Development of the Advanced Energy Design Guide for K-12 Schools – 50% Energy Savings

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NATIONAL RENEWABLE ENERGY LABORATORY

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National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, Colorado 80401
303-275-3000 • www.nrel.gov

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The authors would also like to thank ASHRAE, the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IES), the U.S. Green Building Council (USGBC), and DOE as well as all the members of the *Advanced Energy Design Guide K-12: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (AEDG-K12) project committee (PC) for their valuable input and willingness to share their expertise. Much work went into producing the recommendations in the AEDG-K12, covering the following topic areas: lighting and daylighting; heating, ventilation, and air-conditioning (HVAC); building envelope; plug loads; and operations and maintenance Without the committee's expertise and the differing views, as well as the support of the members' organizations, this report would not have been possible.

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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 K-12 School Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (AEDG-K12) (ASHRAE et al. 2011a). The AEDG-K12 provides recommendations for achieving 50% whole-building energy savings in K-12 schools 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-K12 was developed in collaboration with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IES), the U.S. Green Building Council (USGBC), and the U.S. Department of Energy (DOE).

The AEDG-K12 is the second AEDG for K-12 school buildings; the first was part of a series of six AEDGs targeting 30% energy savings over levels achieved by following the *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-K12 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 Medium to Big Box Retail Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2011b)
- The *Advanced Energy Design Guide for Large Hospitals: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2012).

Each guide provides user-friendly design assistance and recommendations to design, architectural, and engineering firms to achieve energy savings. The AEDG-K12 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; outdoor air treatment; and measurement and verification (M&V). Additional savings recommendations are also included, but are not necessary to achieve the 50% savings goal. These are provided for renewable energy systems and alternative HVAC systems.

The objectives in developing this TSD were to:

- Document the development of the baseline and low-energy K-12 school facility 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.
- Validate that the recommendations result in 50% or greater energy savings by climate zone.
- Document the process used to develop the AEDG-K12.

AEDG-K12 Development Process

The AEDG-K12 was developed by a PC representing a diverse group of professionals. Guidance and support were provided through collaboration of ASHRAE, AIA, IES, USGBC, and DOE. PC members were provided by these partner organizations, the ASHRAE Project Committee 90.1 (SPCC 90.1), and the ASHRAE Technical Committee on Education Facilities (TC 7.6). A steering committee was assembled to oversee the development process, made up of representatives of ASHRAE, AIA, IESNA, USGBC, and DOE. These partner organizations 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 recommendation characteristics.

The PC followed steering committee guidance to develop a plan for completing the AEDG-K12. Key milestones were determined based on a final publication date using a schedule similar to those developed for previous guides, including two peer review periods corresponding with a 60% completion draft (technical refinement) and a 90% completion draft (final review). Four PC meetings were held at ASHRAE headquarters or at NREL. Six conference calls with the full PC were also held to provide updates on the AEDG-K12's progress toward the peer review and publication milestones.

AEDG-K12 Scope

The AEDG-K12 applies to all sizes and classifications (elementary, middle, and high) of new construction K-12 school buildings. These facilities typically include some or all of the following space types: administrative and office areas; classrooms, hallways and restrooms; gymnasiums with locker rooms and showers; assembly spaces with either flat or tiered seating; food preparation spaces; and libraries or media centers. The AEDG-K12 does not consider atypical specialty spaces such as indoor pools, wet laboratories (e.g., chemistry), "dirty" dry laboratories (e.g., woodworking and auto shops), or other unique spaces that generate extraordinary heat or pollution. Its primary focus is new construction, but recommendations may be applicable to facilities undergoing total renovation; and in part to many other K-12 school renovation, addition, remodeling, and modernization projects (including changes to one or more systems in existing buildings).

The AEDG-K12 does not include all the components listed in Standard 90.1-2004. It focuses only on a building's primary energy systems, so the underlying energy analysis presumes that all the other components are built according to the criteria in Standard 90.1-2004.

Certain aspects of school design, including steam heat, modular classrooms, vehicle and other maintenance areas, domestic water well piping, and sewage disposal, were excluded from the AEDG-K12. They were too complex to include given the scope of the project.

The AEDG-K12 is not intended to substitute for rating systems or references that address the full range of sustainable issues in K-12 school design, such as acoustics, productivity, indoor air quality, water efficiency, landscaping, and transportation, except as they relate to energy use; nor is it a design text. The AEDG-K12 assumes good design skills and expertise in K-12 school design. The AEDG-K12 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-K12. The following steps describe how the energy savings potential of the AEDG-K12's recommendations was determined:

1. Develop "typical" K-12 school facility prototypes

For building characteristics that are not specified by Standard 90.1-2004, but that are needed to develop code-compliant baseline models, the primary and secondary school DOE Commercial Reference Buildings (Deru et al. 2010) were used. A "typical" prototype is an energy model that is a representative example of a K-12 school facility. The high-level building characteristics for the two prototype models are shown in Table ES–1.

Table ES–1 AEDG-K12 Prototype Characteristics

Building Characteristic	AEDG-K12 Prototype	
Building type	Primary school	Secondary school
Size (ft²)	73,930	210,810
Number of floors	1	2
Number of students	650	1,200
Space types	Auditorium, art classroom, cafeteria, classroom, corridor, gym, kitchen, library, lobby, mechanical room, office, restroom	Art classroom, cafeteria, classroom, corridor, gym, kitchen, library, lobby, mechanical room, office, restroom
Wall constructions	Mass	Mass
Roof construction	Insulation entirely above deck	Insulation entirely above deck
Window area	35% window to gross wall area	35% window to gross wall area
Peak plug loads (W/ft²)	1.7	1.3
Percent conditioned	Fully heated and cooled	Fully heated and cooled
HVAC system types	Multizone VAV in classroom wings and common areas; packaged single zone in gym, kitchen, cafeteria	Multizone VAV in classroom wings and common areas; packaged single zone in gym, kitchen, cafeteria

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

The baseline primary and secondary school energy modeling assumptions and methods were documented, including the building envelope characteristics, building internal loads and operating schedules, ventilation rates and schedules, HVAC equipment efficiency, operation, control and sizing, fan power assumptions, and SWH. The baseline models for the primary and secondary schools were developed by applying the criteria in Standard 90.1-2004 to the prototype characteristics. The criteria in Standard 90.1-2004 were used as the baselines to calculate energy savings for the AEDG-K12 recommendations.

3. Create the low-energy models based on the recommended energy efficiency technologies in the AEDG-K12

The final recommendations included in the AEDG-K12 were determined based on an iterative process using the PC's expertise and results from modeling the recommendations. To quantify the potential energy savings from the final recommended energy efficiency measures in the AEDG-K12, the low-energy building models were developed by implementing the energy efficiency technologies listed here:

- Enhanced building opaque envelope insulation, window glazing, and overhangs
- Reduced lighting power density and installation of occupancy sensors
- Daylighting in classrooms, resource rooms, cafeterias, gyms, and multipurpose rooms
- Exterior lighting power density reductions
- Plug load reductions and improved controls
- High-performance commercial kitchen equipment and ventilation
- Demand-controlled ventilation and energy recovery ventilators
- DOASs
- High-efficiency HVAC equipment
- High-efficiency SWH equipment.

4. Verify the recommendations meet or exceed the 50% energy savings goal of the AEDG-K12

Energy savings from the final recommendations in the AEDG-K12 are documented. Recommendations are provided based on the climate zone, school type, and type of low-energy HVAC system used. To verify savings over the range of design options, low-energy versions of the primary and secondary schools with three types of low-energy HVAC systems were modeled. The low-energy HVAC system types include a VAV air handling system with a DOAS (VAV DOAS), an FCU system with a DOAS (FCU DOAS), and a GSHP system with a DOAS (GSHP DOAS). The recommendations in the AEDG-K12 result in more than 50% savings in all climate zones, for both the primary and secondary school, for all HVAC system types. Table ES–2 summarizes the percent savings for each prototype model in each climate zone. Figure ES–1 shows the process applied to determine energy savings.

Table ES–2 Percent Savings Over Standard 90.1-2004

Climate Zone	Representative City	Primary School			Secondary School		
		VAV DOAS	FCU DOAS	GSHP DOAS	VAV DOAS	FCU DOAS	GSHP DOAS
1A	Miami, Florida	58.0%	67.9%	56.5%	56.5%	64.8%	55.4%
2A	Houston, Texas	59.7%	68.0%	60.6%	58.2%	65.2%	58.8%
2B	Phoenix, Arizona	62.2%	69.6%	63.1%	59.1%	66.7%	60.6%
3A	Atlanta, Georgia	55.2%	62.5%	57.4%	55.1%	61.4%	56.4%
3B:CA	Los Angeles, California	51.1%	58.4%	54.6%	51.7%	57.8%	53.5%
3B	Las Vegas, Nevada	56.1%	63.6%	58.4%	55.1%	62.8%	57.3%
3C	San Francisco, California	53.3%	58.7%	58.3%	54.4%	59.2%	57.6%
4A	Baltimore, Maryland	56.9%	62.7%	60.1%	57.5%	62.5%	59.5%
4B	Albuquerque, New Mexico	56.4%	61.6%	59.8%	56.9%	61.6%	58.9%
4C	Seattle, Washington	54.8%	59.2%	59.9%	56.5%	60.1%	59.7%
5A	Chicago, Illinois	57.2%	62.1%	60.9%	58.0%	62.1%	60.4%
5B	Denver, Colorado	56.3%	60.7%	60.9%	57.4%	61.1%	60.1%
6A	Minneapolis, Minnesota	58.9%	62.9%	63.2%	59.6%	62.9%	62.3%
6B	Helena, Montana	57.6%	61.1%	63.1%	58.7%	61.6%	62.1%
7	Duluth, Minnesota	59.2%	62.1%	64.5%	59.8%	62.2%	63.3%
8	Fairbanks, Alaska	55.3%	57.5%	62.8%	55.4%	57.2%	60.5%

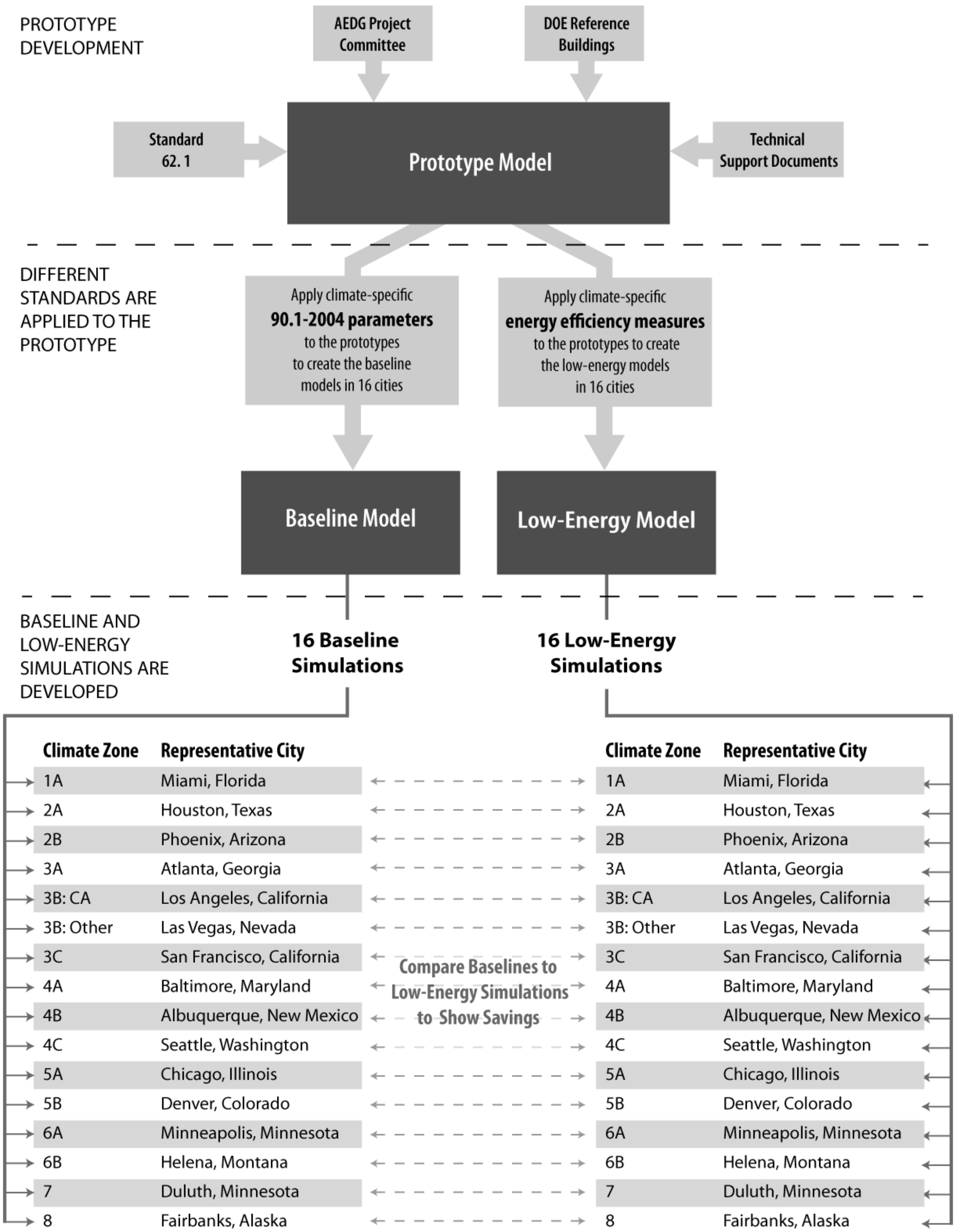


Figure ES–1 Flow diagram of modeling process
(Credit: Marjorie Schott/NREL)

Nomenclature

AEDG	Advanced Energy Design Guide
AEDG-K12	Advanced Energy Design Guide for K-12 School Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building
AIA	American Institute of Architects
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
Btu	British thermal unit
C	Celsius, centigrade
CFL	compact fluorescent lamp
cfm	cubic feet per minute
c.i.	continuous insulation
COP	coefficient of performance
DCV	demand-controlled ventilation
DOAS	dedicated outdoor air system
DOE	U.S. Department of Energy
DX	direct expansion
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
GSHP	ground source heat pump
h	hour
HC	heat capacity
HID	high-intensity discharge
HVAC	heating, ventilation, and air conditioning
IES, IESNA	Illuminating Engineering Society of North America
in.	inch
J	joule
K	kelvin
LED	light-emitting diode
LPD	lighting power density
Ls	linear system
m	meter
min	minute
NAFA	National Air Filtration Association

NEMA	National Electrical Manufacturers Association
NREL	National Renewable Energy Laboratory
OA	outdoor air
Pa	Pascal
PC	project committee
PF	projection factor
PSZ	packaged single zone
RFP	request for proposal
RFQ	request for qualification
SC	steering committee
SHGC	solar heat gain coefficient
SRI	solar reflectance index
SWH	service water heating
TSD	Technical Support Document
USGBC	U.S. Green Building Council
VAV	variable air volume
VFD	variable frequency drive
VLT	visible light transmittance
W	watt
w.c.	water column

Contents

Figures and Tables

Figures

All figures credit Eric Bonnema/NREL unless otherwise noted.

Tables

1. Introduction

The *Advanced Energy Design Guide for K-12 School Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (AEDG-K12) (ASHRAE et al. 2011a) was written to help owners and designers of elementary, middle, and high schools achieve 50% whole-building energy savings compared to the minimum requirements of the *ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings* (Standard 90.1-2004) (ASHRAE 2004b). Depending on the individual school districts, grades are divided into elementary schools (grades K through 5), middle schools (grades 6 through 8), and high schools (grades 9 through 12). Included in the AEDG-K12 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; outdoor air (OA) treatment; and service water heating (SWH). Additional savings recommendations are also included, but not necessary for the 50% savings goal. These recommendations are provided for additional HVAC strategies and renewable energy systems.

The AEDG-K12 is intended to show that the 50% target is not only achievable, but surpassable. Case studies show schools 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-K12 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 the goal in each climate zone, the AEDG-K12 provides ways to meet the 50% target and build energy-efficient K-12 schools 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-K12 was developed by a project committee (PC) representing a diverse group of experienced professionals. Guidance and support was provided through a collaboration of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the American Institute of Architects (AIA), the Illuminating Engineering Society of North America (IES), the U.S. Green Building Council (USGBC), and the U.S. Department of Energy (DOE).

The AEDG-K12 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 Medium to Big Box Retail Buildings: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2011b)
- The *Advanced Energy Design Guide for Large Hospitals: Achieving 50% Energy Savings Toward a Net Zero Energy Building* (ASHRAE et al. 2012)

1.1 Objectives

One of the National Renewable Energy Laboratory's (NREL) tasks in developing the AEDG-K12 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 of the eight U.S. climate zones and corresponding subzones.
- Develop recommendations that meet a numeric goal value: The energy savings goal is a hard value as opposed to an approximate target. As in past AEDGs, the AEDG-K12 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-K12, this Technical Support Document (TSD) was developed to document the process used to develop the AEDG-K12 and the analysis and modeling performed to support that development. The specific objectives were to:

- Document the process and schedule used for developing the AEDG-K12.
- Document prototypical K-12 school characteristics.
- Document the EnergyPlus modeling assumptions used to establish 50% energy savings.
- Document the baseline and low-energy EnergyPlus K-12 school models.
- Demonstrate that the recommendations result in 50% or greater energy savings by climate zone.

1.2 Scope of the AEDG and TSD

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-K12 applies to all sizes and classifications of K-12 school buildings with administrative and office areas, classrooms, hallways, restrooms, gymnasiums, assembly spaces, food preparation spaces, and dedicated spaces such as media centers and science laboratories. The AEDG-K12 does not consider atypical specialty spaces such as indoor pools, wet laboratories such as chemistry laboratories, "dirty" dry laboratories such as woodworking and auto shops, or other unique spaces that generate extraordinary heat or pollution. Certain aspects of school design, including steam heat, modular classrooms, vehicle and other maintenance areas, domestic water well piping, and sewage disposal, are excluded from the AEDG-K12. They were too complex to include given the scope of the project. Significant energy efficiency opportunities may be available with these aspects, and AEDG-K12 users are encouraged to take advantage of these opportunities.

The AEDG-K12 is also not intended to substitute for rating systems or references that address the full range of sustainability issues in schools, such as acoustics, productivity, indoor air quality, water efficiency, landscaping, and transportation, except as they relate to operational energy consumption. The AEDG-K12 contains recommendations only and is not a code or standard.

The guides in the AEDG series also do not provide detailed documentation for developing recommendations or energy savings details. This TSD describes the process and methodology for the development of the AEDG-K12 and provides the technical details that were used to determine energy savings, including model inputs and assumptions.

1.3 AEDG-K12 Layout and Content

The introduction (Chapter 1) contains information about the project goal and scope, as well as instructions for use. Chapter 2 provides resources for those who want to understand and adopt an integrated process for designing, constructing, and operating energy-efficient K-12 school facilities. The AEDG-K12 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 phase of the design process. This chapter addresses the details and best practices of an integrated design process, and discusses the benefits and features of integrated design, and step-by-step details about the phases of the process. This chapter also discusses cost control strategies and best practices, as well as key design strategies for controlling capital costs to help the users overcome the notion that more efficient buildings must also cost more.

Chapter 3 presents 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. This chapter also presents seven detailed case studies that illustrate techniques and methods discussed in the AEDG-K12. EUIs are provided to benchmark these buildings against future buildings. All these case studies use some of the recommendations in the tables, but predate the publication of the AEDG-K12, and were not developed explicitly using those tables. Case studies provide the motivation and the examples for others to follow and validate the recommendations in the AEDG-K12.

Chapter 4 contains the climate-specific recommendation tables, a unique set of energy efficiency recommendations for each of the eight DOE climate zones in the United States. Recommendations are organized by several categories: envelope, electric lighting, daylighting, plug/process loads, commercial kitchen, SWH, HVAC, and M&V. The recommendations are simply one path to reach the 50% energy savings target over Standard 90.1-2004. Other approaches may also save energy; however, identifying all possible solutions is not in the scope of the AEDG-K12; assurance of the savings from other approaches is left to the user. To achieve 50% energy savings, the AEDG-K12 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.

Chapter 5 provides guidance about good 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, quality assurance and commissioning, and bonus savings. The bonus savings section includes areas for additional good practice items that, if implemented properly, should achieve savings beyond the 50% level. Technology case studies with in-depth reviews of various component-specific items are interspersed throughout the chapter.

The envelope how-to section contains climate zone-specific information about explicit types of walls, roofs, floors, doors, insulation, infiltration, and vertical fenestration. The daylighting how-to section provides tips on general principles; building shape and orientation with respect to daylighting; fenestration-to-floor area ratios; analysis tool information; glare control and direct beam radiation elimination; daylighting space types and layouts, including space type-specific top and sidelighting strategies; controls; photosensor specification and photocell placement; and system commissioning. The lighting how-to section details best practices for interior finishes, specific lamp and ballast types, lighting layouts, control strategies for specific space types, and exterior lighting power and control.

The plug load how-to section in Chapter 5 provides general guidance, methods to save energy involving computer and information technology equipment, as well as staff and occupant equipment; methods to reduce parasitic loads; discussions on implementing ENERGY STAR® equipment; and information on the role of the electricity distribution system in saving energy. This section also contains detailed information on designing an energy-efficient kitchen with how-to tips, including general guidance and ways to select energy-efficient kitchen equipment; minimizing exhaust/ventilation and hot water energy use; high-efficiency walk-in refrigeration systems; and operating considerations to save energy.

The SWH how-to section in Chapter 5 discusses the best types of systems for schools, proper sizing of the systems, choosing energy-efficient systems, the best locations for the system components, and solar hot water systems. The HVAC section includes best practices for ground source heat pump (GSHP) systems; fan coil unit (FCU) systems; multiple-zone variable air volume (VAV) air handling systems; dedicated outdoor air systems (DOASs); exhaust air energy recovery; chilled water systems; heating water systems; condenser water systems; load calculations; ventilation air; equipment efficiencies; part-load dehumidification; economizers; demand-controlled ventilation; system-level control strategies; thermal zoning ductwork design; duct insulation; duct sealing; exhaust air systems; testing, adjusting, and balancing; air cleaning; relief versus return fans; zone controls; heating sources; noise control; and proper maintenance. 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 and using the building as a teaching tool.

The bonus savings section in Chapter 5 includes good practices for natural ventilation and naturally conditioned spaces, thermal storage, thermal mass, thermal displacement ventilation, evaporative cooling, photovoltaic systems, wind turbine power, transpired solar collectors, and power purchase agreements.

1.4 Report Organization

This report is presented in five sections: Section 1 introduces the AEDG-K12 and the supporting background information; Section 2 outlines the development process of the AEDG-K12; 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-K12; and Section 5 documents the final recommendations and energy savings.

The AEDG-K12 scoping document can be found in Appendix A. Additional information on the PC development process is included in Appendix B. Appendix C includes the summary responses to the remarks received on the AEDG-K12 review drafts. Appendix D contains tabular data of the schedules used in the energy models; and Appendix E and Appendix F contain EnergyPlus IDF snippets of the ground heat exchanger and refrigeration models, respectively.

2. AEDG-K12 Development Process

The AEDG-K12 was developed by a PC representing a diverse group of professionals. Guidance and support were provided through a collaboration of ASHRAE, AIA, IESNA, USGBC, and DOE. Publication of the AEDG-K12 was accomplished by two separate committees: a steering committee (SC) that provided high level guidance and a PC that developed the guide.

2.1 Steering Committee

The SC was composed of representatives of the partner organizations and guided the PC in developing the AEDG-K12. The SC was composed of a chair, one representative from each partner organization (AIA, IES, USGBC, ASHRAE, and DOE), and liaisons from ASHRAE SSPC 90.1 and ASHRAE TC 7.6, and one ASHRAE staff member; for a total of nine people. The guidance 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 to achieve 50% savings over Standard 90.1-2004 in K-12 schools.
- Produce recommendations in a technically sound AEDG for K-12 schools.
- 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, which included:

- The baseline for energy use evaluation is annual site energy consumption.
- Address the practical how-to; user-friendly information needs of the AEDG-K12's intended users (designers in medium to large firms, design/build contractors, and construction firms).
- The interaction of building components and systems will need to be considered rather than having all the savings come from individual parts (savings from integration of systems is encouraged). Accommodate, to the extent practical, design flexibility through use of packages of efficiency measures that users may choose from.
- Adopt a prescriptive recommendation approach with packages of measures. This will include envelope, mechanical, lighting, and water heating measures. The document 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.
- In addition to prescriptive energy efficiency measures, the AEDG-K12 should contain "how to" guidance to help the designer construct an energy-efficient school facility. The document 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-K12 should ease the burden for the designers and give school 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 the geographic regions or illustrate particular items or recommended techniques.

The full scoping document can be seen in Appendix A.

2.1.1 Inclusion of Economics and Cost

The purpose of the AEDG-K12 is to assist designers in the design of energy-efficient schools. The AEDG-K12 should focus on the goal of 50% energy savings, rather than on installations that meet a payback threshold. Although cost and payback are considered, the PC viewed it as secondary in importance to achieving buildings that use 50% less energy than one built to the minimum requirements of Standard 90.1-2004.

The AEDG-K12 does include numerous cost control strategies and best practices; the case studies help to reinforce the claim that high-performance schools can be built within typical budgets.

2.2 Approval Authority

The final approval for the AEDG-K12 was the responsibility of the SC. Committee members from various interested parties were responsible for reflecting the opinions of the partner organizations that they represented. This included consulting with their organizations, obtaining buy-in during the process, and providing peer reviews. Efforts were made to agree on the content, as is done during the development of the *ASHRAE Handbook: Fundamentals* (ASHRAE 2009); however, the AEDG-K12 is not a consensus document.

2.3 Project Committee Organization and Membership

The AEDG-K12 was developed by a PC administered under ASHRAE's Special Project procedures. The AEDG-K12 PC was designated as ASHRAE Special Project 134 (SP-134), and included membership from each partner organization. Table 2–1 lists the PC members and the organizations they represent. Some members are not affiliated with a partner organization. In these cases, the function of that member is listed instead.

Table 2–1 AEDG-K12 PC Organization Chart

Member	Organization/Function
Shanti Pless	Chair
Merle McBride	Vice chair
Mike Nicklas	AIA representative
Chad McSpadden	IES representative
Craig Kohring	IES representative
Ozgem Ornektekin	USGBC representative
Robert Kobet	USGBC representative
Ken Seibert	ASHRAE representative
John Murphy	ASHRAE representative
Peter Jefferson	Member at large
Mark Ryles	Member at large
Don Colliver	SC liaison
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 K-12 schools. Each represented SC organization 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-K12's development.

2.4 Development Schedule and Process

Following SC guidance, the PC developed a one-year plan for completing the AEDG-K12. 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 eight 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-K12 development.

The iterative development of the prototype, baseline, and low-energy models included discussion 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-K12 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 and the corresponding low-energy models, including daylighting types, HVAC systems, and envelope recommendations.
6. Present the low-energy modeling results to the PC and identify recommendations that do not result in 50% energy savings.
7. Fine-tune the recommendations to achieve at least 50% whole-building energy savings in all climate zones for each school type.
8. Document final recommendations for the AEDG-K12 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.

