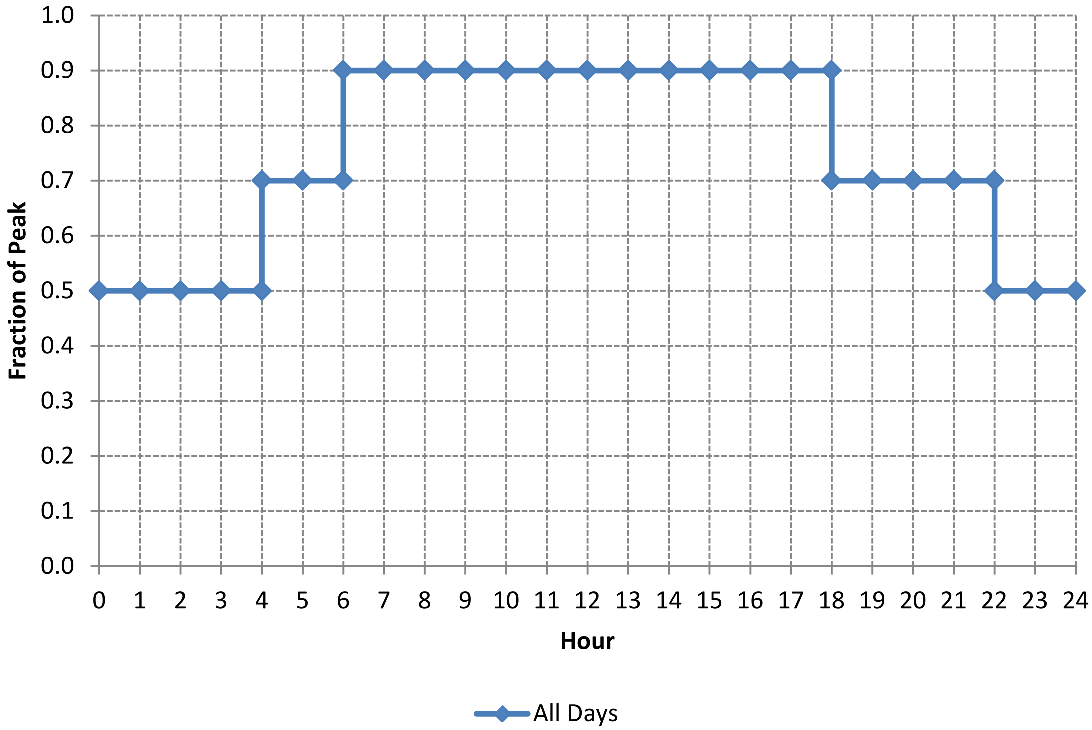

Figure 3–21 Dining lighting schedule

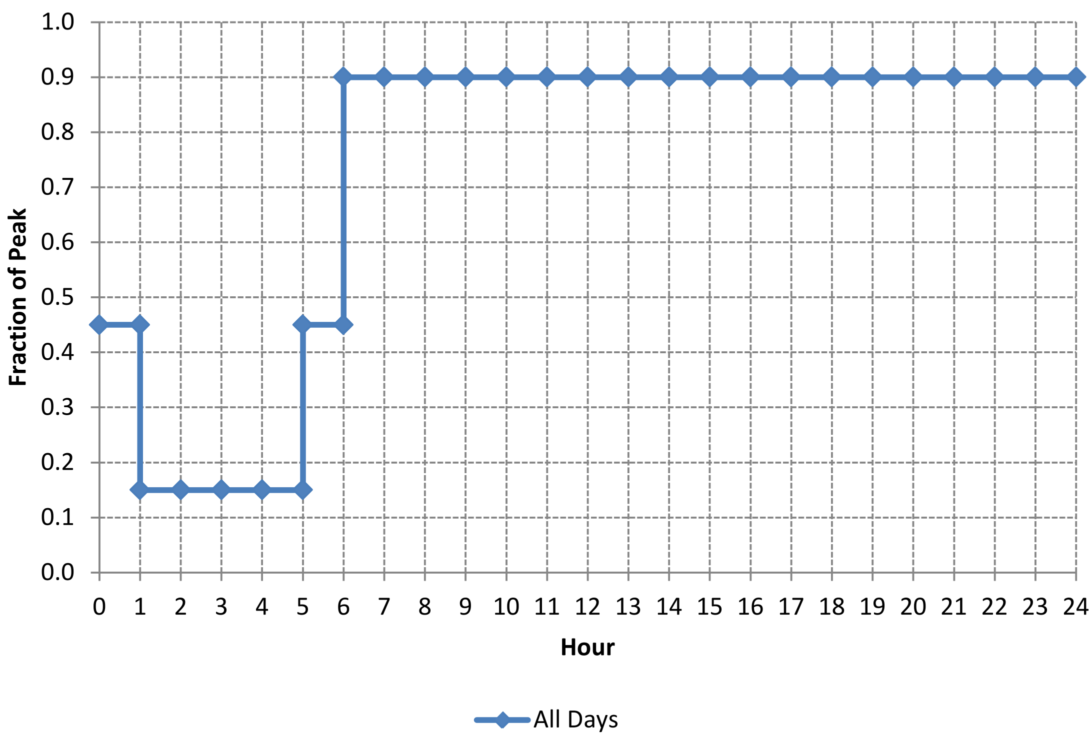

Figure 3–22 Patient lighting schedule

3.3.3.2 Exterior Lighting

Two types of exterior lights were modeled: façade lighting and parking garage lighting. The façade lighting value of 5 W per linear foot of façade length was taken from Table 9.4.5 in Standard 90.1-2004 (ASHRAE 2004b). The model has 2,350 ft of façade, resulting in a façade lighting power of 11,750 W. The PC members provided information from their experience working on hospital projects to determine the lighting power for the parking garage, as follows:

- Assumed 1,500 parking spaces for the 150-bed, 427,173-ft^2 hospital
- Assumed each parking space was 8.5 ft × 17.5 ft (~150 ft^2 per space)
- 150 ft^2 × 1,500 = 225,000 ft^2 of parking spaces
- Assumed twice the amount of area for drives, ramps, etc.; resulting in a total garage area of 450,000 ft^2
- Assumed an LPD of 0.2 W/ft^2, taken from Standard 90.1-2004 Table 9.4.5 (ASHRAE 2004b)
- This results in 90,000 W of lighting power for the parking garage.

The façade lights were controlled by an astronomical clock that turned the lights on when the sun set and off when the sun rose. The parking garage lights were on 24/7.

3.3.4 Plug and Process Loads

PPLs are notoriously difficult to estimate. The PPLs were adapted from Bonnema et al. (2010b) based on PC input. The values in Bonnema et al. (2010b) are from the *Green Guide for Health Care: Best Practices for Creating High Performance Healing Environments, Version 2.2* (GGHC) (GGHC 2007). The electricity and gas process loads for the food preparation space type were derived from an *ASHRAE Transactions* article regarding the estimation of food service loads and profiles (ASHRAE 2001). Table 3–23 shows a summary of the PPLs used in the baseline model and Table 3–24 shows the mapping from the space types in the model to the GGHC. Values for space types without direct mapping to the GGHC were estimated.

Table 3–24 Baseline Model PPLs

No.	Space Type	Electric Plug Load Density (W/ft²)	Electric Process Load Density (W/ft²)	Gas Process Load Density (W/ft²)
1	Anesthesia gas storage	–	–	–
2	Cafeteria	0.10	–	–
3	Clean workroom/holding	2.00	–	–
4	Conference room	0.10	–	–
5	Corridor/transition	0.10	–	–
6	Dining room	0.10	–	–
7	Examination/treatment room	1.00	–	–
8	Food preparation center	1.00	17.50	173.70
9	Laboratory	1.00	3.00	–
10	Lobby area	0.10	–	–
11	Locker	0.25	–	–
12	Lounge	1.00	–	–
13	Mechanical/electrical room	0.20	–	–
14	Medical supply/medication room	1.00	–	–
15	Nurse station	0.50	0.50	–
16	Nursery	1.00	–	–
17	Office	0.50	–	–
18	Operating suite	1.00	3.00	–
19	Patient room	1.25	–	–
20	Pharmacy	1.00	–	–
21	Physical therapy	1.00	–	–
22	Procedure room	1.00	3.00	–
23	Radiology/imaging	1.00	8.00	–
24	Reception/waiting	0.10	–	–
25	Recovery room	1.00	1.00	–
26	Restroom	0.10	–	–
27	Soiled workroom/holding	–	–	–
28	Sterilizer equipment room	1.00	5.00	7.00
29	Storage/receiving	1.00	–	–
30	Trauma/emergency room	1.00	3.00	–
31	Triage	1.00	–	–
Whole-Building Area Weighted Average		0.74	0.73	1.66

Table 3–25 PPL GGHC Space Type Mapping

No.	Space Type	Mapping to GGHC Table OCC-1 (Plug Loads)	Mapping to GGHC Table P-1 (Process Loads)
1	Anesthesia gas storage	Anesthesia storage	–
2	Cafeteria	–	–
3	Clean workroom/holding	Clean utility/workroom	–
4	Conference room	Conference rooms	–
5	Corridor/transition	Corridors	–
6	Dining room	Dining room	–
7	Examination/treatment room	Treatment/examination	–
8	Food preparation center	Kitchen, food preparation	Full service kitchen
9	Laboratory	Laboratory	Labs
10	Lobby area	Waiting areas/lounges	–
11	Locker	Lockers	–
12	Lounge	Waiting areas/lounges	–
13	Mechanical/electrical room	Janitors closet/utility	–
14	Medical supply/medication room	Surgical supply	–
15	Nurse station	Nursing stations – general	Nursing units
16	Nursery	Nursery, general	–
17	Office	–	–
18	Operating suite	Operating room	Surgical suite
19	Patient room	Patient room	–
20	Pharmacy	Pharmacy/medicine room	–
21	Physical therapy	Physical therapy	–
22	Procedure room	Trauma	Emergency department
23	Radiology/imaging	X-ray	Imaging department
24	Reception/waiting	Waiting areas/lounges	–
25	Recovery room	Recovery	ICU/CCU
26	Restroom	Bathroom/public	–
27	Soiled workroom/holding	–	–
28	Sterilizer equipment room	Sterilizer room	Central sterile
29	Storage/receiving	Unsterile supply	–
30	Trauma/emergency room	Trauma	Emergency department
31	Triage	–	–

The peak values in Table 3–23 were modified with hour-by-hour multiplier schedules in EnergyPlus. The PPL schedules were adapted by the PC from those in Bonnema et al. (2010b). The PC modified the schedules reflective of standard practice. Table 3–25 maps each space type in the model to its PPL schedule.

Table 3–26 PPL Schedule Matrix

No.	Space Type	Electric Plug Load Schedule	Electric Process Load Schedule	Gas Process Load Schedule
1	Anesthesia gas storage	–	–	–
2	Cafeteria	Figure 3–24	–	–
3	Clean workroom/holding	Figure 3–23	–	–
4	Conference room	Figure 3–22	–	–
5	Corridor/transition	Figure 3–23	–	–
6	Dining room	Figure 3–25	–	–
7	Examination/treatment room	Figure 3–22	–	–
8	Food preparation center	Figure 3–25	Figure 3–25	Figure 3–25
9	Laboratory	Figure 3–23	Figure 3–23	–
10	Lobby area	Figure 3–23	–	–
11	Locker	Figure 3–23	–	–
12	Lounge	Figure 3–23	–	–
13	Mechanical/electrical room	Figure 3–22	–	–
14	Medical supply/medication room	Figure 3–23	–	–
15	Nurse station	Figure 3–23	–	–
16	Nursery	Figure 3–23	–	–
17	Office	Figure 3–22	–	–
18	Operating suite	Figure 3–23	Figure 3–23	–
19	Patient room	Figure 3–23	–	–
20	Pharmacy	Figure 3–23	–	–
21	Physical therapy	Figure 3–22	–	–
22	Procedure room	Figure 3–22	Figure 3–22	–
23	Radiology/imaging	Figure 3–23	Figure 3–23	–
24	Reception/waiting	Figure 3–23	–	–
25	Recovery room	Figure 3–23	–	–
26	Restroom	Figure 3–23	–	–
27	Soiled workroom/holding	–	–	–
28	Sterilizer equipment room	Figure 3–23	Figure 3–23	Figure 3–23
29	Storage/receiving	Figure 3–22	Figure 3–22	–
30	Trauma/emergency room	Figure 3–23	Figure 3–23	–
31	Triage	Figure 3–23	–	–

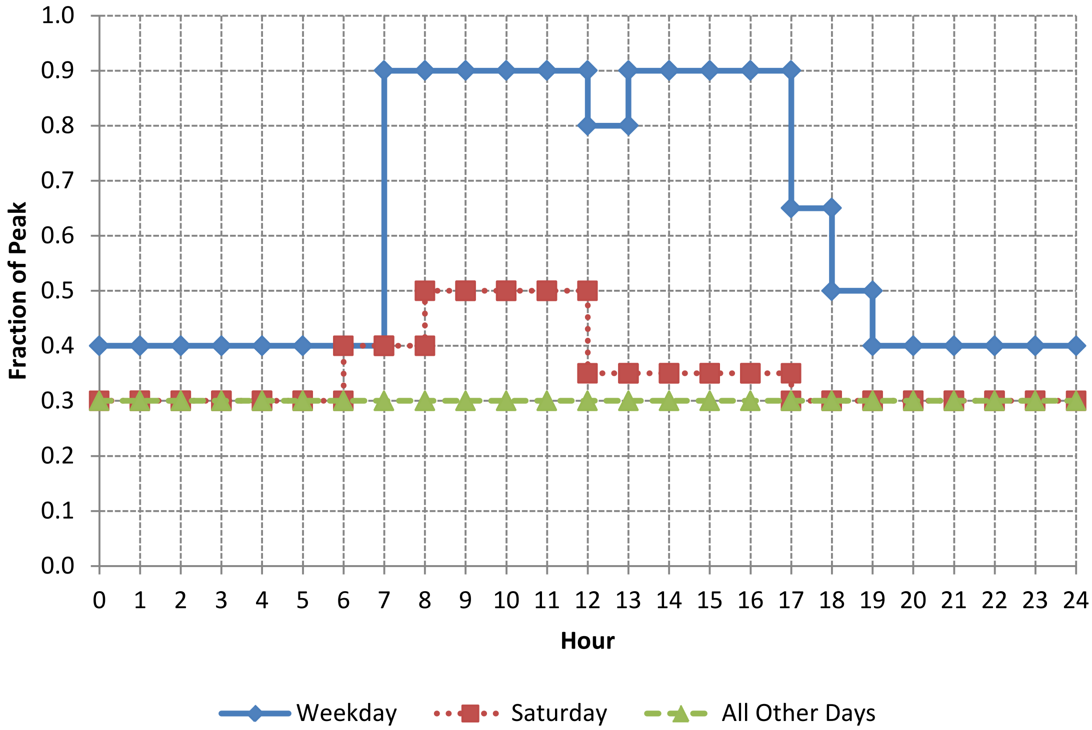

Figure 3–23 Office PPL schedule

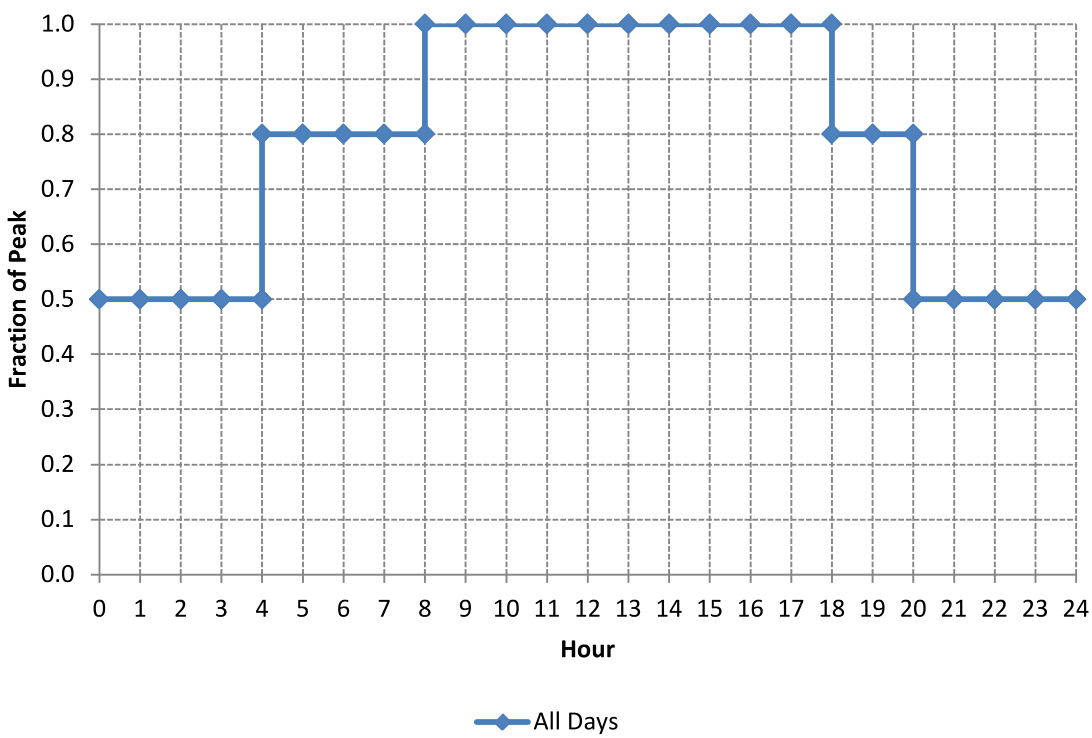

Figure 3–24 24/7 PPL schedule

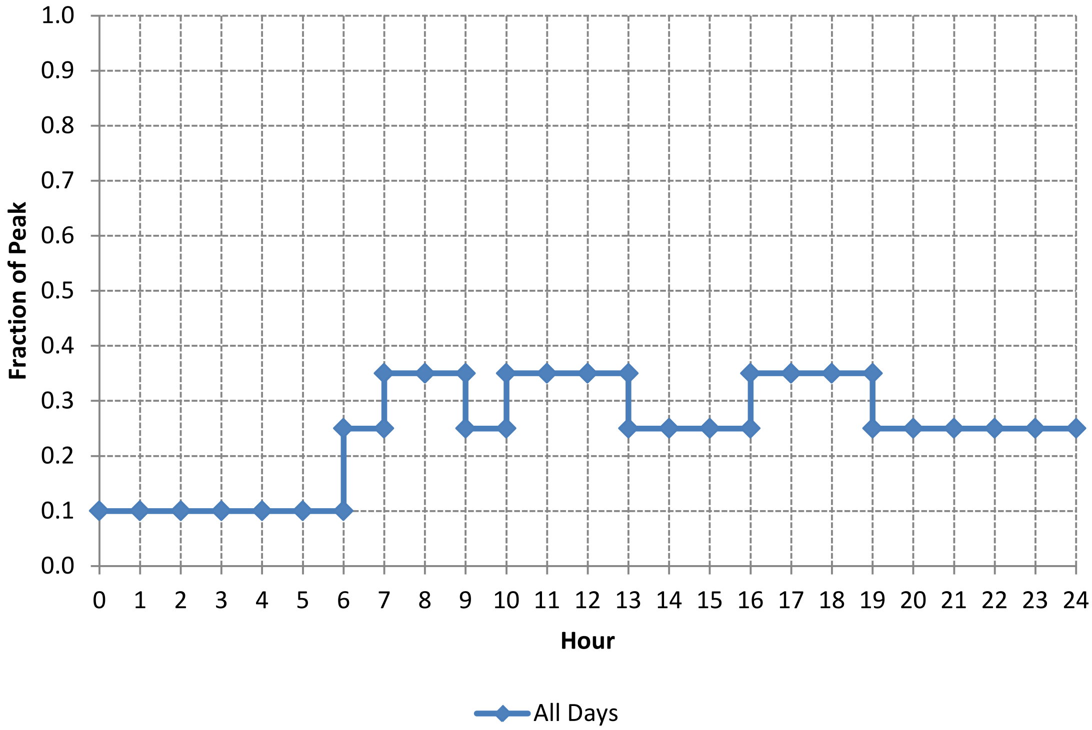

Figure 3–25 Food preparation center PPL schedule 1

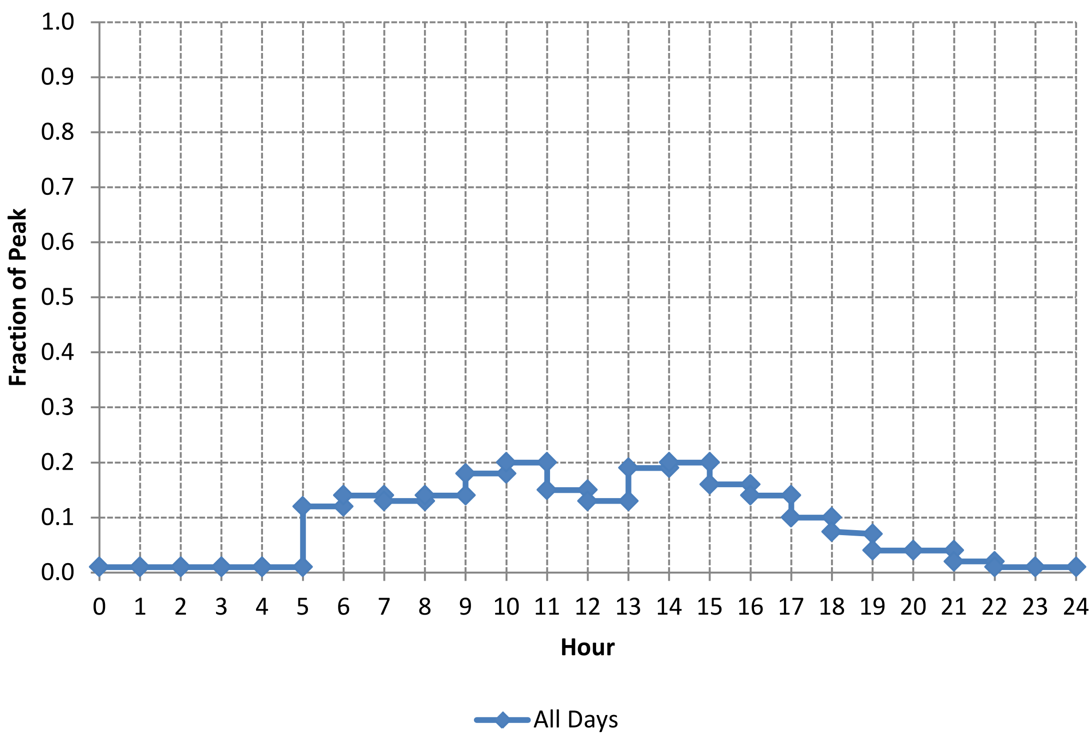

Figure 3–26 Food preparation center PPL schedule 2

3.3.5 Elevators

A total elevator load of 72,000 W was modeled. This value was determined with the help of the PC. The peak elevator load was modified by the schedule in Figure 3–26. The elevator load is not applied to any zone; the elevator equipment was assumed to be located on the roof.