Because the AEDG-K12 was developed under the ASHRAE Special Project procedures, and not the standards development procedures, the peer reviews were not considered public. However, review copies were made available to all partner organizations, and to the various ASHRAE bodies (SPCC 90.1 and TC 7.6) represented by the PC membership. Interested parties could also download review copies from the ASHRAE website during the advertised review period. The responses to the remarks and suggestions received from the review drafts are summarized in Appendix C.

3. Evaluation Approach

This chapter describes the analysis methods used to support development of the AEDG-K12. It explains how the prototype, baseline, and low-energy models were developed, and how the resultant energy savings were quantified.

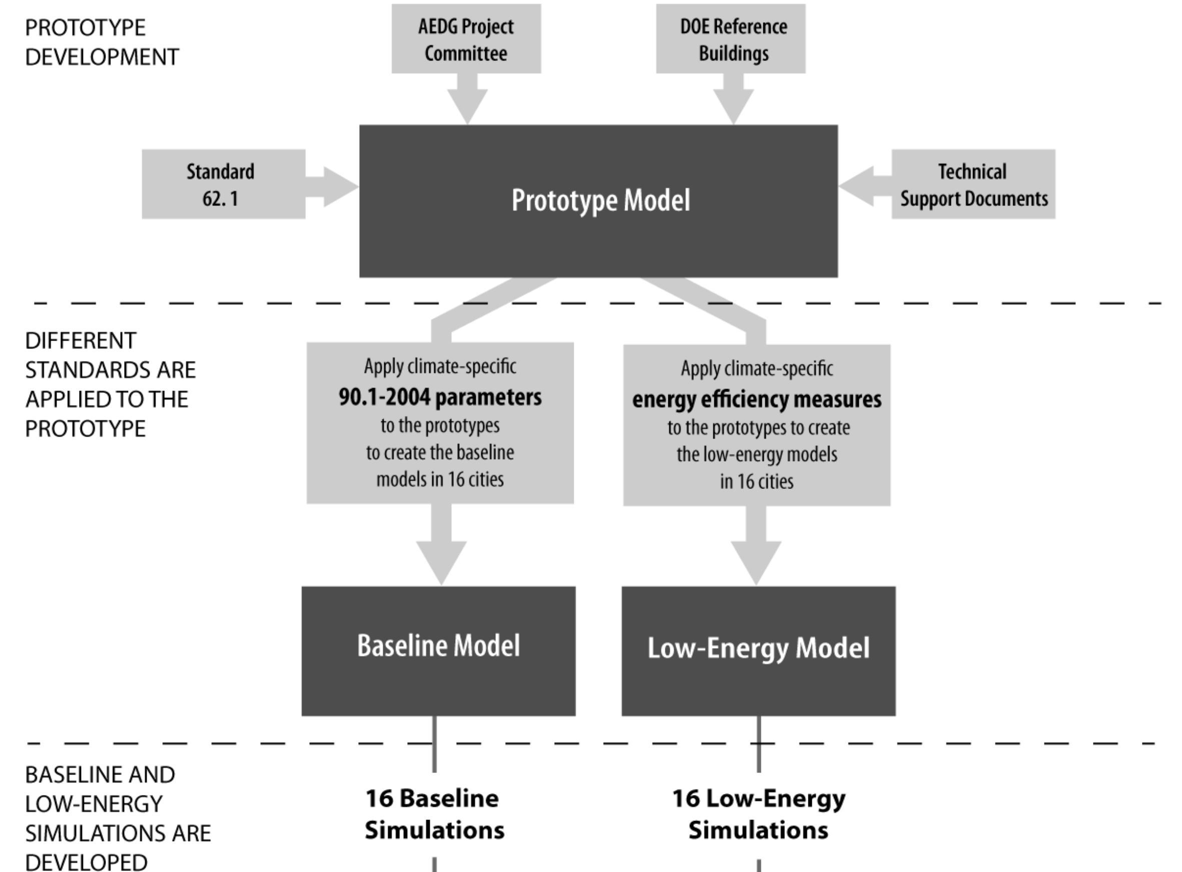
3.1 Determining Energy Savings

The purpose of the building energy simulation analysis is to assess and quantify the energy savings potential of the final AEDG-K12 recommendations. All AEDGs contain a set of energy efficiency recommendations for all eight 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-K12, this was Standard 90.1-2004.

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

- Develop "typical" K-12 school prototype characteristics.
- Create baseline models from the prototypes that are minimally code compliant with Standard 90.1-2004.
- Use energy modeling iteratively to help inform AEDG-K12 recommendations and ultimately create complete low-energy models based on the final recommended energy-efficient technologies in the AEDG-K12.
- Verify 50% energy savings were achieved for each of the three investigated HVAC system types in the AEDG-K12 across the eight U.S. climate zones and corresponding subzones.

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



Climate Zone	Representative City	Climate Zone	Representative City
1A	Miami, Florida	1A	Miami, Florida
2A	Houston, Texas	2A	Houston, Texas
2B	Phoenix, Arizona	2B	Phoenix, Arizona
3A	Atlanta, Georgia	3A	Atlanta, Georgia
3B: CA	Los Angeles, California	3B: CA	Los Angeles, California
3B: Other	Las Vegas, Nevada	3B: Other	Las Vegas, Nevada
3C	San Francisco, California	3C	San Francisco, California
4A	Baltimore, Maryland	4A	Baltimore, Maryland
4B	Albuquerque, New Mexico	4B	Albuquerque, New Mexico
4C	Seattle, Washington	4C	Seattle, Washington
5A	Chicago, Illinois	5A	Chicago, Illinois
5B	Denver, Colorado	5B	Denver, Colorado
6A	Minneapolis, Minnesota	6A	Minneapolis, Minnesota
6B	Helena, Montana	6B	Helena, Montana
7	Duluth, Minnesota	7	Duluth, Minnesota
8	Fairbanks, Alaska	8	Fairbanks, Alaska

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, or 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-K12 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 loads that are code regulated are included in the total energy use of the building. Unregulated loads typically include plug and some process loads. The "whole-building" energy savings indicate the savings when all the loads (regulated and unregulated) are included in the energy savings calculations. In general, for the same level of percent savings, whole-building savings are more challenging to attain than regulated loads savings. The AEDG-K12 uses the "whole-building" energy savings method for determining energy savings.

3.1.3 Modeling Methods

EnergyPlus version 7.0 (DOE 2011) was used to complete the energy simulations in the AEDG-K12. This software was selected as it is a tool that 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-K12 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 (three HVAC system types) models for each prototype (primary and secondary school) for a total of eight separate seed (starting point) energy models. The Opt-E-Plus software then took these eight seed models and "swept" them across the 16 cities representing the eight 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-K12 (for the low-energy models). This resulted in 128 (32 baseline and 96 low-energy) energy models.

3.1.3.1 Climate Zones

The AEDGs contain a unique set of energy efficiency recommendations for each of the eight climate zones and three corresponding subzones in the United States (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.

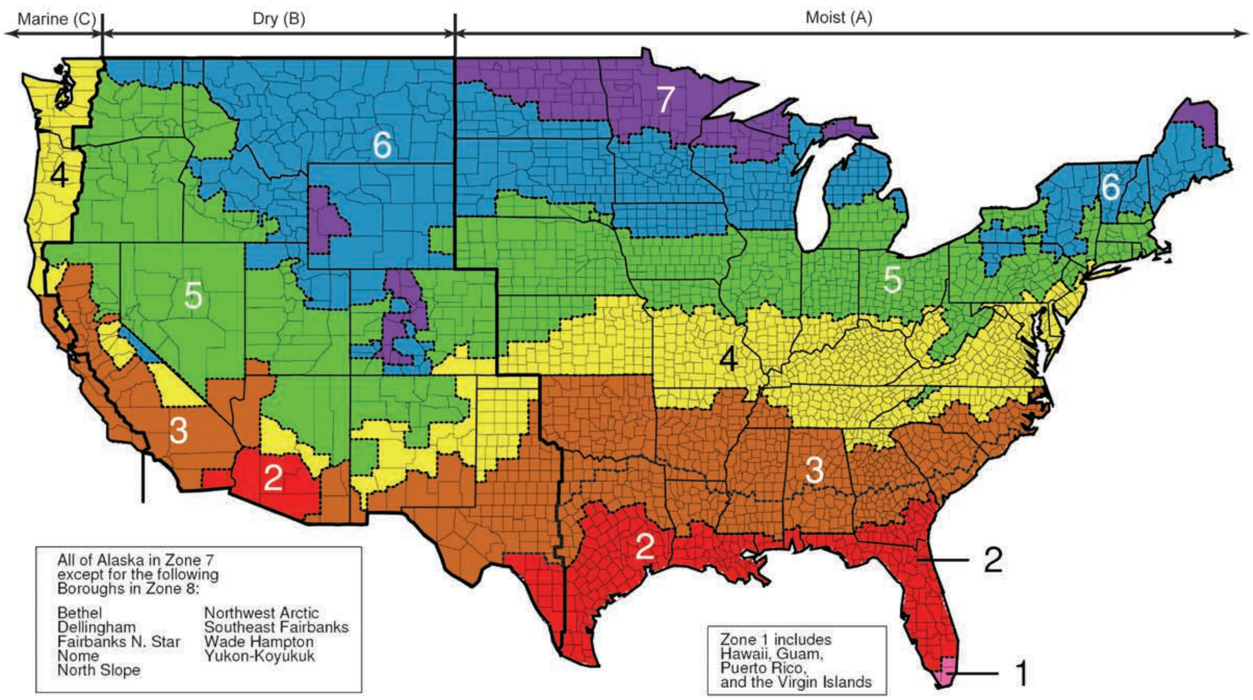


Figure 3–2 DOE climate zones and representative cities
(Credit: (DOE 2003))

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 2 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-K12, the primary and secondary school DOE Commercial Reference Building models (Deru et al. 2010) were used as a starting point to help define certain building characteristics that were not code regulated. The space types in these models can be seen in Table 3–1. The prototype model characteristics remained consistent between the baseline and low-energy models.

Table 3–1 Prototype Space Types

Space Type	Primary School	Secondary School
Auditorium		X
Art classroom	X	X
Cafeteria	X	X
Classroom	X	X
Corridor	X	X
Gym/multipurpose room	X	X
Kitchen	X	X
Library/media center	X	X
Lobby	X	X
Mechanical room	X	X
Office	X	X
Restroom	X	X

The primary and secondary school DOE Commercial Reference Building models were derived mainly from Pless et al. (2007). Table 3–2 presents a summary of the prototype models.

Table 3–2 Prototype Model Summary

Characteristic	Primary School	Secondary School
Size (ft^2)	73,962	210,892
Number of floors	1	2
Number of students	650	1,200
Window-to-wall ratio	35%	35%
Wall construction	Mass	Mass
Roof construction	Insulation entirely above deck	Insulation entirely above deck

3.2.1 Geometry

Table 3–3 shows a geometric breakdown of each zone of the primary school prototype and Figure 3–3 shows the zone layout for the model. Table 3–4 and Figure 3–4 and Figure 3–5 show the same information for the secondary school prototype model.

Table 3–3 and Table 3–4 also show a mapping of each zone to a space type. These space types are referenced throughout the rest of the TSD when describing other model inputs (lighting, plug loads, etc.).

Table 3–3 Primary School Zone Geometry Breakdown

Zone Type	Space Type	Qty.	Dimensions (ft × ft)	Zone Area (ft²)	Total Area (ft²)
Corner classroom	Classroom	6	36.09 × 29.53	1,066	6,396
Large classroom group	Classroom	5	173.88 × 29.53	5,134	25,670
Small classroom group	Classroom	1	114.83 × 29.53	3,391	3,391
Art classroom	Art room	1	59.06 × 29.53	1,744	1,744
Classroom corridors	Corridor	3	209.97 × 9.84	2,067	6,201
Lobby	Lobby	1	62.34 × 29.53	1,841	1,841
Main corridor	Corridor	1	42.65 × 137.80	5,877	5,877
Mechanical room	Mechanical	1	19.69 × 137.80	2,713	2,713
Restrooms	Restroom	1	62.34 × 32.81	2,045	2,045
Media center	Library/media center	1	62.34 × 68.90	4,295	4,295
Offices	Office	1	68.90 × 68.90	4,747	4,747
Gym	Gym/multipurpose room	1	68.90 × 55.77	3,843	3,843
Kitchen	Kitchen	1	68.90 × 26.25	1,808	1,808
Cafeteria	Cafeteria	1	68.90 × 49.21	3,391	3,391

Table 3–4 Secondary School Zone Geometry Breakdown

Zone Type	Space Type	Quantity	Dimensions (ft × ft)	Zone Area (ft²)	Total Area (ft²)
Corner classroom	Classroom	6 – first floor 6 – second floor	36.09 × 29.53	1,066	12,792
Large classroom group	Classroom	6 – first floor 5 – second floor	173.88 × 29.53	5,135	56,485
Small classroom group	Classroom	1 – second floor	114.83 × 29.53	3,391	3,391
Art classroom	Art room	1 – second floor	59.06 × 29.53	1,744	1,744
Classroom corridors	Corridor	3 – first floor 3 – second floor	209.97 × 16.40	3,444	20,664
Lobby	Lobby	1 – first floor 1 – second floor	49.21 × 45.93	2,260	4,520
Main corridor	Corridor	1 – first floor 1 – second floor	49.21 × 249.34	12,270	24,540
Mechanical room	Mechanical	1 – first floor 1 – second floor	124.67 × 29.53	3,682	7,364
Restrooms	Restroom	1 – first floor 1 – second floor	49.21 × 45.93	2,260	4,520
Library	Library/media center	1 – first floor	78.74 × 114.83	9,042	9,042
Offices	Office	1 – first floor 1 – second floor	124.67 × 45.93	5,726	11,452
Gym	Gym/multipurpose room	1 – first floor	124.67 × 170.60	21,269	21,269
Kitchen	Kitchen	1 – second floor	78.74 × 29.53	2,325	2,325
Cafeteria	Cafeteria	1 – second floor	78.74 × 85.30	6,717	6,717
Auditorium	Auditorium	1 – first floor	124.67 × 85.30	10,634	10,634
Auxiliary gym	Gym/multipurpose room	1 – first floor	78.74 × 170.60	13,433	13,433

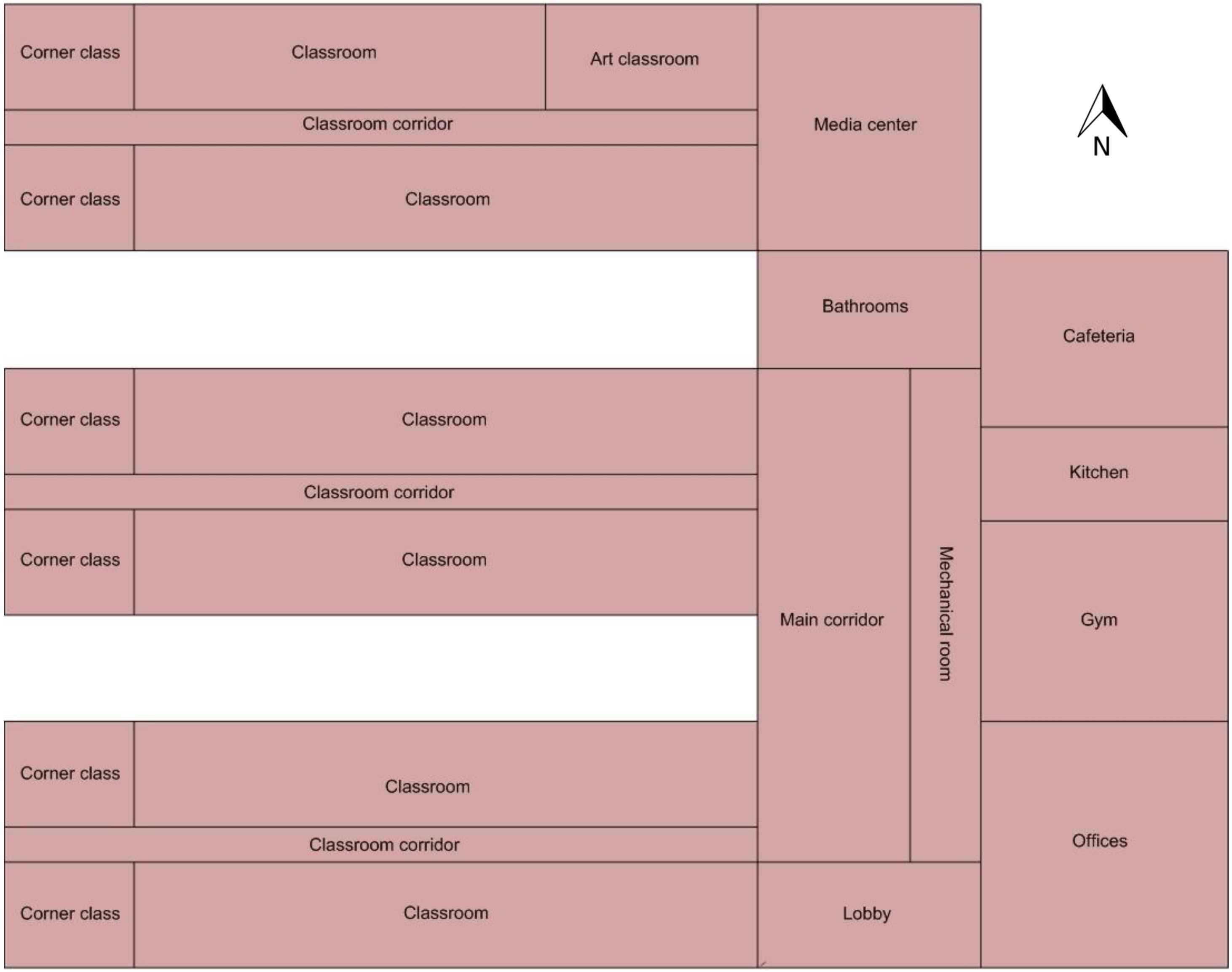


Figure 3–3 Primary school zone layout

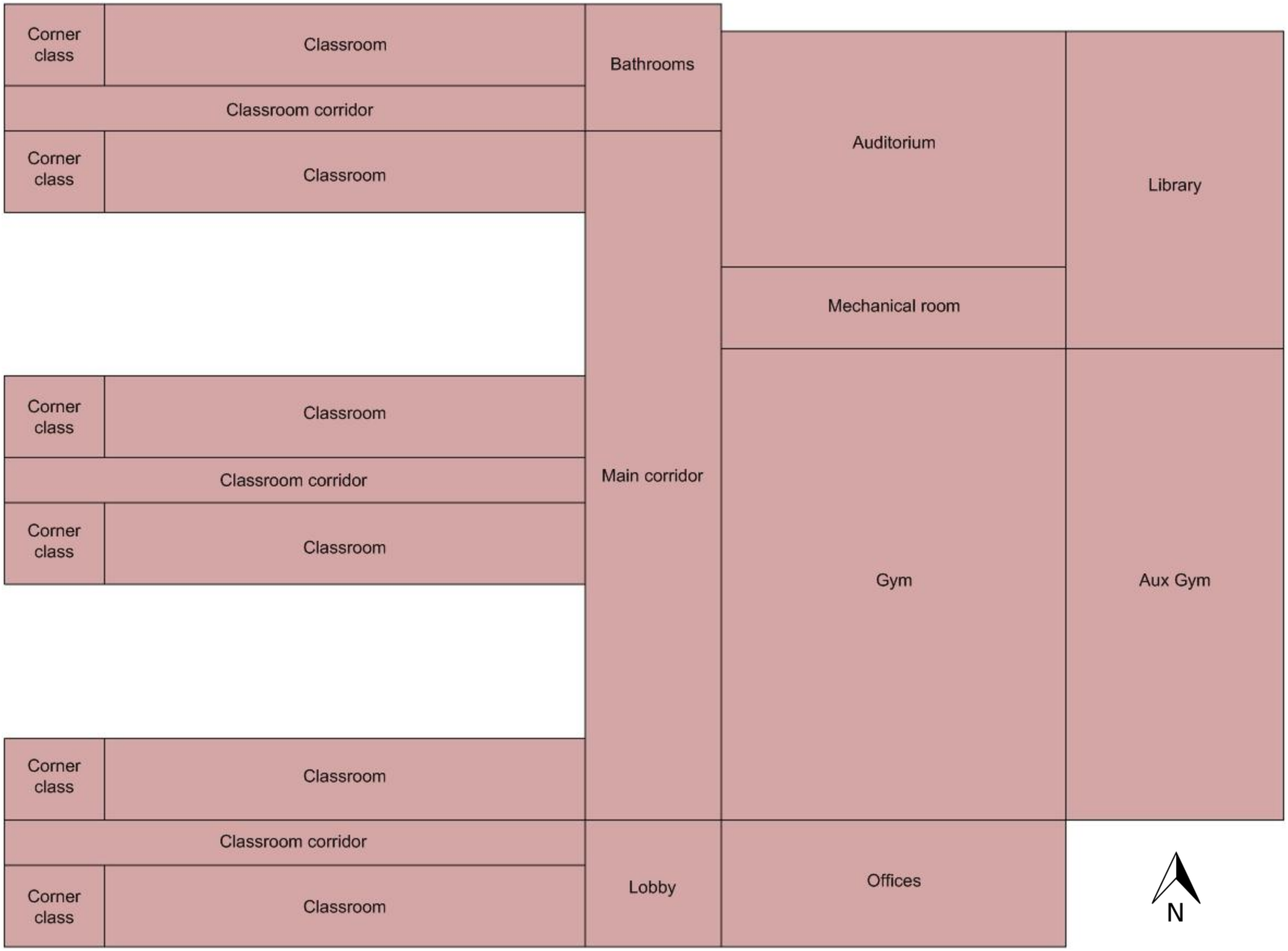


Figure 3–4 Secondary school zone layout – first floor

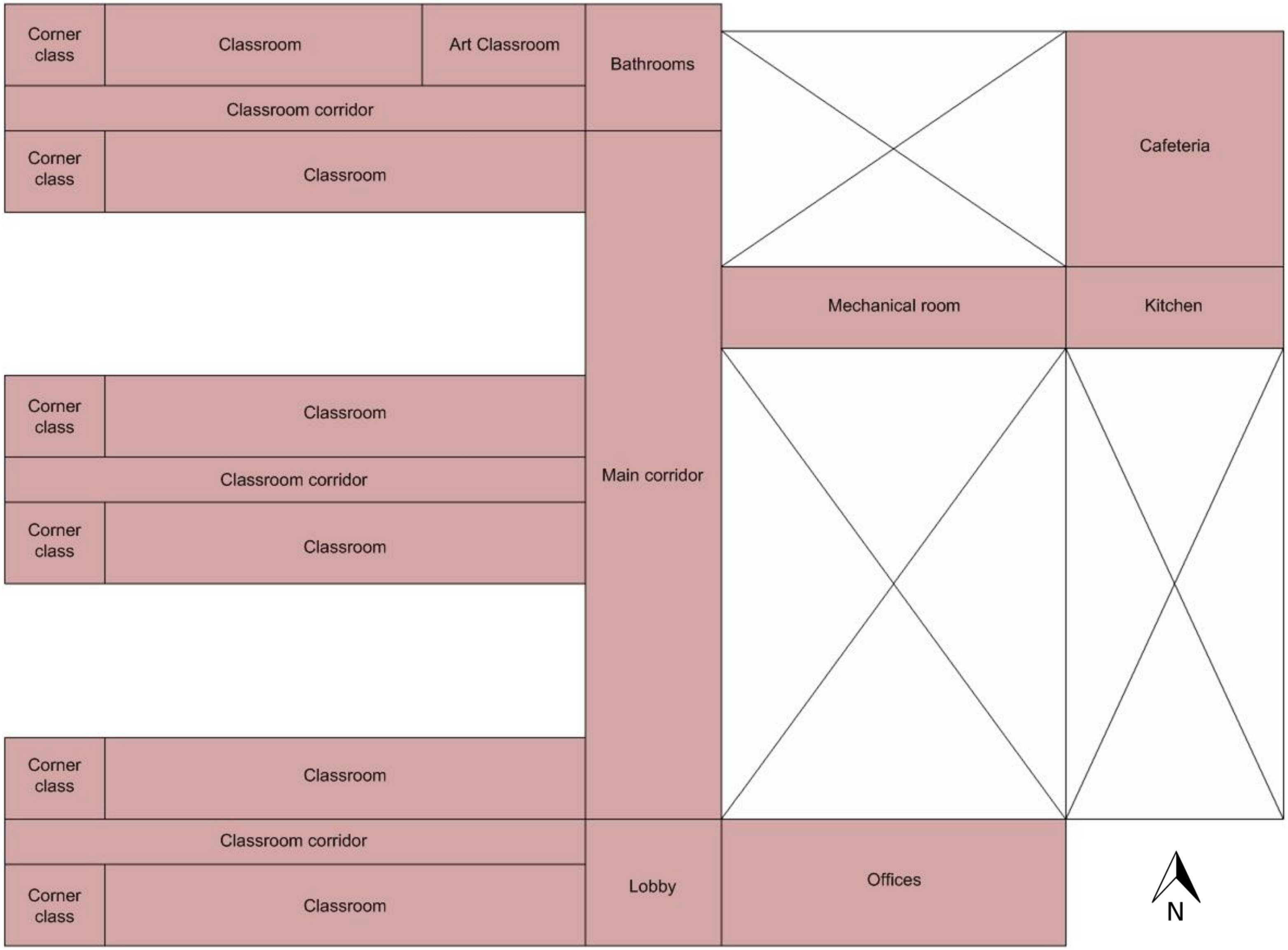


Figure 3–5 Secondary school zone layout – second floor

Table 3–5 provides a breakdown of the prototype models by space type.

Table 3–5 Prototype Space Type Breakdown

Space Type	Primary School		Secondary School	
	Area (ft²)	Percent of Total	Area (ft²)	Percent of Total
Auditorium	0	0%	10,634	5%
Art classroom	1,744	2%	1,744	1%
Cafeteria	3,391	5%	6,717	3%
Classroom	35,457	48%	72,668	34%
Corridor	12,078	16%	45,204	21%
Gym/multipurpose room	3,843	5%	34,702	16%
Kitchen	1,808	2%	2,325	1%
Library/media center	4,295	6%	9,042	4%
Lobby	1,841	2%	4,520	2%
Mechanical room	2,713	4%	7,364	3%
Office	4,747	6%	11,452	5%
Restroom	2,045	3%	4,520	2%
Total	73,962	100%	210,892	100%

3.2.2 Ventilation and Occupancy

Table 6-1 in Standard 62.1-2004 (ASHRAE 2004a) was used to determine the ventilation requirements for the models. Table 3–6 shows space types in the models, their mapping to the "Occupancy Category" column in Standard 62.1-2004 Table 6-1, and the ventilation rates.