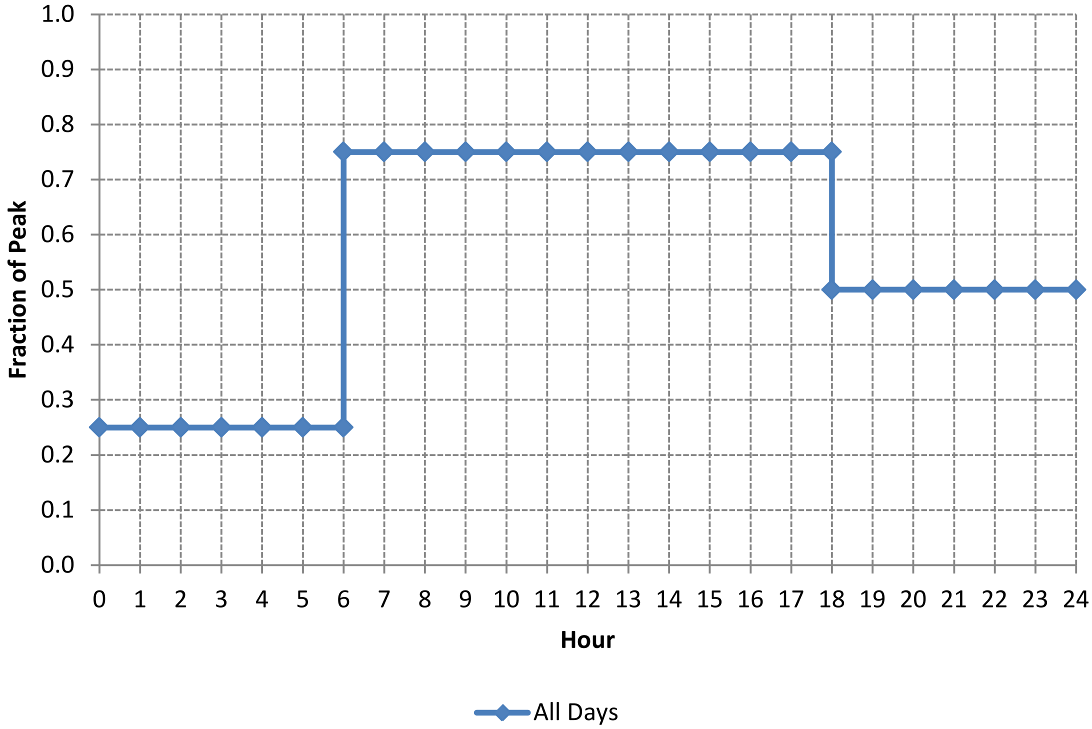

Figure 3–27 Elevator schedule

3.3.6 Heating, Ventilation, and Air Conditioning

The baseline model was conditioned with a traditional VAV reheat system. The system consisted of VAV AHUs and a central plant with a noncondensing boiler and water-cooled chiller.

3.3.6.1 Hot Water System

The hot water system was served by a noncondensing, natural gas-fired, 80% efficient boiler that supplied water to the AHU heating coils and VAV box reheat coils according to an OA reset-based supply water temperature set point. The OA reset set point schedule was as follows: 180°F at an outdoor temperature ≤ 20°F, 150°F at an outdoor temperature ≥ 50°F. The upper and lower bounds of this schedule were taken from Section G3.1.3.4 of Standard 90.1-2004 (ASHRAE 2004b). When OA temperatures fell within the 20°–50°F range, the supply water temperature value was linearly interpolated. Water was circulated through the hot water system via a 75% efficient variable-speed pump with 80 ft of head.

The boiler efficiency was modeled strictly as a function of its operating part-load ratio (PLR), which is the heating load divided by the steady-state heating capacity at any point in time. The cubic equation used to model the boiler efficiency was $0.626 + 0.649 \times PLR - 0.777 \times PLR^2 +$

0.314 × PLR^3 (Bonnema et al. 2010a). Figure 3–27 shows the boiler efficiency as a function of PLR curve.

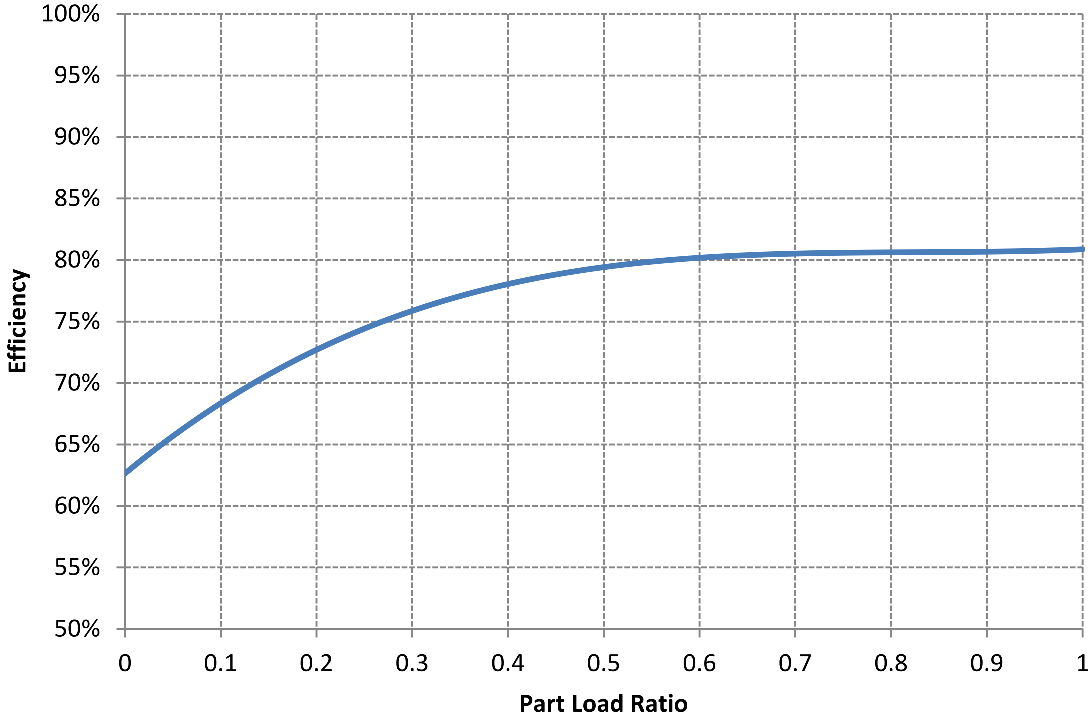

Figure 3–28 Baseline boiler efficiency

3.3.6.2 Chilled Water System

The chilled water system was supplied by a water-cooled, variable-speed, 6.1 coefficient of performance (COP) centrifugal chiller. Its performance curves were taken from Bonnema et al. (2010a). Water was supplied to the AHU chilled water coils at 44°F with a design return water temperature of 56°F. The cooling tower was modeled as a variable-speed cross-flow open cooling tower with a design approach temperature (outlet water temperature minus inlet air wet-bulb temperature) of 7°F and a design range temperature (inlet water temperature minus outlet water temperature) of 10°F. Water was circulated through the chilled water system via a 75% efficient variable-speed pump with 75 ft of head. The condenser loop contained a 75% efficient constant-speed pump with 60 ft of head.

3.3.6.3 Air Handling Units

Each floor of the energy model and the operating suite on the second floor had its own VAV AHU for a total of eight VAV AHUs serving the building. The AHUs contained hot water preheat coils and chilled water cooling coils and had a constant leaving air temperature set point of 55°F. Section 5.10.1 of Standard 62.1-2004 (ASHRAE 2004a) states that an occupied space's RH shall be no higher than 65%. Standard 170-2008 lowers this requirement further by mandating a maximum humidity of 60%. Therefore, the cooling coils in all applicable AHUs were controlled in such a way as to prevent the RH of the control zones from rising higher than 60%.

Each AHU contained a 60% efficient variable-speed fan with an 8-in. w.c. pressure drop. Each was equipped with a 1,000-kW, 354-gal/h electric, direct-injection steam humidifier to maintain the control zone's interior RH at 30% or higher, as mandated by Standard 170-2008 (ASHRAE 2008). Although gas humidifiers are generally favored over electric devices in a hospital setting, electric humidifiers are the only option in EnergyPlus. For each AHU, a control zone with high OA requirements was chosen in an attempt to ensure that all zones served by that AHU met the required minimum RH set point throughout the year. Because of variations in latent loads caused by varying occupancy and SWH loads in each zone, the RH in any zone is unlikely to always be within the required tolerances.

Each thermal zone in the energy model was equipped with VAV terminal unit with a hot water reheat coil. The terminal box minimum flow fraction (ratio of actual flow to maximum flow) was set to 0.3 in space types that do not have total airflow requirements in Table 3–11. For the space types that do have total airflow requirements in Table 3–11, the minimum flow of the terminal unit was set on a zone-by-zone basis to ensure that the total airflow rates specified in Table 3–11 were met.

All heating coils were connected to the hot water system described in Section 3.3.6.1; all cooling coils were connected to the chilled water system described in Section 3.3.6.2.

3.3.6.4 Operating Suite Air Handling Unit

The operating suite AHU was modeled identically to the AHUs described in Section 3.3.6.3, except the leaving air temperature set point was fixed at 49°F instead of 55°F and the modeled fan pressure drop was raised to 12 in. w.c.

3.3.7 Service Water Heating

Except for the SWH flow rates in the kitchen and patient rooms, design flow rate values for SWH loads were taken from GGHC (2007). The GGHC does not explicitly provide flow rates, but it does provide design thermal loads by space type, in units of Btu/h/person. For this TSD, these design loads were converted to design flow rates based on the thermodynamic properties of water and an assumed temperature rise of 95ºF in the SWH system.

The kitchen SWH design flow rate and schedule values were taken directly from the Full Service Restaurant Reference Building Model (Deru et al. 2011). The design flow rate and schedule for the patient room SWH loads were based on data for nursing homes found in Table 7 of Chapter 49 in the *2007 ASHRAE Handbook – HVAC Applications* (ASHRAE 2007). The patient room SWH schedule was developed such that the total and peak daily water use matched the values found in the table. Table 3–26 provides an overview of the design (peak) flow rates by space type.

Table 3–27 SWH Loads

No.	Space Type	Design Flow Rate (gal/h/person)
1	Anesthesia gas storage	–
2	Cafeteria	0.379
3	Clean workroom/holding	–
4	Conference room	0.190
5	Corridor/transition	–
6	Dining room	0.379
7	Examination/treatment room	0.379
8	Food preparation center	133.0 (gal/h)
9	Laboratory	0.758
10	Lobby area	0.126
11	Locker	–
12	Lounge	–
13	Mechanical/electrical room	–
14	Medical supply/medication room	–
15	Nurse station	0.19
16	Nursery	0.379
17	Office	–
18	Operating suite	1.267
19	Patient room	18.4 (gal/h)
20	Pharmacy	0.190
21	Physical therapy	0.190
22	Procedure room	0.758
23	Radiology/imaging	0.758
24	Reception/waiting	–
25	Recovery room	0.379
26	Restroom	–
27	Soiled workroom/holding	0.758
28	Sterilizer equipment room	0.758
29	Storage/receiving	–
30	Trauma/emergency room	0.758
31	Triage	0.758

All SWH load schedules except those in the food preparation center and patient room zones referenced their respective zone occupancy schedules. Figure 3–28 and Figure 3–29 provide the SWH use schedules associated with the food preparation center and patient room zones.

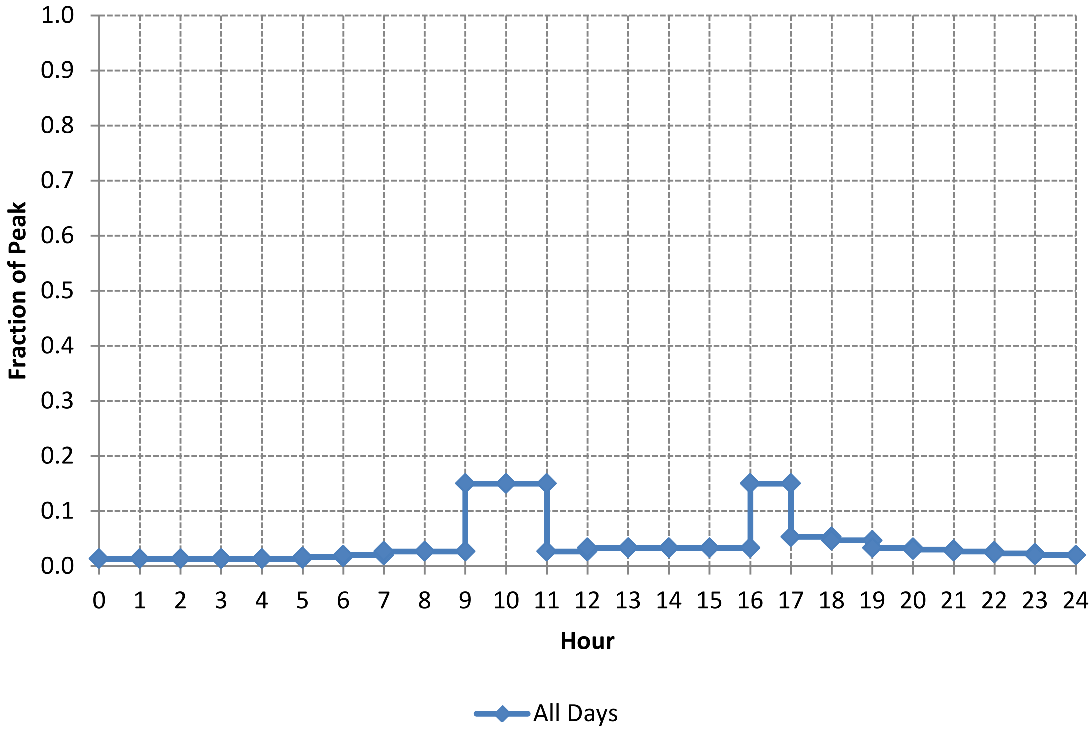

Figure 3–29 Food preparation center SWH schedule

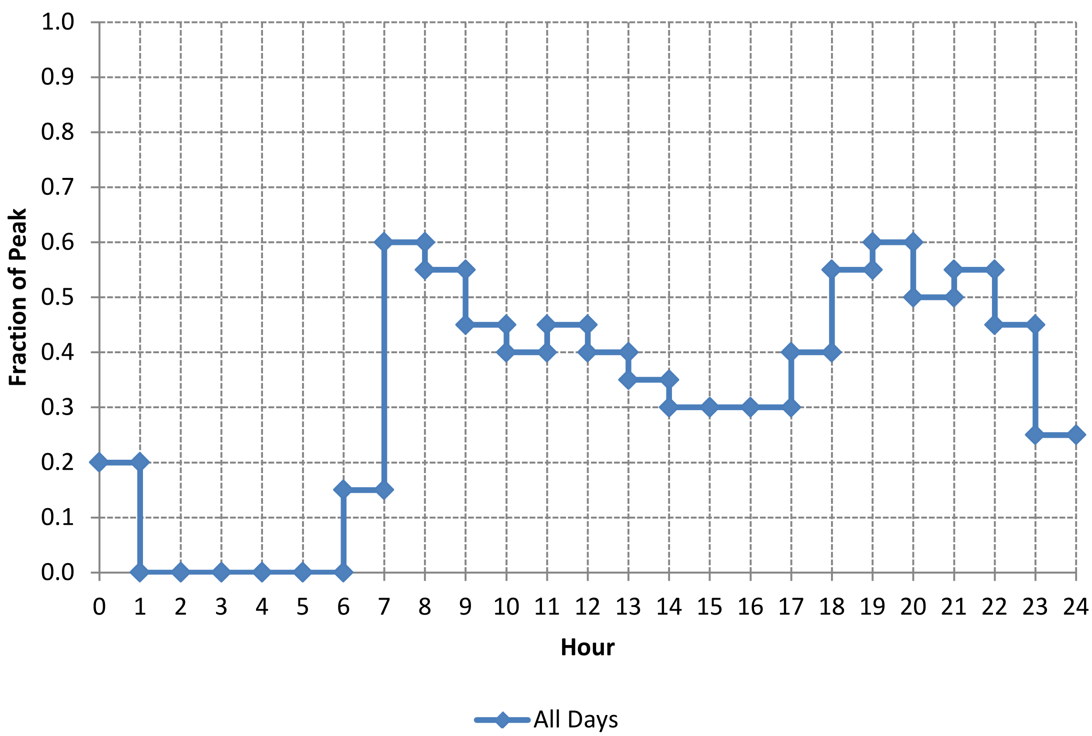

Figure 3–30 Patient SWH schedule

The SWH loads for the baseline model were met via an 80% efficient natural gas water heater. Water was circulated through the SWH system by a 75% efficient constant-speed pump with 60 ft of head.

3.3.8 Baseline Simulation Results

Table 3–27 and Table 3–28 present the simulation results for the baseline model. These results are presented graphically in Figure 3–30.

Table 3–28 Baseline Simulation Results, Climate Zones 1A–4A

End Use (kBtu/ft²yr)	1A	2A	2B	3A	3B:CA	3B	3C	4A
Interior equipment (electric)	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8
Interior equipment (gas)	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Elevators (electric)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Interior lighting (electric)	28.1	28.1	28.1	28.1	28.1	28.1	28.1	28.1
Exterior lighting (electric)	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7
Preheat (gas)	0.6	4.5	3.6	5.3	2.2	3.9	6.2	8.9
Reheat (gas)	55.9	60.0	58.8	57.3	59.8	49.8	63.4	62.0
Cooling (electric)	54.0	45.7	35.9	35.2	28.1	26.1	22.7	30.7
Fans (electric)	40.6	40.2	42.8	39.8	39.8	40.3	39.5	39.2
Pumps (electric)	17.3	16.2	13.9	14.4	11.5	11.1	10.2	14.2
SWH (gas)	3.9	4.7	4.2	5.4	5.3	4.7	5.9	6.0
Humidification (electric)	0.1	1.2	4.4	4.3	0.4	11.5	0.1	7.4
Refrigeration (electric)	2.5	2.2	2.3	2.0	1.8	2.1	1.6	1.9
Total	247.3	247.2	238.3	236.2	221.4	221.9	222.1	242.9

Table 3–29 Baseline Simulation Results, Climate Zones 4B–8

End Use (kBtu/ft²yr)	4B	4C	5A	5B	6A	6B	7	8
Interior equipment (electric)	29.8	29.8	29.8	29.8	29.8	29.8	29.8	29.8
Interior equipment (gas)	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1
Elevators (electric)	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.8
Interior lighting (electric)	28.1	28.1	28.1	28.1	28.1	28.1	28.1	28.1
Exterior lighting (electric)	6.7	6.7	6.7	6.7	6.7	6.7	6.7	6.7
Preheat (gas)	5.5	7.8	12.4	7.5	16.2	11.5	18.6	33.2
Reheat (gas)	42.6	61.2	64.1	44.8	65.2	52.3	66.0	79.0
Cooling (electric)	19.2	21.8	26.2	17.2	23.0	15.2	17.7	11.9
Fans (electric)	42.2	39.1	39.1	41.7	39.0	40.1	39.0	39.7
Pumps (electric)	8.9	10.4	13.7	8.7	13.0	8.5	11.2	8.8
SWH (gas)	5.9	6.3	6.6	6.5	7.0	7.1	7.8	8.7
Humidification (electric)	14.1	1.5	9.1	12.6	13.2	13.6	16.0	24.0
Refrigeration (electric)	1.8	1.6	1.8	1.7	1.8	1.7	1.6	1.6
Total	212.8	222.3	245.4	213.4	250.9	222.4	250.6	279.5

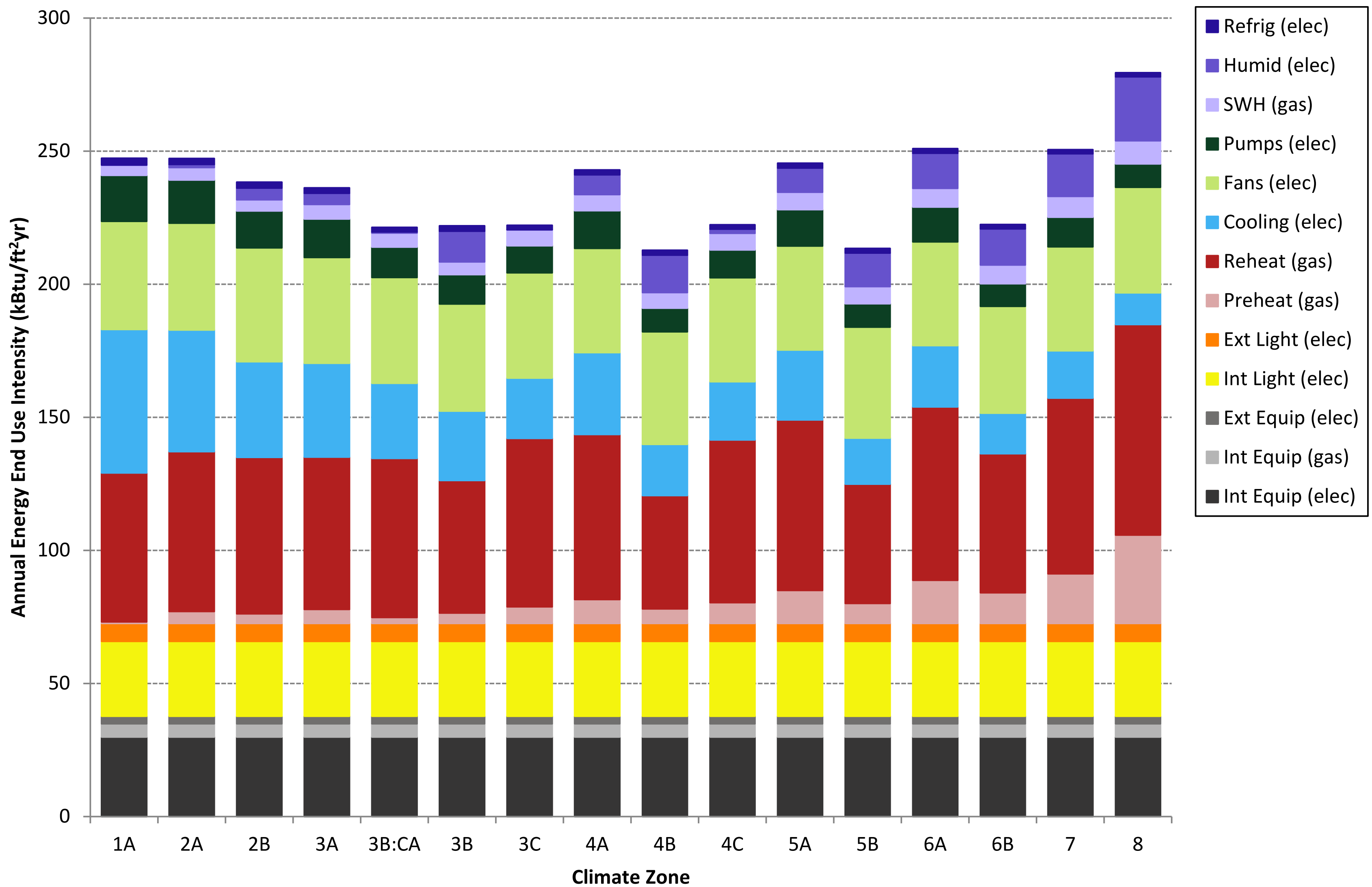

Figure 3–31 Baseline simulation results

3.4 Low-Energy Model Development and Assumptions

Extensive modeling was used to determine the effectiveness of all considered AEDG-LH recommendations. This section documents the energy models that incorporated the final set of AEDG-LH recommendations.

3.4.1 Envelope

3.4.1.1 Exterior Walls

The exterior walls in the low-energy models were modeled exactly the same as in the baseline model, except for the insulation layer, which was increased in the low-energy models. The low-energy exterior wall R- and U-values resulting from this insulation addition are shown in Table 3–29; the baseline values are included for easy comparison.

Table 3–30 Low-Energy Exterior Wall Constructions

Climate Zone	Assembly U-Factor (Btu/h·ft²·°F)		Insulation R-Value, Nominal (h·ft²·°F/Btu)	
	Baseline Model	Low-Energy Models	Baseline Model	Low-Energy Models
1	U-0.580	U-0.151	NR	R-5.7 c.i.
2	U-0.580	U-0.123	NR	R-7.6 c.i.
3	U-0.151	U-0.090	R-5.7 c.i.	R-11.4 c.i.
4	U-0.151	U-0.080	R-5.7 c.i.	R-13.3 c.i.
5	U-0.123	U-0.080	R-7.6 c.i.	R-13.3 c.i.
6	U-0.104	U-0.062	R-9.5 c.i.	R-19.5 c.i.
7	U-0.090	U-0.062	R-11.4 c.i.	R-19.5 c.i.
8	U-0.080	U-0.062	R-13.3 c.i.	R-19.5 c.i.

3.4.1.2 Roofs

The roofs in the low-energy models were modeled exactly as in the baseline model, except for the insulation layer, which was increased in the low-energy models. The low-energy roof R- and U-values resulting from this insulation addition are provided in Table 3–30; the baseline values are included for easy comparison.

Table 3–31 Low-Energy Roof Constructions

Climate Zone	Assembly U-Factor (Btu/h·ft²·°F)		Insulation R-Value, Nominal (h·ft²·°F/Btu)	
	Baseline Model	Low-Energy Models	Baseline Model	Low-Energy Models
1	U-0.063	U-0.048	R-15.0 c.i.	R-20.0 c.i.
2	U-0.063	U-0.039	R-15.0 c.i.	R-25.0 c.i.
3	U-0.063	U-0.039	R-15.0 c.i.	R-25.0 c.i.
4	U-0.063	U-0.032	R-15.0 c.i.	R-30.0 c.i.
5	U-0.063	U-0.032	R-15.0 c.i.	R-30.0 c.i.
6	U-0.063	U-0.032	R-15.0 c.i.	R-30.0 c.i.
7	U-0.063	U-0.028	R-15.0 c.i.	R-35.0 c.i.
8	U-0.048	U-0.028	R-20.0 c.i.	R-35.0 c.i.

The AEDG-LH recommends solar reflectance indexes of 78 in climate zones 1–3. To model this recommendation, the roof membrane solar reflectance was set to 0.7 (from 0.3) and the roof membrane visible absorption was set to 0.3 (from 0.7) in climate zones 1–3.

3.4.1.3 Slab-on-Grade Floors

The floors and ground temperatures in the low-energy models were modeled exactly as those in the baseline model.

3.4.1.4 Fenestration

The U-factors, SHGCs, and VLTs of the view windows that were used in the low-energy models are shown in Table 3–31; the baseline values are included for easy comparison.

Table 3–32 Low-Energy View Window Constructions

Climate Zone	U-Factor (Btu/h·ft²·°F)		SHGC		VLT	
	Baseline Model	Low-Energy Models	Baseline Model	Low-Energy Models	Baseline Model	Low-Energy Models
1 (A)	1.22	0.65	0.25	0.25	0.250	0.25
2 (A,B)	1.22	0.65	0.25	0.25	0.250	0.25
3 (A,B)	0.57	0.65	0.25	0.60	0.318	0.60
3 (C)	1.22	0.65	0.34	0.60	0.340	0.60
4 (A,B,C)	0.57	0.44	0.39	0.38	0.495	0.38
5 (A,B)	0.57	0.42	0.39	0.25	0.495	0.25
6 (A,B)	0.57	0.42	0.39	0.25	0.495	0.25
7	0.57	0.34	0.49	0.40	0.490	0.40
8	0.46	0.34	0.49*	0.40	0.490*	0.40

*No requirement, value from preceding climate zone used

3.4.1.5 Overhangs

The low-energy model implemented overhangs on the south façade windows with no offset and a projection factor (ratio of overhang length to window height) of 0.5.

3.4.2 Infiltration

Infiltration in the low-energy model was treated the same as in the baseline model, with one key exception: the infiltration rate factor was reduced by 16.7% to 0.05 cfm/ft². This reduction was attributed to an assumed higher envelope construction quality (greater attention was paid to the details of building envelope air barrier installation during construction).

3.4.3 Electric Lighting

3.4.3.1 Interior Lighting

The LPDs used in the low-energy models are listed in Table 3–32; the baseline values are included for easy comparison. The lighting schedules were the same as those used in the baseline model. Table 3–32 also shows which space types in the low-energy model included additional daylighting controls or occupancy sensors. The LPD for space types with occupancy sensors include an additional 10% LPD reduction. This reduction was taken on top of the recommended LPD for each space type from the AEDG-LH. Daylighting controls were modeled as continuous dimming to OFF and consisted of one daylighting reference point per zone, which controlled all the lighting in that zone. Daylighting controls were modeled in applicable spaces that already had windows. The daylighting sensor was given a set point of 40 fc. Although patient rooms may appear to be good candidates for daylighting (based on room size and proximity to outside walls), in reality, the window shades are often drawn for sleeping during recovery. Patient room lighting patterns are thus unpredictable, so they are not suitable candidates for daylighting.

Table 3–33 Low-Energy Model LPDs

No.	Space Type	Baseline LPD (W/ft²)	Low-Energy LPD (W/ft²)	Occupancy Sensor (Yes/No)	Daylight Sensor (Yes/No)
1	Anesthesia gas storage	0.90	0.72	Yes	No
2	Cafeteria	0.90	0.90	No	Yes
3	Clean workroom/holding	1.10	0.72	Yes	No
4	Conference room	1.30	0.99	Yes	Yes
5	Corridor/transition	1.00	0.70	No	Yes
6	Dining room	0.90	0.90	No	Yes
7	Examination/treatment room	1.50	0.99	Yes	No
8	Food preparation center	1.20	1.20	No	No
9	Laboratory	1.40	0.90	No	No
10	Lobby area	1.30	0.80	No	Yes
11	Locker	0.60	0.60	No	No
12	Lounge	0.80	0.80	No	Yes
13	Mechanical/electrical room	1.50	0.72	Yes	No
14	Medical supply/medication room	1.40	0.99	Yes	No
15	Nurse station	1.00	1.00	No	Yes
16	Nursery	0.60	0.60	No	No
17	Office	1.10	0.72	Yes	Yes
18	Operating suite	2.20	2.00	No	No
19	Patient room	1.70	0.70	No	No
20	Pharmacy	1.20	1.20	No	No
21	Physical therapy	0.90	0.90	No	No
22	Procedure room	2.70	2.00	No	No
23	Radiology/imaging	0.40	0.40	No	No
24	Reception/waiting	1.30	0.90	No	Yes
25	Recovery room	0.80	0.80	No	No
26	Restroom	0.90	0.72	Yes	No
27	Soiled workroom/holding	1.10	0.72	Yes	No
28	Sterilizer equipment room	0.90	0.81	Yes	No
29	Storage/receiving	0.90	0.63	Yes	No
30	Trauma/emergency room	2.70	1.20	No	No
31	Triage	2.70	2.00	No	No
Whole-Building Area Weighted Average		1.35	0.87	n/a	n/a

3.4.3.2 Exterior Lighting

The façade lighting in the low-energy models was set to 2.5 W per linear foot of façade length (USGBC 2009), resulting in 5,875 W of façade lighting power. As in the baseline model, the façade lights were controlled by an astronomical clock that turned the lights on when the sun set and off when the sun rose.

Energy was saved in the parking garage by using daylight to light the perimeter areas and installing energy-efficient fixtures. The determination of the low-energy parking garage lighting power follows:

- The garage size (450,000 ft^2) remains consistent with Section 3.3.3.2.
- The garage was assumed to be five stories tall with a 300-ft × 300-ft footprint, resulting in 90,000 ft^2 per story. The top floor is covered.
- The exterior lights 30 ft in from the exterior were assumed to be shut off during the day.
- A 32,400-ft^2 perimeter (per story) was assumed in which the lights were controlled by an astronomical clock that turned the lights on when the sun set and off when the sun rose.
- A 240-ft × 240-ft (57,600-ft^2) core (per story) was assumed in which the lights were always on.
- 0.1 W/ft^2 were assumed for a low-energy parking garage, resulting in 45,000 W of installed lighting power.
- This 45,000 W of installed lighting power was divided between the perimeter and core at 28,800 W for the core (where the lights were always on) and 16,200 W for the perimeter (where the lights were off during the day).

3.4.4 Plug and Process Loads

The PPLs for the low-energy models are shown in Table 3–33; the baseline values are included for easy comparison. The PPL schedules used were the same as those used in the baseline model. The electric PPLs in the low-energy models represent a 10% reduction over baseline models. The PC felt this was a conservative broad quantification of the AEDG-LH plug load recommendations.

Table 3–34 Low-Energy Model Electric PPLs

No.	Space Type	Electric Plug Load Density (W/ft²)		Electric Process Load Density (W/ft²)		Gas Process Load Density (W/ft²)	
		BL*	LE**	BL*	LE**	BL*	LE**
1	Anesthesia gas storage	–	–	–	–	–	–
2	Cafeteria	0.10	0.09	–	–	–	–
3	Clean workroom/holding	2.00	1.80	–	–	–	–
4	Conference room	0.10	0.09	–	–	–	–
5	Corridor/transition	0.10	0.09	–	–	–	–
6	Dining room	0.10	0.09	–	–	–	–
7	Examination/treatment room	1.00	0.90	–	–	–	–
8	Food preparation center	1.00	0.90	17.50	15.75	173.70	156.33
9	Laboratory	1.00	0.90	3.00	2.70	–	–
10	Lobby area	0.10	0.09	–	–	–	–
11	Locker	0.25	0.23	–	–	–	–
12	Lounge	1.00	0.90	–	–	–	–
13	Mechanical/electrical room	0.20	0.18	–	–	–	–
14	Medical supply/medication room	1.00	0.90	–	–	–	–
15	Nurse station	0.50	0.45	0.50	0.45	–	–
16	Nursery	1.00	0.90	–	–	–	–
17	Office	0.50	0.45	–	–	–	–
18	Operating suite	1.00	0.90	3.00	2.70	–	–
19	Patient room	1.25	1.13	–	–	–	–
20	Pharmacy	1.00	0.90	–	–	–	–
21	Physical therapy	1.00	0.90	–	–	–	–
22	Procedure room	1.00	0.90	3.00	2.70	–	–
23	Radiology/imaging	1.00	0.90	8.00	7.20	–	–
24	Reception/waiting	0.10	0.09	–	–	–	–
25	Recovery room	1.00	0.90	1.00	0.90	–	–
26	Restroom	0.10	0.09	–	–	–	–
27	Soiled workroom/holding	–	–	–	–	–	–
28	Sterilizer equipment room	1.00	0.90	5.00	4.50	7.00	6.30
29	Storage/receiving	1.00	0.90	–	–	–	–
30	Trauma/emergency room	1.00	0.90	3.00	2.70	–	–
31	Triage	1.00	0.90	–	–	–	–
Whole-Building Area Weighted Average		0.74	0.67	0.73	0.66	1.66	1.49

*Baseline
**Low-energy

3.4.5 Elevators

In the low-energy models, a 75% reduction was applied to the baseline load of 72,000 W, because regenerative traction-type elevators were assumed to be installed. This reduction was determined by the PC. The elevator operation schedule remained the same as in the baseline model.

3.4.6 Heating, Ventilation, and Air Conditioning

Although many types of HVAC systems can be used in hospitals, the AEDG-LH provides recommendations for three common low-energy HVAC system types:

- A WSHP with a boiler, a fluid cooler, and a DOAS for ventilation
- An FCU with a chiller, a boiler, and a DOAS for ventilation
- An advanced VAV AHU with separate OA treatment, a chiller, a heat recovery chiller, and a boiler.

More than one HVAC system type was analyzed to give AEDG-LH users flexibility in designing high-performance hospitals. The PC used members' experience in designing hospitals to determine the HVAC system types to include in the AEDG-LH, and they felt these three types were widely applicable, readily available, and comparatively common. Energy modeling showed that all three system types (when coupled with the other recommendations) met or exceeded the 50% savings goal. The AEDG-LH discusses more variations among the modeled system types, but the PC decided to model only the most common configurations. A central theme to all the recommended HVAC system types was decoupling the ventilation air from the zone heating and cooling.

3.4.6.1 Hot Water System

The hot water system was served by a condensing, natural gas-fired, 90% efficient boiler that supplied water to the low-energy model heating coils according to an OA reset-based supply water temperature set point. The OA reset set point schedule was 140°F at an OA temperature ≤ 0°F, 130°F at an OA temperature ≥ 60°F. The upper and lower bounds of this schedule were based on PC best practices. When OA temperatures fell within the 0°–60°F range, the supply water temperature value was linearly interpolated. Water was circulated through the hot water system via an 80% efficient variable-speed pump with 60 ft of head.

The hot water system served the following coils: the DOAS water preheat coils (Section 3.4.6.3), the FCU water heating coils (Section 3.4.6.5), the advanced VAV AHU water preheat coils, and the advanced VAV water reheat coils (Section 3.4.6.6).

The boiler efficiency was modeled strictly as a function of its operating PLR, which is the heating load divided by the steady-state heating capacity at any point in time. The liner equation used to model the boiler efficiency is $0.967 - 0.167 \times PLR$ (Bonnema et al. 2010a). Figure 3–31 shows the boiler efficiency as a function of PLR curve.

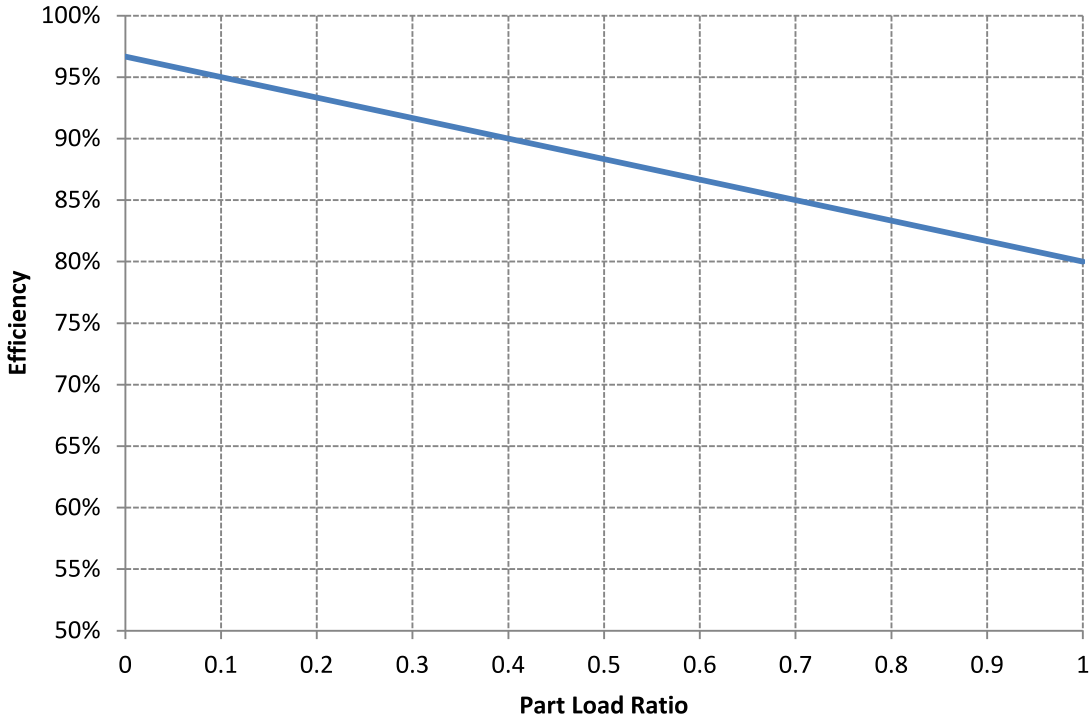

Figure 3–32 Low-energy boiler efficiency

3.4.6.2 Chilled Water System

All low-energy models utilized a chilled water system supplied by a water-cooled, variable-speed, 6.5-COP centrifugal chiller. Its performance curves were taken from Bonnema et al. (2010a). Water was supplied to the chilled water coils at 44°F with a design return water temperature of 56°F. The cooling tower was modeled as a variable-speed, cross-flow, open cooling tower with a design approach temperature (outlet water temperature minus inlet air wet-bulb temperature) of 7°F and a design range temperature (inlet water temperature minus outlet water temperature) of 10°F. Water was circulated through the chilled water system via an 80% efficient variable-speed pump with 50 ft of head. The condenser loop contained an 80% efficient variable-speed pump with 40 ft of head.

The chilled water system served the following coils: the DOAS water cooling coils (Section 3.4.6.3), the FCU water cooling coils (Section 3.4.6.5), and the advanced VAV AHU water cooling coils (Section 3.4.6.6). The advanced VAV chilled water system contained a supplemental heat recovery chiller.

3.4.6.3 Dedicated Outdoor Air System

The VAV-reheat systems that provided heating and cooling in the baseline model were replaced with a DOAS in the WSHP and FCU low-energy models; space conditioning was handled through other means (with a WSHP or an FCU). The DOAS provided ventilation air in the WSHP and FCU low-energy models. The DOAS were modeled with a water preheat coil, a water cooling coil, and a VAV fan. The VAV fan had a fan efficiency of 70% and a system pressure drop of 6.0 in. w.c. The DOAS also included an energy recovery ventilator (ERV) and DCV capability for spaces that did not have airflow requirements in Standard 170-2008.