Table 3–6 Ventilation Rates by Space Type

Space Type	Occupancy Category (From Table 6-1 in 62.1-2004)	People OA Rate (cfm/person)	Area OA Rate (cfm/ft²)	Peak Occupant Density (#/1000 ft²)
Auditorium	Educational Facilities::Music/theater/dance	10.0	0.06	35
Art room	Educational Facilities::Art classroom	10.0	0.18	20
Cafeteria	Food and Beverage Service::Cafeteria/fast food dining	7.5	0.18	100
Classroom	Educational Facilities::Classrooms (age 9 plus)	10.0	0.12	35
Corridor	General::Corridors	0.0	0.06	0
Gym/multipurpose room	Educational Facilities::Multi-use assembly	7.5	0.06	100
Kitchen	See Table 3–7			
Library/media center	Educational Facilities::Media center	10.0	0.12	25
Lobby	General::Corridors	0.0	0.06	0
Mechanical	General::Corridors	0.0	0.06	0
Office	Office Buildings::Office space	5.0	0.06	5
Restroom	See Table 3–7			

The kitchen and restroom space types have no explicit ventilation requirement in Table 6-1 of Standard 62.1-2004; however, these spaces do have minimum exhaust rates according to Table 6-4 in Standard 62.1-2004 of 0.70 cfm/ft². Determining the rate for the restrooms was more difficult, as the square foot exhaust rate is not provided. Table 6-4 in Standard 62.1-2004 specifies toilet exhaust per water closet. Table 403.1 in the 2006 International Plumbing Code requires one water closet per 50 occupants. This resulted in 13 water closets for the primary school (650 students) and 24 for the secondary school (1,200 students). The exhaust rate from Table 6-4 in Standard 62.1-2004 is 70 cfm per water closet. This resulted in an exhaust requirement of 910 cfm for the primary school and 1,680 cfm for the secondary school. Using the areas of the restroom zones from Table 3–5 and rounding to one significant figure, this translates to 0.4 cfm/ft² for the primary and secondary schools. The ventilation rates for the kitchen and restroom(s) were then set to be equal to the exhaust rates. The occupancy of the kitchen was set to zero because the process loads in that zone account for most of the total load. The occupancy in the restrooms was also set to zero because the occupancy rate was highly variable. Table 3–7 summarizes this information.

Table 3–7 Ventilation and Exhaust Rates by Space Type

Space Type	Occupancy Category (From Table 6-4 in 62.1-2004)	Exhaust Rate (cfm/ft²)	People OA Rate (cfm/person)	Area OA Rate (cfm/ft²)	Peak Occupant Density (#/1000 ft²)
Kitchen	Kitchen – commercial	0.7	0.0	0.7	0
Restroom	Toilets – public	0.4	0.0	0.4	0

The peak occupant densities in Table 3–6 and Table 3–7 were modified by schedules in EnergyPlus. Table 3–8 maps each space type in the model to its occupancy schedule. In general, the primary and secondary schools have different schedules; except for the library/media center occupancy schedule, which is the same for both models. The PC adapted the schedules in the models from those in (Deru et al. 2010). The PC modified the schedules in Deru et al. (2010) using members' experience with schools along with submetered data collected from schools they have built.

Table 3–8 Occupancy Schedule Matrix

Space Type	Schedule	
	Primary School	**Secondary School**
Auditorium	Not applicable	Figure 3–15
Art room	Figure 3–7	Figure 3–11
Cafeteria	Figure 3–8	Figure 3–12
Classroom	Figure 3–7	Figure 3–11
Corridor	Zero occupant density	Zero occupant density
Gym/multipurpose room	Figure 3–9	Main gym: Figure 3–13 Auxiliary gym: Figure 3–16
Kitchen	Zero occupant density	Zero occupant density
Library/media center	Figure 3–6	Figure 3–6
Lobby	Zero occupant density	Zero occupant density
Mechanical	Zero occupant density	Zero occupant density
Office	Figure 3–10	Figure 3–14
Restroom	Zero occupant density	Zero occupant density