Each ERV was modeled as a rotary heat exchanger with a 60% sensible effectiveness, 60% latent effectiveness, and a 0.5-in. w.c. pressure drop. The ERVs were equipped with supply air bypass frost control that could cycle off the supply airflow through the heat exchanger while the exhaust air continued to flow through the heat exchanger. The fraction of time that the supply flow through the heat exchanger was cycled off was dependent on the OA inlet temperature with respect to the threshold temperature (–10°F), the initial defrost time fraction (0.167 = 10 min/60 min), and the rate of change of defrost time fraction (0.024/C = 1.44 min/60 min per degree C temperature difference). The supply air was assumed to be bypassed around the heat exchanger during frost control operation (i.e., the total supply flow was not reduced during defrost, but merely bypassed around the heat exchanger).

The water preheat coils were served by the hot water system described in Section 3.4.6.1; the water cooling coils were served by the chilled water system described in Section 3.4.6.2. The DOAS contained the same humidifier as the baseline AHU. The ventilation air from the DOAS was delivered to the zone at 55°F via a VAV terminal unit that could vary the ventilation rate. In EnergyPlus, DCV was modeled by varying the per-person OA requirement (see Table 3–11) based on the occupancy schedule for that zone (see Figure 3–8 through Figure 3–12). No DCV was modeled in spaces with total airflow requirements in Standard 170-2008.

3.4.6.4 Water Source Heat Pump System

In this low-energy model variation, each zone served by the DOAS (all zones except the operating suite) also had a two-speed WSHP. The heat pumps represented best-in-class efficiency levels, with a cooling COP of 5, a heating COP of 5.7, and 55% efficient constant-speed fans that cycled with the load (0.3-in. w.c. pressure drop). The units had supplemental electric resistance heat.

The heat pumps rejected or extracted energy from a single plant loop that was served by an 80% efficient variable-speed pump with 60 ft of head and a loop temperature set point range of 68°–86°F. The heat rejection loop included a boiler and an evaporative fluid cooler to maintain the loop temperature. The boiler on the loop was a 90% efficient, natural gas-fired, condensing boiler with identical performance to the one described in Section 3.4.6.1; the loop temperature was kept above 68°F. A single-speed evaporative fluid cooler kept the loop temperature below 86°F.

3.4.6.5 Fan Coil Unit System

In this low-energy model variation, each zone served by the DOAS (all zones except the operating suite) had a four-pipe FCU. The FCU consisted of a water heating coil, a water cooling coil, and a 55% efficient constant-speed fan that cycled with load (0.3-in. w.c. pressure drop).

The FCUs were connected to the hot water system described in Section 3.4.6.1; the chilled water system described in Section 3.4.6.2.

3.4.6.6 Advanced Variable Air Volume System

In this low-energy model variation, all zones except the operating suite were served by a VAV AHU that was very similar to the baseline system. This HVAC option provided the central maintenance convenience of a traditional VAV-reheat system (as the baseline had), but significantly reduced the wasteful reheat energy via an additional chiller with heat recovery capability, separate OA treatment, and aggressive AHU leaving air temperature reset. In the traditional VAV reheat system in the baseline model, the OA was mixed with the return air and the full volume of air was cooled to the AHU leaving air temperature set point. In a hospital with minimum air change requirements, this results in a large volume of cold air requiring reheat at the terminal unit to maintain space comfort. In the advanced VAV configuration, the OA was separately conditioned to 50°F before being mixed with the return air. This mixed air was then conditioned to the leaving air temperature set point. This configuration saves energy because the entire volume of air that flows through the AHU is not cooled to a low temperature to satisfy dehumidification requirements. Rather, only the OA is cooled and mixed with warmer, already dehumidified return air. Then, this mixture is cooled (if necessary) to an aggressively reset leaving air temperature set point, which was determined according to the cooling demand of the warmest zone (e.g., the resulting temperature set point was the highest supply air temperature necessary to meet the cooling requirements of all the zones). Compared to the fixed AHU leaving air temperature set point in the baseline, this advanced VAV strategy minimized zone reheat coil energy.

Each AHU contained a VAV fan with a fan efficiency of 70%, a motor efficiency of 95%, and a system pressure drop of 6.0 in. w.c. Each AHU also included an ERV and DCV capability for spaces that did not have airflow requirements prescribed in Standard 170-2008.

Each ERV was modeled as a rotary heat exchanger with a 60% sensible effectiveness, 60% latent effectiveness, and a 0.5-in. w.c. pressure drop. The ERVs were equipped with supply air bypass frost control that could cycle off the supply flow through the heat exchanger while the exhaust air continued to flow through the heat exchanger. The fraction of time that the supply flow through the heat exchanger was cycled off was dependent on the OA inlet temperature with respect to the threshold temperature (–10°F), the initial defrost time fraction (0.167 = 10 min/60 min), and the rate of change of defrost time fraction (0.024/C = 1.44 min/60 min per degree C temperature difference). The supply air was assumed to be bypassed around the heat exchanger during frost control operation (i.e., the total supply flow was not reduced during defrost, but merely bypassed around the heat exchanger).

The separate OA treatment section of each AHU could vary the ventilation rate based on demand. In EnergyPlus, DCV was modeled by varying the per-person OA requirement (see Table 3–11) based on the occupancy schedule for that zone (see Figure 3–8 through Figure 3–12). No DCV was modeled in spaces with total airflow requirements in Standard 170-2008.

The water preheat coils in the AHUs were served by the hot water system described in Section 3.4.6.1 and the water cooling coils were served by the chilled water system described in Section 3.4.6.2; a supplemental heat recovery chiller was added to the chilled water system. The advanced VAV AHUs contained the same humidifier as the baseline AHUs.

The aggressive AHU leaving air temperature reset strategy employed by the advanced VAV system does not entirely eliminate reheat energy. There are still cooling load imbalances in the zones on the same AHU, so reheat at some terminal units is inevitable. To handle this, the chilled water loop in the advanced VAV model was supplemented with a smaller heat recovery chiller (condenser water heat recovery) to offset as much reheat energy as possible. For this TSD, the condenser water from the heat recovery chiller was used to preheat water for the VAV terminal box reheat coils in lieu of a cooling tower. A chiller with the same properties as that in Section 3.4.6.2 was modeled; except the COP was 4.55 (heat recovery chillers are less efficient than standard chillers). The heat recovery chiller operating in series with the chiller is described in Section 3.4.6.2; the chilled water first passes through the heat recovery chiller and then through the standard chiller. The heat recovery chiller was sized to run at a PLR of 1.0 year round; the standard chiller modulated to meet any additional cooling load. Sizing of the heat recovery chiller was crucial and was dependent on heating and cooling load (and thus climate zone). The sizing logic follows:

- Climate zone 1A: The heat recovery chiller was sized on the reheat load.
- Climate zone 2A–4B: The heat recovery chiller was sized on the average winter cooling load.
- Climate zone 4C–8: The heat recovery chiller was sized on the average summer reheat load.

The sizing values were determined from a preliminary annual simulation in EnergyPlus; the values were rounded and binned to reduce the complexity of the final simulation. Table 3–34 shows sizing information about the heat recovery chiller by climate zone along with the heating energy that was recovered, the remaining heating energy that was met with the boiler described in Section 3.4.6.1, and the total reduction in heating energy.

Table 3–35 Heat Recovery Chiller Information

No.	Climate Zone	Heat Recovery Chiller Capacity (tons)	Heating Energy Recovered (kBtu/ft²yr)	Remaining Heating Energy (kBtu/ft²yr)	Heating Energy Reduction
1	1A	120	19.7	0.0	100%
2	2A	280	19.5	0.0	100%
3	2B	280	10.5	2.4	81%
4	3A	280	17.1	0.0	100%
5	3B:CA	280	14.0	1.6	90%
6	3B	280	8.5	4.6	65%
7	3C	210	10.2	4.9	68%
8	4A	280	17.9	0.0	100%
9	4B	210	5.4	5.6	49%
10	4C	120	6.4	9.4	41%
11	5A	120	7.8	10.2	43%
12	5B	120	4.5	7.4	38%
13	6A	120	6.3	12.0	34%
14	6B	120	6.3	10.3	38%
15	7	120	4.8	12.4	28%
16	8	120	3.5	17.0	17%

The aggressive AHU leaving air temperature setback allows for a lower temperature reheat loop. This also pairs well with a heat recovery chiller, because heat recovery chillers cannot supply water as hot as a boiler. The reheat coil loop temperature setback was 110°F (from 140°F in Section 3.4.6.1) at an OA temperature of ≤ 0°F, 100°F (from 130°F in Section 3.4.6.1) at an OA temperature of ≥ 60°F. The upper and lower bounds of this schedule were based on PC best practices. When OA temperatures fell within the 0°–60°F range, the supply water temperature value was linearly interpolated. This temperature setback strategy applied to the reheat coil water loop only; the AHU heating coil loop remained the same as in Section 3.4.6.1.

The advanced VAV systems also employed a zone airflow setback strategy in which the total airflow requirements specified in Standard 170-2008 were removed and the VAV terminal box minimum stop was set to 0.3 during unoccupied hours (between 6:00 p.m. and 6:00 a.m.). This strategy was applied to all spaces with total airflow requirements in Standard 170-2008 except patient rooms, laboratories, pharmacy, and the emergency department.

3.4.6.7 Operating Suite Air Handling Unit

The operating suite AHU was identical to that in the baseline model, except a zone airflow setback strategy was used in which the total airflow requirements specified in Standard 170-2008 were removed and the VAV terminal box minimum stop was set to 0.3 during unoccupied hours (between 6:00 p.m. and 6:00 a.m.). The cooling set point was raised from 65°F to 68°F to account for using LED surgery task lights that radiate less heat to the space and thus do not require such a low cooling set point.

3.4.7 Service Water Heating

The SWH in the low-energy models was identical to that in the baseline model, except that the water heaters were 90% efficient instead of 80% efficient and the circulation pump was 80% efficient with 40 ft of head instead of 75% efficient with 60 ft of head. The PC felt that the pump head could be lowered by this amount based on better piping design and equipment selection.

4. Energy Targets

Careful goal setting is required to design and construct high-performance buildings. The goal of the AEDG-LH is to provide guidance to procure buildings that consume at least 50% less energy than a computer-modeled Standard 90.1-2004 (ASHRAE 2004b) compliant baseline. To better define this goal, an absolute whole-building energy target—a single number that defines the energy performance of a building—should be set as a best practice, inasmuch as the lower the number, the more energy efficient the building. The AEDG-LH provides these targets to help users set goals for their building designs. These targets can be used to select design teams as part of a procurement strategy, to set early design goals, to track the design development progress, and to help designers and owners ensure that the desired level of performance is achieved. The energy targets in the AEDG-LH are applicable to most large hospitals with typical program and use profiles. The AEDG-LH energy targets were designed to simplify the process of setting whole-building absolute energy use targets.

The prescriptive path in the AEDG-LH represents one way, but not the only way, to achieve industry best practice energy performance. Specifying whole-building absolute energy use targets gives a user the freedom to reach the performance goal with an approach that best fits the project's overall goals and constraints (including those unrelated to energy performance). Use of the whole-building absolute energy targets documented in the AEDG-LH can eliminate most of the analysis that may otherwise be required to specify energy performance goals, because the targets embody the knowledge required to set practical, aggressive energy performance goals. The AEDG-LH energy target tables can be used to specify an absolute energy target and then analysis efforts can focus on achieving industry best practice energy performance rather than on defining a reference point against which to measure performance. For a more detailed discussion, see Leach et al. (2012).

The whole-building absolute energy targets for the AEDG-LH were developed in accordance with the following approach:

1. Start with the hospital models from Bonnema et al. (2010b); these models are minimally compliant with Standard 90.1-2004 (ASHRAE 2004b).
2. Update the models according to the AEDG-LH PC's expert guidance. Pay special attention to aspects that are not prescribed by Standard 90.1-2004, including schedules and unregulated PPLs. The goal is to develop a model that accurately captures typical (common practice) whole-building energy use for large hospitals. The final models used for the analyses are defined in Section 3.3 of this report.
3. Simulate the industry-vetted baseline model across a set of climate zones that fully represent the variations in the U.S. climate zones (Figure 3–2). Benchmark modeling results against available sector data and solicit input from the PC. Make any necessary corrections to the model inputs and simulate. Iterate until results are in line with sector data and industry expectations for baseline energy performance by climate zone.
4. Set climate-specific absolute energy targets representing 50% savings beyond Standard 90.1-2004 by halving baseline whole-building energy performance results. Confirm through whole-building energy simulation and a case study survey (including PC member projects) that the 50% savings targets are feasible and representative of industry best practice energy performance.

The outcome of this process can be seen in Table 4–1. The results represent 50% savings over the baseline model, which was compliant with Standard 90.1-2004 (ASHRAE 2004b). The PC members confirmed that these results were in line with their expectations for 50% savings.

Whole-building absolute targets are supplemented with key end use energy targets (PPLs, lighting systems, and HVAC systems). Although the end use targets need not be met to achieve the whole-building target, these targets provide guidance about how energy use is likely to be distributed throughout a large hospital; they can also inform end use energy budgets. Programmatic requirements are relatively constant in hospitals; accordingly, the AEDG-LH whole-building and end use energy targets are likely to apply reasonably well to most projects. The AEDG-LH energy targets do not take into account the energy use of specialty or unique spaces that generate extraordinary heat or pollution. Such space types should be analyzed separately; their predicted energy use can be combined with the AEDG-LH targets to determine an area-weighted, whole-building energy use target that correctly reflects all energy uses.

Table 4–1 Large Hospital Energy Targets

Climate Zone	PPLs (kBtu/ft²yr)	Lighting (kBtu/ft²yr)	HVAC (kBtu/ft²yr)	Total (kBtu/ft²yr)
1A	38	18	68	124
2A			68	124
2B			63	119
3A			62	118
3B:CA			55	111
3B			55	111
3C			55	111
4A			65	121
4B			50	106
4C			55	111
5A			67	123
5B			51	107
6A			69	125
6B			55	111
7			69	125
8			84	140

5. Evaluation Results

This section contains the PC-approved energy efficiency recommendations for the AEDG-LH and the resulting energy savings. End use comparison figures are provided; the end use data are also presented in tabular format.

5.1 Recommendation Tables for 50% Energy Savings

This section provides the recommendation tables that are presented in the AEDG-LH. The recommendations represent a way to achieve 50% energy savings over Standard 90.1-2004 in a typical large hospital. The PC recognizes that there are other ways of achieving the 50% 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 "Comply with 90.1," the AEDG-LH is providing no recommendation for this component or system. In these cases, the user must meet the more stringent of either the applicable version of Standard 90.1 or the local code requirements.

The opaque envelope recommendations are presented for different climate zones by roof type, wall type, floor type, slab type, and door type. Recommendations for the thermal characteristics of the vertical fenestration are provided. Interior lighting recommendations, including LPD, lamp efficacy, ballast specification, controls, daylighting system integration, and exterior LPDs and controls are presented. PPL recommendations are provided. SWH efficiency recommendations are provided for electric and gas water heaters. Many types of HVAC systems could be used in large hospitals, but the AEDG-LH provides recommendations for each of the following three system types:

- A WSHP with a boiler, a fluid cooler, and a DOAS for ventilation
- An FCU with a chiller, a boiler, and a DOAS for ventilation
- An advanced VAV AHU with separate OA treatment, a chiller, a heat recovery chiller, and a boiler.

Unique recommendations for cooling, heating, and fan efficiencies are included for each HVAC system type in the climate-specific recommendations. Either DCV or ERVs are also recommended for each HVAC system type.

The AEDG-LH recommendation tables (ASHRAE et al. 2012) are shown in Table 5–1 and Table 5–2.

Table 5–1 AEDG-LH Recommendations: Climate Zones 1–4

	Item	Component	Climate Zone 1 Recommendation	Climate Zone 2 Recommendation	Climate Zone 3 Recommendation	Climate Zone 4 Recommendation
Envelope	Form/space planning	Proper zoning	Group similar space types within the building footprint			
	Roofs	Insulation entirely above deck	R-20.0 c.i.	R-25.0 c.i.		R-30.0 c.i.
		Solar reflectance index	78			Comply with 90.1*
	Walls	Mass (HC < 7 Btu/ft^2)	R-5.7 c.i.	R-7.6 c.i.	R-11.4 c.i.	R-13.3 c.i.
		Steel framed	R-13.0 + R-7.5 c.i.			
		Below-grade walls	Comply with 90.1*		R-7.5 c.i. (comply with 90.1* in 3A)	R-7.5 c.i.
	Floors	Mass	R-4.2 c.i.	R-10.4 c.i.	R-12.5 c.i.	R-14.6 c.i.
		Steel framed	R-19.0	R-30.0		R-38.0
	Slabs	Unheated	Comply with 90.1*			
		Heated	R-7.5 for 12 in.	R-10.0 for 12 in.	R-15.0 for 24 in.	R-20 for 24 in.
	Doors	Swinging	U-0.70			U-0.50
		Nonswinging	U-1.45	U-0.50		
	Vestibules	At primary visitor building entrance	Comply with 90.1*			
	Continuous air barriers	Continuous air barriers	Entire building envelope			
	Vertical fenestration (full assembly – NFRC rating)	Window-to-wall ratio	40% of net wall (floor to ceiling)			
		Thermal transmittance (Btu/h·ft^2·°F)	Nonmetal framing windows = 0.56; metal framing windows = 0.65			Nonmetal framing windows = 0.38; metal framing windows = 0.44
		Solar heat gain coefficient	Nonmetal framing windows = 0.25; metal framing windows = 0.25		Nonmetal framing windows = 0.41; metal framing windows = 0.60	Nonmetal framing windows = 0.26; metal framing windows = 0.38
		Light-to-solar gain ratio	All orientations ≥ 1.5			
		Exterior sun control	South orientations only – PF = 0.5			
Daylighting and Lighting	Form-driving daylighting option	All spaces	Comply with LEED for healthcare credits IEQ 8.1 (daylighting) and IEQ 8.2 (views)			
		Diagnostic and treatment block	Shape the building footprint and form such that the area within 15 ft of the perimeter exceeds 40% of the floorplate			
		Inpatient units	Ensure that 75% of the occupied space, not including patient rooms, lies within 20 ft of the perimeter			
		Staff areas (exam rooms,	Design the building form to maximize access to natural light, through sidelighting			

	Item	Component	Climate Zone 1 Recommendation	Climate Zone 2 Recommendation	Climate Zone 3 Recommendation	Climate Zone 4 Recommendation
		nurse stations, offices, corridors); public spaces (waiting, reception); and other regularly occupied spaces as applicable	and toplighting			
	Nonform-driven daylighting option	Staff areas (exam rooms, nurse stations, offices, corridors) and public spaces (waiting, reception)	Add daylight controls to any space within 15 ft of a perimeter window			
	Interior finishes	Room interior surface average reflectance	Ceilings ≥ 80%; walls ≥ 70%			
	Interior lighting	Lighting power density	Whole buildings = 0.9 W/ft²; Space by space per Table 5-4 in AEDG-LH			
		Light source efficacy (mean lumens per watt)	T8 and T5 < 2 ft = 92; T8 and T5 < 2 ft = 85; all other < 50			
		Ballasts – 4 ft T8 lamps	Nondimming = NEMA premium; dimming = NEMA premium program start			
		Ballasts – fluorescent and HID	Electronic			
		Dimming controls daylight harvesting	Dim all fixtures in daylighted zones			
		Lighting controls – general	Manual ON, auto/timed OFF in all areas as possible			
		Surgery task lights	Use LED lights exclusively			
		Exit signage	0.1-0.2 W light emitting capacitor exit signs exclusively			
	Exterior lighting	Façade and landscape lighting	LPD = 0.15 W/ft²			
		Parking lots and drives	LPD = 0.1 W/ft²			
		All other exterior lighting	LPD = Comply with 90.1*; auto reduce to 25% (12am-6am)			
PPL	Equipment choices	Computers	Laptops = minimum 2/3 total computers; all others = mini desktop computers			
		ENERGY STAR equipment	All computers, equipment, appliances			
		Vending machines	Delamp and specify best-in-class efficiency			
	Controls	Computer power control	Network control with power-saving modes and control during unoccupied hours or IT enterprise power management software			
		Occupancy sensors	Office plug occupancy sensors			
		Timer switches	Water coolers, coffee makers, small appliances = auto OFF during unoccupied			

	Item		Component	Climate Zone 1 Recommendation	Climate Zone 2 Recommendation	Climate Zone 3 Recommendation	Climate Zone 4 Recommendation
				hours			
	Kitchen equipment		Cooking equipment	ENERGY STAR or California rebate-qualified equipment			
			Refrigeration equipment	6 in. insulation on low-temp walk-in equipment, insulated floor, LED lighting, floating-head pressure controls, liquid pressure amplifier, subcooled liquid refrigerant, evaporative condenser			
			Exhaust hoods	Side panels, larger overhangs, rear seal at appliances, proximity hoods, VAV demand-based exhaust			
	Process loads		Elevators	Traction elevators for all elevators and regenerative traction elevators for all high-use elevators			
SWH	Service water heating		Gas water heater (condensing)	95% efficiency			
			Point-of-use water heater	0.81 EF or 81% Et			
			Electric-heat-pump water heater	2.33 EF			
			Pipe insulation (d < 1.5 in./d ≥ 1.5 in.)	1.0 in./1.5 in.			
HVAC	Heating System		No central steam – use hot water distribution system	Point-of-use steam for humidification and sterilization			
	Surgery	Central air-handling system	Water-cooled chiller	6.5 COP			
			Water-circulation pumps	VFD and NEMA premium			
			Cooling towers	VFD on tower fans			
			Boiler efficiency	90% Ec			
			Maximum fan power	bhp ≤ supply cfm × 0.0012 + A**			
			Economizer	Comply with 90.1*			
	Nonsurgery	Water-source heat pump (WSHP) system with DOAS	WSHP part-load/full-load cooling efficiency	15.0/17.6 EER			
			WSHP part-load/full-load heating efficiency	5.0/5.7 COP			
			WSHP compressor capacity control	Two-speed or variable-speed			
			Water-circulation pumps	VFD and NEMA premium			
			Closed-circuit cooling tower	VFD on fans			
			Boiler efficiency	90% Ec			