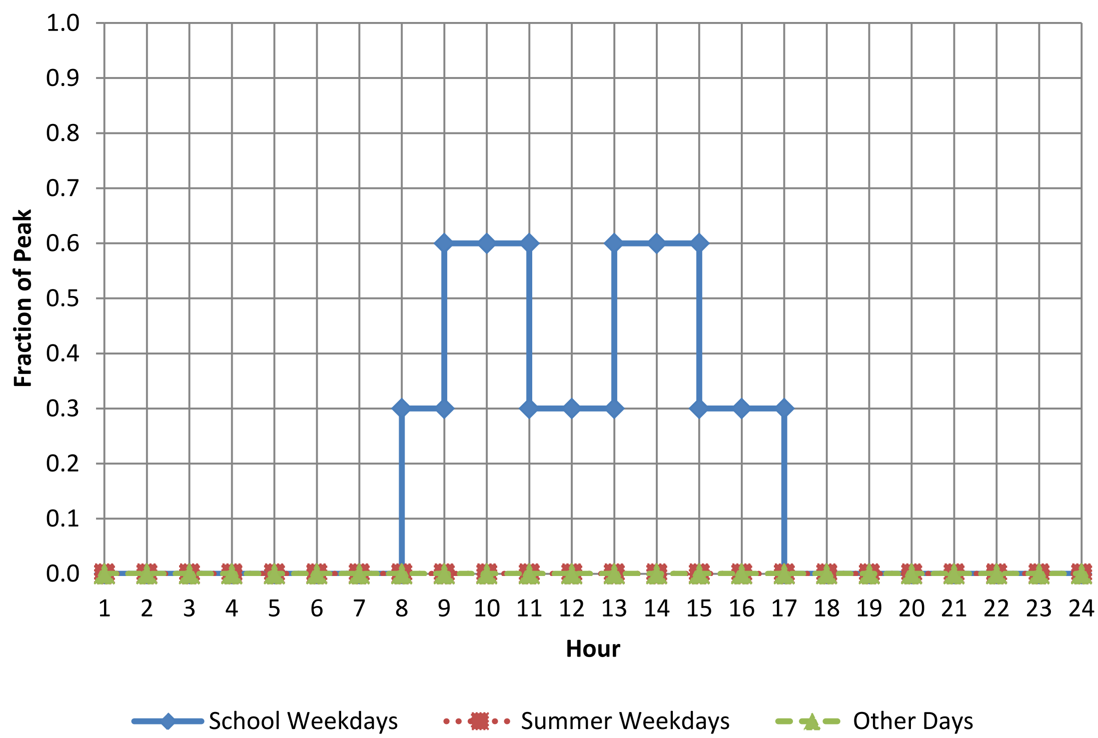


Figure 3–6 Library/media center occupancy schedule

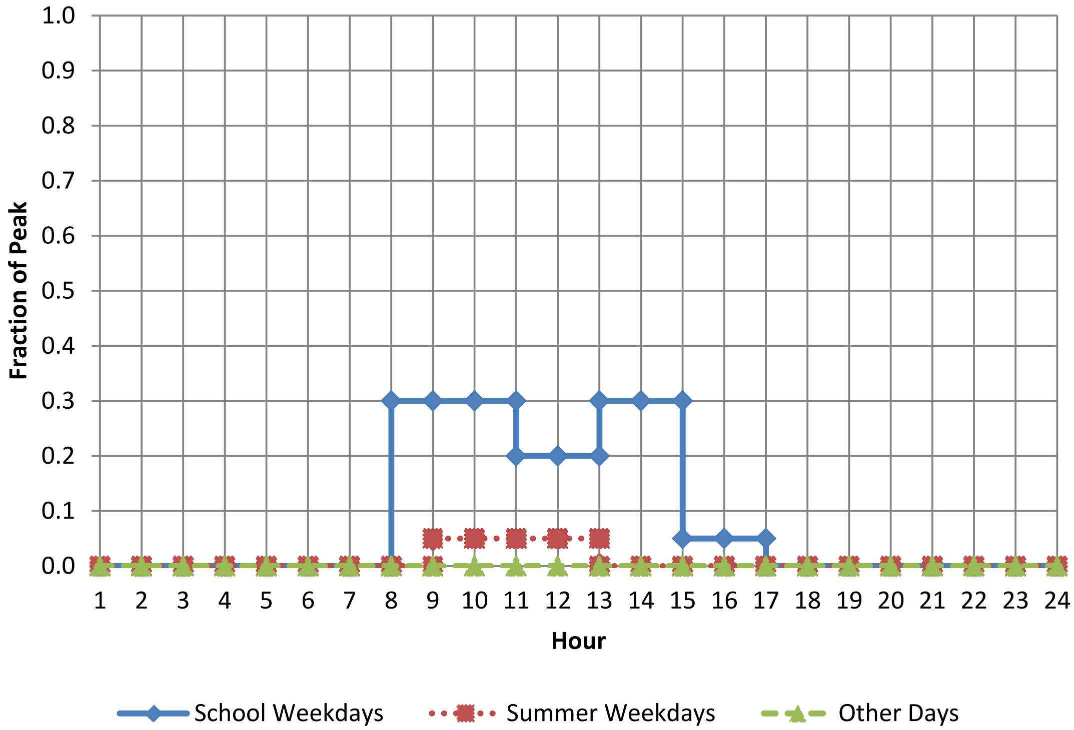


Figure 3–7 Primary school general occupancy schedule

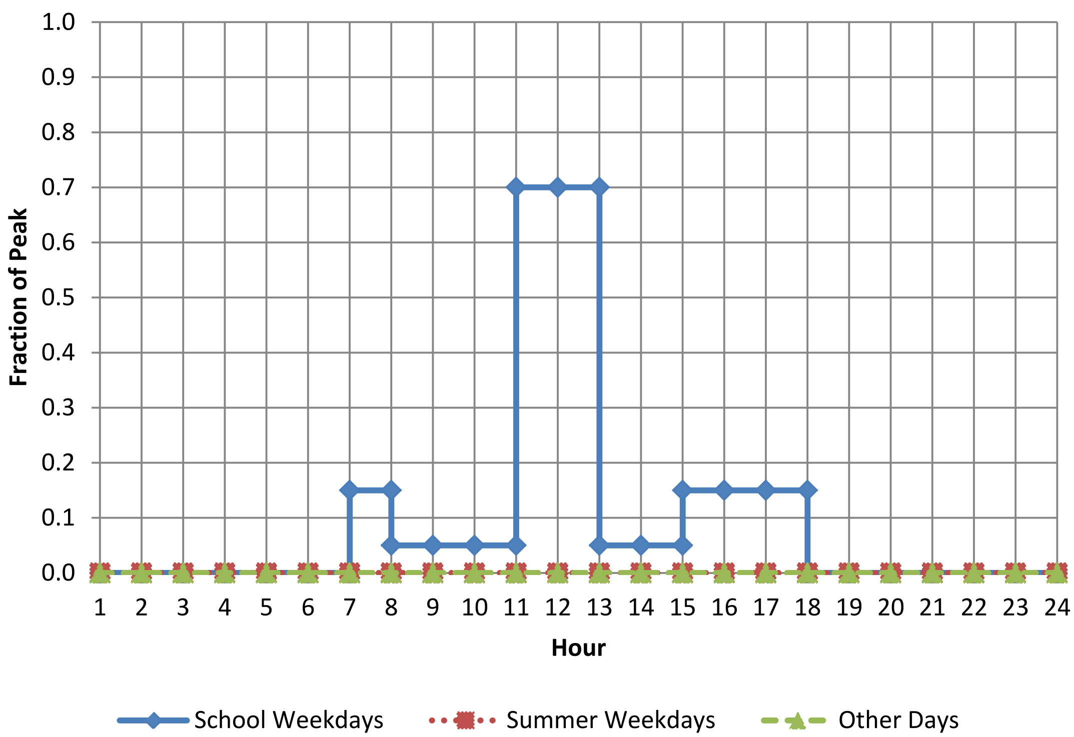


Figure 3–8 Primary school cafeteria occupancy schedule

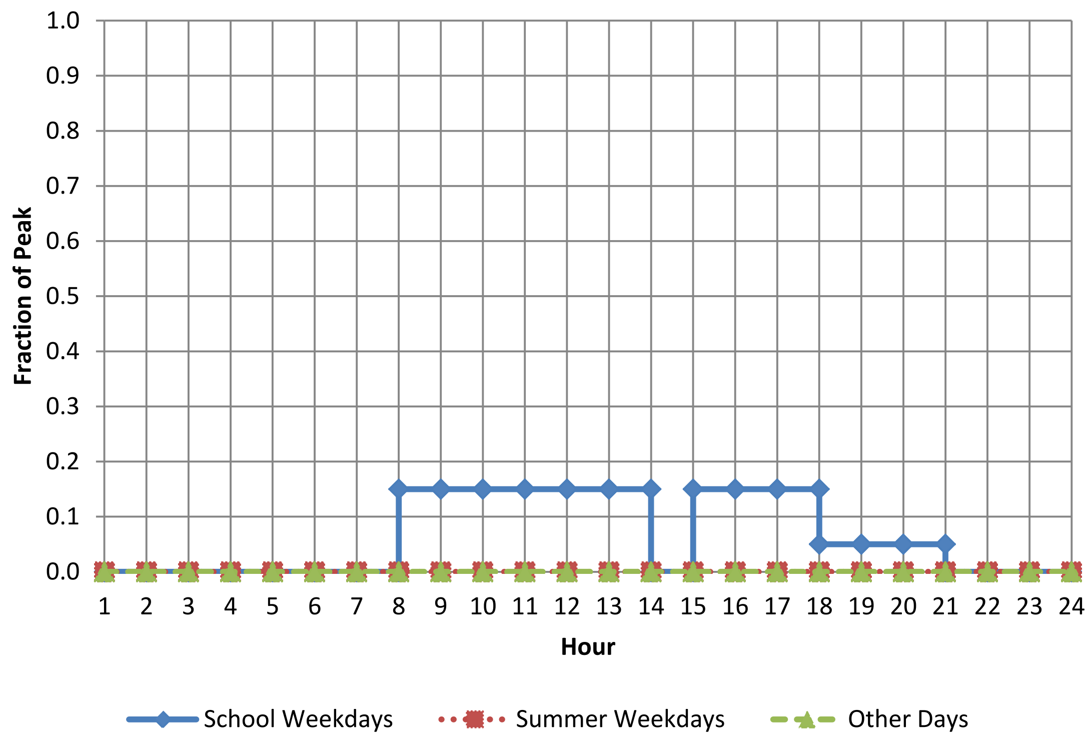


Figure 3–9 Primary school gym occupancy schedule

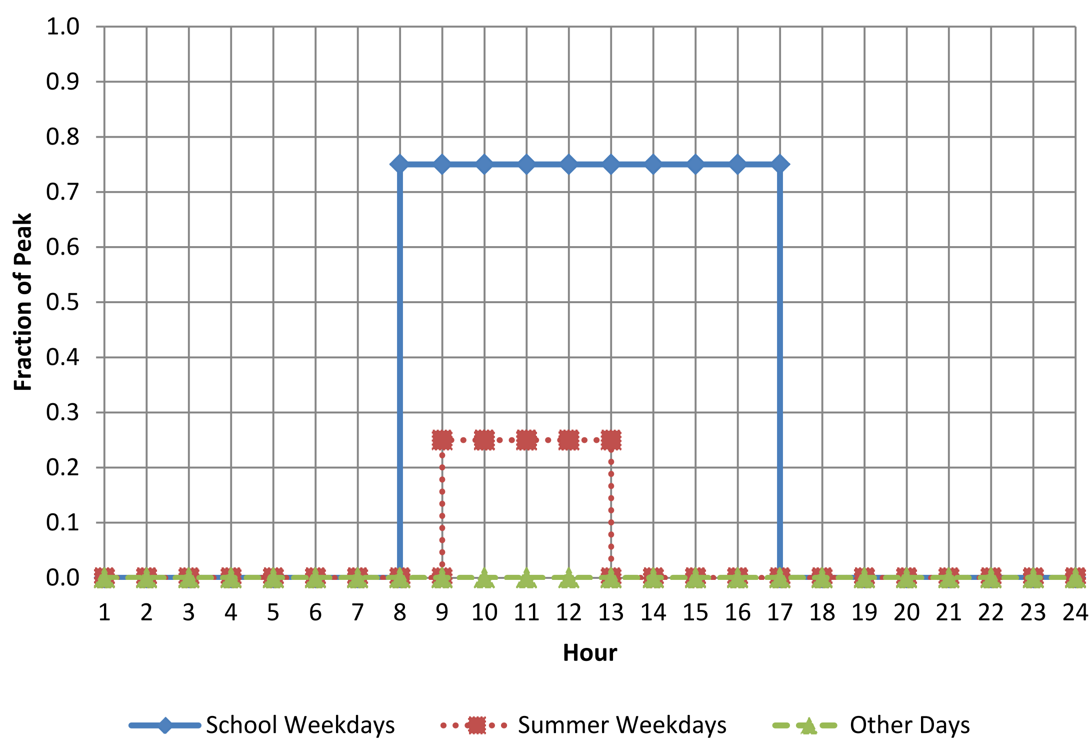


Figure 3–10 Primary school office occupancy schedule

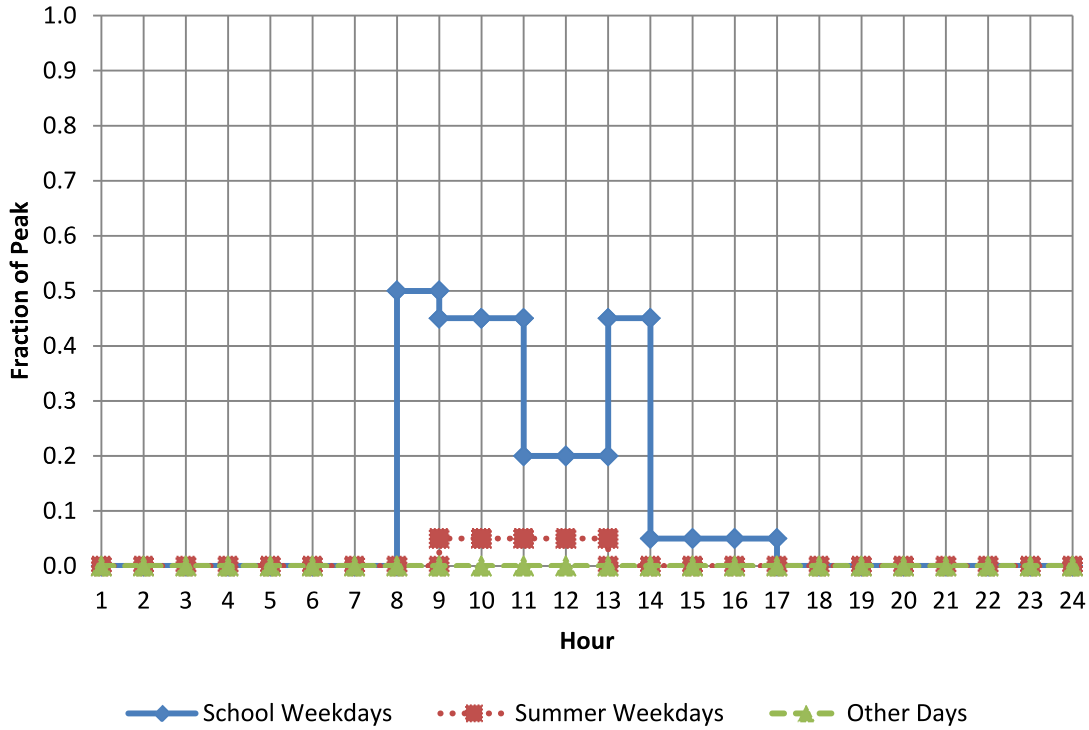


Figure 3–11 Secondary school general occupancy schedule

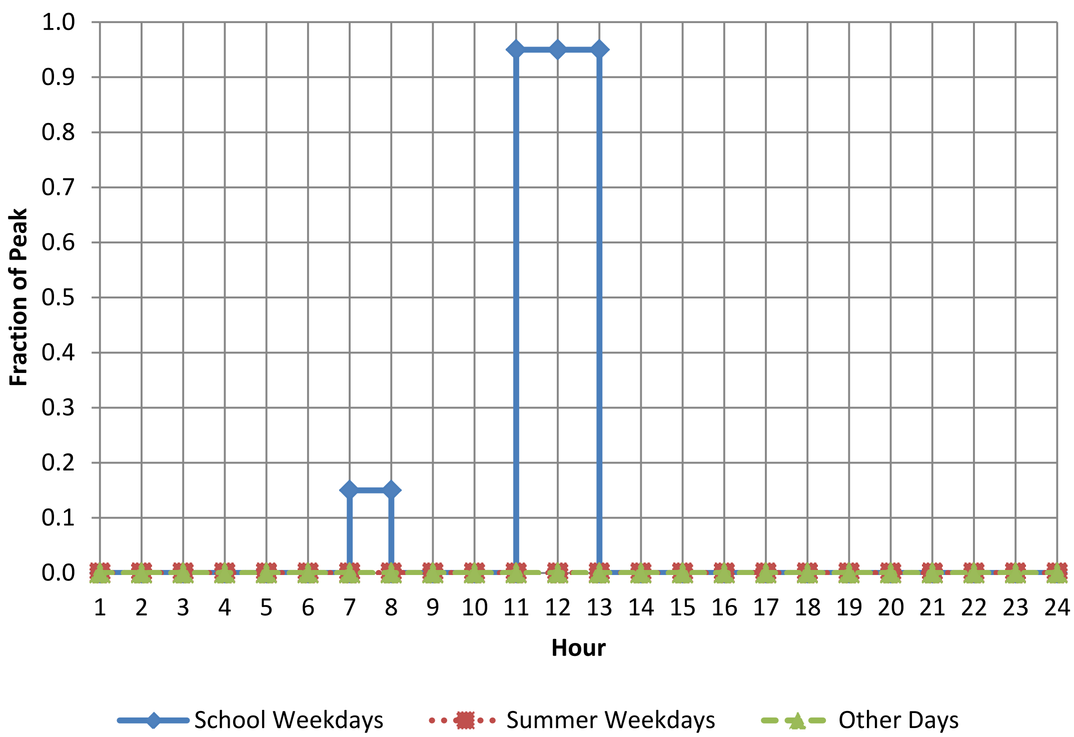


Figure 3–12 Secondary school cafeteria occupancy schedule

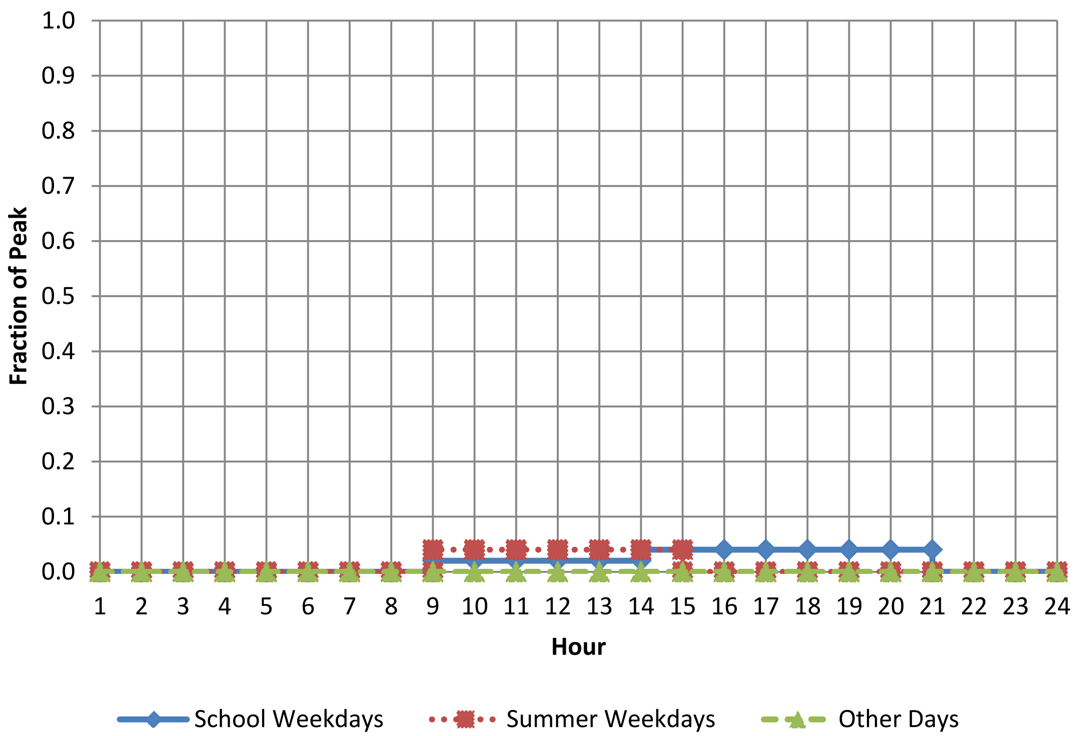


Figure 3–13 Secondary school gym occupancy schedule

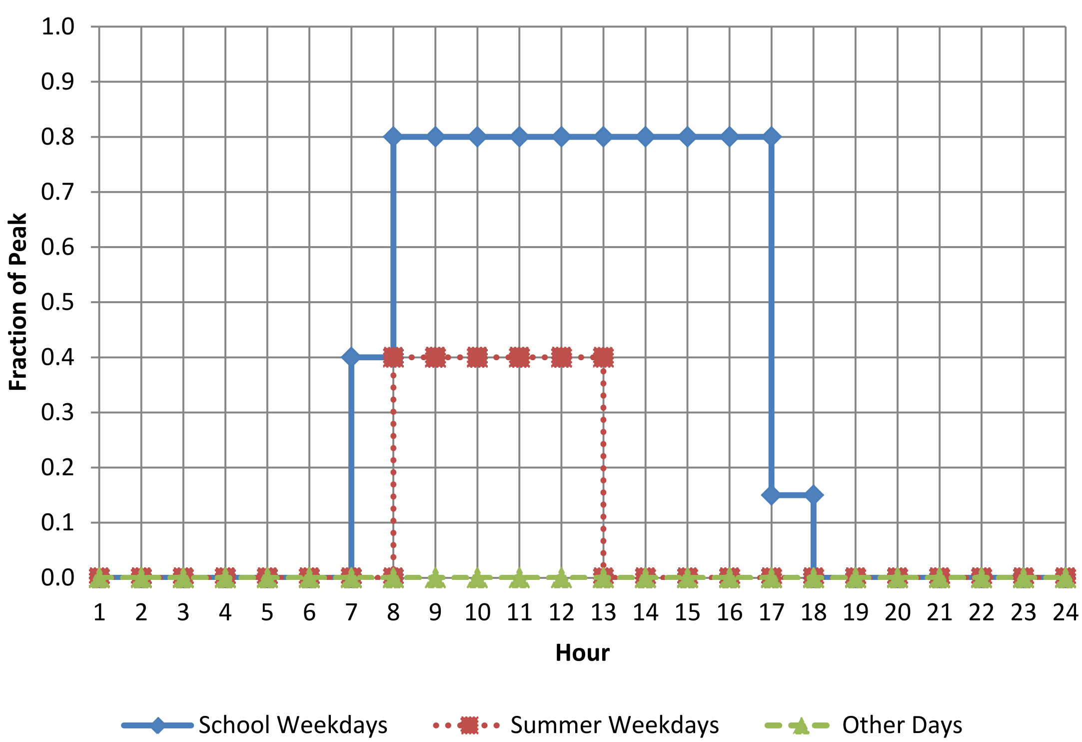


Figure 3–14 Secondary school office occupancy schedule

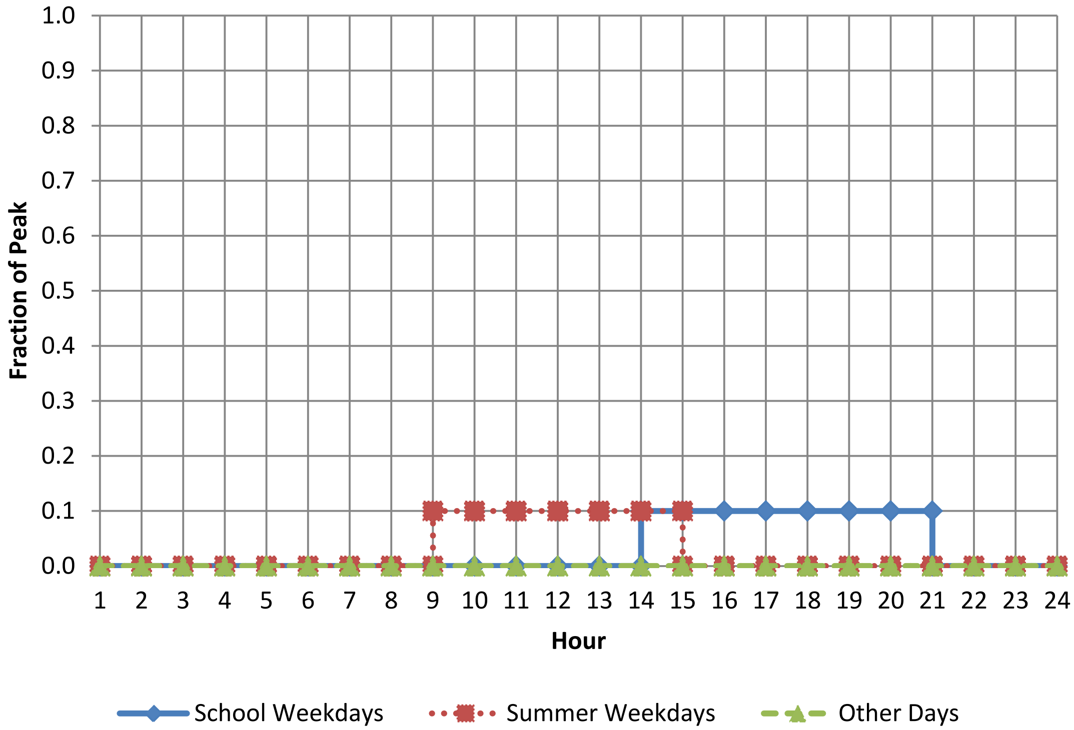


Figure 3–15 Secondary school auditorium occupancy schedule

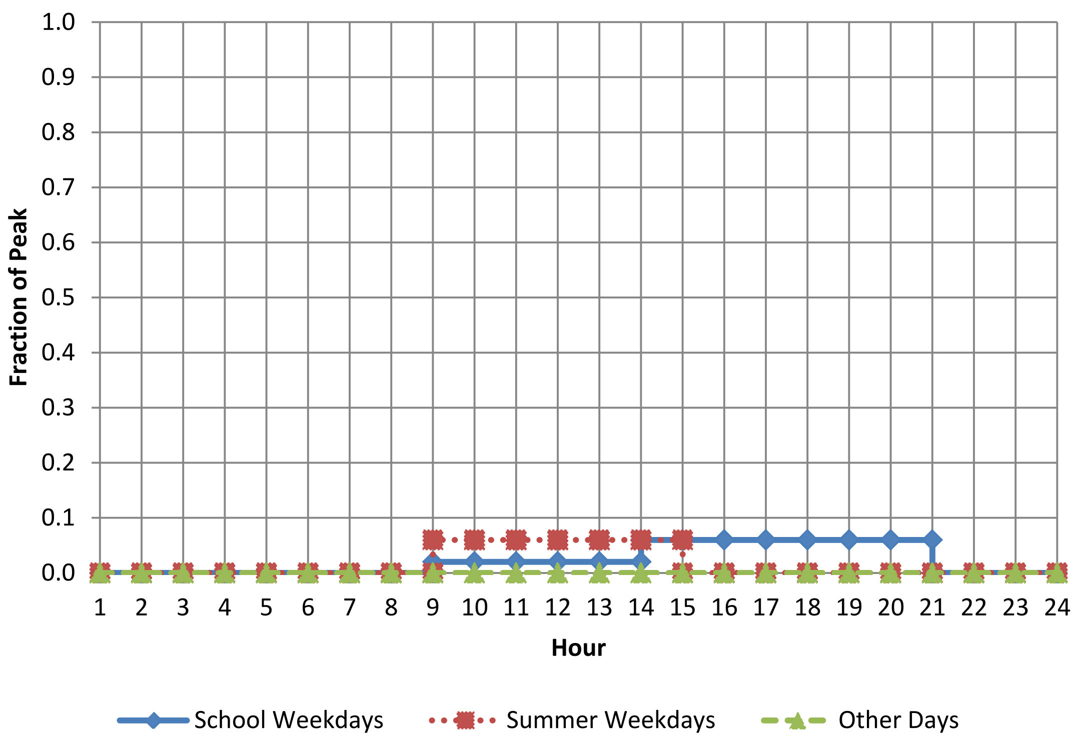


Figure 3–16 Secondary school auxiliary gym occupancy schedule

3.2.3 Infiltration

Infiltration 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. Infiltration is also known as air leakage into a building (ASHRAE 2009).

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

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/ft^2 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/ft^2 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. (2010).

Because a large amount 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 0.5 during HVAC system operation. The infiltration schedule was a simple multiplier that in this case reduced the total infiltration by half. This schedule changed 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. A different infiltration schedule was applied to the gym (and the auditorium in the secondary school) for the extended hours this space would be occupied. The infiltration schedules can be seen in Figure 3–17 (primary school) and Figure 3–18 (secondary school).

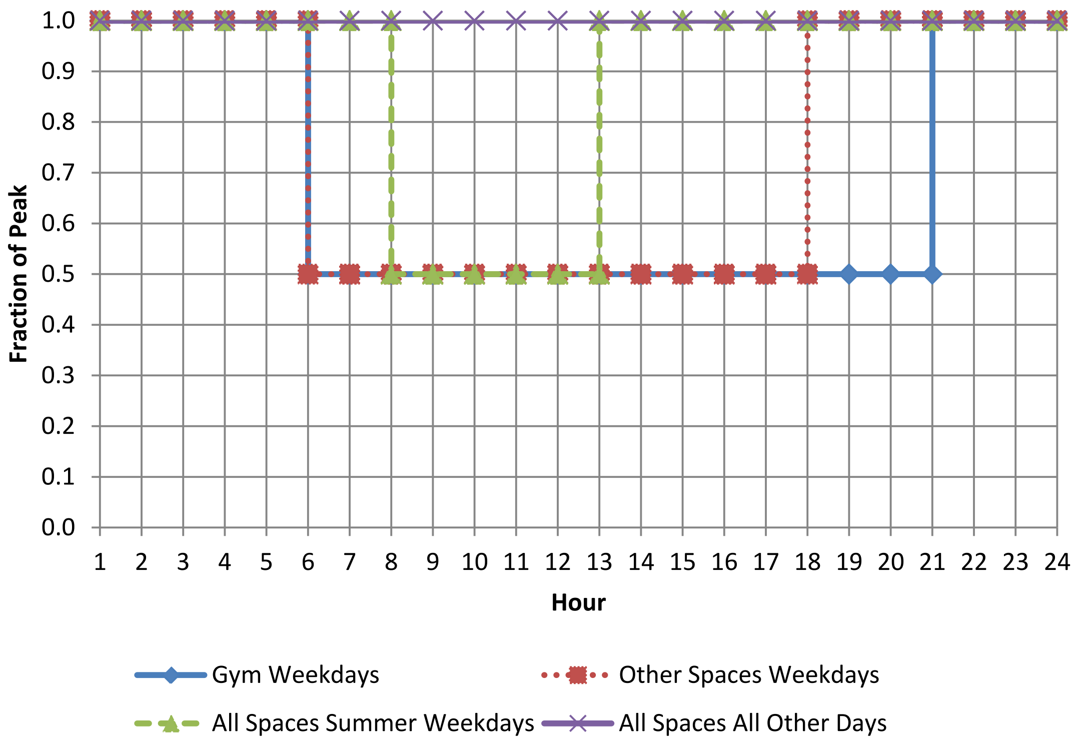


Figure 3–17 Primary school infiltration schedule

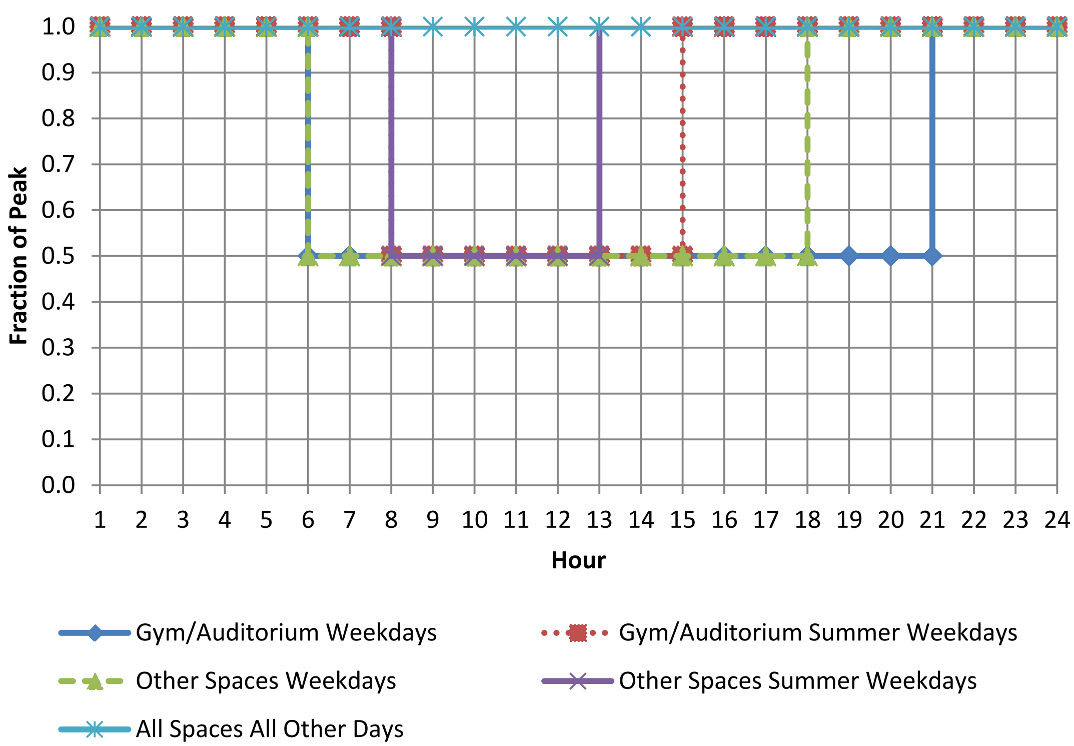


Figure 3–18 Secondary school infiltration schedule

3.2.4 Thermostat Set Points

The thermostat set points in the models were derived from those in Deru et al. (2010). The PC modified the set points based on members' experience designing schools. The heating set point schedule is shown in Figure 3–19 and the cooling set point schedule is shown in Figure 3–20. These schedules and remain consistent between the baseline and low-energy models.

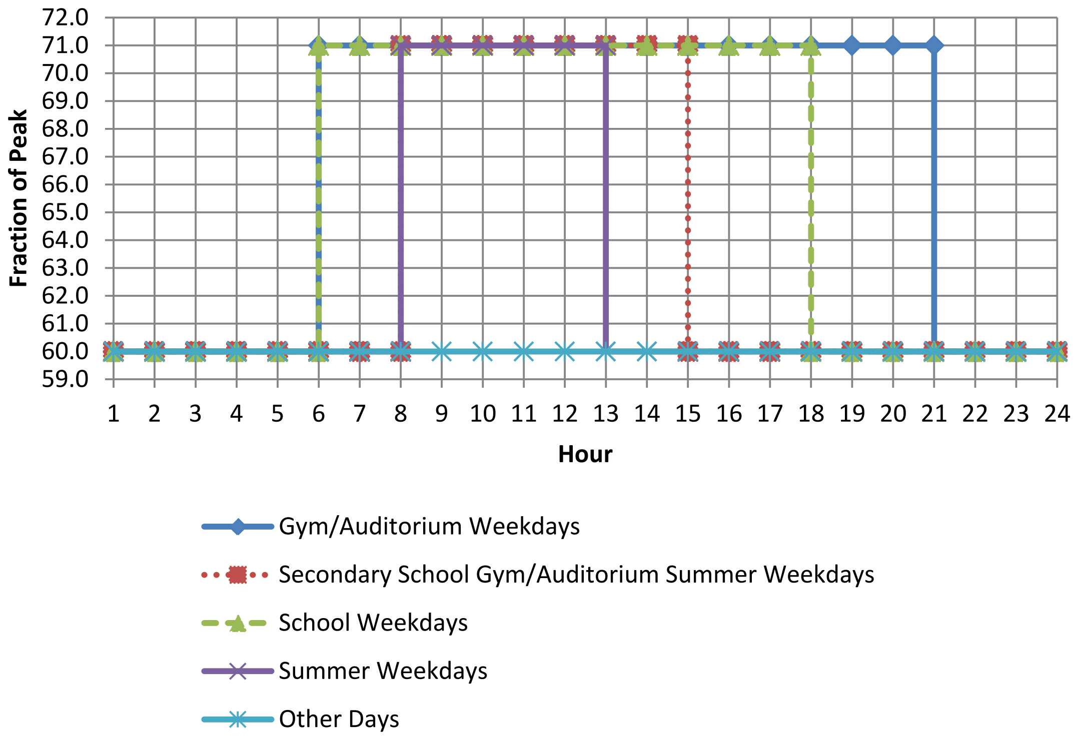


Figure 3–19 Heating set point schedule

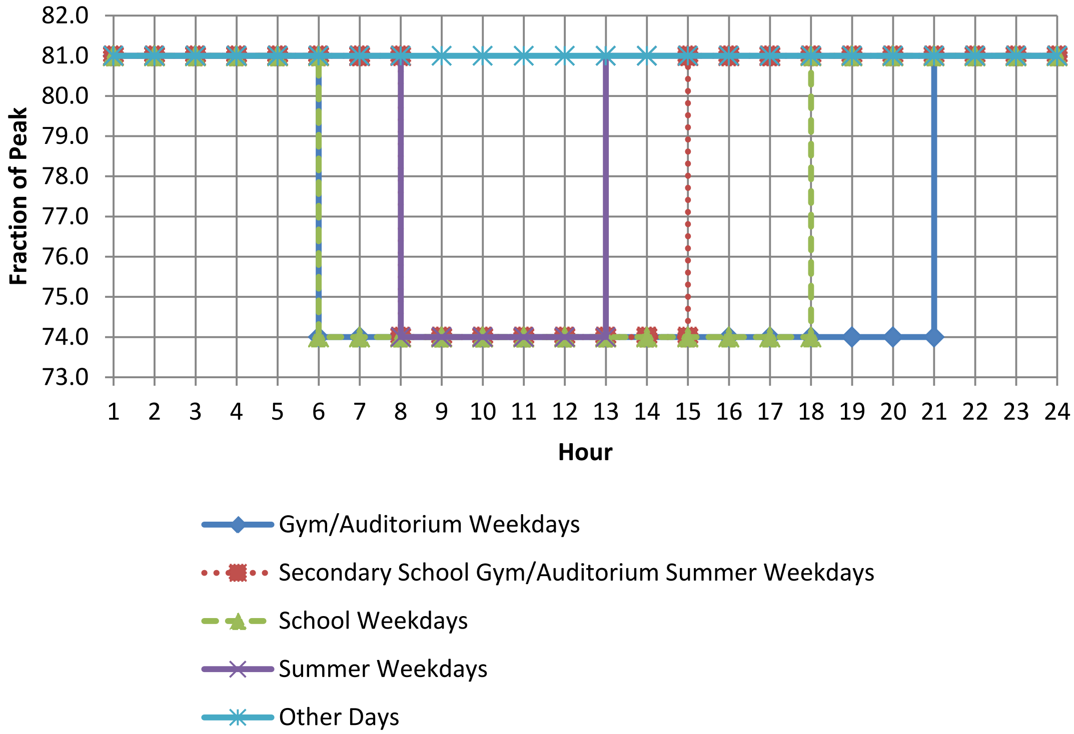


Figure 3–20 Cooling set point schedule

3.2.5 Elevators

The secondary school model contains two stories and thus has elevators. Information from the DOE Commercial Reference secondary school (Deru et al. 2010) was used, which contains two 14,610-W elevator motors with an efficiency of 91%, resulting in a total elevator load of 32,110 W. The peak elevator load is modified by the schedule in Figure 3–21. The elevator load is applied to the second floor mechanical room zone. The primary school has no elevators.

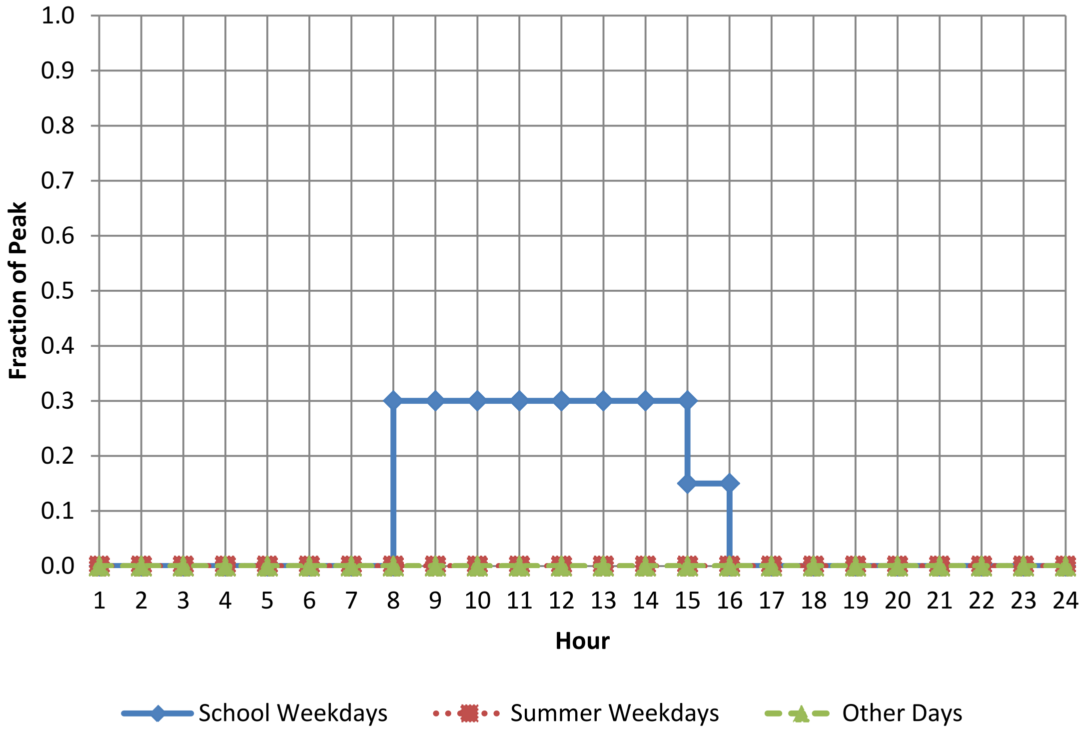


Figure 3–21 Secondary school elevator schedule

3.3 Baseline Model Development and Assumptions

The baseline models were derived from the prototype models by applying Standard 90.1-2004 as well as PC expertise for items not covered by the Standard 90.1-2004, such as plug and process loads.

Figure 3–22 shows a rendering of the primary school baseline model, and Figure 3–23 shows a rendering of the secondary school baseline model.

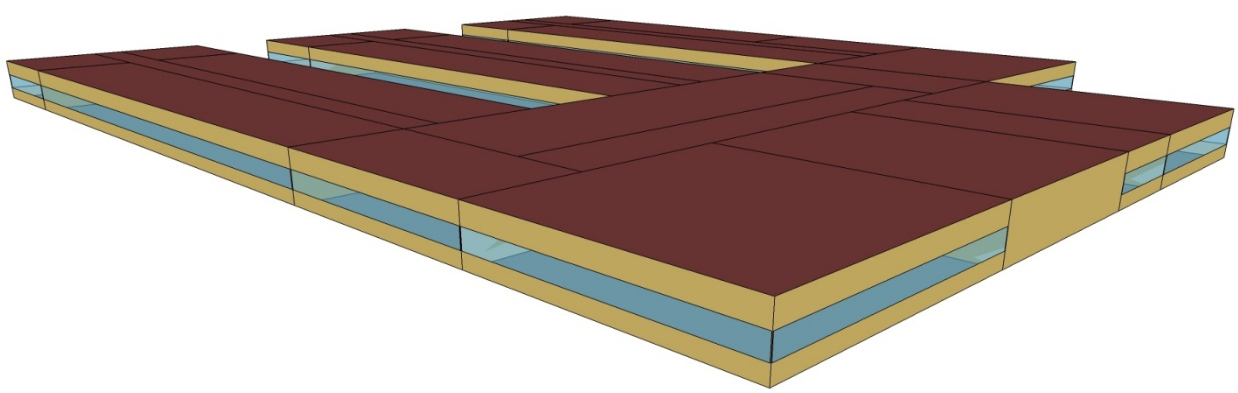


Figure 3–22 Primary school baseline model rendering

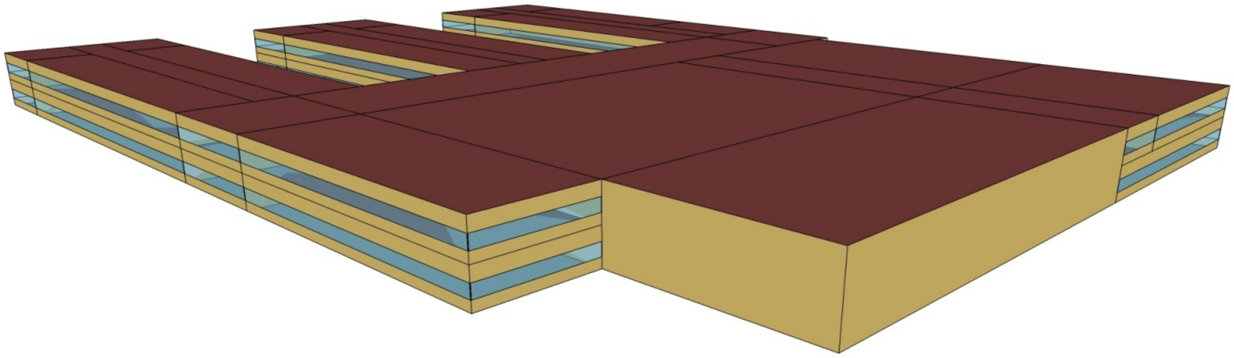


Figure 3–23 Secondary school baseline model rendering

3.3.1 Envelope

The PC assumed, based on the experience of those in the K-12 school construction industry, that these facilities are typically constructed with mass exterior walls, built-up roofs, and slab-on-grade floors. These constructions represent common practices. There are some regional variations, but the PC felt that mass walls and built-up roofs were the most common techniques.

The baseline K-12 school facility envelope characteristics were developed to meet the prescriptive design option requirements in accordance with Standard 90.1-2004 Section 5.2. For the Standard 90.1-2004 baselines, 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 schools were 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 R- and U-values are listed in Table 3–9.

Table 3–9 Baseline Exterior Wall Constructions

Climate Zone	Assembly U-Factor ($Btu/h{\cdot}ft^2{\cdot}°F$)	Insulation R-Value, Nominal ($h{\cdot}ft^2{\cdot}°F/Btu$)
1–2	U-0.580	No insulation requirement (NR)
3–4	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 was assembled assuming 8-in. medium weight concrete blocks with a density of 140 lb/ft^3 and solid grouted cores. The mass wall includes the following layers:

- Exterior air film (calculated by EnergyPlus)
- 1-in. exterior stucco
- 8-in. concrete block, 140 lb/ft^3
- 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 "TARP" algorithm in EnergyPlus for surface heat transfer film coefficients was used, and to calculate the thermal performance of the exterior air films, the "DOE-2" algorithm in EnergyPlus for surface heat transfer film coefficients was used. These are based on linearized radiation coefficients that are separate from the convection coefficients, as determined by surface roughness, wind speed, and terrain. However, standardized combined film coefficients were used to target assembly U-factors; these coefficients can be seen in (DOE 2011).

Table 3–10 Standard Film Coefficients

Surface Class	Interior Film Coefficient (h·ft^2·°F/Btu)	Exterior Film Coefficient (h·ft^2·°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 models. 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 roof U-factors are included in Table 3–11.

Table 3–11 Baseline Roof Constructions

Climate Zone	Assembly U-Factor (Btu/h·ft^2·°F)	Insulation R-Value, Nominal (h·ft^2·°F/Btu)
1–7	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 buildings were modeled with 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 models, the program was used to run a simple building in each location with the slab insulation requirements in Standard 90.1-2004. The program reports 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 3–12 and Table 3–13).

Table 3–12 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 3–13 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. Most of the building (except the gym and auditorium) had an overall fraction of fenestration to gross wall area of 35%; 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 3–14 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 for consistency, because the AEDG-K12 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 3–14 Baseline Window Constructions

Climate Zone	U-Factor (Btu/h·ft²·°F)	SHGC	VLT
1 (A,B)	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,C)	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 Electric Lighting

3.3.2.1 Interior Lighting

The lighting power densities (LPDs) used in the baseline models are listed in Table 3–15. These values were determined by using the space-by-space method in Standard 90.1-2004, Table 9.6.1 (ASHRAE 2004b).

Table 3–15 LPD by Space Type

Space Type	90.1-2004 Table 9.6.1 Space Type	LPD (W/ft²)
Auditorium	Audience/Seating Area	0.9
Art room	Classroom/lecture/training	1.4
Cafeteria	Dining area	0.9
Classroom	Classroom/lecture/training	1.4
Corridor	Corridor/transition	0.5
Gym/multipurpose room	Gymnasium/Exercise Center::Playing Area	1.4
Kitchen	Food preparation	1.2
Library/media center	Library::Reading Area	1.2
Lobby	Lobby	1.3
Mechanical	Electrical/mechanical	1.5
Office	Office-Enclosed	1.1
Restroom	Restrooms	0.9
Calculated whole-building – primary school		1.2
Calculated whole-building – secondary school		1.1

The peak values in Table 3–15 are modified with hour-by-hour multiplier schedules in EnergyPlus. The primary and the secondary schools use the schedules in Figure 3–24. The lighting schedules were adapted by the PC from those in Deru et al. (2010). The PC modified the schedules using members' experience with schools along with submetered data collected from schools they have built.

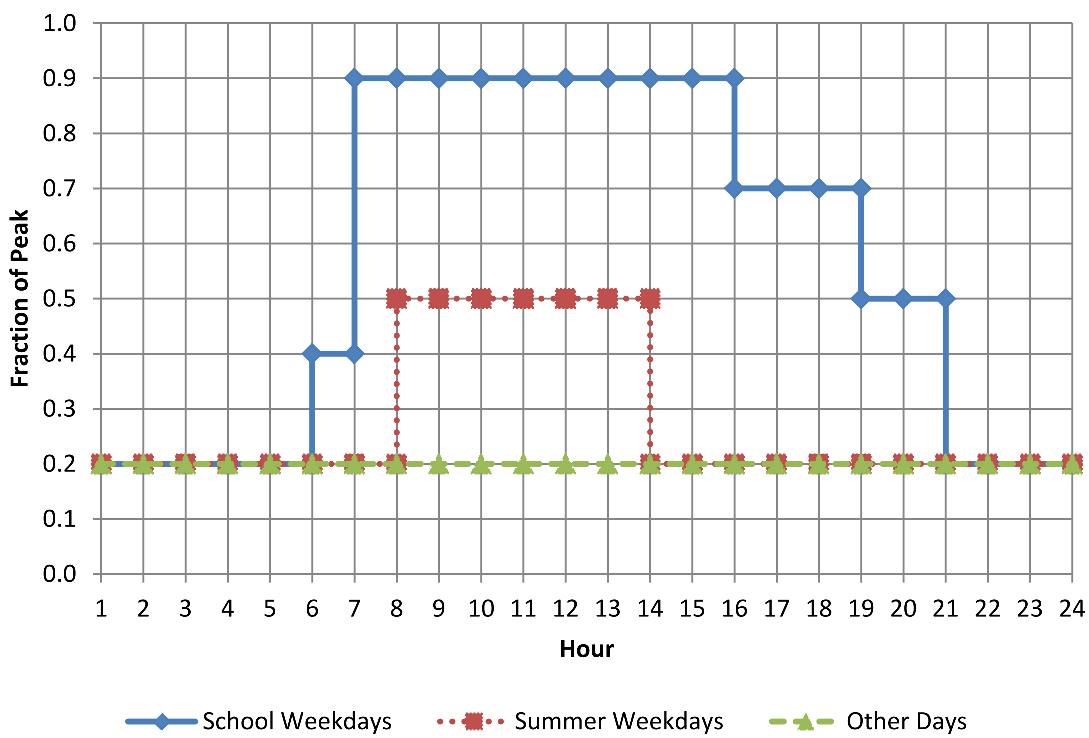


Figure 3–24 Baseline lighting schedule

3.3.2.2 *Exterior Lighting*

The primary school had 5,547 W of exterior lighting; the secondary school had 47,450 W of exterior lighting (Deru et al. 2010). In both models, the lights were controlled by an astronomical clock that turned the lights on when the sun set and off when the sun rose.

3.3.3 Plug and Process Loads

The plug and process loads were adapted from the DOE Commercial Reference Building (Deru et al. 2010) energy models based on PC input. Table 3–16 shows a summary of the plug and process loads used in the models.

Table 3–16 Baseline Model Plug and Process Loads

Space Type	Primary School		Secondary School	
	Electric Loads (W/ft²)	Gas Loads (Btuh/ft²)	Electric Loads (W/ft²)	Gas Loads (Btuh/ ft²)
Auditorium	n/a	–	0.2	–
Art classroom	6.3	–	6.3	–
Cafeteria	0.5	–	1.8	–
Classroom	1.4	–	0.9	–
Corridor	–	–	0.2	–
Gym/multipurpose room	–	–	0.2	–
Kitchen	16.7	57.8	12.9	115.0
Library/media center	0.5	–	0.9	–
Lobby	–	–	0.4	–
Mechanical room	–	–	0.4	–
Office	0.5	–	1.0	–
Restroom	–	–	0.4	–
Calculated whole building	1.3	n/a	0.8	n/a

The peak values in Table 3–16 are modified with hour-by-hour multiplier schedules in EnergyPlus. All the primary school electric loads (except those for the art room and kitchen) are modified by the schedules shown in Figure 3–25. The primary school kitchen loads are modified by the schedules depicted in Figure 3–26 (electric equipment) and Figure 3–27 (gas equipment). Likewise for the secondary school: all the electric loads (except for the art room and kitchen loads) are modified by the schedules illustrated in Figure 3–28; the kitchen loads are modified by schedules detailed in Figure 3–29 (electric equipment) and Figure 3–30 (gas equipment). The electric equipment (not including the kitchen loads) schedules in the model were adapted by the PC from those in Deru et al. (2010). The PC modified the schedules using members' experience with schools along with submetered data collected from schools they have built. See Section 3.3.3.1 and 3.3.3.2 for discussion about the development of the kitchen electric and gas equipment schedules as well as the art room schedules.

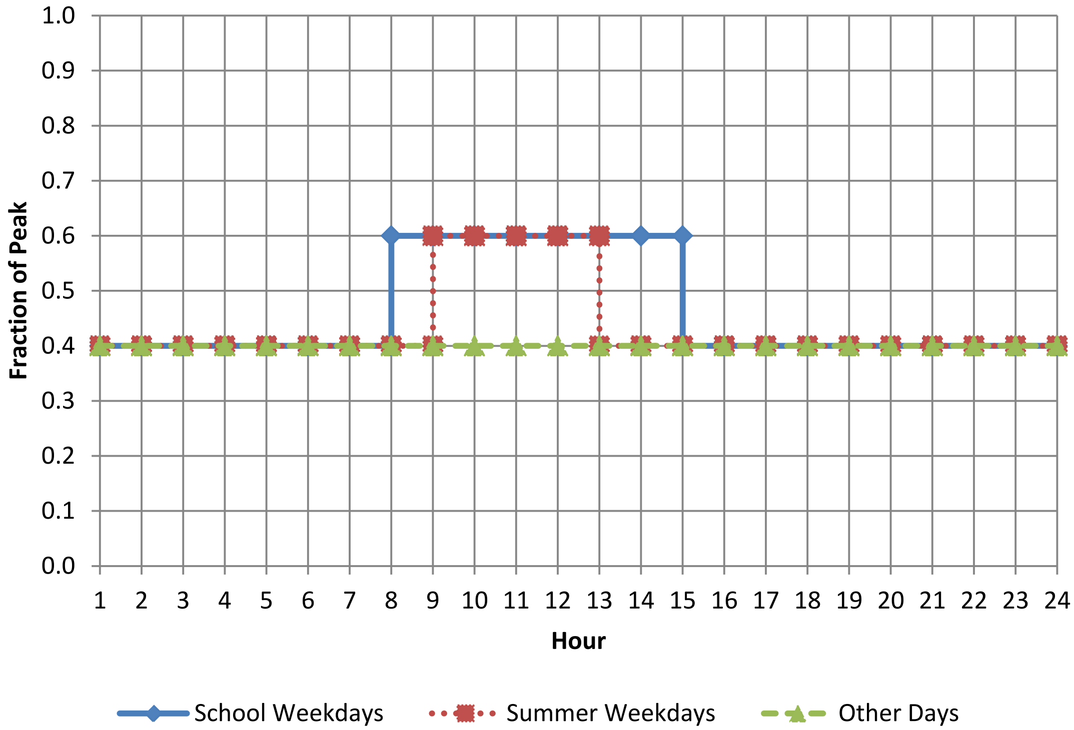


Figure 3–25 Primary school baseline electric equipment schedule

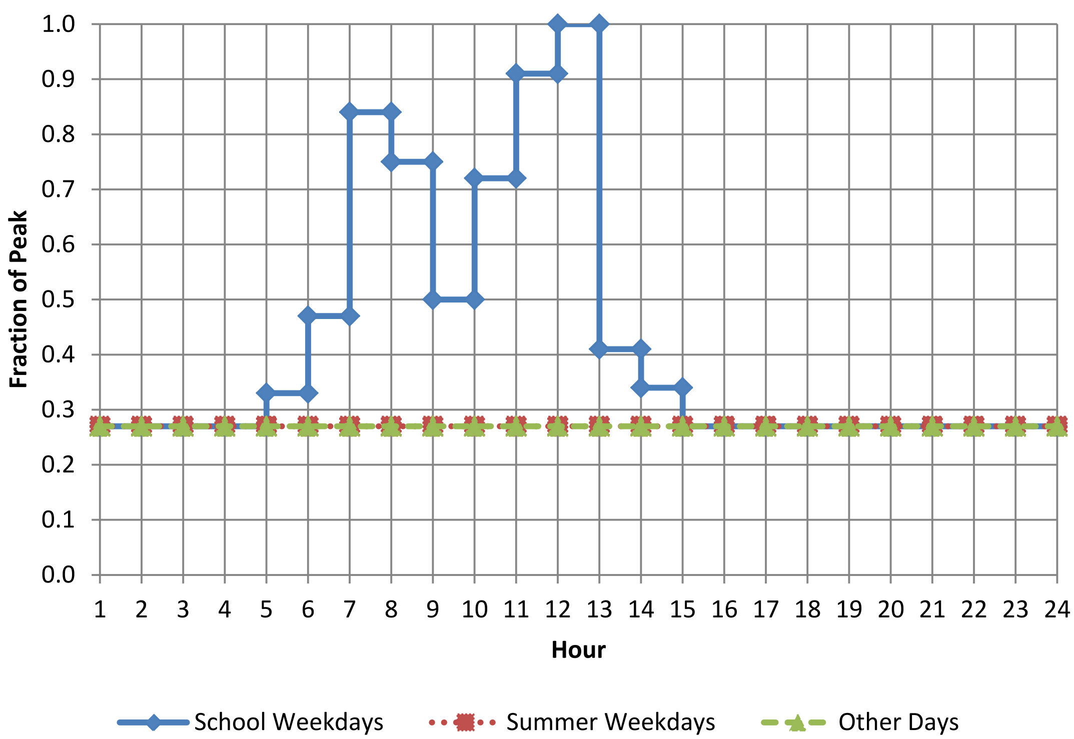


Figure 3–26 Primary school baseline kitchen electric equipment schedule

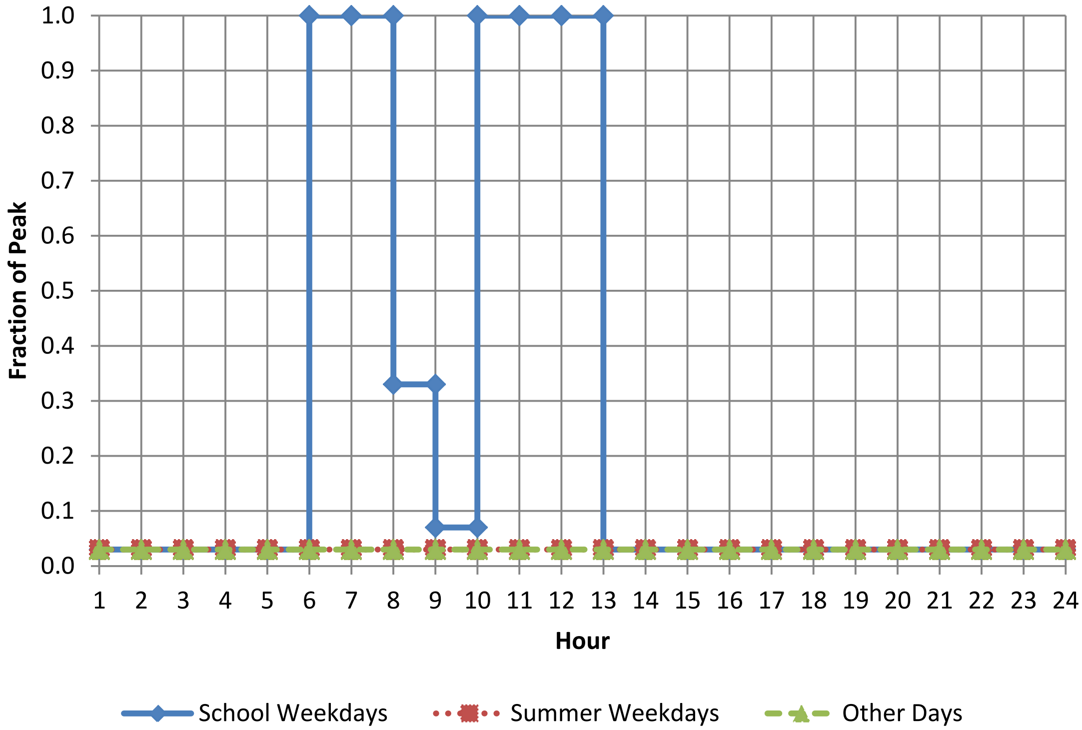


Figure 3–27 Primary school baseline kitchen gas equipment schedule

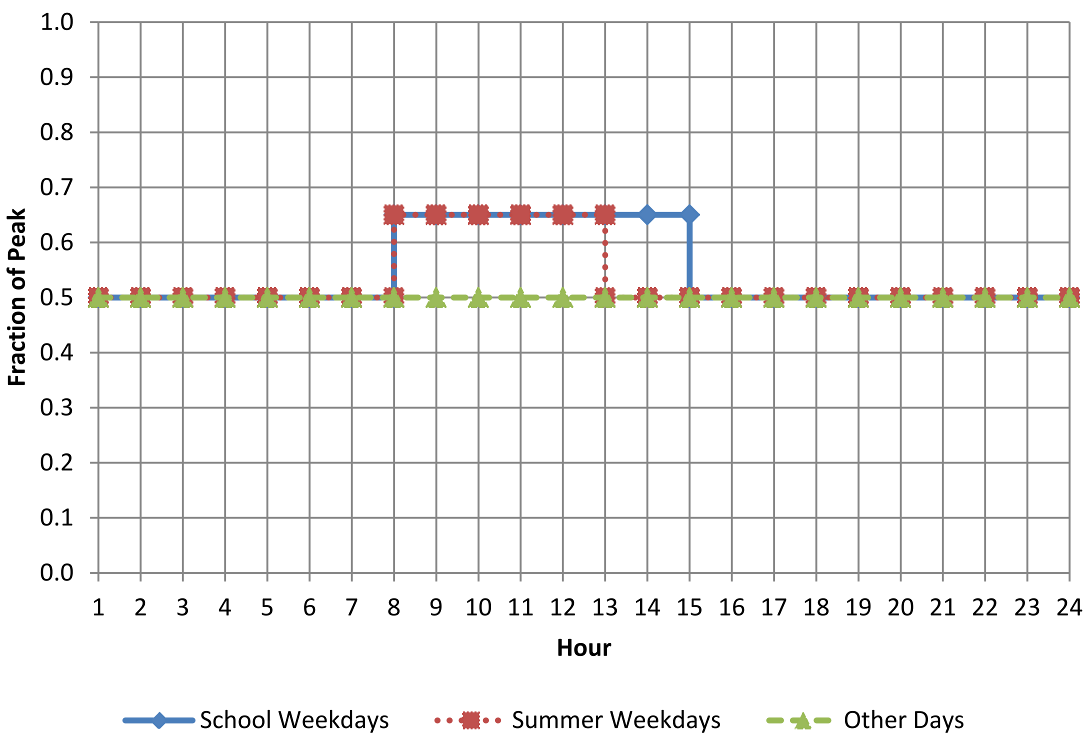


Figure 3–28 Secondary school baseline electric equipment schedule

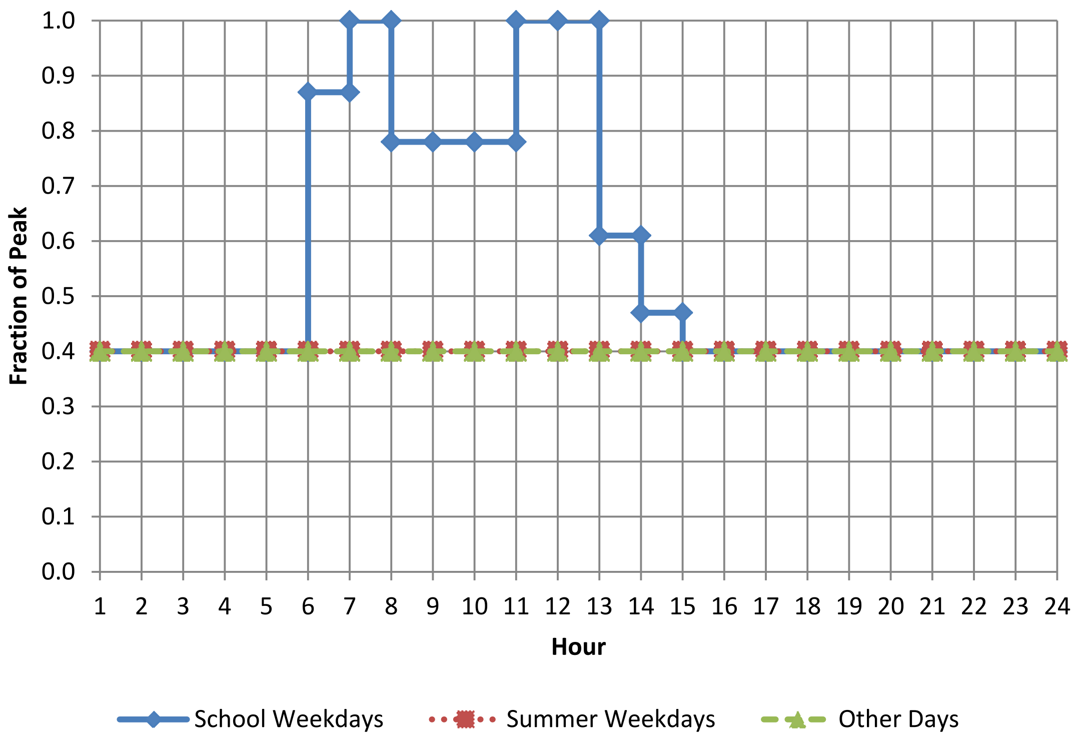


Figure 3–29 Secondary school baseline kitchen electric equipment schedule

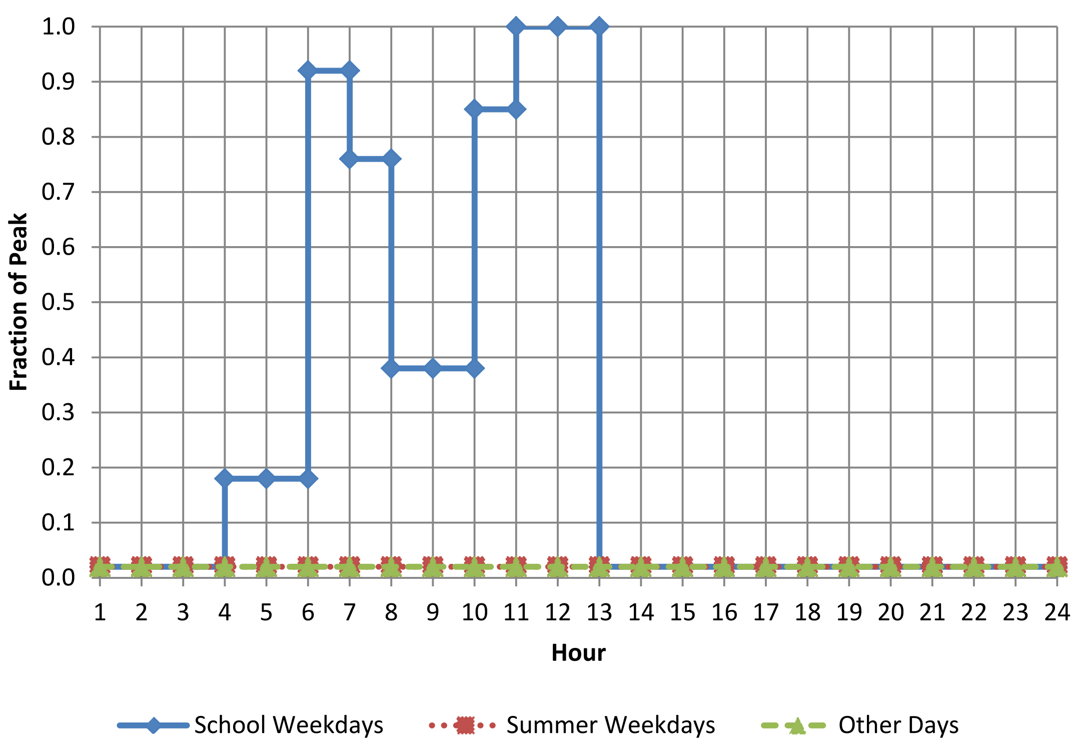


Figure 3–30 Secondary school baseline kitchen gas equipment schedule

3.3.3.1 Primary School Reference Building Comparison

Table 3–17 shows a comparison of the plug and process loads between the AEDG-K12 primary school energy model and the starting point DOE Commercial Reference primary school model (Deru et al. 2010). Values that differ are highlighted; an explanation for the differences (by space type) follows the table.

Table 3–17 Primary School Plug and Process Load Comparison to Reference Building

Space Type	AEDG-K12 Model		Reference Building Model	
	Electric Loads (W/ft^2)	Gas Loads ($Btu/h/ft^2$)	Electric Loads (W/ft^2)	Gas Loads ($Btu/h/ft^2$)
Art classroom	6.3	–	n/a	–
Cafeteria	0.5	–	2.4	–
Classroom	1.4	–	1.4	–
Corridor	–	–	0.4	–
Gym/multipurpose room	–	–	0.5	–
Kitchen	16.7	57.8	17.7	302.6
Library/media center	0.5	–	1.4	–
Lobby	–	–	0.4	–
Mechanical room	–	–	0.9	–
Office	0.5	–	1.0	–
Restroom	–	–	0.4	–

Art classroom: In the AEDG-K12 model, an art classroom was substituted for the computer classroom in the DOE Commercial Reference Building model (Deru et al. 2010). This decision was based on PC input that most schools use laptop carts that they transfer from room to room in lieu of dedicated computer laboratories. Also, the Reference Building primary school did not include an art room, and the PC felt that was common enough to primary schools to include one. The art room electric load includes an 11,000-W kiln similar to the KM-1227-3 (Skutt 2012). The kiln was an exception to the plug and process loads modeled as firing during January–June and September–December from 4:00 p.m. on the fifteenth of each month to 6:00 a.m. on the sixteenth. This results in 10 firings per year at 14 hours each, for an annual total of 140 hours.

Corridor, gym/multipurpose room, lobby, mechanical room, restroom: In these space types, the PC reduced the Reference Building plug load values to zero. The PC did not believe that plug loads in these spaces are very common and thus should be set to zero.

Cafeteria, library, and office: The PC felt 0.5 W/ft^2 was a more realistic number for the type of equipment that would typically be found in these space types.

Kitchen: Table 3–18 and Table 3–19 show the energy load profile data used to develop the kitchen loads. The data in the tables represent "typical" K-12 kitchens, and fractional quantities are used in some instances (e.g., 1 in 2 kitchens has a toaster, so the quantity is 0.5). The PC consulted with a commercial kitchen expert to help develop these data, which represent a typical K-12 school kitchen. The use factor column represents the fraction of rated power the equipment will draw during service. These data were transformed into an input for electric equipment in EnergyPlus by determining the peak gas or electricity value of the day and using the rest of the data to determine the multiplier schedules depicted in Figure 3–26 for electric equipment and Figure 3–27 for gas equipment.

Table 3–18 Primary School Baseline Kitchen Load Profile – Electric Equipment

Qty.	Appliance	Avg. Input Rate (kW)	Use Factor	Hour (kW) 1–6	7	8	9	10	11	12	13	14	15	16–24	Total per day (kW)
1.0	Steamer	6.20	0.5	0.00	0.00	0.00	0.00	0.00	3.10	3.10	3.10	0.00	0.00	0.00	9.3
1.0	Hot holding cabinet	2.00	1.0	0.00	2.00	2.00	2.00	0.00	2.00	2.00	2.00	0.00	0.00	0.00	12.0
8.0	Steam table	1.01	0.5	0.00	0.00	4.04	0.00	0.00	0.00	4.04	4.04	0.00	0.00	0.00	12.1
0.5	Toaster	1.50	0.5	0.00	0.00	0.38	0.00	0.00	0.00	0.38	0.38	0.00	0.00	0.00	1.1
4.0	Warming drawer	0.20	0.5	0.00	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.00	0.00	0.00	2.8
4.0	Heat lamp	1.00	0.5	0.00	0.00	2.00	2.00	2.00	2.00	2.00	2.00	0.00	0.00	0.00	12.0
2.5	Microwave	0.40	0.5	0.00	0.00	0.50	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	1.5
4.0	Soup warmer	0.50	1.0	0.00	2.00	2.00	0.00	0.00	2.00	2.00	0.00	0.00	0.00	0.00	8.0
2.0	Coffee brewer	1.00	0.8	0.00*	1.60	1.60	1.60	1.60	1.60	1.60	1.60	0.00	0.00	0.00	12.8
5.0	Cold table	0.20	1.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	24.0
1.0	Ice machine	0.90	1.0	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	21.6
1.0	Ice machine	1.99	1.0	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	47.8
6.0	Prep table	0.20	1.0	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	28.8
2.5	Undercounter refrigerator	0.10	1.0	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	6.0
2.0	Undercounter freezer	0.20	1.0	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	9.6
5.0	Refrigerator/solid	0.19	1.0	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	22.8
2.0	Freezer/solid	0.46	1.0	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	22.1
1.3	Freezer/glass	0.50	1.0	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	15.6
1.0	Dish machine, conveyor	4.50	1.0	0.00	0.00	2.25	4.50	1.00	1.00	2.25	4.50	2.25	1.00	0.00	18.8
1.0	Dish machine, booster heater	4.00	1.0	0.00	0.00	2.00	4.00	2.00	1.00	1.00	4.00	2.00	1.00	0.00	17.0
Total (kW)				8.3**	14.3	25.4	22.8	15.3	21.9	27.5	30.3	12.5	10.3	8.3	306

* 0.00 for hours 1-5, 1.60 in hour 6 only
** 8.3 for hours 1-5, 9.9 in hour 6 only

Table 3–19 Primary School Baseline Kitchen Load Profile – Gas Equipment

Qty.	Appliance	Avg. Input Rate (kBtu/h)	Use Factor	Hour (kBtu/h)						Total per day (kBtu/h)
				1–6	7-8	9	10	11–13	14–24	
0.1	Braising pan	24.9	1.0	0.00	2.49	2.49	0.00	2.49	0.00	14.9
1.0	Griddle	26.4	1.0	1.00	26.40	26.40	1.00	26.40	1.00	176.4
0.1	Combi oven	35.0	1.0	0.00	3.50	3.50	3.50	3.50	0.00	24.5
1	Convection oven	21.8	1.0	1.00	21.80	1.00	1.00	21.80	1.00	128.0
1	Range oven	18.3	1.0	0.50	18.30	0.50	0.50	18.30	0.50	101.0
1	Open top range	32.0	1.0	1.00	32.00	1.00	1.00	32.00	1.00	179.0
Total (kBtu/h)				3.5	104.5	34.9	7.0	104.5	3.5	624

3.3.3.2 Secondary School Reference Building Comparison

Table 3–20 shows a comparison of the plug and process loads between the AEDG-K12 energy model and the starting point DOE Commercial Reference Building model (Deru et al. 2010). Values that differ are highlighted with an explanation for the differences (by space type) following the table.

Table 3–20 Secondary School Plug and Process Load Comparison to Reference Building

Space Type	AEDG-K12 Model		Reference Building Model	
	Electric Loads (W/ft²)	Gas Loads (Btu/h/ft²)	Electric Loads (W/ft²)	Gas Loads (Btu/h/ft²)
Art classroom	6.3	–	n/a	–
Auditorium	0.2	–	0.5	–
Cafeteria	1.8	–	1.8	–
Classroom	0.9	–	0.9	–
Corridor	0.2	–	0.4	–
Gym/multipurpose room	0.2	–	0.5	–
Kitchen	20.6	115.0	20.7	389.0
Library/media center	0.9	–	0.9	–
Lobby	0.4	–	0.4	–
Mechanical room	0.4*	–	0.4*	–
Office	1.0	–	1.0	–
Restroom	0.4	–	0.4	–

* The first floor mechanical room has an additional elevator load detailed in Section 3.2.5

Art classroom: In the AEDG-K12 model, an art classroom was substituted for the computer classroom in the DOE Commercial Reference Building model (Deru et al. 2010). This decision was based on PC input that most schools use laptop carts that they transfer from room to room in lieu of dedicated computer laboratories. Also, the Reference Building secondary school was missing an art room, and the PC felt that was common enough to secondary schools to include one. The art room electric load includes an 11,000-W kiln similar to the KM-1227-3 (Skutt 2012). The kiln was modeled as firing during January–June and September–December from 4:00 p.m. to midnight on the first, eighth, and twenty-second of each month as well as from 4:00 p.m. on the fifteenth of each month to 6:00 a.m. on the sixteenth. This results in 40 firings per year, 30 at 8 hours, and 10 at 14 hours, for a total of 380 hours of operation per year.