	Item		Component	Climate Zone 1 Recommendation	Climate Zone 2 Recommendation	Climate Zone 3 Recommendation	Climate Zone 4 Recommendation
			Maximum fan power	0.4 W/cfm			
			Exhaust-air energy recovery in DOAS	A (humid zones) = 60% total effectiveness; B (dry zones) = 60% sensible effectiveness			
			DOAS ventilation control	DCV with VFD			
		Fan-coil system with DOAS	Water-cooled chiller	6.5 COP			
			Water-circulation pumps	VFD and NEMA premium			
			Cooling towers	VFD on fans			
			Boiler efficiency	90% Ec			
			Maximum fan power	0.4 W/cfm			
			FCU fans	Multiple speed			
			Exhaust-air energy recovery in DOAS	A (humid zones) = 60% total effectiveness; B (dry zones) = 60% sensible effectiveness			
			DOAS ventilation control	DCV with VFD			
		Mixed-air VAV system with separate OA treatment and heat recovery system	Heat recovery water cooled chiller	4.55 COP			
			Water-cooled chiller	6.5 COP			
			Water-circulation pumps	VFD and NEMA premium			
			Cooling towers	VFD on tower fans			
			Boiler efficiency	90% Ec			
			Maximum fan power	bhp ≤ supply cfm × 0.0012 + A**			
			Economizer	Comply with 90.1*			
			Exhaust-air energy recovery in DOAS	A (humid zones) = 60% total effectiveness; B (dry zones) = 60% sensible effectiveness			
			DOAS ventilation control	DCV with VFD			
	Ducts and dampers		OA damper	Motorized			
			Duct seal class	Seal class A			
			Insulation level	R-6			
	Measurement and verification		Electrical submeters	Design and circuit for separate submeters for lighting, HVAC, general 120 V, service water heating, renewables, and whole building			
			Benchmarking	Benchmark monthly energy use			
			Training	Facility operator on continuous benchmarking			

*Meet the more stringent of either the most current version of Standard 90.1 or the local code requirements
**A is defined in Table 6.5.3.1.1A in Standard 90.1-2010 (ASHRAE 2010)

Table 5–2 AEDG-LH Recommendations: Climate Zones 5–8

	Item	Component	Climate Zone 5 Recommendation	Climate Zone 6 Recommendation	Climate Zone 7 Recommendation	Climate Zone 8 Recommendation
Envelope	Form/space planning	Proper zoning	Group similar space types within the building footprint			
	Roofs	Insulation entirely above deck	R-30.0 c.i.		R-35.0 c.i.	
		Solar reflectance index	Comply with 90.1*			
	Walls	Mass (HC < 7 Btu/ft²)	R-13.3 c.i.	R-19.5 c.i.		
		Steel framed	R-13.0 + R-15.6 c.i.	R-13.0 + R-18.8 c.i.		
		Below-grade walls	R-7.5 c.i.	R-10.0 c.i.	R-15.0 c.i.	
	Floors	Mass	R-14.6 c.i.	R-16.7 c.i.	R-20.9 c.i.	R-23.0 c.i.
		Steel framed	R-38.0		R-49.0	R-60.0
	Slabs	Unheated	Comply with 90.1*	R-10 for 24 in.	R-20 for 24 in.	
		Heated	R-20.0 for 24 in.	R-20 for 48 in.	R-25 for 48 in.	R-20 full slab
	Doors	Swinging	U-0.50			
		Nonswinging	U-0.50			
	Vestibules	At primary visitor building entrance	Comply with 90.1*			
	Continuous air barriers	Continuous air barriers	Entire building envelope			
	Vertical fenestration (full assembly – NFRC rating)	Window-to-wall ratio	40% of net wall (floor to ceiling)			
		Thermal transmittance (Btu/h·ft²·°F)	Nonmetal framing windows = 0.35; metal framing windows = 0.42		Nonmetal framing windows = 0.33; metal framing windows = 0.34	Nonmetal framing windows = 0.25; metal framing windows = 0.34
		Solar heat gain coefficient	Nonmetal framing windows = 0.25; metal framing windows = 0.25		Nonmetal framing windows = 0.40; metal framing windows = 0.40	
		Light-to-solar gain ratio	All orientations ≥ 1.5			
		Exterior sun control	South orientations only – PF = 0.5			
Daylighting and Lighting	Form-driving daylighting option	All spaces	Comply with LEED for healthcare credits IEQ 8.1 (daylighting) and IEQ 8.2 (views)			
		Diagnostic and treatment block	Shape the building footprint and form such that the area within 15 ft of the perimeter exceeds 40% of the floorplate			
		Inpatient units	Ensure that 75% of the occupied space, not including patient rooms, lies within 20 ft of the perimeter			
		Staff areas (exam rooms, nurse stations, offices, corridors); public spaces	Design the building form to maximize access to natural light, through sidelighting and toplighting			

	Item	Component	Climate Zone 5 Recommendation	Climate Zone 6 Recommendation	Climate Zone 7 Recommendation	Climate Zone 8 Recommendation
		(waiting, reception); and other regularly occupied spaces as applicable				
	Nonform-driven daylighting option	Staff areas (exam rooms, nurse stations, offices, corridors) and public spaces (waiting, reception)	Add daylight controls to any space within 15 ft of a perimeter window			
	Interior finishes	Room interior surface average reflectance	Ceilings ≥ 80%; walls ≥ 70%			
	Interior lighting	Lighting power density	Whole buildings = 0.9 W/ft²; Space by space per Table 5-4 in AEDG-LH			
		Light source efficacy (mean lumens per watt)	T8 and T5 < 2 ft = 92; T8 and T5 < 2 ft = 85; all other < 50			
		Ballasts – 4 ft T8 lamps	Nondimming = NEMA premium; dimming = NEMA premium program start			
		Ballasts – fluorescent and HID	Electronic			
		Dimming controls daylight harvesting	Dim all fixtures in daylighted zones			
		Lighting controls – general	Manual ON, auto/timed OFF in all areas as possible			
		Surgery task lights	Use LED lights exclusively			
		Exit signage	0.1-0.2 W light emitting capacitor exit signs exclusively			
	Exterior lighting	Façade and landscape lighting	LPD = 0.15 W/ft²			
		Parking lots and drives	LPD = 0.1 W/ft²			
		All other exterior lighting	LPD = Comply with 90.1*; auto reduce to 25% (12am-6am)			
PPL	Equipment choices	Computers	Laptops = minimum 2/3 total computers; all others = mini desktop computers			
		ENERGY STAR equipment	All computers, equipment, appliances			
		Vending machines	Delamp and specify best-in-class efficiency			
	Controls	Computer power control	Network control with power saving modes and control during unoccupied hours or IT enterprise power management software			
		Occupancy sensors	Office plug occupancy sensors			
		Timer switches	Water coolers, coffee makers, small appliances = auto OFF during unoccupied hours			
	Kitchen equipment	Cooking equipment	ENERGY STAR or California rebate-qualified equipment			

	Item		Component	Climate Zone 5 Recommendation	Climate Zone 6 Recommendation	Climate Zone 7 Recommendation	Climate Zone 8 Recommendation
			Refrigeration equipment	6 in. insulation on low-temp walk-in equipment, insulated floor, LEDs, floating-head pressure controls, liquid pressure amplifier, subcooled liquid refrigerant, evaporative condenser			
			Exhaust hoods	Side panels, larger overhangs, rear seal at appliances, proximity hoods, VAV demand-based exhaust			
	Process loads		Elevators	Traction elevators for all elevators and regenerative traction elevators for all high-use elevators			
SWH	Service water heating		Gas water heater (condensing)	95% efficiency			
			Point-of-use water heater	0.81 EF or 81% Et			
			Electric heat pump water heater	2.33 EF			
			Pipe insulation (d < 1.5 in./d ≥ 1.5 in.)	1.0 in./1.5 in.			
HVAC	Heating System		No central steam – use hot water distribution system	Point-of-use steam for humidification and sterilization			
	Surgery	Central air-handling system	Water-cooled chiller	6.5 COP			
			Water-circulation pumps	VFD and NEMA premium			
			Cooling towers	VFD on tower fans			
			Boiler efficiency	90% Ec			
			Maximum fan power	bhp ≤ supply cfm × 0.0012 + A**			
			Economizer	Comply with 90.1*			
	Nonsurgery	Water-source heat pump (WSHP) system with DOAS	WSHP part-load/full-load cooling efficiency	15.0/17.6 EER			
			WSHP part-load/full-load heating efficiency	5.0/5.7 COP			
			WSHP compressor capacity control	Two-speed or variable-speed			
			Water-circulation pumps	VFD and NEMA premium			
			Closed-circuit cooling tower	VFD on fans			
			Boiler efficiency	90% Ec			
			Maximum fan power	0.4 W/cfm			
			Exhaust-air energy	A (humid zones) = 60% total effectiveness; B (dry zones) = 60% sensible			

	Item		Component	Climate Zone 5 Recommendation	Climate Zone 6 Recommendation	Climate Zone 7 Recommendation	Climate Zone 8 Recommendation
			recovery in DOAS	effectiveness			
			DOAS ventilation control	DCV with VFD			
		Fan-coil system with DOAS	Water-cooled chiller	6.5 COP			
			Water-circulation pumps	VFD and NEMA premium			
			Cooling towers	VFD on fans			
			Boiler efficiency	90% Ec			
			Maximum fan power	0.4 W/cfm			
			FCU fans	Multiple speed			
			Exhaust -air energy recovery in DOAS	A (humid zones) = 60% total effectiveness; B (dry zones) = 60% sensible effectiveness			
			DOAS ventilation control	DCV with VFD			
		Mixed-air VAV system with separate OA treatment and heat recovery system	Heat recovery water cooled chiller	4.55 COP			
			Water-cooled chiller	6.5 COP			
			Water-circulation pumps	VFD and NEMA premium			
			Cooling towers	VFD on tower fans			
			Boiler efficiency	90% Ec			
			Maximum fan power	bhp ≤ supply cfm × 0.0012 + A**			
			Economizer	Comply with 90.1*			
			Exhaust-air energy recovery in DOAS	A (humid zones) = 60% total effectiveness; B (dry zones) = 60% sensible effectiveness			
			DOAS ventilation control	DCV with VFD			
	Ducts and dampers		OA damper	Motorized			
			Duct seal class	Seal class A			
			Insulation level	R-6			
	Measurement and verification		Electrical submeters	Design and circuit for separate submeters for lighting, HVAC, general 120V, service water heating, renewables, and whole building			
			Benchmarking	Benchmark monthly energy use			
			Training	Facility operator on continuous benchmarking			

*Meet the more stringent of either the most current version of Standard 90.1 or the local code requirements
**A is defined in Table 6.5.3.1.1A in Standard 90.1-2010 (ASHRAE 2010)

5.2 Energy Savings Results

When the AEDG-LH recommendations were compiled and the final low-energy models simulated, the 50% savings goal was met or exceeded in all climate zones for all HVAC system types. Table 5–3 illustrates the energy savings results.

Table 5–3 Percent Savings Over Standard 90.1-2004

Climate Zone	Representative City	WSHP DOAS	FCU DOAS	Advanced VAV
1A	Miami, Florida	52.3%	53.3%	50.4%
2A	Houston, Texas	54.5%	54.9%	52.1%
2B	Phoenix, Arizona	55.9%	56.5%	53.3%
3A	Atlanta, Georgia	53.7%	54.0%	52.5%
3B:CA	Los Angeles, California	55.9%	55.4%	52.4%
3B	Las Vegas, Nevada	53.8%	54.2%	52.2%
3C	San Francisco, California	57.5%	56.5%	54.4%
4A	Baltimore, Maryland	55.1%	55.1%	55.0%
4B	Albuquerque, New Mexico	53.1%	54.6%	52.1%
4C	Seattle, Washington	56.8%	55.9%	53.9%
5A	Chicago, Illinois	55.4%	55.4%	53.9%
5B	Denver, Colorado	53.7%	54.7%	52.4%
6A	Minneapolis, Minnesota	56.1%	55.9%	54.8%
6B	Helena, Montana	55.5%	55.5%	54.1%
7	Duluth, Minnesota	56.8%	56.4%	55.7%
8	Fairbanks, Alaska	59.2%	57.8%	58.3%

Energy savings are relative to Standard 90.1-2004 (ASHRAE 2004b) baseline energy use, and include plug loads in the baseline and low-energy models. The analysis shows that the recommendations in the AEDG-LH meet or exceed the goal of 50% energy savings and that this goal can be met with a range of HVAC system types.

The simulation results are presented in Table 5–4 through Table 5–9 and Figure 5–1 through Figure 5–3, broken out by low-energy model HVAC system type (see Section 3.4.6 for details about the HVAC system types).

5.2.1 Water Source Heat Pump System

Table 5–4 WSHP System Simulation Results, Climate Zones 1A–4A

End Use (kBtu/ft²yr)	1A	2A	2B	3A	3B:CA	3B	3C	4A
Interior equipment (electric)	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
Interior equipment (gas)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Elevators (electric)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Interior lighting (electric)	17.3	17.4	17.3	17.4	17.3	17.3	17.4	17.2
Exterior lighting (electric)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Heating (electric)	0.6	0.7	0.6	0.8	0.6	0.7	0.8	0.9
Heating (gas)	5.5	5.6	4.6	5.7	4.9	4.1	4.8	6.8
Cooling (electric)	33.3	27.0	21.8	22.4	16.2	17.2	13.1	19.6
Fans (electric)	13.8	13.8	13.9	13.8	13.7	13.9	13.7	13.8
Pumps (electric)	7.0	6.4	5.0	5.9	3.6	4.1	3.1	5.8
SWH (gas)	3.4	4.1	3.7	4.8	4.7	4.2	5.3	5.4
Humidification (electric)	0.0	0.6	1.4	2.0	0.1	4.5	0.1	3.3
Refrigeration (electric)	2.5	2.2	2.3	2.0	1.8	2.1	1.6	1.9
Total energy	117.9	112.3	105.1	109.3	97.5	102.6	94.4	109.1
Percent savings	52.3%	54.5%	55.9%	53.7%	55.9%	53.8%	57.5%	55.1%

Table 5–5 WSHP System Simulation Results, Climate Zones 4B–8

End Use (kBtu/ft²yr)	4B	4C	5A	5B	6A	6B	7	8
Interior equipment (electric)	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
Interior equipment (gas)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Elevators (electric)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Interior lighting (electric)	17.1	17.3	17.2	17.2	17.1	17.1	17.2	17.4
Exterior lighting (electric)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Heating (electric)	1.2	0.9	1.1	0.6	1.2	0.8	1.1	1.6
Heating (gas)	2.7	5.4	8.0	3.5	9.3	5.5	10.3	16.8
Cooling (electric)	13.9	12.9	17.8	12.8	16.0	11.2	13.0	9.4
Fans (electric)	13.9	13.8	13.8	13.9	13.8	13.9	13.8	13.8
Pumps (electric)	2.7	3.4	5.7	2.7	5.3	2.5	4.2	2.6
SWH (gas)	5.3	5.6	5.8	5.8	6.2	6.3	6.9	7.7
Humidification (electric)	6.7	0.7	3.8	6.0	5.1	5.5	5.8	8.5
Refrigeration (electric)	1.9	1.6	1.8	1.7	1.8	1.7	1.6	1.6
Total energy	99.8	96.0	109.5	98.8	110.2	98.9	108.3	113.9
Percent savings	53.1%	56.8%	55.4%	53.7%	56.1%	55.5%	56.8%	59.2%

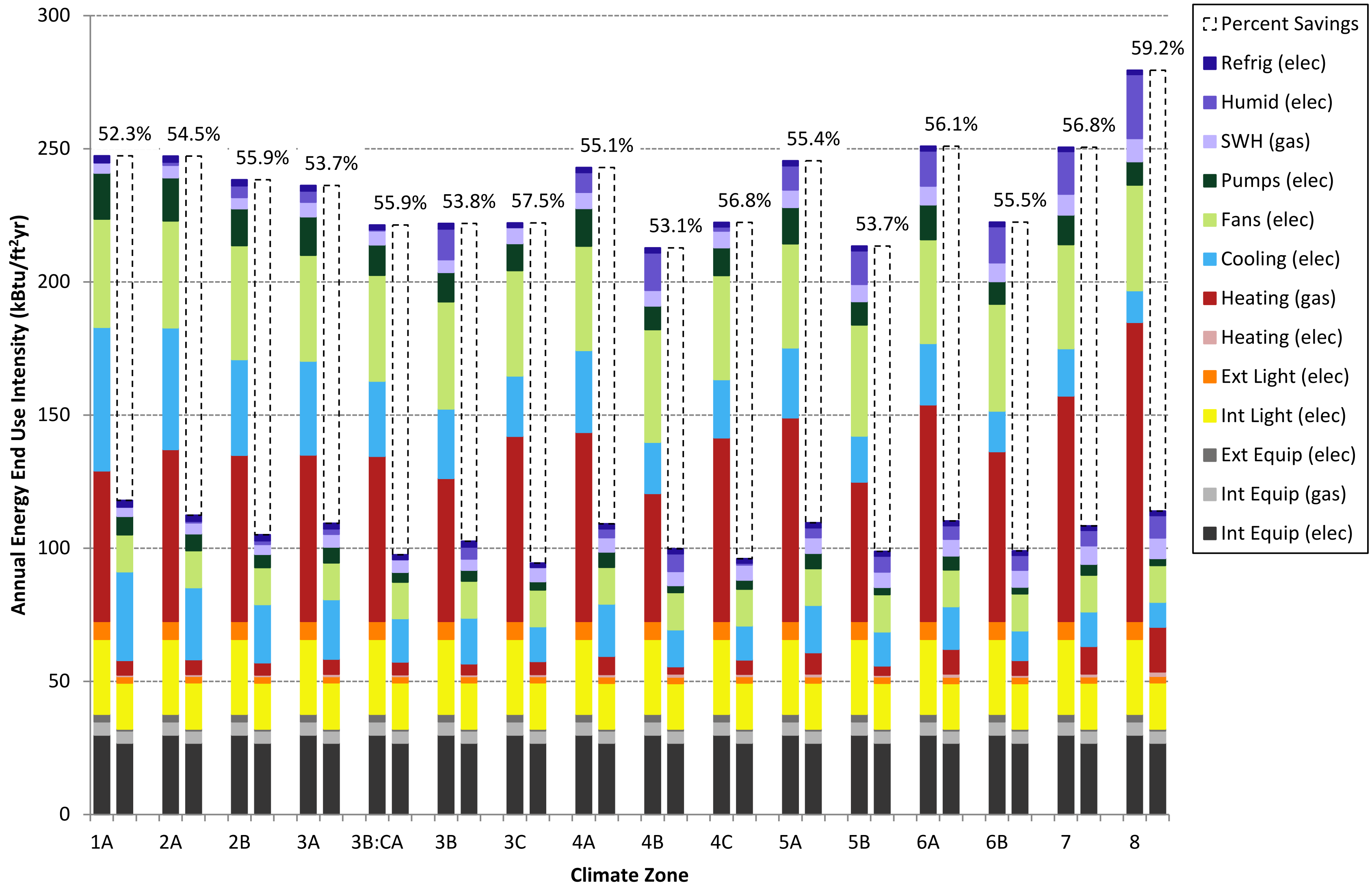

Figure 5–1 WSHP system simulation results

5.2.2 Fan Coil System

Table 5–6 FCU Simulation Results, Climate Zones 1A–4A

End Use (kBtu/ft²yr)	1A	2A	2B	3A	3B:CA	3B	3C	4A
Interior equipment (electric)	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
Interior equipment (gas)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Elevators (electric)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Interior lighting (electric)	17.3	17.4	17.3	17.4	17.3	17.3	17.4	17.2
Exterior lighting (electric)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Heating (gas)	8.2	9.0	7.6	9.4	8.1	7.3	8.8	11.1
Cooling (electric)	29.0	23.7	18.1	19.0	14.4	13.7	11.5	16.5
Fans (electric)	14.2	14.2	14.2	14.2	14.1	14.2	14.0	14.1
Pumps (electric)	6.4	5.9	4.7	5.5	3.8	4.0	3.3	5.4
SWH (gas)	3.4	4.1	3.7	4.8	4.7	4.2	5.3	5.4
Humidification (electric)	0.0	0.5	1.2	1.8	0.1	4.3	0.1	3.0
Refrigeration (electric)	2.5	2.2	2.3	2.0	1.8	2.1	1.6	1.9
Total energy	115.5	111.5	103.7	108.6	98.7	101.7	96.5	109.0
Percent savings	53.3%	54.9%	56.5%	54.0%	55.4%	54.2%	56.5%	55.1%