Auditorium, corridor, gym/multipurpose room: In these space types, the PC lowered the Reference Building plug load values, as members' experience showed that plug loads in these spaces are lower than in the Reference Building model.

Kitchen: Table 3–21 and Table 3–22 show the energy load profile data used to develop the kitchen loads. The data in the tables represent "typical" K-12 kitchens, and fractional quantities are used in some instances (e.g., 1 in 2 kitchens has an underfired broiler, so the quantity is 0.5). The PC consulted with a commercial kitchen expert to help develop these data, which represent a typical K-12 school kitchen. The use factor column represents the fraction of rated power the equipment will draw during service. These data were transformed into an input for electric equipment in EnergyPlus by determining the peak electricity or gas value of the day and using the rest of the data to determine the multiplier schedule in Figure 3–29 for electric equipment and Figure 3–30 for gas equipment.

Table 3–21 Secondary School Baseline Kitchen Load Profile – Electric Equipment

Qty.	Appliance	Avg. Input Rate (kW)	Use Factor	Hour (kW)											Total Per Day (kW)
				1–6	7	8	9	10	11	12	13	14	15	16–24	
1.0	Steamer	6.98	1.0	0.00	3.49	3.49	0.00	0.00	6.98	6.98	0.00	0.00	0.00	0.00	20.9
3.0	Hot holding cabinet	2.00	0.5	0.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	0.00	0.00	0.00	21.0
10.0	Steam table	1.01	0.5	0.00	5.05	5.05	5.05	5.05	5.05	5.05	5.05	0.00	0.00	0.00	35.4
2.0	Contact toaster	1.50	0.5	0.00	3.00	3.00	0.00	0.00	0.00	3.00	3.00	0.00	0.00	0.00	12.0
1.5	Conveyor toaster	1.80	0.5	0.00	2.70	2.70	0.00	0.00	0.00	2.70	2.70	0.00	0.00	0.00	10.8
8.0	Warming drawer	0.20	0.5	0.00	1.60	1.60	1.60	1.60	1.60	1.60	1.60	0.00	0.00	0.00	11.2
5.0	Heat lamp	0.25	1.0	0.00	1.25	1.25	1.25	1.25	1.25	1.25	1.25	0.00	0.00	0.00	8.8
3.0	Microwave	0.40	0.5	0.00	1.20	1.20	1.20	1.20	1.20	1.20	1.20	0.00	0.00	0.00	8.4
5.0	Soup warmer	0.50	0.5	0.00	2.50	2.50	2.50	2.50	2.50	2.50	2.50	0.00	0.00	0.00	17.5
3.0	Coffee brewer	1.00	0.5	0.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	0.00	0.00	0.00	21.0
2.5	Soft serve	0.20	0.5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	12.0
2.0	Drink machine	0.20	0.5	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	9.6
6.0	Cold table	0.10	0.5	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	14.4
1.0	Ice machine	1.99	1.0	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	1.99	47.8
1.0	Ice machine	2.79	1.0	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79	2.79	67.0
8.0	Prep table	0.20	0.5	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	38.4
4.0	Undercounter refrigerator	0.09	1.0	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	8.9
2.0	Undercounter freezer	0.23	1.0	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	11.0
6.0	Refrigerator/solid	0.19	1.0	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	26.6
2.5	Freezer/solid	0.46	1.0	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	1.14	27.4
2.0	Freezer/glass	0.46	1.0	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	22.1
1.0	Dish machine, conveyor	4.50	1.0	0.00	4.50	4.50	1.00	1.00	1.00	4.50	4.50	2.25	2.25	0.00	25.5
1.0	Dish machine, booster heater	4.00	1.0	0.00	4.00	4.00	1.00	1.00	1.00	4.00	4.00	4.00	0.00	0.00	23.0
Total (kW)				11.9	47.2	47.2	31.5	31.5	38.5	50.7	43.7	18.1	14.1	11.9	501

Table 3–22 Secondary School Baseline Kitchen Load Profile – Gas Equipment

Qty.	Appliance	Avg. Input Rate (kBtu/h)	Use Factor	Hour (kBtu/h)								Total Per Day (kBtu/h)
				1–3	4–6	7	8	9–10	11	12–13	14–24	
1.00	Braising pan	24.9	0.5	0.00	0.00	12.45	12.45	6.23	12.45	12.45	0.00	74.7
0.50	Underfired broiler	105.0	0.5	1.00	1.00	1.00	1.00	1.00	26.25	26.25	1.00	99.8
2.00	French fryer	37.1	0.5	1.00	1.00	37.10	37.10	18.55	37.10	37.10	1.00	239.6
2.00	Standard griddle	26.4	0.5	0.50	0.50	26.40	26.40	13.20	26.40	26.40	0.50	166.9
4.00	Convection oven	21.8	0.5	1.00	1.00	43.60	43.60	21.80	43.60	43.60	1.00	278.6
1.00	Conveyor oven	80.2	0.5	0.00	0.00	0.00	0.00	0.00	0.00	40.10	0.00	80.2
2.00	Deck oven	44.7	0.5	0.00	44.70	44.7	0.00	0.00	0.00	0.00	0.00	178.8
1.25	Range oven	18.3	0.5	0.00	0.00	11.44	11.44	5.72	11.44	11.44	0.00	68.6
1.25	Open top range	32.0	0.5	1.00	1.00	20.00	20.00	10.00	20.00	20.00	1.00	137.0
2.00	Steam kettle	50.0	0.5	0.00	0.00	50.00	50.00	25.00	50.00	50.00	0.00	300.0
Total (kBtu/h)				4.5	49.2	246.7	202.0	101.5	227.2	267.3	4.5	1,624

3.3.4 Heating, Ventilation, and Air Conditioning

Both baseline models were similarly zoned; that is, a central area was composed of common spaces that connected classroom wings. The classroom wings and most of the central common spaces were served by variable air volume (VAV) HVAC systems; the specialty spaces with unusual loads (auditorium, cafeteria, kitchen, gym) were served by packaged single zone (PSZ) HVAC systems.

3.3.4.1 Layout

Figure 3–31 shows the HVAC layout of the primary school baseline model. Zones with the same color are on the same HVAC system; the VAV systems serve multiple zones; the PSZ systems serve only one zone. Figure 3–32 and Figure 3–33 show the same information for the secondary school baseline model. The auditorium, gym, and auxiliary gym are two-story spaces.

3.3.4.2 Packaged Single Zone Systems

Both the primary and secondary school baseline models had PSZ systems serving the auditorium, cafeteria, gym, and kitchen. The PSZ systems had 80% efficient natural gas-fired furnaces, direct expansion (DX) cooling coils with a coefficient of performance (COP) of 3.5, 30% efficient constant air volume fans with 1.5 in. w.c. pressure drop, and differential enthalpy-controlled economizers. Per Standard 90.1-2004 (ASHRAE 2004b), economizers were not used in climate zones 1A, 2A, 3A, and 4A. These systems have OA dampers that close during unoccupied periods.

3.3.4.3 Variable Air Volume Systems

Both the primary and secondary school baseline models used VAV systems to serve the classrooms, corridors, library/media centers, lobbies, mechanical rooms, offices, and restrooms. The primary school and secondary school VAV air handlers had water preheat coils; the primary school had DX cooling coils with a COP of 3.2; the secondary school had water cooling coils. The primary school had a 25% efficient supply fan; the secondary school had a 40% efficient supply fan; both schools had 80% efficient fan motors with a system pressure drop of 4.5 in. w.c. The primary and secondary school air handlers had a leaving air set point temperature of 55°F and differential enthalpy-controlled economizers. Per Standard 90.1-2004 (ASHRAE 2004b), economizers were not used in climate zones 1A, 2A, 3A, and 4A. These systems have OA dampers that close during unoccupied periods. Both schools had terminal units with hot water reheat coils and a 0.3 minimum flow fraction. The heating plant for both schools contained an 80% efficient atmospheric natural gas-fired boiler with an 80% efficient pump that had 60 ft w.c. of pump head. The secondary school cooling plant contained a 2.8 COP air-cooled chiller with an 80% efficient pump that had 75 ft w.c. of pump head.

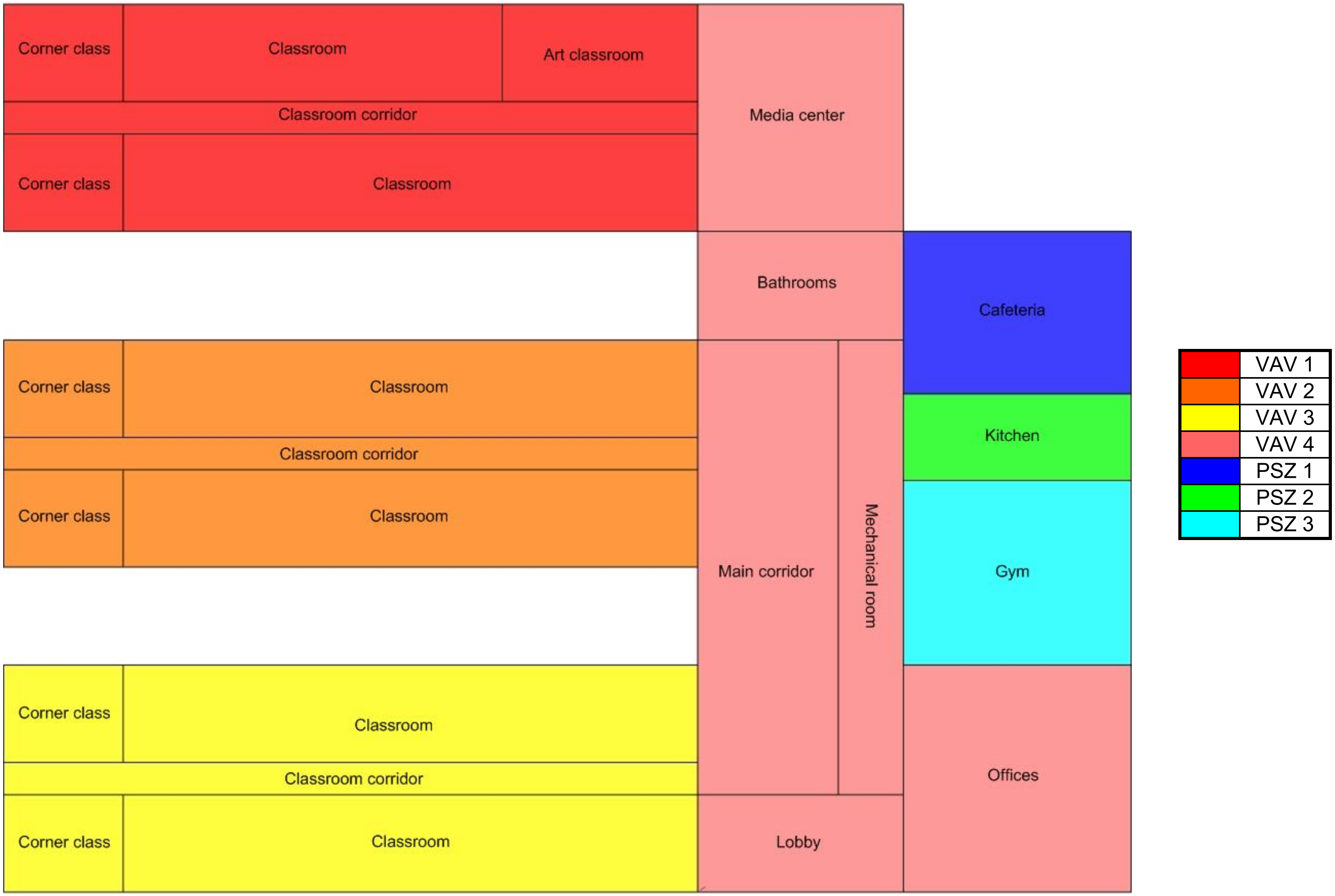


Figure 3–31 Primary school HVAC layout

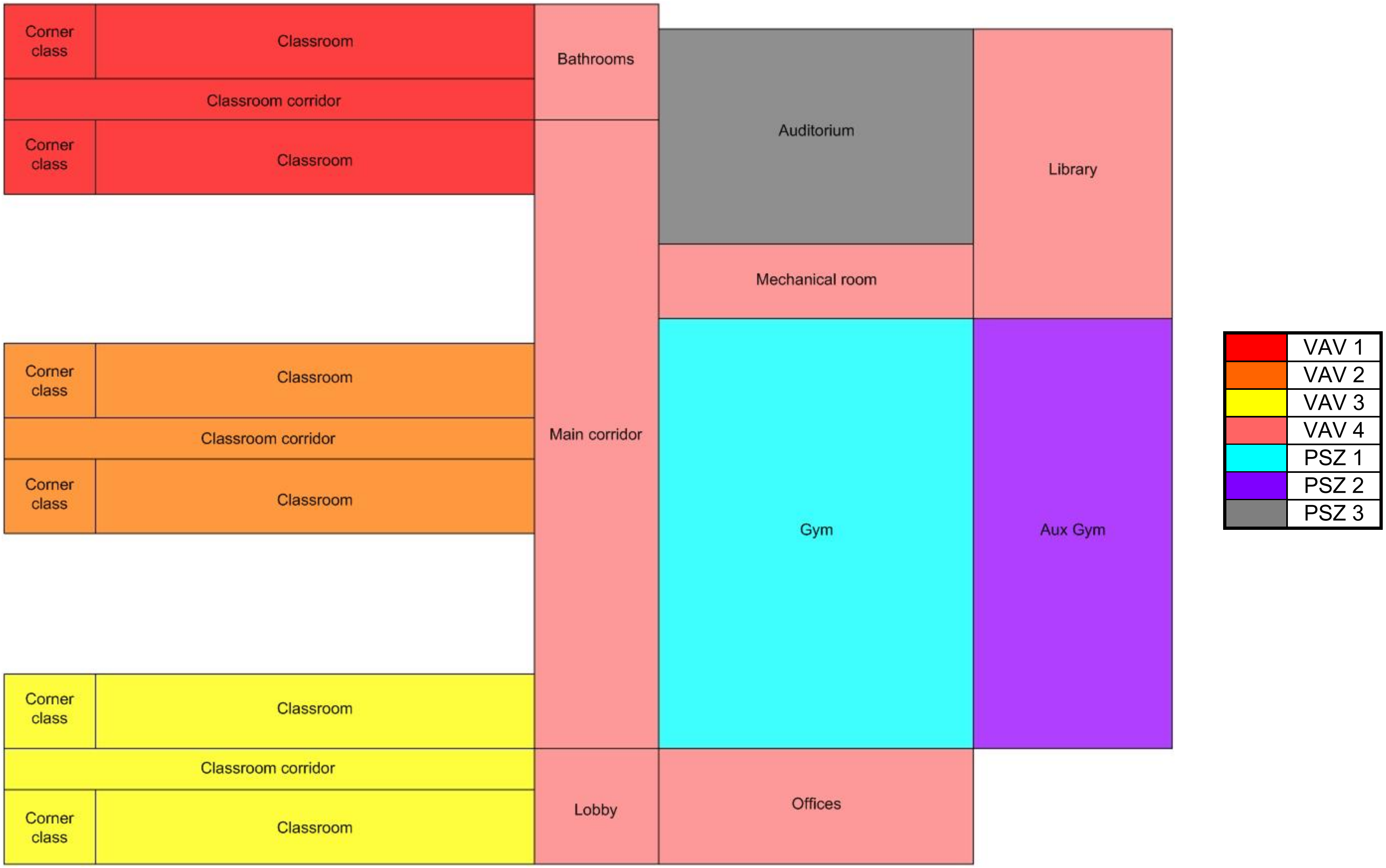


Figure 3–32 Secondary school HVAC layout – first floor

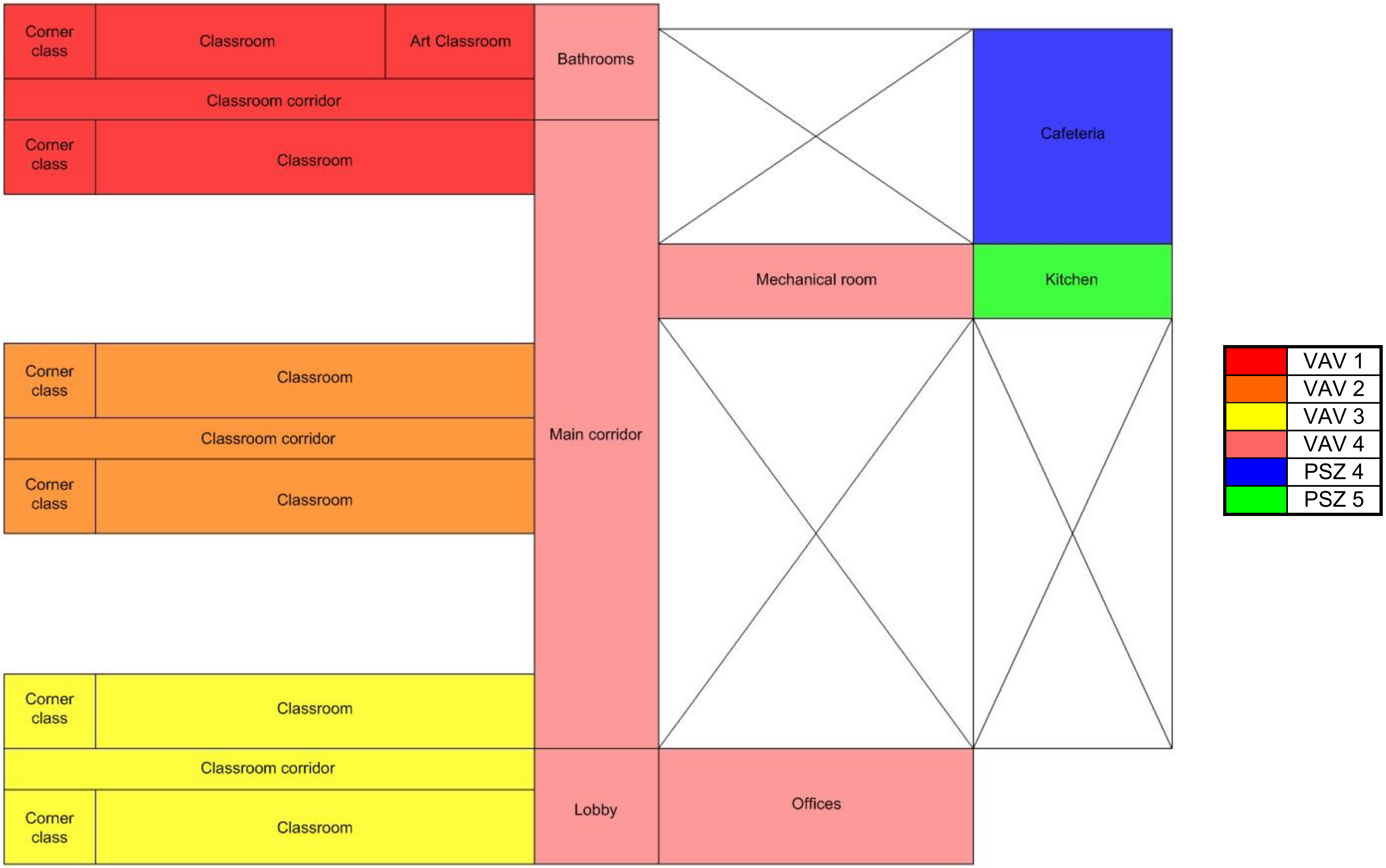


Figure 3–33 Secondary school HVAC layout – second floor

3.3.5 Service Water Heating

None of the SWH values were modified from those in the two DOE Commercial Reference school buildings (Deru et al. 2010). Both the primary school and secondary school baseline models had an 80% efficient natural gas-fired storage tank water heater, and the secondary school had an 80% efficient variable-speed circulation pump with 39,228 Pa of head. The primary school had no circulation pump. The primary school model had water use in the restroom and kitchen; the restroom had a peak flow rate of 0.942 gal/min and the kitchen had a peak flow rate of 1.667 gal/min. The secondary school had water use in the restroom, kitchen, and gym (showers); the restroom had a peak flow rate of 0.870 gal/min, the kitchen had a peak flow rate of 2.217 gal/min, and the gym (showers) had a peak flow rate of 3.158 gal/min. (See Deru et al. (2010) for more information on how these values were determined.) The peak flow rates for the restroom and kitchen zones in both models are modified by the schedule in Figure 3–34. The peak flow rates for the showers in the secondary school gym are modified by Figure 3–35.

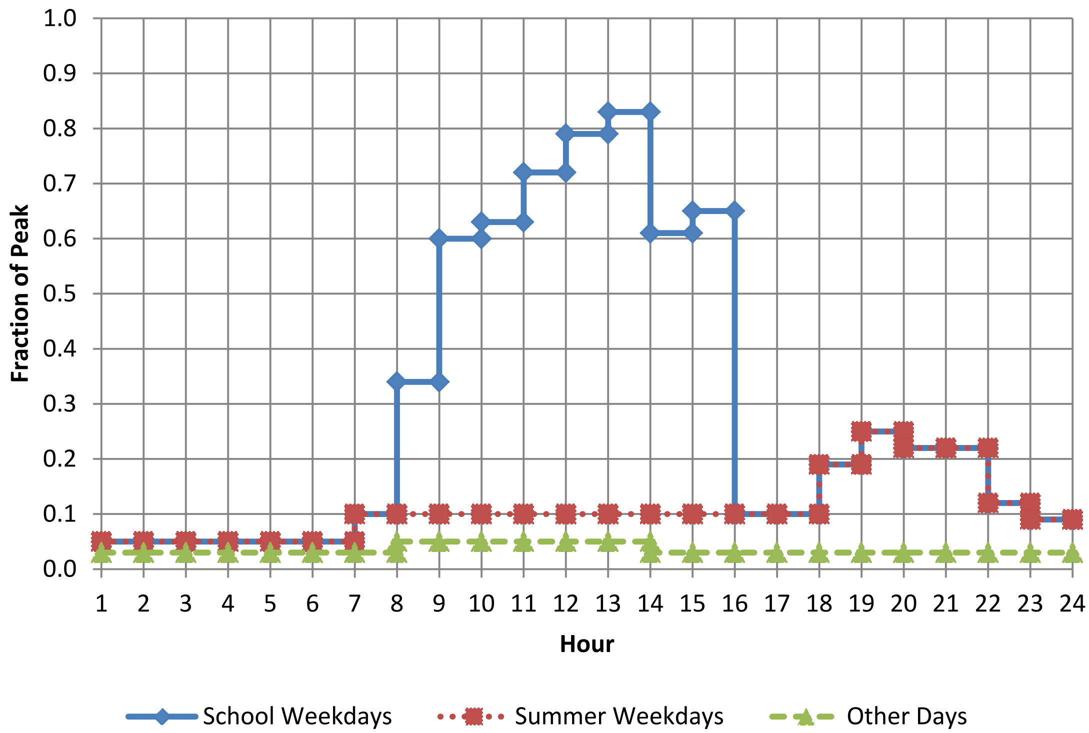


Figure 3–34 General SWH schedule

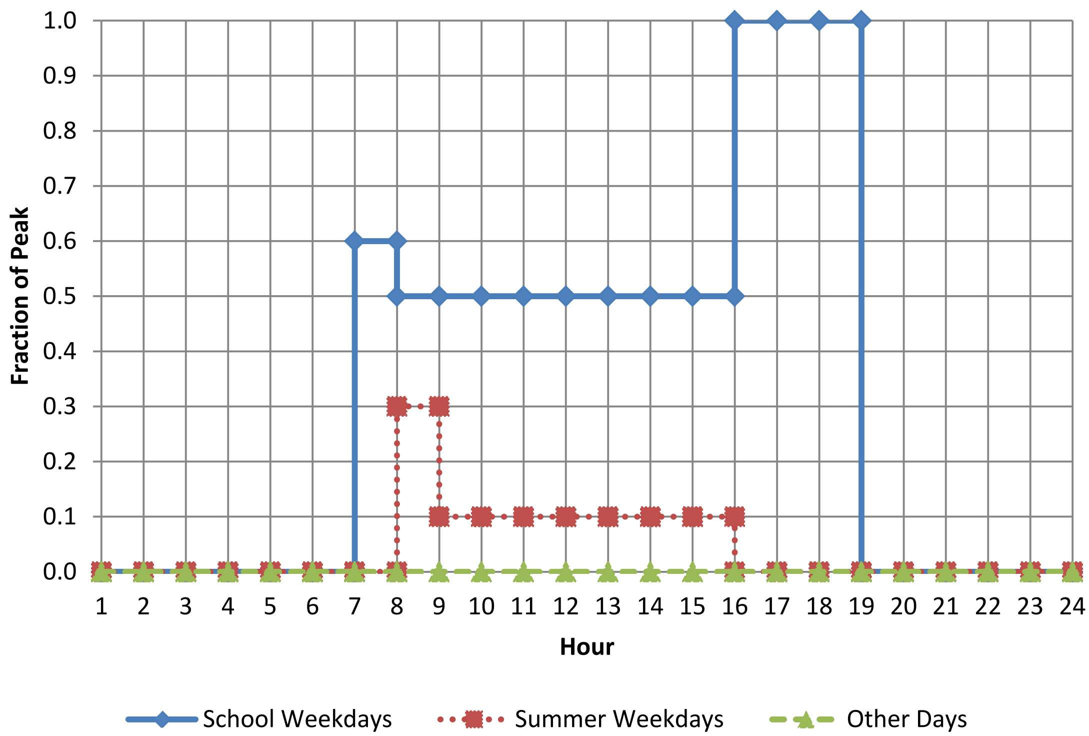


Figure 3–35 Secondary school shower SWH schedule

3.3.6 Refrigeration

The kitchen refrigeration inputs were not modified from those in the primary and secondary school DOE Commercial Reference Buildings (Deru et al. 2010). Each school has a walk-in cooler and freezer; the equipment in the secondary school is twice as large as that in the primary school. Table 3–23 shows an overview of the refrigeration equipment in the models.

Table 3–23 Refrigeration Models

Model	Case Type	Walk-in Area (ft^2)	Operating Temperature (°F)
Primary school	Walk-in freezer	120	–9.4
	Walk-in cooler	120	35.6
Secondary school	Walk-in freezer	240	–9.4
	Walk-in cooler	240	35.6

The full EnergyPlus input data file refrigeration objects can be found in Appendix F.

3.3.7 Baseline Simulation Results

Table 3–24 and Table 3–25 present the simulation results for the baseline primary school. These results are presented graphically in Figure 3–36. Table 3–26 and Table 3–27 present the simulation results for the baseline secondary school. These results are presented graphically in Figure 3–37.

Table 3–24 Primary School Baseline Simulation Results, Climate Zones 1A–4A

End Use (kBtu/ft²yr)	1A	2A	2B	3A	3B:CA	3B	3C	4A
Interior equipment (electric)	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
Interior equipment (gas)	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Interior lighting (electric)	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
Exterior lighting (electric)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heating (gas)	0.5	8.4	6.1	12.4	3	7.4	9.3	21.9
Cooling (electric)	22.6	16.6	16.2	7.5	4.4	9	2.1	5.9
Fans (electric)	11.6	11.1	13.8	8.3	6.8	9.6	8.6	8.2
Pumps (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SWH (gas)	0.9	1.2	1.1	1.5	1.4	1.3	1.7	1.7
Refrigeration (electric)	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1
Total	68.7	70.4	70.3	62.8	48.7	60.4	54.7	70.7

Table 3–25 Primary School Baseline Simulation Results, Climate Zones 4B–8

End Use (kBtu/ft²yr)	4B	4C	5A	5B	6A	6B	7	8
Interior equipment (electric)	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
Interior equipment (gas)	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
Interior lighting (electric)	14.6	14.6	14.6	14.6	14.6	14.6	14.6	14.6
Exterior lighting (electric)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heating (gas)	14.6	20.9	30.1	22.0	41.6	34.4	49.8	80.5
Cooling (electric)	4.7	1.2	4.3	2.9	3.4	1.8	1.5	0.8
Fans (electric)	8.7	6.7	8.1	8.2	8.6	8.3	8.6	9.4
Pumps (electric)	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.1
SWH (gas)	1.7	1.8	1.9	1.9	2.1	2.1	2.3	2.6
Refrigeration (electric)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Total	62.7	63.6	77.4	68.0	88.8	79.6	95.3	126.4

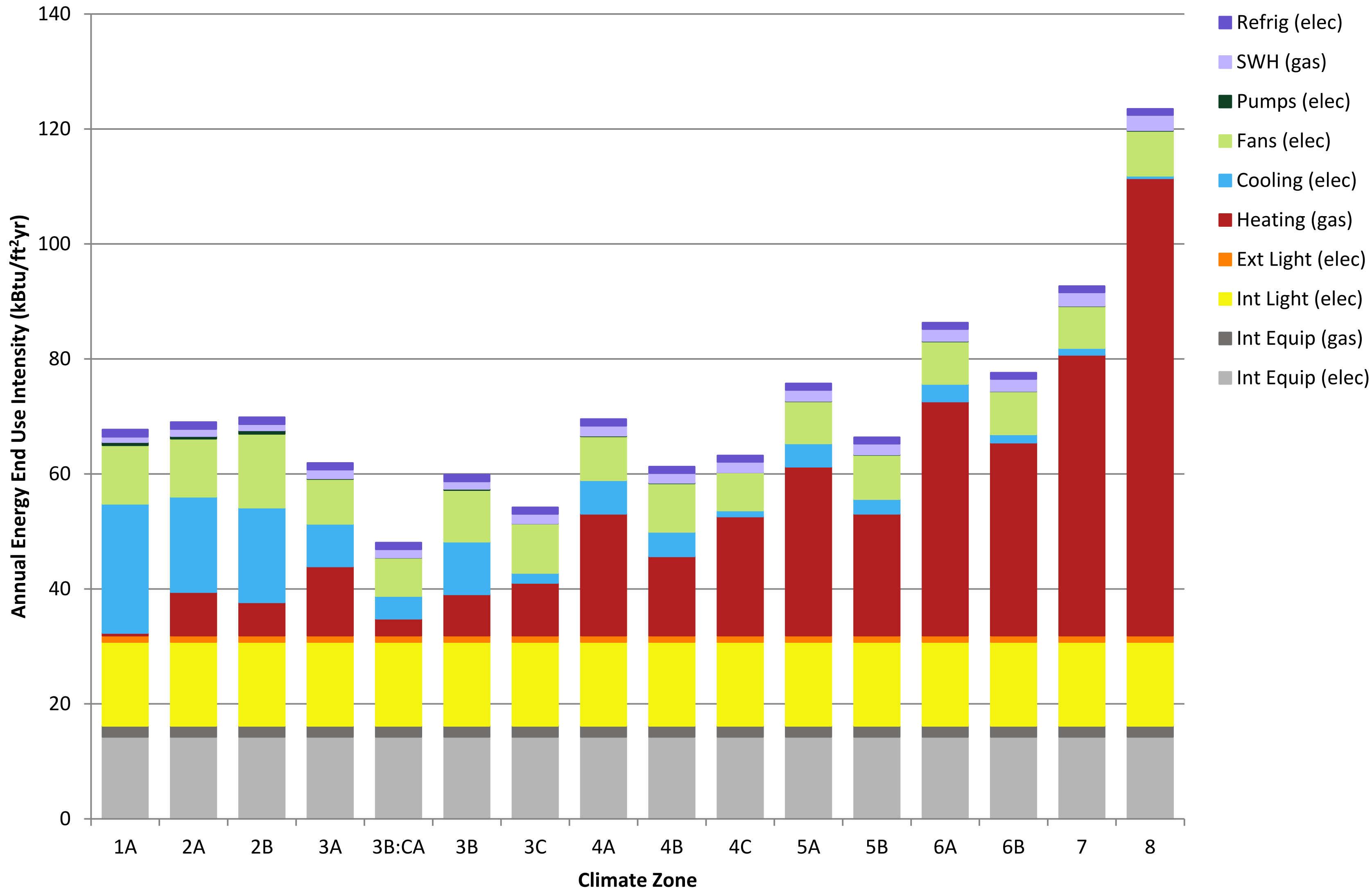


Figure 3–36 Primary school baseline simulation results

Table 3–26 Secondary School Baseline Simulation Results, Climate Zones 1A–4A

End Use (kBtu/ft²yr)	1A	2A	2B	3A	3B:CA	3B	3C	4A
Interior equipment (electric)	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Interior equipment (gas)	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Interior lighting (electric)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Exterior lighting (electric)	3.4	3.4	3.4	3.4	3.4	3.4	3.4	3.3
Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heating (gas)	0.5	7.9	5.2	12.8	2.7	7.0	10.3	23.1
Cooling (electric)	23.6	17.0	17.4	8.1	3.5	10.7	1.4	6.5
Fans (electric)	13.5	13.3	15.2	11.6	10.3	12.7	10.6	11.2
Pumps (electric)	2.4	1.9	1.8	1.3	0.7	1.1	0.5	1.1
SWH (gas)	0.8	1.1	1.0	1.4	1.3	1.2	1.5	1.6
Refrigeration (electric)	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
Total	72.3	72.7	72.0	66.6	49.9	64.1	55.7	74.8

Table 3–27 Secondary School Baseline Simulation Results, Climate Zones 4B–8

End Use (kBtu/ft²yr)	4B	4C	5A	5B	6A	6B	7	8
Interior equipment (electric)	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Interior equipment (gas)	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Interior lighting (electric)	14.0	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Exterior lighting (electric)	3.4	3.3	3.4	3.3	3.3	3.3	3.3	3.3
Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Heating (gas)	14.8	22.8	31.5	22.4	42.9	34.6	51.4	81.4
Cooling (electric)	4.8	1.1	4.3	3.0	3.4	1.7	1.3	0.6
Fans (electric)	12.9	10.0	11.1	12.2	11.2	11.7	11.0	10.8
Pumps (electric)	0.6	0.4	0.8	0.4	0.7	0.4	0.4	0.3
SWH (gas)	1.5	1.7	1.8	1.7	1.9	1.9	2.2	2.4
Refrigeration (electric)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Total	66.0	67.3	80.9	71.0	91.4	81.6	97.6	126.8

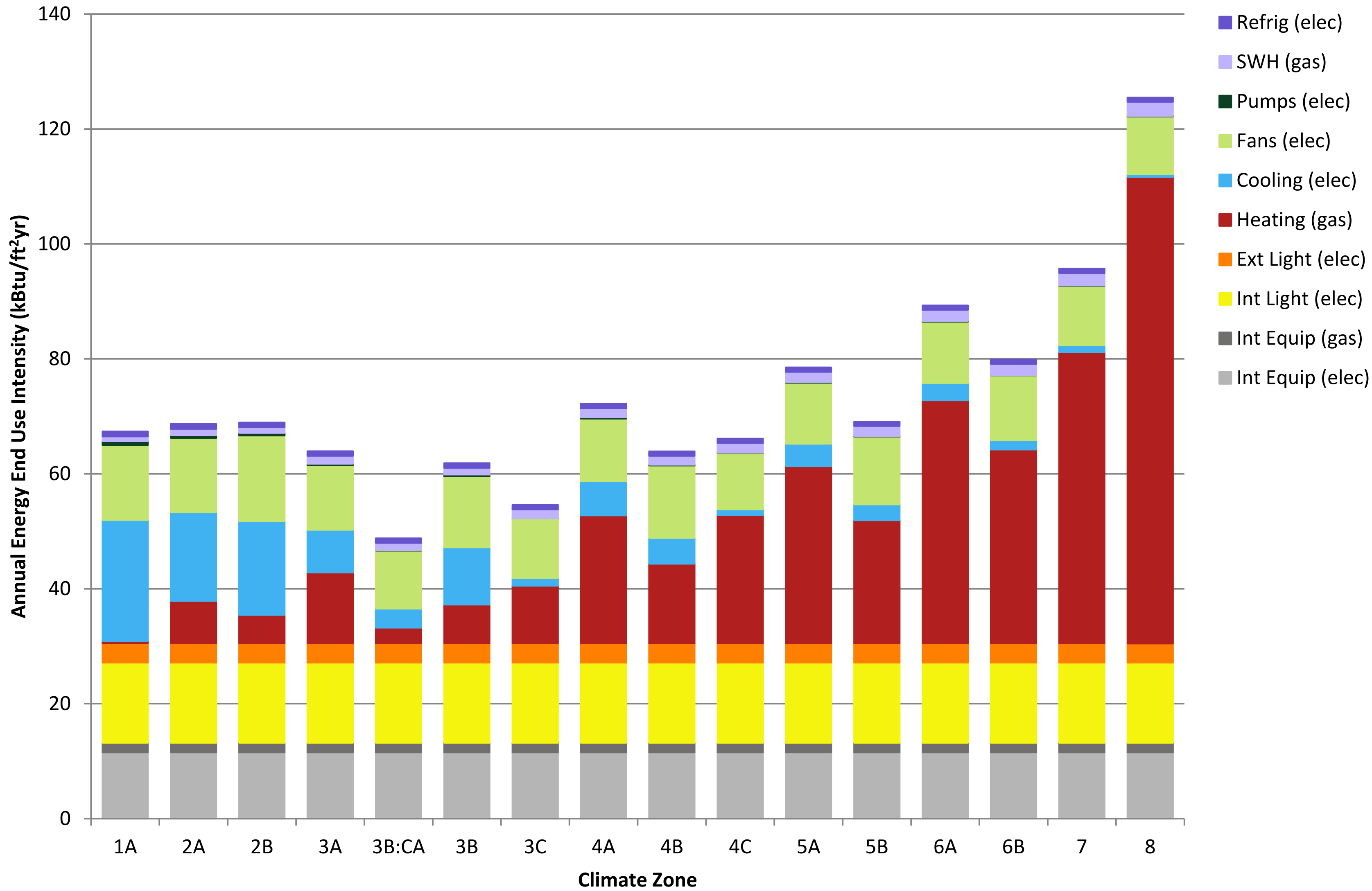


Figure 3–37 Secondary school baseline simulation results

3.4 Low-Energy Model Development and Assumptions

Extensive modeling was used to determine the effectiveness of all considered AEDG-K12 recommendations. This process was iterated until the final set of recommendations was developed. This section documents energy models with the final set of AEDG-K12 recommendations.

Figure 3–38 shows a rendering of the primary school baseline model, and Figure 3–39 shows a rendering of the secondary school baseline model.

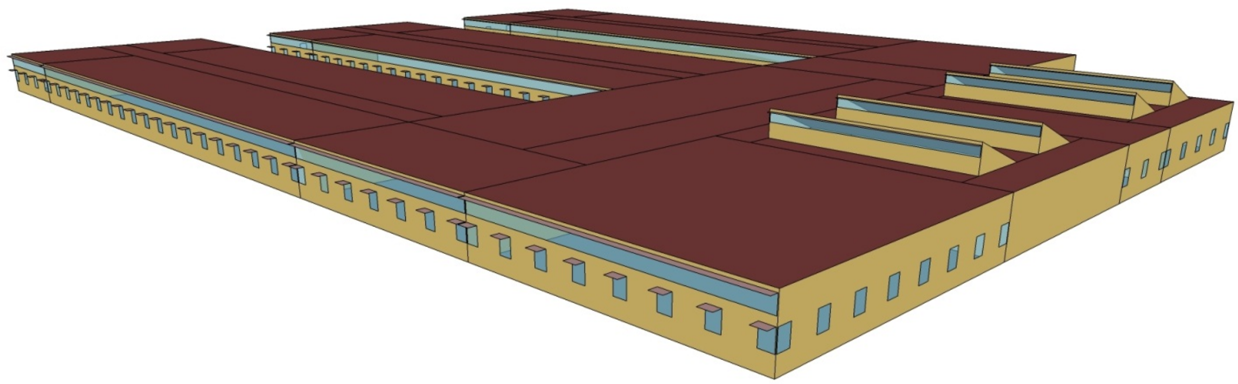


Figure 3–38 Primary school low-energy model rendering

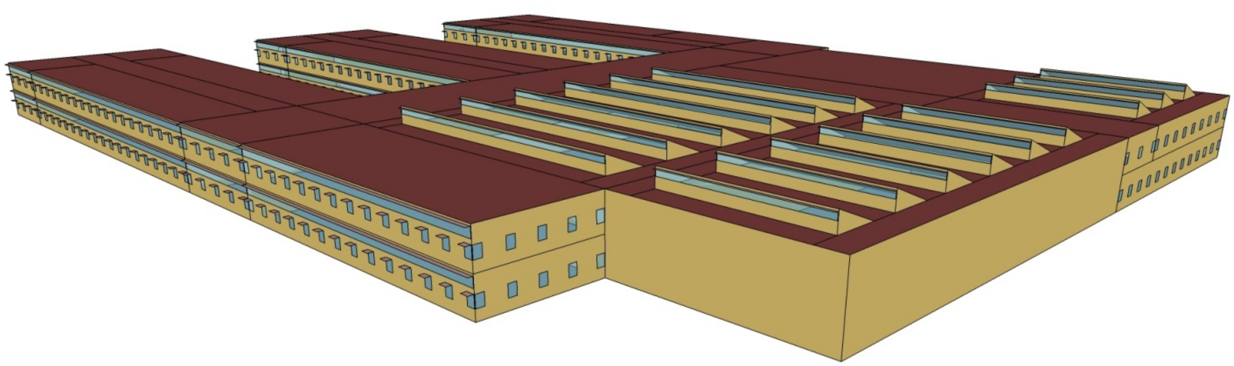


Figure 3–39 Secondary school low-energy model rendering

3.4.1 Envelope

To determine the envelope criteria, the PC used a public review draft of Standard 90.1-2013 (Addendum BB) and wanted to make sure that the envelope criteria for the AEDG-K12 were at least as stringent. The thought process was that both documents would be published in similar time frames and that the criteria should be relatively equivalent. It is important to note that 90.1-2013 was still going through the public review process at that time, so the most recent version available was used.

3.4.1.1 Exterior Walls

The exterior walls in both the primary and secondary school low-energy models were modeled exactly the same as in the baseline models, except for the insulation layer. The low-energy exterior wall R- and U-values are shown in Table 3–28; the baseline values are included for easy comparison.

Table 3–28 Low-Energy Exterior Wall Constructions

Climate Zone	Assembly U-Factor (Btu/h·ft²·°F)		Insulation R-Value, Nominal (h·ft²·°F/Btu)	
	Baseline Models	Low-Energy Models	Baseline Models	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 both the primary and secondary school low-energy models were modeled exactly as in the baseline models, except for the insulation layer. The low-energy roof R- and U-values used are provided in Table 3–29; the baseline values are included for easy comparison.

Table 3–29 Low-Energy Roof Constructions

Climate Zone	Assembly U-Factor (Btu/h·ft²·°F)		Insulation R-Value, Nominal (h·ft²·°F/Btu)	
	Baseline Models	Low-Energy Models	Baseline Models	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.

3.4.1.3 Slab-on-Grade Floors

Both the primary and secondary school low-energy model floors were modeled exactly as those in the baseline models.

3.4.1.4 View Fenestration

The U-factors, SHGCs, and VLTs of the view windows that were used in both the primary and secondary school low-energy models are shown in Table 3–30; the baseline values are included for easy comparison.

Table 3–30 Low-Energy View Window Constructions

Climate Zone	U-Factor (Btu/h·ft²·°F)		SHGC		VLT	
	Baseline Models	Low-Energy Models	Baseline Models	Low-Energy Models	Baseline Models	Low-Energy Models
1 (A,B)	1.22	0.56	0.25	0.25	0.250	0.280
2 (A,B)	1.22	0.45	0.25	0.25	0.250	0.280
3 (A,B)	0.57	0.41	0.25	0.25	0.318	0.280
3 (C)	1.22	0.41	0.34	0.25	0.340	0.280
4 (A,B,C)	0.57	0.38	0.39	0.26	0.495	0.290
5 (A,B)	0.57	0.35	0.39	0.26	0.495	0.290
6 (A,B)	0.57	0.35	0.39	0.35	0.495	0.390
7	0.57	0.33	0.49	0.40	0.490	0.440
8	0.46	0.25	0.49	0.40	0.490	0.440

3.4.1.5 Daylight Fenestration

Both the primary and secondary school low-energy models had the same overall fraction of fenestration to gross wall area as the baseline models (35%); however, instead of individual fenestration objects distributed evenly on applicable exterior surfaces as in the baseline models, the low-energy models used punch windows for the view fenestration and a separate clerestory ribbon window to provide daylight. These daylight fenestration objects had different properties than the view glass (see Table 3–31).

Table 3–31 Low-Energy Daylight Window Constructions

Climate Zone	U-Factor (Btu/h·ft²·°F)	SHGC	VLT
All	0.97	0.58	0.81

3.4.2 Electric Lighting

3.4.2.1 Interior Lighting

The LPDs used in the low-energy models are listed in Table 3–32, with the baseline values included for easy comparison. Most of the space types used the same lighting schedule as the baseline model; however, the low-energy models included additional daylighting analysis that used hour-by-hour lighting dimming schedules for certain spaces types. Table 3–32 also shows which space types used the baseline lighting schedule and which included daylighting. (See Section 3.4.7 for more information on the daylighting analysis.)

Table 3–32 Low-Energy LPD by Space Type

Space Type	Baseline LPD (W/ft²)	Low-Energy LPD (W/ft²)	Schedule
Auditorium	0.9	0.5	See Figure 3–24
Art room	1.4	0.8	See Section 3.4.7
Cafeteria	0.9	0.7	See Section 3.4.7
Classroom	1.4	0.8	See Section 3.4.7
Corridor	0.5	0.4	See Figure 3–24
Gym/multipurpose room	1.4	1.0	See Section 3.4.7
Kitchen	1.2	0.8	See Figure 3–24
Library/media center	1.2	0.8	See Figure 3–24
Lobby	1.3	0.7	See Figure 3–24
Mechanical	1.5	0.4	See Figure 3–24
Office	1.1	0.6	See Section 3.4.7
Restroom	0.9	0.5	See Figure 3–24
Calculated whole building Primary school	1.2	0.7	n/a
Calculated whole building Secondary school	1.1	0.7	n/a

3.4.2.2 Exterior Lighting

The primary school had 2,219 W of exterior lighting; the secondary school had 18,980 W of exterior lighting. In both models, the lights were controlled by an astronomical clock that turned the lights on when the sun set and off when the sun rose. The low-energy models also employed an energy-saving feature that turned the lights to quarter power from midnight to 6:00 a.m.

3.4.3 Plug and Process Loads

The plug and process loads for the low-energy models are shown in Table 3–33 (electric) and Table 3–34 (gas) next to the baseline model values for easy comparison. (See Section 3.4.3.1 for details about the gas process loads.)

Table 3–33 Low-Energy Model Electric Plug and Process Loads

Space Type	Primary School		Secondary School	
	Baseline (W/ft²)	Low-Energy (W/ft²)	Baseline (W/ft²)	Low-Energy (W/ft²)
Auditorium	n/a	n/a	0.20	0.12
Art classroom	6.30	3.78	6.30	3.78
Cafeteria	0.50	0.30	1.80	1.08
Classroom	1.40	0.84	0.90	0.54
Corridor	0.00	0.00	0.20	0.12
Gym/multipurpose room	0.00	0.00	0.20	0.12
Kitchen	16.70	14.20	12.90	12.00
Library/media center	0.50	0.30	0.90	0.54
Lobby	0.00	0.00	0.40	0.24
Mechanical room	0.00	0.00	0.40	0.24
Office	0.50	0.30	1.00	0.60
Restroom	0.00	0.00	0.40	0.24
Calculated whole building	1.3	0.9	0.8	0.5

Table 3–34 Low-Energy Model Gas Process Loads

Space Type	Primary School		Secondary School	
	Baseline (Btuh/ft²)	Low-Energy (Btuh/ft²)	Baseline (Btuh/ft²)	Low-Energy (Btuh/ft²)
Kitchen	57.8	53.0	115.0	94.5

The electric plug and process loads in the low-energy models represent a space-by-space 40% reduction over baseline models (except the kitchen, see Section 3.4.3.1). This 40% reduction was determined by calculating the plug load that a typical energy-efficient school would have and comparing it to a typical school. None of the calculated values were used in the models; instead, the calculation was performed only to determine the percent reduction to apply to the baseline. The calculation for the percent plug load reduction follows:

- Low-energy instructional computer loads: Assuming 3.8 students per computer (Education Week 2005), the primary school with 650 students has about 171 student computers and the secondary school with 1,200 students has approximately 316 computers. Assuming 30-W laptops or mini-desktops and 18-W light-emitting diode (LED) backlit flat panel monitors, the total instructional computer load for the primary school is 8,208 W; for the secondary school it is 15,168 W.
- Low-energy staff computer loads: The PC assumed 20 students per staff member, resulting in 32 (rounded down from 32.5) staff for the primary school and 60 staff for the secondary school. For the same 30-W computer and 18-W monitor as the instruction computers, this results in a staff computer load of 1,536 W for the primary school and 2,880 W for the secondary school.
- Low-energy server loads: An energy-efficient server uses about 48 W per connected computer with a power usage effectiveness of 1.2, resulting in 58 W per computer. For the 171 instructional computers and 32 staff computers in the primary school, this

resulted in a server load of 11,774 W. For the 316 student computers and 60 staff computers in the secondary school, this resulted in a server load of 21,808 W.

- Low-energy staff miscellaneous loads: The PC recognized that the staff would have additional plug-in equipment in the school and made the following assumptions, which resulted in a staff miscellaneous load of 34,019 W for the primary school and 63,786 W for the secondary school:
    - Each staff member has an energy-efficient 80-W television and a 40-W VCR/DVD player.
    - Two staff members share a 125-W refrigerator and a 1,000-W microwave.
    - Four staff members share a 1500-W space heater.
    - Ten staff members share a 5.6-W/gal 10 gal fish tank.
- Low-energy office loads: An additional 85 W per staff member was included for items such as task lights, phones, printers, and other office equipment. This resulted in an office load for the primary school of 2,720 W and 5,100 W for the secondary school.
- Low-energy total: The total plug load for the 73,962 ft^2 primary school is 58,257 W, or 0.8 W/ft^2. The total plug load for the 210,892 ft^2 secondary school is 108,742 W, or 0.5 W/ft^2.

Repeating the same calculation for a typical school with a 150-W computer, a 70-W monitor, a 65 W server with a 1.9 power usage effectiveness (123 W per computer), and 107 W per staff member for office loads results in 107,072 W (1.4 W/ft^2) for the primary school and 199,174 W (0.9 W/ft^2) for the secondary school. Comparing the low-energy plug loads to the typical plug loads shows about a 40% reduction, a value the PC felt was appropriate. The AEDG-K12 provides means to achieve this reduction.

The values in Table 3–33 were modified with hour-by-hour multiplier schedules in EnergyPlus. All the low-energy primary school electric loads (except those for the kitchen) were modified by the schedule shown in Figure 3–40. The primary school kitchen loads were modified by the schedule depicted in Figure 3–41 (electric equipment) and Figure 3–42 (gas equipment). Likewise for the low-energy secondary school, all the electric loads except for the kitchen loads were modified by the schedule illustrated in Figure 3–43; the kitchen loads were modified by the schedule detailed in Figure 3–44 (electric equipment) and Figure 3–45 (gas equipment). The electric equipment (not including the kitchen loads) schedules in the low-energy models have the same values during operating hours as the baseline models; however, for the low-energy models, the schedule values during nonoperating hours were lowered to simulate the improved plug load control recommendations in the AEDG-K12. For the primary school, this schedule value decreased from 0.4 to 0.15 and for the secondary school from 0.5 to 0.25. These schedule modifications were meant to represent items such as computer power management, plug strip controls, and improved central server controls, and are in addition to the plug load reduction in Table 3–33. (See the AEDG-K12 for more details on the plug load reduction strategies. See Section 3.4.3.1 for discussion about the development of the kitchen electric and gas equipment schedules.)