Table 5–7 FCU Simulation Results, Climate Zones 4B–8

End Use (kBtu/ft²yr)	4B	4C	5A	5B	6A	6B	7	8
Interior equipment (electric)	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
Interior equipment (gas)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Elevators (electric)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Interior lighting (electric)	17.1	17.3	17.2	17.2	17.1	17.1	17.2	17.4
Exterior lighting (electric)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Heating (gas)	5.1	9.6	13.0	6.4	14.7	9.4	15.5	24.7
Cooling (electric)	9.5	11.0	14.5	8.5	12.7	7.8	9.9	6.8
Fans (electric)	14.3	14.1	14.1	14.3	14.1	14.2	14.1	14.1
Pumps (electric)	2.8	3.5	5.3	2.8	4.9	2.7	4.1	2.9
SWH (gas)	5.3	5.6	5.8	5.8	6.2	6.3	6.9	7.7
Humidification (electric)	6.2	0.7	3.1	5.4	4.6	5.4	5.5	8.4
Refrigeration (electric)	1.9	1.6	1.8	1.7	1.8	1.7	1.6	1.6
Total energy	96.6	98.0	109.5	96.7	110.8	99.0	109.4	118.0
Percent savings	54.6%	55.9%	55.4%	54.7%	55.9%	55.5%	56.4%	57.8%

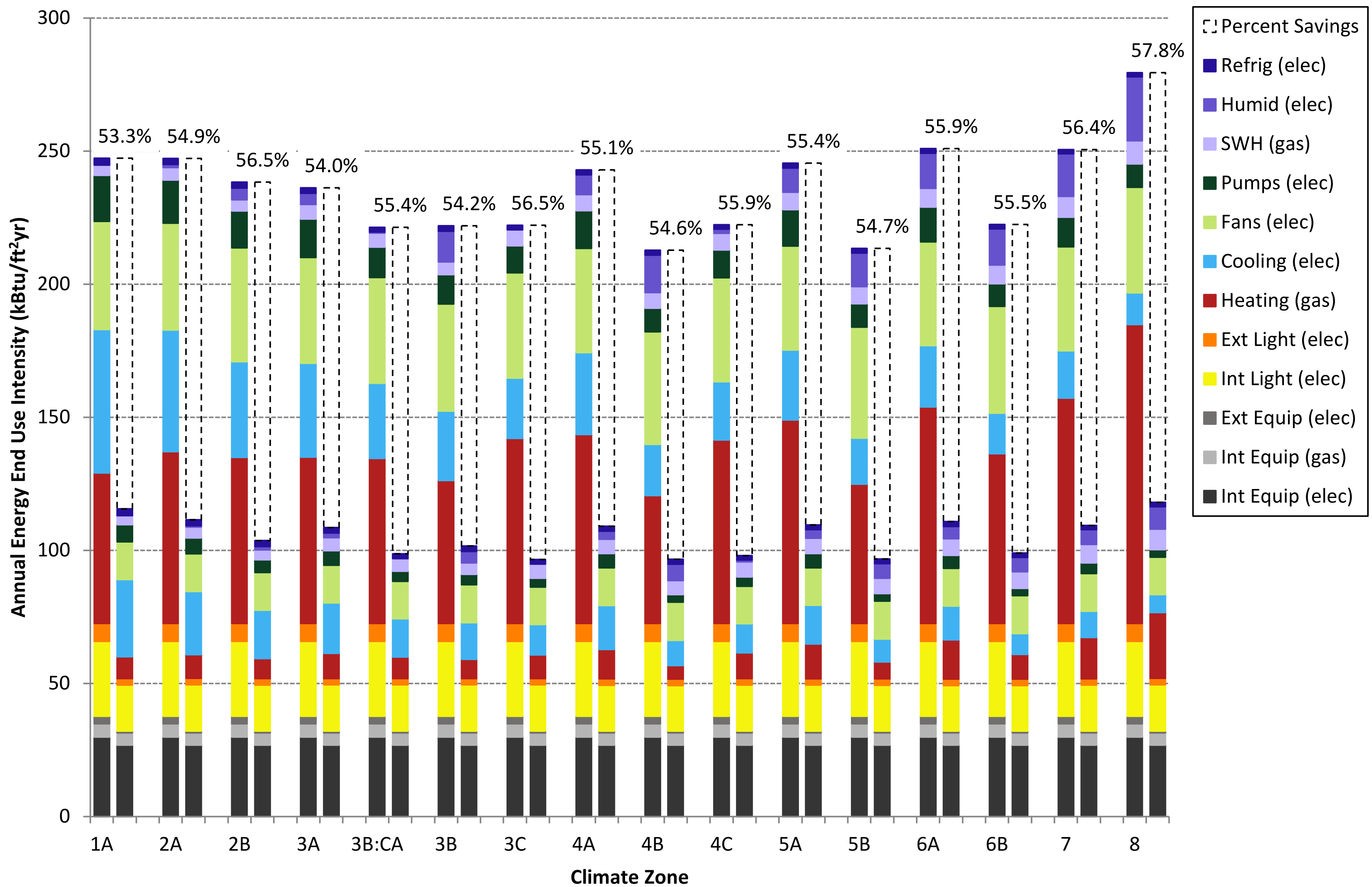

Figure 5–2 FCU simulation results

5.2.3 Advanced Variable Air Volume System

Table 5–8 Advanced VAV System Simulation Results, Climate Zones 1A–4A

End Use ($kBtu/ft^2yr$)	1A	2A	2B	3A	3B:CA	3B	3C	4A
Interior equipment (electric)	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
Interior equipment (gas)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Elevators (electric)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Interior lighting (electric)	17.3	17.4	17.3	17.4	17.3	17.3	17.4	17.2
Exterior lighting (electric)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Heating (gas)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Cooling (electric)	35.8	31.5	25.0	25.2	21.6	19.8	17.9	22.2
Fans (electric)	20.7	20.4	21.6	20.3	19.6	21.4	19.4	20.0
Pumps (electric)	8.2	8.2	6.9	7.7	5.7	6.1	5.1	7.6
SWH (gas)	3.4	4.1	3.7	4.8	4.7	4.2	5.3	5.4
Humidification (electric)	0.0	0.1	0.1	0.3	0.0	0.6	0.0	0.5
Refrigeration (electric)	2.5	2.2	2.3	2.0	1.8	2.1	1.7	1.9
Total energy	122.6	118.4	111.4	112.3	105.3	106.0	101.2	109.4
Percent savings	50.4%	52.1%	53.3%	52.5%	52.4%	52.2%	54.4%	55.0%

Table 5–9 Advanced VAV System Simulation Results, Climate Zones 4B–8

End Use ($kBtu/ft^2yr$)	4B	4C	5A	5B	6A	6B	7	8
Interior equipment (electric)	26.8	26.8	26.8	26.8	26.8	26.8	26.8	26.8
Interior equipment (gas)	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Elevators (electric)	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Interior lighting (electric)	17.1	17.3	17.2	17.2	17.1	17.1	17.2	17.4
Exterior lighting (electric)	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Heating (gas)	0.0	1.6	5.4	1.6	7.3	3.6	8.2	16.1
Cooling (electric)	15.3	16.7	20.4	13.5	18.3	12.5	15.1	11.2
Fans (electric)	22.1	19.7	20.1	21.8	20.1	21.1	20.2	20.7
Pumps (electric)	4.7	5.2	7.2	4.4	6.8	4.3	5.8	4.5
SWH (gas)	5.3	5.6	5.8	5.8	6.2	6.3	6.9	7.7
Humidification (electric)	1.0	0.0	0.7	1.0	1.2	1.0	1.5	2.7
Refrigeration (electric)	1.9	1.7	1.8	1.8	1.8	1.7	1.7	1.6
Total energy	101.8	102.4	113.1	101.5	113.4	102.1	111.1	116.4
Percent savings	52.1%	53.9%	53.9%	52.4%	54.8%	54.1%	55.7%	58.3%

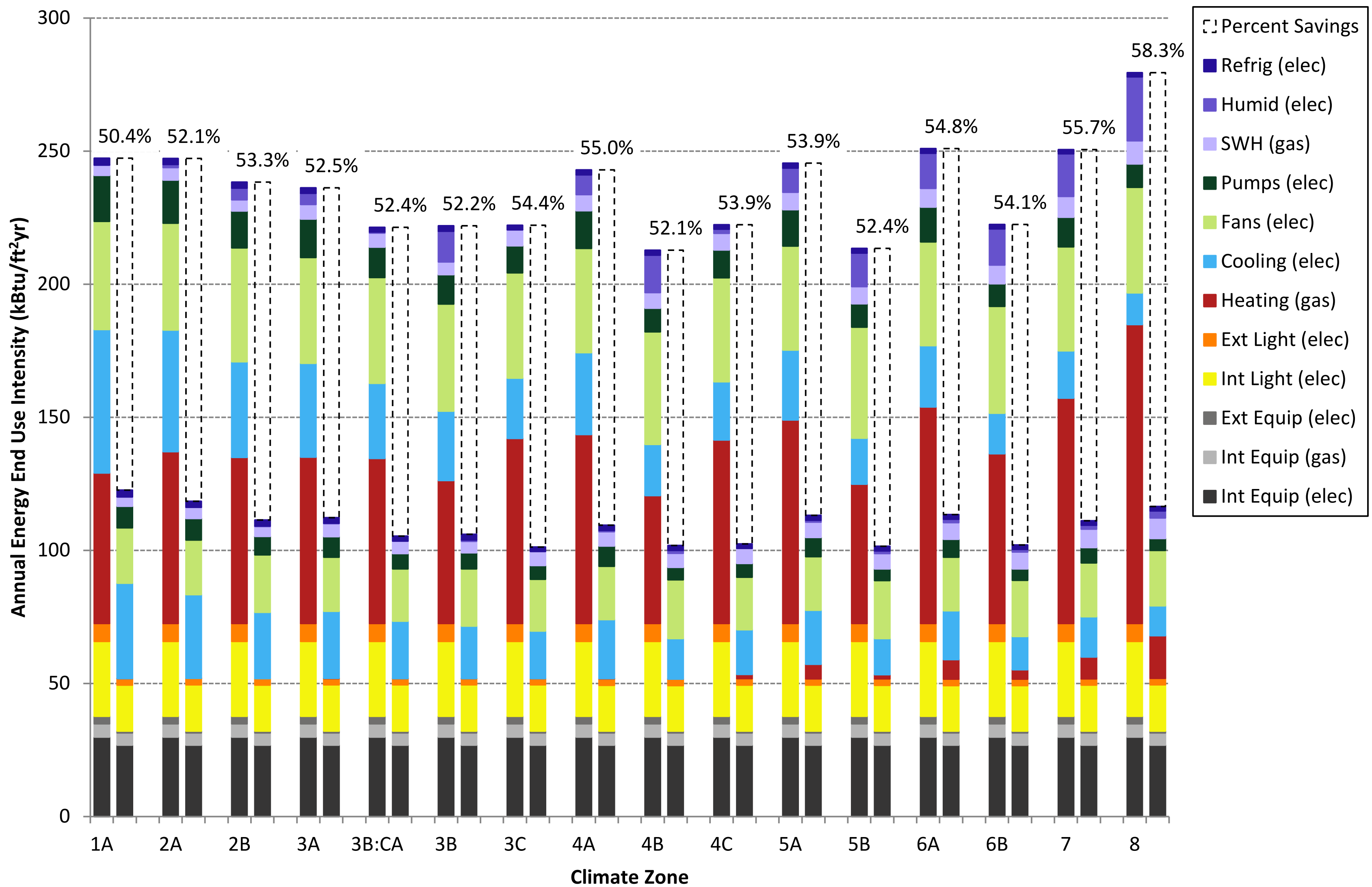

Figure 5–3 Advanced VAV system simulation results

6. Conclusion

This TSD describes the process and methodology used to develop the AEDG-LH, which is intended to provide recommendations for achieving 50% whole-building energy savings in large hospitals over levels achieved by following Standard 90.1-2004 (ASHRAE 2004b). The AEDG-LH was developed in collaboration with ASHRAE, AIA, IES, USGBC, ASHE, and DOE. One of NREL's tasks was to provide the analysis and modeling support to verify energy savings and develop recommendations that met the 50% savings goal. The 50% energy savings target represents a step toward achieving net-zero energy healthcare facilities. Net-zero energy buildings draw equal (or less) energy from outside sources than they generate onsite from renewable energy sources during a given year. The AEDG-LH provides user-friendly design assistance and recommendations to design, architectural, and engineering firms to help achieve energy savings. It includes prescriptive recommendations by climate zone for designing the building envelope, fenestration, lighting systems (including electric lights and daylighting), HVAC systems, building automation and controls, OA treatment, and the SWH system. Additional savings recommendations are also included, but are not necessary for 50% savings. These are provided for alternative HVAC systems and renewable energy systems. The AEDG-LH contains recommendations only and is not a code or standard.

The AEDG-LH provides a simple, easy-to-use guide to help the building designer, contractor, and owner identify a clear, prescriptive path to 50% energy savings over Standard 90.1-2004 (ASHRAE 2004b). In many ways, it is a simple interface to a complex analysis performed using EnergyPlus. The combination of a set of recommendations contained on a single page, along with numerous how-to tips to help the construction team complete the project successfully, should help facilitate increased energy efficiency in new buildings. Case studies of actual hospital applications add to the comprehension of energy efficiency opportunities. The ultimate goal of the AEDG partner organizations is to achieve net-zero energy buildings, and the 50% savings guides represent a step in reaching this goal.

Separate from the AEDG-LH, this TSD was created to chronicle the process used to develop the guide and the analysis performed to support that development. The specific objectives were to document:

- The process and schedule used to develop the AEDG-LH.
- Prototypical large hospital characteristics.
- The EnergyPlus modeling assumptions used to establish 50% energy savings.
- The EnergyPlus baseline and low-energy large hospital models.

In addition, TSD goals were to:

- Present the recommendations for achieving at least 50% savings over Standard 90.1-2004.
- Demonstrate that the recommendations result in 50% or greater energy savings by climate zone.

A partial subset of the information contained in this TSD is included in the AEDG-LH, but the information is too extensive for full inclusion. This TSD provides complete documentation of all the simulation results for each climate zone and HVAC system type covered by the guide. It also provides a technical resource to industry members who are looking to implement AEDG recommendations in real projects.

7. References

ARI. (2002). ANSI/ARI Standard 1200-2002, Commercial Refrigerated Display Cases. Arlington, VA: Air-Conditioning and Refrigeration Institute.

ASHRAE. (1999). ANSI/ASHRAE/IESNA Standard 90.1-1999, Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE (2001). Estimating Food Service Loads and Profiles. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. (2004a). ANSI/ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. (2004b). ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

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

ASHRAE. (2008). ANSI/ASHRAE/ASHE Standard 170, Ventilation of Health Care Facilities. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. (2009). Fundamentals Handbook. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. (2010). ANSI/ASHRAE/IESNA Standard 90.1-2010, Energy Standard for Buildings Except Low-Rise Residential Buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE; AIA; IESNA; NBI; DOE. (2004). Advanced Energy Design Guide for Small Office Buildings: Achieving 30% Energy Savings Toward a Net Zero Energy Building. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE; AIA; IESNA; USGBC; DOE. (2006). Advanced Energy Design Guide for Small Retail Buildings: Achieving 30% Energy Savings Toward a Net Zero Energy Building. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE, AIA, IESNA, USGBC and DOE (2008a). Advanced Energy Design Guide for K-12 School Buildings: Achieving 30% Energy Savings Toward a Net Zero Energy Building, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE; AIA; IESNA; USGBC; DOE. (2008b). Advanced Energy Design Guide for Small Warehouses and Self-Storage Buildings: Achieving 30% Energy Savings Toward a Net Zero Energy Building. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE; AIA; IESNA; USGBC; DOE. (2009a). Advanced Energy Design Guide for Highway Lodging: Achieving 30% Energy Savings Toward a Net Zero Energy Building. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE; AIA; IESNA; USGBC; DOE. (2009b). Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities: Achieving 30% Energy Savings Toward a Net Zero Energy Building. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE; AIA; IESNA; USGBC; DOE. (2011a). Advanced Energy Design Guide for K-12 School Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE; AIA; IESNA; USGBC; DOE. (2011b). Advanced Energy Design Guide for Medium to Big Box Retail Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE; AIA; IESNA; USGBC; DOE. (2011c). Advanced Energy Design Guide for Small to Medium Office Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE; AIA; IESNA; USGBC; DOE. (2012). Advanced Energy Design Guide for Large Hospitals: Achieving 50% Energy Savings Toward a Net Zero Energy Building. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Bonnema, E.; Doebber, I.; Pless, S.; Torcellini, P. (2010a). Technical Support Document: Development of the Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities-30% Guide. Golden, CO: National Renewable Energy Laboratory, NREL/TP-550-46314.

Bonnema, E.; Studer, D.; Parker, A.; Pless, S.; Torcellini, P. (2010b). Large Hospital 50% Energy Savings: Technical Support Document. Golden, CO: National Renewable Energy Laboratory, NREL/TP-550-47867.

Briggs, R.S.; Lucas, R.G.; Taylor, Z.T. (2003). Climate Classification for Building Energy Codes and Standards: Part 1- Development Process. Richland, WA: Pacific Northwest National Laboratory.

Deru, M.; Field, K.; Studer, D.; Benne, K.; Griffith, B.; Torcellini, P.; Liu, B.; Halverson, M.; Winiarski, D.; Rosenberg, M.; Yazdanian, M.; Huang, J.; Crawley D. (2011). U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. Golden, CO: National Renewable Energy Laboratory, NREL/TP-5500-46861.

DOE. (2003). "Map of DOE's Proposed Climate Zones." Washington, D.C.: U.S. Department of Energy Building Energy Codes Program. www.energycodes.gov.

DOE. (2011). EnergyPlus Energy Simulation Software, Version 7.0. Washington, D.C.: U.S. Department of Energy. http://apps1.eere.energy.gov/buildings/energyplus/

GGHC. (2007). "Green Guide for Health Care: Best Practices for Creating High Performance Healing Environments, Version 2.2." Retrieved August 2010, www.gghc.org.

Judkoff, R.; Neymark, J. (1995). International Energy Agency Building Energy Simulation Test (BESTEST) and Diagnostic Method. Golden, CO: National Renewable Energy Laboratory, NREL/TP-472-6231.

Leach, M.; Bonnema, E.; Pless, S.; Torcellini, P. (2012). "Setting Whole-Building Absolute Energy Use Targets for the K-12 School, Retail, and Healthcare Sectors." Presented at the ACEEE Summer Study, Pacific Grove, CA, August 12–17, 2012. Golden, CO: National Renewable Energy Laboratory, NREL/CP-5500-55131.

NREL. (2010). "Opt-E-Plus Software for Commercial Building Optimization." Golden, CO: National Renewable Energy Laboratory, NREL/FS-550-45620.

USGBC. (2009). LEED 2009 Green Building Design and Construction Reference Guide. Washington, D.C.: U.S. Green Building Council.

Appendix A. Scoping Document

This appendix contains an exact copy of the scoping document for the AEDG-LH.

Purpose

To significantly transform the marketplace with speed and scale by providing user-friendly, "how-to" design guidance and efficiency recommendations to owners, operators, designers and builders of large hospitals in order to achieve savings of 50% over ANSI/ASHRAE/IESNA Standard 90.1-2004.

Background

The first series of Advanced Energy Design Guides (AEDGs) included six publications designed to provide recommendations for achieving 30% energy savings over the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-1999 for different building types. This series is similar, but is instead designed to provide recommendations for achieving 50% energy savings over the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004.

Builders and designers, while complying with minimum energy code requirements, often lack the opportunity or have insufficient design fees to pursue innovative, energy-efficient concepts in the design of hospitals. The 50% AEDG for large hospitals will provide prescriptive design assistance in a user-friendly presentation to owners and designers who want to achieve greater energy savings than obtained through minimum code compliance.

Goal

To provide owners and designers of large hospitals with design recommendations and user-friendly modeling tools that will enable them to achieve 50% site energy savings beyond a Standard 90.1-2004 minimally-compliant baseline.

- The recommendations of the guide will meet the 50% savings goal for each of the climate zones covered by the guide.
- The 50% savings goal is a hard goal as opposed to an approximate target, and represents a significant step towards increased energy efficiency from the goal of the 30% AEDG.
- Energy savings will be achieved through the identification of packages of design measures and state-of-the-art building systems and design concepts that result in energy-efficient spaces.

Audience

- Owners and design teams of large hospitals interested in 50% energy savings and supported by energy modeling expertise. This is typically a more sophisticated design team capable of using modeling to evaluate prospective designs to ensure they meet AEDG recommendations.
- Engineers and designers interested in developing the skills needed to produce 50% energy savings in large hospitals.

Recommendation Development Guidelines

- Recommendations are divided into two distinct paths: (1) a prescriptive path, for which tables of recommendations will be provided for the most common 50% design strategies and alternative design strategy subsystem performance and (2) a performance-based path based on whole-building energy use. Prescriptive measures will be assigned performance-based benchmarks. The performance-based path will allow increased design freedom, requiring adherence to a performance-based benchmark only with respect to whole-building energy use intensity.

- Recommendations will be presented in a user-friendly, "how-to" format to ease the burden for the designers and give hospital decision makers an easy-to-follow overview of the design process. Modeling tools designed to enhance the speed and scope of recommendation deployment and adoption will be packaged in a similarly user-friendly manner that minimizes energy modeling experience requirements insofar as possible. Design recommendations need to contain practical design information that can be used within the constraints of typical construction and design fees.
- Recommendations will not specify the implementation of unique products. All recommended products will be required to be available from at least two manufacturers.
- Recommendations will be developed using best practice examples of design and technology, modeled using up-to-date performance inputs.
- Focus will be on illustrating how to use integrated design concepts, design process, and team working relationships to minimize the cost of implementation for AEDG recommendations.

Case Studies

A number of case studies will be included to provide examples of both whole-building integrated design concepts and the implementation of energy-efficient components or techniques. In many instances, case studies will be specific to particular geographic regions (as in the 30% AEDG).

Scope

The 50% AEDG for large hospitals, representing a progression of the 30% AEDG series with respect to energy-efficient design guidelines, will provide prescriptive and performance-based paths to achieving 50% site energy savings in large hospitals. Energy savings will be measured against "baseline" or "reference" buildings for each climate that are minimally code-compliant with respect to Standard 90.1-2004.

For the purposes of this 50% AEDG, we define a large hospital as having the following common space types:

- Cafeterias, kitchens, and dining facilities
- Administrative, conference, lobby, lounge, and office areas
- Reception/waiting areas and examination and treatment rooms
- Clean and soiled workrooms and holding areas
- Nurse stations, nurseries, patient rooms, hallways, lockers, and restrooms
- Operating suites, procedure rooms, recovery rooms, and sterilizer equipment areas
- Pharmacies, medication rooms, and laboratories
- Triage areas and trauma/emergency rooms
- Physical therapy and imaging/radiology rooms
- Storage, receiving, laundry, and mechanical/electrical rooms.

The 50% AEDG for large hospitals will apply to all new construction hospital buildings greater than 100,000 ft^2. Recommendations will be based on a ~427,000 ft^2 hospital prototype. Whole-building models adapted from the prototype designs will be equipped with HVAC systems designed to meet minimum ventilation requirements and maintain comfort standards year-round.

Design recommendations will apply to the following building aspects:

- Opaque envelope and exterior glazing
- Lighting and daylighting systems
- HVAC system design and components
- Building automation and control systems
- Treatment of outside air, including dedicated outdoor air systems (DOAS), energy recovery systems, and dehumidification systems
- Service water heating (SWH) for bathrooms, locker rooms, and food preparation spaces
- Plug and process loads, including medical equipment and kitchen process loads
- Commissioning.

Design recommendations will not be provided for building aspects considered out of the scope of this task, including:

- Campus utilities such as chilled water and steam
- Water use
- Sewage disposal.

The guide is not intended to substitute for rating systems or references that address the full range of sustainable issues in hospitals, such as acoustics, productivity, indoor air quality, water efficiency, landscaping, and transportation, except as they relate to operational energy consumption. Nor will this guide be a design text; we assume that good design skills and expertise in hospital design, in particular, will be required to successfully apply the design recommendations of the guide.

Appendix B. Project Committee Meeting Agendas

B.1 Meeting 1

Large Hospital Advanced Energy Design Guide - 50% Energy Savings
Project Committee Meeting 1 Agenda

ASHRAE Headquarters
1791 Tullie Circle
Atlanta, GA 30329
404-636-8400

Friday, June 17, 2011, 8:00AM – 5:00PM
Saturday, June 18, 2011, 8:00AM – 1:30PM

The Marriott Courtyard serves breakfast to guests. You should have received a breakfast coupon when you checked in with your ASHRAE rate. We can meet in the breakfast area informally at 7:00AM for breakfast. We will identify a place to have dinner as a group on Friday night. Lunches will be brought in by ASHRAE.

Pre meeting action items

- Review scoping document
- Review 30% AEDGs
- Be prepared to share the energy efficiency strategies that you have used in hospitals
- Bring calendars for this summer/fall/winter
- Bring case studies to share

Meeting objectives

- Common understanding of the scope
- Define development process and integration with energy modeling
- Identify team member experiences and roles
- Define general concept on what it takes to get to 50% savings in a hospital
- Form working groups and section assignments

Agenda

Friday, June 17, 2011

1	Welcome/review agenda	Pless	8:00
2	Introductions • Give name/affiliation and experience • Be ready to share the energy efficiency strategies that you have used (what do you think it takes to get to 50% energy savings)	All	8:15
3	AEDG-LH overview • Organization of AEDG series • Committee makeup structure/partnering organization • Scoping document formation • Reference case determination	Pratt/Pless	9:15
4	Review and questions on scoping document	Pratt/Pless	9:30

	• Context of the other AEDGs • Goals and objectives of the AEDG-LH • Target audience • Review of scoping document Peer review process • Discuss if a concept peer review is needed (the SC wants the guides in the same format)		
5	Break	All	10:00
6	Future meeting schedule • Bring your calendars for next summer/fall/winter	Pratt/Pless	10:15
7	Outline of AEDG-LH • Review outline of previous guides • Discuss possible modifications/changes How will this guide be unique? • What will be different about this guide? • What new information will be provided? Assignments of staff to guide sections • Identify section leaders and section contributors	Pratt/Pless	10:45
8	Update on current work in healthcare sector	Loveland	11:15
9	ASHRAE headquarters tour	All	12:00
10	Lunch	All	12:30
11	Presentation on heat pumps in hospitals	Boldt	1:30
12	Energy modeling • Analysis engine and modeling background • Baseline building discussion • Preliminary modeling results • Plans for modeling going forward	Bonnema	2:15
13	Break	All	3:00
14	Group breakout • Lighting/daylighting • Architecture, envelope, and integrated design • HVAC • O&M, commissioning	All	3:15

Saturday, June 18, 2011

1	Group breakout	Groups	8:00
2	Break	All	10:15
3	Group breakout	Groups	10:30
4	Working lunch (discuss case studies)	All	12:00
5	Review • Group breakout sessions • Action items for next meeting	All	1:00
6	Adjourn	All	1:30

B.2 Meeting 2

Large Hospital Advanced Energy Design Guide - 50% Energy Savings
Project Committee Meeting 2 Agenda

NREL
1617 Cole Blvd
Golden, CO 80401
303-275-3000

Thursday, August 4, 2011, 8:00AM – 5:00PM
Friday, August 5, 2011, 8:00AM – 2:00PM

Continental breakfast will be served each morning at 7:45AM at NREL. On Thursday, please meet in the hotel lobby at 7:15 to ride in a shuttle to the NREL visitor's center to be badged. The badges are good for two days, so we can leave the hotel at 7:30 on Friday. We will identify a place to have dinner as a group on Thursday night. Lunches will be brought in by NREL.

Pre meeting action items

- Bring first drafts of your assigned sections
- Bring case studies to include in the guide

Meeting objectives

- Everyone should have all the information they need to complete the first draft by August 17

Agenda

Thursday, August 4, 2011

1	Welcome/review agenda	Pless	8:00
2	RSF tour	All	8:15
3	Section updates • Forward – Vernon, D'Angelo • Integrated design – Loveland, Vernon, Pradinuk, Baum • Building design strategies – Pradinuk, Loveland, All • Opaque envelope – McBride, Baum, Pradinuk • Vertical fenestration – Baum, Pradinuk, McBride • Daylighting – Pradinuk, Baum, Loveland, Gill • Interior/exterior lighting – Gill, D'Angelo, Vernon, Loveland • HVAC systems and considerations – Schwedler, Boldt, Shinn • HVAC ventilation – D'Angelo, Peglow, Boldt, Shinn, Vernon • SWH – Schwedler, Boldt, Shinn Vernon • Plug loads and medical equipment – Peglow, Vernon • Bonus HVAC – Schwedler, Boldt, Shinn • Bonus other – Vernon	All	9:00

4	Break	All	10:30
5	Energy modeling update	Bonnema	10:45
6	Discuss plan for Chapter 3 (performance option) • Determine outline for the chapter, who will contribute • What will be covered in the chapter	All	11:00
7	Lunch	All	12:00
8	Recommendation table review • Plan on including recommendation table by climate zone in the first draft of the guide	Bonnema	1:00
9	Group breakout • Lighting/daylighting • Architecture, envelope, and integrated design • HVAC • O&M, commissioning	All	2:15

Friday, August 5, 2011

1	Group breakout • Lighting/daylighting • Architecture, envelope, and integrated design • HVAC/kitchens • O&M, commissioning	All	8:00
2	Break	All	10:00
3	Group breakout • Lighting/daylighting • Architecture, envelope, and integrated design • HVAC/kitchens • O&M, commissioning	All	10:15
4	Lunch	All	12:00
5	Review • Group breakout sessions • Action items for next meeting	All	1:00
6	Adjourn	All	2:00

B.3 Meeting 3

Large Hospital Advanced Energy Design Guide - 50% Energy Savings
Project Committee Meeting 3 Agenda

ASHE Offices
155 Wacker Drive Suite 400
Chicago, IL 60606

Thursday, September 29, 2011, 8:00AM – 5:00PM
Friday, September 30, 2011, 8:00AM – 2:00PM

The La Quinta Inn serves a free "Bright Side" continental breakfast to guests. We can meet in the breakfast area informally at 7:00AM for breakfast and will walk over to the ASHE offices at 7:45. We will identify a place to have dinner as a group on Thursday night. Lunches will be brought in on Thursday and Friday.

Pre meeting action items

- Conduct detailed review of the first draft
- Review comments assigned to each member and prepare responses to discuss at the meeting
- Bring your calendars to schedule conference calls
- Bring case studies that you would like to include in the AEDG-LH

Meeting objectives

- Address and document responses to remarks
- Identify holes in the draft
- Assign case studies to PC members
- Develop action item list to get next draft completed by October 31
- TBD conference call to discuss progress towards second peer review draft
- "Final" deadline COB October 26, 2011
- Conference call near posting date to verify any additional tweaking
- Second peer review draft posted October 31, 2011

Agenda

Thursday, September 29, 2011

1	Welcome/review agenda • Next meeting in Houston December 8-9 • Next peer review period 10/31-11/11	Pless	8:00
2	Comments on meeting two minutes	All	8:45
3	Old action items review and update	Etheredge	9:00
4	Case study assignments • Whole-building and technology case studies	Pratt	9:15
5	Discuss latest simulation results	Bonnema	9:30
6	Review recommendation table as a group	Bonnema	9:45
7	Break	All	10:00
8	Review comment matrix as a group	All	10:15
9	Lunch	All	12:00

10	Additions to the draft? • How to use steam efficiently on a new campus project where steam is already available • Lighting in patient room bathroom - occupancy/vacancy sensors – special consideration for wet spaces • Associate light switch to particular light fixture in a patient room • Lighting controls falls between the cracks between lighting designer and electrical engineer. • Think about an 'all off' switch at the door for patient room lights, but each one switched on individually • Design the patient room lights to be easier to shut off than turn on • Others?	Bonnema/All	1:00
11	Review comment matrix as a group	All	1:30
12	Break	All	3:00
13	Break into chapter groups to address specific remarks and work on solutions to remarks	All	3:15
14	Break for the day	All	5:00

Friday, September 30, 2011

1	Review departures and coordinate transportation to airport	All	8:00
2	Break into chapter groups to address specific remarks and work on solutions to remarks	All	8:30
3	Break	All	10:00
4	Break into chapter groups to address specific remarks and work on solutions to remarks	All	10:15
5	Lunch	All	12:00
6	Adjourn	All	1:00

B.4 Meeting 4

Large Hospital Advanced Energy Design Guide – 50% Energy Savings
Project Committee Meeting 4 Agenda

MD Anderson
1515 Holcombe Blvd
Houston, TX 77030

Thursday, December 8, 2011, 8:00AM – 5:00PM
Friday, December 9, 2011, 8:00AM – 2:00PM

The Holiday Inn serves breakfast at the Main Street Bar and Grill starting at 6:00AM. We can meet in the breakfast area informally at 6:45 am for breakfast and walk to the meeting location from the hotel together at 7:45. We will identify a place to have dinner as a group on Thursday night. Lunches will be brought in on Thursday and Friday.

Pre meeting action items

- Conduct detailed review of the second draft
- Review comments assigned to each member and prepare responses to discuss at the meeting
- Bring any additional case studies that you would like to include in the AEDG-LH

Meeting objectives

- Address and document responses to remarks
- Identify holes in the draft
- Acknowledgements
- Adding how-to tips references to the tables
- Complete all bibliographical reference information
- Develop action item list to get 95% draft completed by December 16, 2011

Agenda

Thursday, December 8, 2011

1	Welcome/review agenda	Pless	8:00
2	Cover pictures (decide on 2-3 for front, 12 or so for back) • One shot on the front of whole building • Three shots on the back, more freedom here	Pratt/All	8:15
3	Graphics – schedule, content, and process	Pratt	8:30
4	Galley proof review process	Pratt	8:45
5	Case studies • More whole-building case studies • Technology examples (daylighting, HVAC, others?)	Pless	9:00
6	Final energy modeling results	Bonnema	9:30
7	Break	All	10:00
8	Review general draft remarks and determine responses • Overall observations • Problems based on first look? • Major holes in draft?	Pratt	10:15

9	Lunch	All	12:00
10	Break into chapter groups to address specific remarks and work on solutions to remarks. If all remarks have been addressed, then work on preparing the document for the 95% draft	All	1:00
11	Break	All	3:00
12	Break into chapter groups to address specific remarks and work on solutions to remarks. If all remarks have been addressed, then work on preparing the document for the 95% draft	All	3:15
13	Break for the day	All	5:00

Friday, December 9, 2011

1	Review final schedule for completion of the document • Schedule conference call times	Pratt	8:00
2	Break into chapter groups to address specific remarks and work on solutions to remarks. If all remarks have been addressed, then work on preparing the document for the 95% draft	All	8:30
3	Break	All	10:00
4	Break into chapter groups to address specific remarks and work on solutions to remarks. If all remarks have been addressed, then work on preparing the document for the 95% draft	All	10:15
5	Lunch	All	12:00
6	Meeting summary review • Define the work that will need to be done • Define the timing for getting everything done	All	12:45
7	Break into chapter groups to address specific remarks and work on solutions to remarks. If all remarks have been addressed, then work on preparing the document for the 95% draft	All	1:00
8	Adjourn	All	2:00

Appendix C. Schedule Tabular Data

C.1 Occupancy Schedules

Table C–1 Office Occupancy Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
Weekday	0.00	0.00	0.00	0.00	0.00	0.10	0.20	0.95	0.95	0.95	0.95	0.95
Saturday	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.30	0.30	0.30	0.30
All other days	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table C–2 Office Occupancy Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
Weekday	0.50	0.95	0.95	0.95	0.95	0.30	0.30	0.10	0.05	0.05	0.05	0.05
Saturday	0.10	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
All other days	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table C–3 24/7 Occupancy Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.40	0.40	0.40	0.40	0.65	0.65	0.90	0.90	0.90	0.90	0.90	0.90

Table C–4 24/7 Occupancy Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.90	0.90	0.90	0.90	0.90	0.90	0.65	0.65	0.65	0.65	0.40	0.40

Table C–5 Patient Occupancy Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.70	0.80	0.80

Table C–6 Patient Occupancy Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.80	0.80	0.80	0.80	0.80	0.80	0.70	0.70	0.70	0.70	0.70	0.70

Table C–7 Dining Occupancy Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.05	0.00	0.00	0.00	0.00	0.05	0.10	0.40	0.40	0.20	0.50	0.80

Table C–8 Dining Occupancy Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.80	0.70	0.40	0.20	0.50	0.80	0.80	0.50	0.50	0.35	0.20	0.20

Table C–9 Kitchen Occupancy Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.45	0.15	0.15	0.15	0.15	0.45	0.90	0.90	0.90	0.90	0.90	0.90

Table C–10 Kitchen Occupancy Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.60	0.60

C.2 Kitchen Exhaust Fan Schedule

Table C–11 Kitchen Exhaust Fan Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Table C–12 Kitchen Exhaust Fan Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.0	0.0

C.3 Thermostat Set Point Schedules

Table C–13 Office Thermostat Set Point Schedule, Hour 1–12 (°F)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
Heating Saturday	65.0	65.0	65.0	65.0	65.0	65.0	70.0	70.0	70.0	70.0	70.0	70.0
Heating Sunday	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Heating All Other Days	65.0	65.0	65.0	65.0	65.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Cooling Saturday	77.0	77.0	77.0	77.0	77.0	77.0	72.0	72.0	72.0	72.0	72.0	72.0
Cooling Sunday	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0
Cooling All Other Days	77.0	77.0	77.0	77.0	77.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0

Table C–14 Office Thermostat Set Point Schedule, Hour 13–24 (°F)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
Heating Saturday	70.0	70.0	70.0	70.0	70.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Heating Sunday	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Heating All Other Days	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	65.0	65.0	65.0	65.0
Cooling Saturday	72.0	72.0	72.0	72.0	72.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0
Cooling Sunday	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0	77.0
Cooling All Other Days	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	77.0	77.0	77.0	77.0

Table C–15 24/7 Thermostat Set Point Schedule, Hour 1–12 (°F)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
Heating All Days	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Cooling All Days	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0

Table C–16 24/7 Thermostat Set Point Schedule, Hour 13–24 (°F)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
Heating All Days	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Cooling All Days	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0

Table C–17 Dining Thermostat Set Point Schedule, Hour 1–12 (°F)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
Heating All Days	65.0	65.0	65.0	65.0	65.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Cooling All Days	77.0	77.0	77.0	77.0	77.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0

Table C–18 Dining Thermostat Set Point Schedule, Hour 13–24 (°F)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
Heating All Days	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
Cooling All Days	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0	72.0

Table C–19 Kitchen Thermostat Set Point Schedule, Hour 1–12 (°F)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
Heating All Days	65.0	62.0	62.0	62.0	62.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Cooling All Days	68.0	72.0	72.0	72.0	72.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0

Table C–20 Kitchen Thermostat Set Point Schedule, Hour 13–24 (°F)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
Heating All Days	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
Cooling All Days	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0

Table C–21 Operating Thermostat Set Point Schedule, Hour 1–12 (°F)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
Heating All Days	59.0	59.0	59.0	59.0	59.0	59.0	65.0	65.0	65.0	65.0	65.0	65.0
Cooling All Days	74.0	74.0	74.0	74.0	74.0	74.0	65.0	65.0	65.0	65.0	65.0	65.0

Table C–22 Operating Thermostat Set Point Schedule, Hour 13–24 (°F)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
Heating All Days	65.0	65.0	65.0	65.0	65.0	65.0	59.0	59.0	59.0	59.0	59.0	59.0
Cooling All Days	65.0	65.0	65.0	65.0	65.0	65.0	74.0	74.0	74.0	74.0	74.0	74.0

C.4 Elevator Schedule

Table C–23 Elevator Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.25	0.25	0.25	0.25	0.25	0.25	0.75	0.75	0.75	0.75	0.75	0.75

Table C–24 Elevator Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.75	0.75	0.75	0.75	0.75	0.75	0.50	0.50	0.50	0.50	0.50	0.50

C.5 Lighting Schedules

Table C–25 Office Lighting Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
Weekday	0.05	0.05	0.05	0.05	0.05	0.10	0.30	0.90	0.90	0.90	0.90	0.90
Saturday	0.05	0.05	0.05	0.05	0.05	0.05	0.10	0.10	0.30	0.30	0.30	0.30
All other days	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table C–26 Office Lighting Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
Weekday	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.50	0.30	0.20	0.10	0.05
Saturday	0.15	0.15	0.15	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05
All other days	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table C–27 24/7 Lighting Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10–11	11–12
All days	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.90	0.90	0.90	0.90

Table C–28 24/7 Lighting Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.80	0.80

Table C–29 Patient Lighting Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10–11	11–12
All days	0.50	0.50	0.50	0.50	0.70	0.70	0.90	0.90	0.90	0.90	0.90	0.90

Table C–30 Patient Lighting Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.90	0.90	0.90	0.90	0.90	0.90	0.70	0.70	0.70	0.70	0.50	0.50

Table C–31 Dining Lighting Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10–11	11–12
All days	0.45	0.15	0.15	0.15	0.15	0.45	0.90	0.90	0.90	0.90	0.90	0.90

Table C–32 Dining Lighting Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90

C.6 Plug and Process Load Schedules

Table C–33 Office PPL Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
Weekday	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.90	0.90	0.90	0.90	0.90
Saturday	0.30	0.30	0.30	0.30	0.30	0.30	0.40	0.40	0.50	0.50	0.50	0.50
All other days	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Table C–34 Office PPL Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
Weekday	0.80	0.90	0.90	0.90	0.90	0.65	0.50	0.40	0.40	0.40	0.40	0.40
Saturday	0.35	0.35	0.35	0.35	0.35	0.30	0.30	0.30	0.30	0.30	0.30	0.30
All other days	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Table C–35 24/7 PPL Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.50	0.50	0.50	0.50	0.80	0.80	0.80	0.80	1.00	1.00	1.00	1.00

Table C–36 24/7 PPL Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.50	0.50	0.50	0.50

Table C–37 Dining Electric PPL Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.10	0.10	0.10	0.10	0.10	0.10	0.25	0.35	0.35	0.25	0.35	0.35

Table C–38 Dining Electric PPL Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.35	0.25	0.25	0.25	0.35	0.35	0.35	0.25	0.25	0.25	0.25	0.25

Table C–39 Dining Gas PPL Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.01	0.01	0.01	0.01	0.01	0.12	0.14	0.13	0.14	0.18	0.20	0.15

Table C–40 Dining Room Gas PPL Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.13	0.19	0.20	0.16	0.14	0.10	0.07	0.04	0.04	0.02	0.01	0.01

C.7 Service Water Heating Schedules

Table C–41 Patient SWH Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.0133	0.0133	0.0133	0.0133	0.0133	0.0167	0.0200	0.0267	0.0267	0.1500	0.1500	0.0267

Table C–42 Patient SWH Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.0333	0.0333	0.0333	0.0333	0.1500	0.0533	0.0467	0.0333	0.0300	0.0267	0.0233	0.0200

Table C–43 Kitchen SWH Schedule, Hour 1–12 (Fraction of Peak)

Day	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
All days	0.20	0.00	0.00	0.00	0.00	0.00	0.15	0.60	0.55	0.45	0.40	0.45

Table C–44 Kitchen SWH Schedule, Hour 13–24 (Fraction of Peak)

Day	12–13	13–14	14–15	15–16	16–17	17–18	18–19	19–20	20–21	21–22	22–23	23–24
All days	0.40	0.35	0.30	0.30	0.30	0.40	0.55	0.60	0.50	0.55	0.45	0.25

Appendix D. EnergyPlus Refrigeration Objects

D.1 Refrigerated Cases

```
Refrigeration:Case,
  Flr 1 Cafe_Case:1,
  ALWAYS_ON,
  Flr 1 Cafe,
  23.89,
  55,
  378.0,
  0.30,
  1.00,
  5.5,
  1.11,
  DewpointMethod,
  Flr 1 Cafe_Case:1_LatentCaseCreditCurve,
  0.0,
  78.4,
  0.0,
  61.2,
  Flr 1 Cafe_Case:1_CaseLightingSchedule,
  1.0,
  0.0,
  0.0,
  None,
  35,
  1.52,
  1.0,
  0.0,
  OffCycle,
  Flr 1 Cafe_Case:1_DefrostSchedule,
  Flr 1 Cafe_Case:1_DefrostDripDownSchedule,
  None,
  Flr 1 Cafe_Case:1_DefrostEnergyCorrectionCurve,
  0.00,
  Flr 1 Cafe_Case:1_RestockSchedule,
  Flr 1 Cafe_Case:1_CaseCreditSchedule,
  -2.78,
  0.00;

Curve:Cubic,
  Flr 1 Cafe_Case:1_LatentCaseCreditCurve,
  0.3265,
  0.0302,
  0.0007,
  0.00003,
  -55.0,
  55.0;

Schedule:Compact,
  Flr 1 Cafe_Case:1_DefrostSchedule,
  ON/OFF,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.0;
```

```
Schedule:Compact,
  Flr 1 Cafe_Case:1_DefrostDripDownSchedule,
  ON/OFF,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Cafe_Case:1_RestockSchedule,
  Any Number,
  Through: 12/31,
  For:AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Cafe_Case:1_CaseCreditSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Cafe_Case:1_CaseLightingSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 01:00,1.00,
  Until: 05:00,0.00,
  Until: 24:00,1.00;

Refrigeration:Case,
  Flr 1 Cafe_Case:2,
  ALWAYS_ON,
  Flr 1 Cafe,
  23.89,
  55,
  985.0,
  0.30,
  1.00,
  1.8,
  2.22,
  DewpointMethod,
  Flr 1 Cafe_Case:2_LatentCaseCreditCurve,
  0.0,
  118.4,
  0.0,
  236.2,
  Flr 1 Cafe_Case:2_CaseLightingSchedule,
  1.0,
  0.0,
  0.0,
  None,
  35,
  1.52,
  1.0,
  0.0,
  OffCycle,
```

```
    Flr 1 Cafe_Case:2_DefrostSchedule,
    Flr 1 Cafe_Case:2_DefrostDripDownSchedule,
    None,
    Flr 1 Cafe_Case:2_DefrostEnergyCorrectionCurve,
    0.00,
    Flr 1 Cafe_Case:2_RestockSchedule,
    Flr 1 Cafe_Case:2_CaseCreditSchedule,
    -6.67,
    0.00;

  Curve:Cubic,
    Flr 1 Cafe_Case:2_LatentCaseCreditCurve,
    -0.0187,
    0.0458,
    0.0011,
    0.00005,
    -55.0,
    55.0;

  Schedule:Compact,
    Flr 1 Cafe_Case:2_DefrostSchedule,
    ON/OFF,
    Through: 12/31,
    For: AllDays,
    Until: 24:00,0.0;

  Schedule:Compact,
    Flr 1 Cafe_Case:2_DefrostDripDownSchedule,
    ON/OFF,
    Through: 12/31,
    For: AllDays,
    Until: 24:00,0.0;

  Schedule:Compact,
    Flr 1 Cafe_Case:2_RestockSchedule,
    Any Number,
    Through: 12/31,
    For:AllDays,
    Until: 24:00,0.0;

  Schedule:Compact,
    Flr 1 Cafe_Case:2_CaseCreditSchedule,
    Fraction,
    Through: 12/31,
    For: AllDays,
    Until: 24:00,0.0;

  Schedule:Compact,
    Flr 1 Cafe_Case:2_CaseLightingSchedule,
    Fraction,
    Through: 12/31,
    For: AllDays,
    Until: 01:00,1.00,
    Until: 05:00,0.00,
    Until: 24:00,1.00;

  Refrigeration:Case,
```

```
    Flr 1 Cafe_Case:3,
    ALWAYS_ON,
    Flr 1 Cafe,
    23.89,
    55,
    1528.0,
    0.30,
    1.00,
    7.3,
    1.11,
    DewpointMethod,
    Flr 1 Cafe_Case:3_LatentCaseCreditCurve,
    0.0,
    77.5,
    0.0,
    252.6,
    Flr 1 Cafe_Case:3_CaseLightingSchedule,
    1.0,
    0.0,
    0.0,
    None,
    35,
    1.52,
    1.0,
    0.0,
    OffCycle,
    Flr 1 Cafe_Case:3_DefrostSchedule,
    Flr 1 Cafe_Case:3_DefrostDripDownSchedule,
    None,
    Flr 1 Cafe_Case:3_DefrostEnergyCorrectionCurve,
    0.00,
    Flr 1 Cafe_Case:3_RestockSchedule,
    Flr 1 Cafe_Case:3_CaseCreditSchedule,
    -3.33,
    0.00;

  Curve:Cubic,
    Flr 1 Cafe_Case:3_LatentCaseCreditCurve,
    -0.0187,
    0.0458,
    0.0011,
    0.00005,
    -55.0,
    55.0;

  Schedule:Compact,
    Flr 1 Cafe_Case:3_DefrostSchedule,
    ON/OFF,
    Through: 12/31,
    For: AllDays,
    Until: 24:00,0.0;

  Schedule:Compact,
    Flr 1 Cafe_Case:3_DefrostDripDownSchedule,
    ON/OFF,
    Through: 12/31,
    For: AllDays,
```

```
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Cafe_Case:3_RestockSchedule,
  Any Number,
  Through: 12/31,
  For:AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Cafe_Case:3_CaseCreditSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Cafe_Case:3_CaseLightingSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 01:00,1.00,
  Until: 05:00,0.00,
  Until: 24:00,1.00;

Refrigeration:Case,
  Flr 1 Cafe_Case:4,
  ALWAYS_ON,
  Flr 1 Cafe,
  23.89,
  55,
  1105.0,
  0.30,
  1.00,
  1.8,
  1.11,
  DewpointMethod,
  Flr 1 Cafe_Case:4_LatentCaseCreditCurve,
  0.0,
  54.2,
  0.0,
  82.0,
  Flr 1 Cafe_Case:4_CaseLightingSchedule,
  1.0,
  0.0,
  0.0,
  None,
  35,
  1.52,
  1.0,
  0.0,
  OffCycle,
  Flr 1 Cafe_Case:4_DefrostSchedule,
  Flr 1 Cafe_Case:4_DefrostDripDownSchedule,
  None,
  Flr 1 Cafe_Case:4_DefrostEnergyCorrectionCurve,
  0.00,
```

```
  Flr 1 Cafe_Case:4_RestockSchedule,
  Flr 1 Cafe_Case:4_CaseCreditSchedule,
  -6.67,
  0.00;

Curve:Cubic,
  Flr 1 Cafe_Case:4_LatentCaseCreditCurve,
  -0.0187,
  0.0458,
  0.0011,
  0.00005,
  -55.0,
  55.0;

Schedule:Compact,
  Flr 1 Cafe_Case:4_DefrostSchedule,
  ON/OFF,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Cafe_Case:4_DefrostDripDownSchedule,
  ON/OFF,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Cafe_Case:4_RestockSchedule,
  Any Number,
  Through: 12/31,
  For:AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Cafe_Case:4_CaseCreditSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Cafe_Case:4_CaseLightingSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 01:00,1.00,
  Until: 05:00,0.00,
  Until: 24:00,1.00;
```

D.2 Refrigeration Walk-in Units

```
Refrigeration:WalkIn,
  Flr 1 Food Storage_Walkin:1,
  ALWAYS_ON,
  14538.00,
  -17.78,
```

```
    -27.22,
    335.00,
    Flr 1 Food Storage_Walkin:1_HeatingPowerSchedule,
    335.00,
    0.00,
    0.00,
    Flr 1 Food Storage_Walkin:1_WalkinLightingSchedule,
    HotFluid,
    TemperatureTermination,
    Flr 1 Food Storage_Walkin:1_DefrostSchedule,
    Flr 1 Food Storage_Walkin:1_DefrostDripDownSchedule,
    592.00,
    0.3,
    Flr 1 Food Storage_Walkin:1_RestockSchedule,
    1.36,
    16.79,
    5.68,
    Flr 1 Food Storage,
    51.88,
    0.23,
    0.00,
    0.00,
    2.27,
    Flr 1 Food Storage_Walkin:1_ReachInDoorSchedule,
    2.23,
    1.83,
    2.27,
    Flr 1 Food Storage_Walkin:1_StockingDoorSchedule,
    None;

  Schedule:Compact,
    Flr 1 Food Storage_Walkin:1_HeatingPowerSchedule,
    Fraction,
    Through: 12/31,
    For: AllDays,
    Until: 24:00,1.00;

  Schedule:Compact,
    Flr 1 Food Storage_Walkin:1_DefrostSchedule,
    ON/OFF,
    Through: 12/31,
    For: AllDays,
    Until: 24:00,0.0;

  Schedule:Compact,
    Flr 1 Food Storage_Walkin:1_DefrostDripDownSchedule,
    ON/OFF,
    Through: 12/31,
    For: AllDays,
    Until: 24:00,0.0;

  Schedule:Compact,
    Flr 1 Food Storage_Walkin:1_RestockSchedule,
    Fraction,
    Through: 12/31,
    For: AllDays,
    Until: 24:00,0.00;
```

```
Schedule:Compact,
  Flr 1 Food Storage_Walkin:1_ReachInDoorSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.00;

Schedule:Compact,
  Flr 1 Food Storage_Walkin:1_StockingDoorSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.104;

Schedule:Compact,
  Flr 1 Food Storage_Walkin:1_WalkinLightingSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 01:00,1.00,
  Until: 05:00,0.00,
  Until: 24:00,1.00;

Refrigeration:WalkIn,
  Flr 1 Food Storage_Walkin:2,
  ALWAYS_ON,
  11146.00,
  0.00,
  -6.11,
  0.00,
  Flr 1 Food Storage_Walkin:2_HeatingPowerSchedule,
  361.00,
  0.00,
  0.00,
  Flr 1 Food Storage_Walkin:2_WalkinLightingSchedule,
  Electric,
  TemperatureTermination,
  Flr 1 Food Storage_Walkin:2_DefrostSchedule,
  Flr 1 Food Storage_Walkin:2_DefrostDripDownSchedule,
  7495.00,
  0.3,
  Flr 1 Food Storage_Walkin:2_RestockSchedule,
  1.36,
  44.56,
  5.68,
  Flr 1 Food Storage,
  99.61,
  0.38,
  0.00,
  0.00,
  2.27,
  Flr 1 Food Storage_Walkin:2_ReachInDoorSchedule,
  2.23,
  1.83,
  2.27,
  Flr 1 Food Storage_Walkin:2_StockingDoorSchedule,
```

```
  None;

Schedule:Compact,
  Flr 1 Food Storage_Walkin:2_HeatingPowerSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,1.00;

Schedule:Compact,
  Flr 1 Food Storage_Walkin:2_DefrostSchedule,
  ON/OFF,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Food Storage_Walkin:2_DefrostDripDownSchedule,
  ON/OFF,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.0;

Schedule:Compact,
  Flr 1 Food Storage_Walkin:2_RestockSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.00;

Schedule:Compact,
  Flr 1 Food Storage_Walkin:2_ReachInDoorSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.00;

Schedule:Compact,
  Flr 1 Food Storage_Walkin:2_StockingDoorSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 24:00,0.104;

Schedule:Compact,
  Flr 1 Food Storage_Walkin:2_WalkinLightingSchedule,
  Fraction,
  Through: 12/31,
  For: AllDays,
  Until: 01:00,1.00,
  Until: 05:00,0.00,
  Until: 24:00,1.00;
```

D.3 Refrigeration Compressor Racks

```
Refrigeration:System,
  RackA,
  RackA_CaseList,
```

```
    ,
    RackA_RefrigCond,
    RackA_CompressorList,
    23.9000,
    R404a,
    ConstantSuctionTemperature,
    ,
    ,
    ,
    ,
    Refrigeration;

  Refrigeration:CaseAndWalkInList,
    RackA_CaseList,
    Flr 1 Food Storage_Walkin:1;

  Refrigeration:CompressorList,
    RackA_CompressorList,
    RackA_RefrigerationCompressor:1,
    RackA_RefrigerationCompressor:2,
    RackA_RefrigerationCompressor:3,
    RackA_RefrigerationCompressor:4;

  Refrigeration:Compressor,
    RackA_RefrigerationCompressor:1,
    RackA_RefrigerationCompressor:1_PowerCurve,
    RackA_RefrigerationCompressor:1_CapacityCurve,
    ,
    20,
    ,
    0;

  Curve:Bicubic,
    RackA_RefrigerationCompressor:1_PowerCurve,
    3578.2032,
    -100.5180,
    -2.8709,
    332.9306,
    -3.1162,
    8.2501,
    -0.0124,
    0.0138,
    0.0440,
    -0.0273,
    -50,
    0,
    15,
    60;

  Curve:Bicubic,
    RackA_RefrigerationCompressor:1_CapacityCurve,
    71345.8877,
    2469.2655,
    29.8532,
    -670.7492,
    -2.3309,
    -21.1323,
```

```
    0.1181,
    0.0194,
    -0.2112,
    -0.0274,
    -50,
    0,
    15,
    60;

  Refrigeration:Compressor,
    RackA_RefrigerationCompressor:2,
    RackA_RefrigerationCompressor:2_PowerCurve,
    RackA_RefrigerationCompressor:2_CapacityCurve,
    ,
    20,
    ,
    0.0;

  Curve:Bicubic,
    RackA_RefrigerationCompressor:2_PowerCurve,
    3868.6801,
    -150.6204,
    -4.1300,
    367.5018,
    -2.5386,
    10.2457,
    -0.0179,
    0.0050,
    0.0682,
    -0.0253,
    -50,
    0,
    15,
    60;

  Curve:Bicubic,
    RackA_RefrigerationCompressor:2_CapacityCurve,
    83948.4788,
    2886.4330,
    34.5121,
    -869.2620,
    -0.5200,
    -25.7393,
    0.1386,
    0.0089,
    -0.2375,
    -0.0084,
    -50,
    0,
    15,
    60;

  Refrigeration:Compressor,
    RackA_RefrigerationCompressor:3,
    RackA_RefrigerationCompressor:3_PowerCurve,
    RackA_RefrigerationCompressor:3_CapacityCurve,
    ,
```

```
    20,
    ,
    0;

  Curve:Bicubic,
    RackA_RefrigerationCompressor:3_PowerCurve,
    6788.3090,
    -145.6596,
    -5.7067,
    379.8006,
    -1.9109,
    9.9172,
    -0.0352,
    0.0081,
    0.0607,
    -0.0083,
    -50,
    0,
    15,
    60;

  Curve:Bicubic,
    RackA_RefrigerationCompressor:3_CapacityCurve,
    110283.0447,
    3781.0868,
    45.0826,
    -1233.8244,
    2.5951,
    -35.3244,
    0.1782,
    -0.0118,
    -0.3205,
    0.0117,
    -50,
    0,
    15,
    60;

  Refrigeration:Compressor,
    RackA_RefrigerationCompressor:4,
    RackA_RefrigerationCompressor:4_PowerCurve,
    RackA_RefrigerationCompressor:4_CapacityCurve,
    ,
    20,
    ,
    0;

  Curve:Bicubic,
    RackA_RefrigerationCompressor:4_PowerCurve,
    6993.8389,
    -183.7223,
    -6.2814,
    515.4503,
    -3.1073,
    13.4058,
    -0.0391,
    0.0120,
```

```
  0.0850,
  -0.0223,
  -50,
  0,
  15,
  60;

Curve:Bicubic,
  RackA_RefrigerationCompressor:4_CapacityCurve,
  127158.1672,
  4318.6255,
  51.3812,
  -1415.9300,
  3.3916,
  -40.6434,
  0.2034,
  -0.0198,
  -0.3621,
  0.0284,
  -50,
  0,
  15,
  60;

Refrigeration:Condenser:AirCooled,
  RackA_RefrigCond,
  RackA_RefrigCond_HeatRejectionCurve,
  0.0,
  Fixed,
  12190,
  0.2,
  RackA_RefrigCond_CondenserNode,
  ;

Curve:Linear,
  RackA_RefrigCond_HeatRejectionCurve,
  0.0,
  3150.0,
  11.0,
  22.2;

Refrigeration:System,
  RackB,
  RackB_CaseList,
  ,
  RackB_RefrigCond,
  RackB_CompressorList,
  23.9000,
  R404a,
  ConstantSuctionTemperature,
  ,
  ,
  ,
  ,
  Refrigeration;

Refrigeration:CaseAndWalkInList,
```

```
  RackB_CaseList,
  Flr 1 Café_Case:1,
  Flr 1 Cafe_Case:2,
  Flr 1 Cafe_Case:3,
  Flr 1 Cafe_Case:4,
  Flr 1 Food Storage_Walkin:2;

Refrigeration:CompressorList,
  RackB_CompressorList,
  RackB_RefrigerationCompressor:5,
  RackB_RefrigerationCompressor:6,
  RackB_RefrigerationCompressor:7,
  RackB_RefrigerationCompressor:8;

Refrigeration:Compressor,
  RackB_RefrigerationCompressor:5,
  RackB_RefrigerationCompressor:5_PowerCurve,
  RackB_RefrigerationCompressor:5_CapacityCurve,
  ,
  20,
  ,
  0.0;

Curve:Bicubic,
  RackB_RefrigerationCompressor:5_PowerCurve,
  2095.1965,
  -149.5634,
  -4.5309,
  278.5201,
  -2.5286,
  7.2106,
  -0.0331,
  0.0103,
  0.0440,
  -0.0208,
  -45,
  12.5,
  15,
  60;

Curve:Bicubic,
  RackB_RefrigerationCompressor:5_CapacityCurve,
  59036.7273,
  2126.3716,
  25.3058,
  -494.9468,
  -4.6853,
  -20.1289,
  0.0893,
  0.0442,
  -0.2063,
  -0.0117,
  -45,
  12.5,
  15,
  60;
```

```
Refrigeration:Compressor,
  RackB_RefrigerationCompressor:6,
  RackB_RefrigerationCompressor:6_PowerCurve,
  RackB_RefrigerationCompressor:6_CapacityCurve,
  ,
  20,
  ,
  0.0;

Curve:Bicubic,
  RackB_RefrigerationCompressor:6_PowerCurve,
  2095.1965,
  -149.5634,
  -4.5309,
  278.5201,
  -2.5286,
  7.2106,
  -0.0331,
  0.0103,
  0.0440,
  -0.0208,
  -45,
  12.5,
  15,
  60;

Curve:Bicubic,
  RackB_RefrigerationCompressor:6_CapacityCurve,
  59036.7273,
  2126.3716,
  25.3058,
  -494.9468,
  -4.6853,
  -20.1289,
  0.0893,
  0.0442,
  -0.2063,
  -0.0117,
  -45,
  12.5,
  15,
  60;

Refrigeration:Compressor,
  RackB_RefrigerationCompressor:7,
  RackB_RefrigerationCompressor:7_PowerCurve,
  RackB_RefrigerationCompressor:7_CapacityCurve,
  ,
  20,
  ,
  0.0;

Curve:Bicubic,
  RackB_RefrigerationCompressor:7_PowerCurve,
  2090.3791,
  -211.4469,
  -5.7776,
```

```
    350.9617,
    -2.9293,
    9.8556,
    -0.0351,
    0.0093,
    0.0687,
    -0.0329,
    -45,
    12.5,
    15,
    60;

  Curve:Bicubic,
    RackB_RefrigerationCompressor:7_CapacityCurve,
    71643.5016,
    2576.5805,
    31.7798,
    -696.9437,
    -1.7162,
    -24.1652,
    0.1079,
    0.0103,
    -0.2815,
    -0.0304,
    -45,
    12.5,
    15,
    60;

  Refrigeration:Compressor,
    RackB_RefrigerationCompressor:8,
    RackB_RefrigerationCompressor:8_PowerCurve,
    RackB_RefrigerationCompressor:8_CapacityCurve,
    ,
    20,
    ,
    0.0;

  Curve:Bicubic,
    RackB_RefrigerationCompressor:8_PowerCurve,
    2090.3791,
    -211.4469,
    -5.7776,
    350.9617,
    -2.9293,
    9.8556,
    -0.0351,
    0.0093,
    0.0687,
    -0.0329,
    -45,
    12.5,
    15,
    60;

  Curve:Bicubic,
    RackB_RefrigerationCompressor:8_CapacityCurve,
```

```
    71643.5016,
    2576.5805,
    31.7798,
    -696.9437,
    -1.7162,
    -24.1652,
    0.1079,
    0.0103,
    -0.2815,
    -0.0304,
    -45,
    12.5,
    15,
    60;

  Refrigeration:Condenser:AirCooled,
    RackB_RefrigCond,
    RackB_RefrigCond_HeatRejectionCurve,
    0.0,
    Fixed,
    12190,
    0.2,
    RackB_RefrigCond_CondenserNode,
    ;

  Curve:Linear,
    RackB_RefrigCond_HeatRejectionCurve,
    0.0,
    3150.0,
    11.0,
    22.2;
```