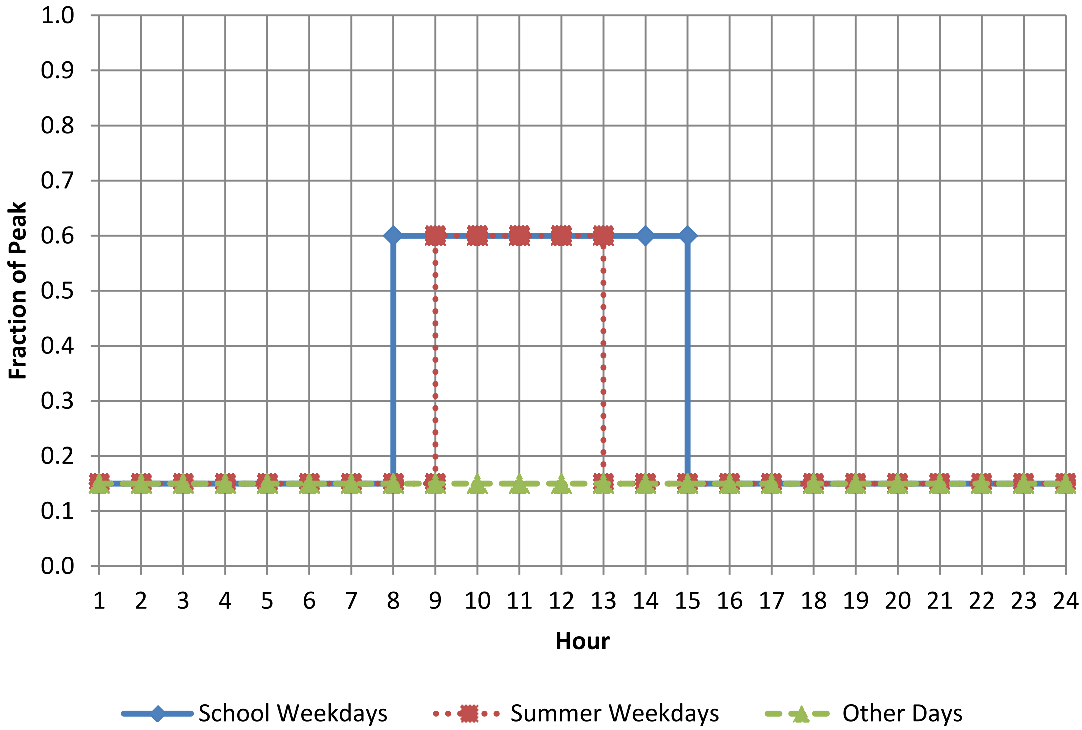


Figure 3–40 Primary school low-energy electric equipment schedule

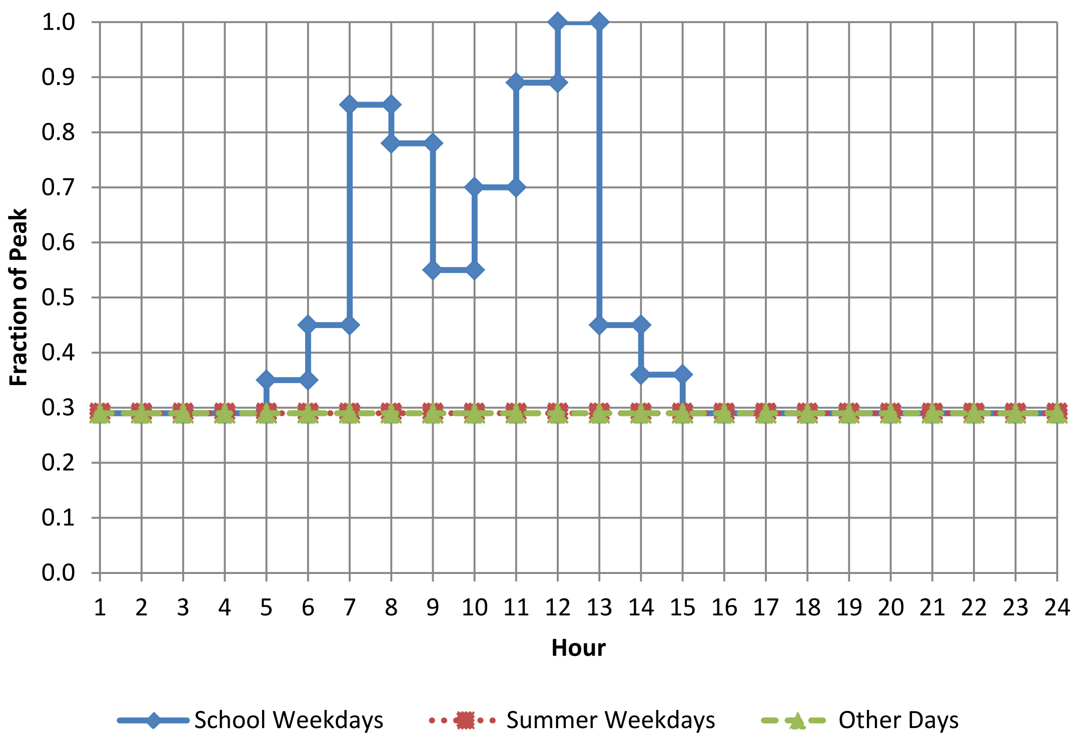


Figure 3–41 Primary school low-energy kitchen electric equipment schedule

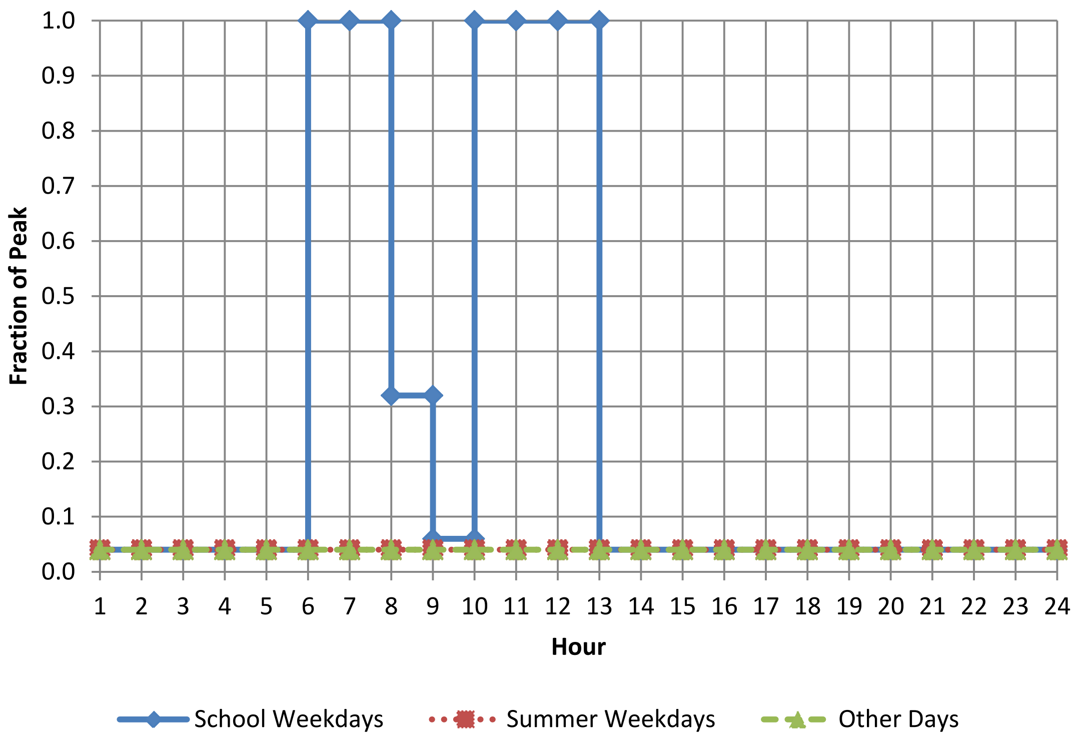


Figure 3–42 Primary school low-energy kitchen gas equipment schedule

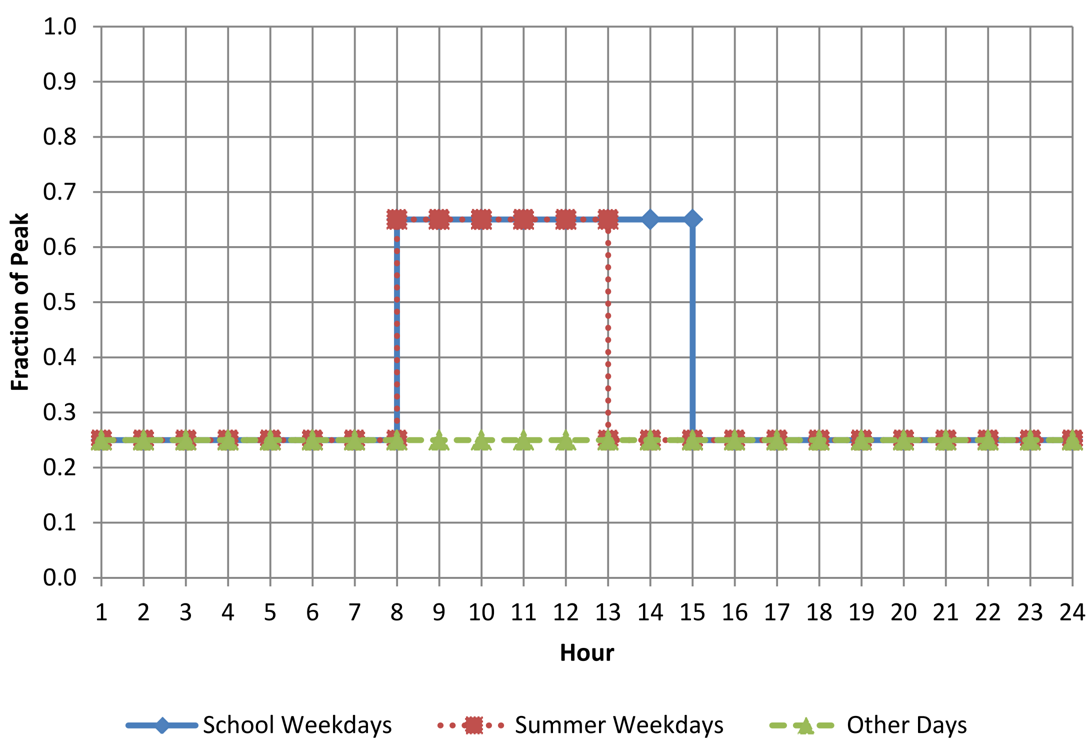


Figure 3–43 Secondary school low-energy electric equipment schedule

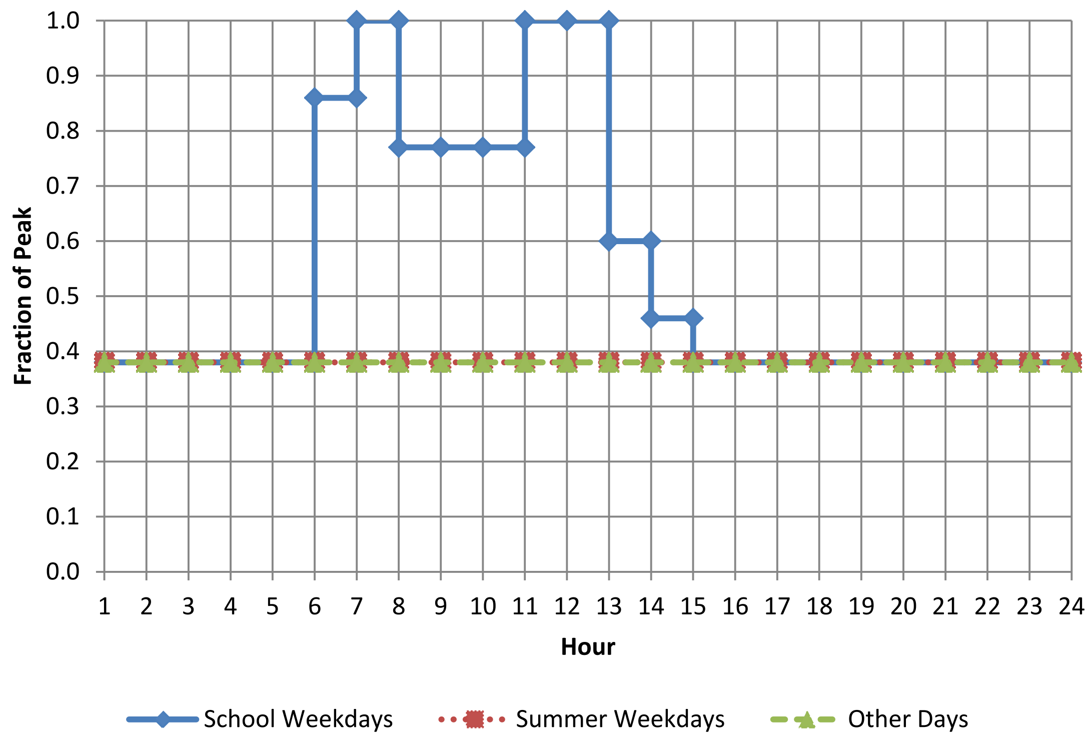


Figure 3–44 Secondary school low-energy kitchen electric equipment schedule

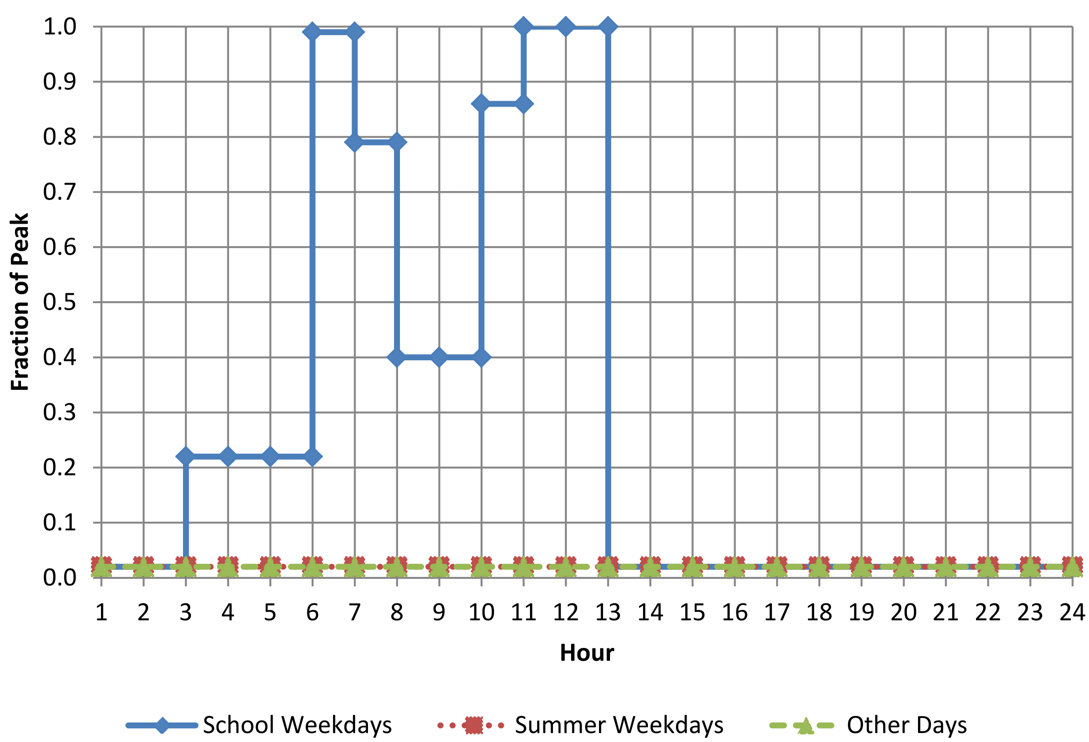


Figure 3–45 Secondary school low-energy kitchen gas equipment schedule

3.4.3.1 Low-Energy Kitchen

For the primary school, Table 3–35 and Table 3–37 show the energy load profile data used in development of the kitchen loads. These data were transformed into an input for electric equipment in EnergyPlus by determining the maximum value of the day and using the rest of the data to determine the multiplier schedule shown in Figure 3–40 for electric equipment and Figure 3–42 for gas equipment.

For the secondary school, Table 3–36 and Table 3–38 show the energy load profile data used in development of the kitchen loads. The data in the tables are to represent "typical" K-12 kitchens, and fractional quantities are used in some instances (e.g., 1 in 2 kitchens has a toaster, so the quantity is 0.5). The PC consulted with a commercial kitchen expert to help develop these data, which represent a best-in-class K-12 school kitchen. The use factor column represents the fraction of rated power the equipment will draw during service. These data were transformed into an input for electric equipment in EnergyPlus by determining the maximum value of the day and using the rest of the data to determine the multiplier schedule in Figure 3–44 for electric equipment and Figure 3–45 for gas equipment.

Table 3–35 Primary School Low-Energy Kitchen Load Profile – Electric Equipment

Qty.	Appliance	Avg. Input Rate (kW)	Use Factor	Hour (kW)											Total per day (kW)
				1–6	7	8	9	10	11	12	13	14	15	16–24	
1.0	Steamer	4.13	0.5	0.00	0.00	0.00	0.00	0.00	2.06	2.06	2.06	0.00	0.00	0.00	6.2
1.0	Hot holding cabinet	0.40	1.0	0.00	0.40	0.40	0.40	0.00	0.40	0.40	0.40	0.00	0.00	0.00	2.4
8.0	Steam table	0.80	0.5	0.00	0.00	3.20	0.00	0.00	0.00	3.20	3.20	0.00	0.00	0.00	9.6
0.5	Toaster	1.50	0.5	0.00	0.00	0.38	0.00	0.00	0.00	0.38	0.38	0.00	0.00	0.00	1.1
4.0	Warming drawer	0.10	0.5	0.00	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.00	0.00	0.00	1.4
4.0	Heat lamp	1.00	0.5	0.00	0.00	2.00	2.00	2.00	2.00	2.00	2.00	0.00	0.00	0.00	12.0
2.5	Microwave	0.40	0.5	0.00	0.00	0.50	0.00	0.00	0.50	0.50	0.00	0.00	0.00	0.00	1.5
4.0	Soup warmer	0.50	1.0	0.00	2.00	2.00	0.00	0.00	2.00	2.00	0.00	0.00	0.00	0.00	8.0
2.0	Coffee brewer	1.00	0.8	0.00*	1.60	1.60	1.60	1.60	1.60	1.60	1.60	0.00	0.00	0.00	12.8
5.0	Cold table	0.20	1.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	24.0
1.0	Ice machine	0.77	1.0	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	0.77	18.5
1.0	Ice machine	1.70	1.0	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	40.8
6.0	Prep table	0.20	1.0	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	28.8
2.5	Undercounter refrigerator	0.10	1.0	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	6.0
2.0	Undercounter freezer	0.20	1.0	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	9.6
5.0	Refrigerator/solid	0.13	1.0	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	15.6
2.0	Freezer/solid	0.36	1.0	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	17.3
1.3	Freezer/glass	0.50	1.0	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65	15.6
1.0	Dish machine, conveyor	4.50	1.0	0.00	0.00	2.25	4.50	1.00	1.00	2.25	4.50	2.25	1.00	0.00	18.8
1.0	Dish machine, booster heater	4.00	1.0	0.00	0.00	2.00	4.00	2.00	1.00	1.00	4.00	2.00	1.00	0.00	17.0
Total (kW)				7.3**	11.5	21.9	20.0	14.1	18.1	22.9	25.7	11.6	9.3	7.3	267

* 0.00 for hours 1-5, 1.60 in hour 6 only
** 7.3 for hours 1-5, 8.9 in hour 6 only

Table 3–36 Secondary School Low-Energy Kitchen Load Profile – Electric Equipment

Qty.	Appliance	Avg. Input Rate (kW)	Use Factor	Hour (kW)											Total per day (kW)
				1–6	7	8	9	10	11	12	13	14	15	16–24	
1.0	Steamer	4.13	1.0	0.00	2.06	2.06	0.00	0.00	4.13	4.13	0.00	0.00	0.00	0.00	12.4
3.0	Hot holding cabinet	0.40	0.5	0.00	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.00	0.00	0.00	4.2
10.0	Steam table	0.80	0.5	0.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	0.00	0.00	0.00	28.0
2.0	Contact toaster	1.50	0.5	0.00	3.00	3.00	0.00	0.00	0.00	3.00	3.00	0.00	0.00	0.00	12.0
1.5	Conveyor toaster	1.80	0.5	0.00	2.70	2.70	0.00	0.00	0.00	2.70	2.70	0.00	0.00	0.00	10.8
8.0	Warming drawer	0.10	0.5	0.00	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.00	0.00	0.00	5.6
5.0	Heat lamp	0.25	1.0	0.00	1.25	1.25	1.25	1.25	1.25	1.25	1.25	0.00	0.00	0.00	8.8
3.0	Microwave	0.40	0.5	0.00	1.20	1.20	1.20	1.20	1.20	1.20	1.20	0.00	0.00	0.00	8.4
5.0	Soup warmer	0.50	0.5	0.00	2.50	2.50	2.50	2.50	2.50	2.50	2.50	0.00	0.00	0.00	17.5
3.0	Coffee brewer	1.00	0.5	0.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00	0.00	0.00	0.00	21.0
2.5	Soft serve	0.20	0.5	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	12.0
2.0	Drink machine	0.20	0.5	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	9.6
6.0	Cold table	0.10	0.5	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60	14.4
1.0	Ice machine	1.70	1.0	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	1.70	40.8
1.0	Ice machine	2.37	1.0	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	56.9
8.0	Prep table	0.20	0.5	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	1.60	38.4
4.0	Undercounter refrigerator	0.09	1.0	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	0.37	8.9
2.0	Undercounter freezer	0.23	1.0	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46	11.0
6.0	Refrigerator/solid	0.13	1.0	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	18.7
2.5	Freezer/solid	0.36	1.0	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	21.6
2.0	Freezer/glass	0.46	1.0	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	22.1
1.0	Dish machine, conveyor	4.50	1.0	0.00	4.50	4.50	1.00	1.00	1.00	4.50	4.50	2.25	2.25	0.00	25.5
1.0	Dish machine, booster heater	4.00	1.0	0.00	4.00	4.00	1.00	1.00	1.00	4.00	4.00	4.00	0.00	0.00	23.0
Total (kW)				10.6	40.2	40.2	26.0	26.0	30.1	42.3	38.2	16.9	12.9	10.6	432

Table 3–37 Primary School Low-Energy Kitchen Load Profile – Gas Equipment

Qty.	Appliance	Avg. Input Rate (kBtu/h)	Use Factor	Hour (kBtu/h)						Total per day (kBtu/h)
				1–6	7–8	9	10	11–13	14–24	
0.1	Braising pan	15.1	1.0	0.00	1.51	1.51	0.00	1.51	0.00	9.1
1.0	Griddle	24.4	1.0	1.00	24.40	24.40	1.00	24.40	1.00	164.4
0.1	Combi oven	25.8	1.0	0.00	2.58	2.58	2.58	2.58	0.00	18.1
1	Convection oven	16.6	1.0	1.00	16.60	1.00	1.00	16.60	1.00	102.0
1	Range oven	18.3	1.0	0.50	18.30	0.50	0.50	18.30	0.50	101.0
1	Open top range	32.0	1.0	1.00	32.00	1.00	1.00	32.00	1.00	179.0
Total (kBtu/h)				3.5	95.4	31.0	6.1	95.4	3.5	574

Table 3–38 Secondary School Low-Energy Kitchen Load Profile – Gas Equipment

Qty.	Appliance	Avg. Input Rate (kBtu/h)	Use Factor	Hour (kBtu/h)								Total per day (kBtu/h)
				1–3	4–6	7	8	9-10	11	12–13	14–24	
1.00	Braising pan	15.1	0.5	0.0	0.0	7.55	7.55	3.78	7.55	7.55	0.00	45.3
0.50	Underfired broiler	68.5	0.5	1.00	1.00	1.00	1.00	1.00	17.13	17.13	1.00	72.4
2.00	French fryer	25.6	0.5	1.00	1.00	25.60	25.60	12.80	25.60	25.60	1.00	170.6
2.00	Standard griddle	24.4	0.5	0.50	0.50	24.40	24.40	12.20	24.40	24.40	0.50	154.9
4.00	Convection oven	16.6	0.5	1.00	1.00	33.20	33.20	16.60	33.20	33.20	1.00	216.2
1.00	Conveyor oven	60.9	0.5	0.00	0.00	0.00	0.00	0.00	0.00	30.45	0.00	60.9
2.00	Deck oven	44.7	0.5	0.00	44.70	44.70	0.00	0.00	0.00	0.00	0.00	178.8
1.25	Range oven	18.3	0.5	0.00	0.00	11.44	11.44	5.72	11.44	11.44	0.00	68.6
1.25	Open top range	32.0	0.5	1.00	1.00	20.00	20.00	10.00	20.00	20.00	1.00	137.0
2.00	Steam kettle	50.0	0.5	0.00	0.00	50.00	50.00	25.00	50.00	50.00	0.00	300.0
Total (kBtu/h)				4.5	49.2	217.9	173.2	87.1	189.3	219.8	4.5	1,405

3.4.4 Heating, Ventilation, and Air Conditioning

Although many types of HVAC systems could be used in K-12 schools, the AEDG-K12 provides recommendations for one of the following three common low-energy HVAC system types:

- Ground source heat pump (GSHPs) with a DOAS for ventilation
- Fan coils unit (FCU) with a water chiller, a water boiler, and a DOAS for ventilation
- Multizone, VAV air handling unit with a water chiller, a DOAS for ventilation, and perimeter radiant heat located in the zones

More than one HVAC system type is provided to give users of the AEDG-K12 flexibility in designing high-performance K-12 schools. The PC used members' experience in designing K-12 schools to determine the HVAC system types to include in the AEDG-K12, and they felt these three types were widely applicable, readily available, and comparatively common. Energy modeling showed that all three system types (along with the other recommendations) met or exceeded the 50% savings goals. The AEDG-K12 discusses more variations among the modeled system types, but the PC decided to model only the most common configurations.

The HVAC zoning for the low-energy models was similar to the baseline models. The classroom wings and most of the central common spaces that were served by VAV HVAC systems in the baseline models were served by multizone DOASs with zone-level space conditioning in the low-energy models. This was a central theme to the HVAC recommendations for spaces; that is, decoupling the ventilation need from the zone heating and cooling.

The specialty spaces (auditorium, cafeteria, kitchen, and gym) were served by PSZ HVAC systems in the low-energy model; however, these systems represent best-in-class efficiency instead of code-minimum efficiency levels (as used in the baseline models).

3.4.4.1 Packaged Single Zone Systems

As in the baseline models, the primary and secondary school low-energy models had PSZ systems serving the auditoriums, cafeterias, gyms, and kitchens. The PSZ systems included 80% efficient natural gas-fired furnaces, 4.0 COP DX cooling coils, 60% efficient constant air volume fans with 1.0 in. w.c. pressure drop, and differential enthalpy-controlled economizers. Economizers were not used in climate zones 1A, 2A, 3A, and 4A per Standard 90.1-2004 (ASHRAE 2004b). The PSZ units added demand-controlled ventilation (DCV) and energy recovery ventilators (ERVs) in all climate zones that were modeled with a 75% sensible effectiveness, 69% latent effectiveness, and a 0.5 in w.c. pressure drop. The ERVs were equipped with exhaust-only frost control, with a threshold temperature of –10°F, an initial defrost time fraction of 0.083 min/min, and a defrost time increase rate of 0.024 (min/min)/°C. DCV was modeled in EnergyPlus by varying the per-person OA requirement (see Table 3–6) based on the occupancy schedule for that zone (see Figure 3–6 through Figure 3–16).

3.4.4.2 Dedicated Outdoor Air Systems

The VAV-reheat systems that provided heating and cooling in the baseline models were replaced with DOASs in the low-energy models; space conditioning was handled through other means (with a GSHP, FCU, or VAV cooling and baseboard heating). All low-energy models used DOASs in the zones that were served by VAV-reheat systems in the baseline models (see Figure 3–31 through Figure 3–33). The DOASs provided ventilation air for the classrooms, corridors, library/media center, lobbies, mechanical rooms, offices, and restrooms in all low-energy models. The DOASs were modeled with a water preheat coil, a water cooling coil, and a VAV fan. The VAV fan had a fan efficiency of 69%, a motor efficiency of 90%, and a system pressure drop of 4.0 in. w.c. The DOAS also included DCV capability and ERVs. Each ERV was modeled with a 75% sensible effectiveness, 69% latent effectiveness, and a 0.5 in. w.c. pressure drop. The ERVs were equipped with exhaust-only frost control, with a threshold temperature of –10°F, an initial defrost time fraction of 0.083 min/min, and a defrost time increase rate of 0.024 (min/min)/°C. The water preheat coils were served by a 90% efficient natural gas-fired condensing boiler coupled to a 90% efficient variable-speed pump with 119,563 Pa of head. The cooling coils were served by an air-cooled chiller with a COP of 2.93 coupled to a 90% efficient variable-speed pump with 149,453 Pa of head. The ventilation air from the DOAS was delivered to the zone via a VAV terminal unit that was capable of varying the ventilation rate. In EnergyPlus, DCV was modeled by varying the per-person OA requirement (see Table 3–6) based on the occupancy schedule for that zone (see Figure 3–6 through Figure 3–16). Figure 3–46 shows the DOAS configuration for the GSHP and FCU HVAC system configuration, and Figure 3–47 shows the configuration for the VAV system.

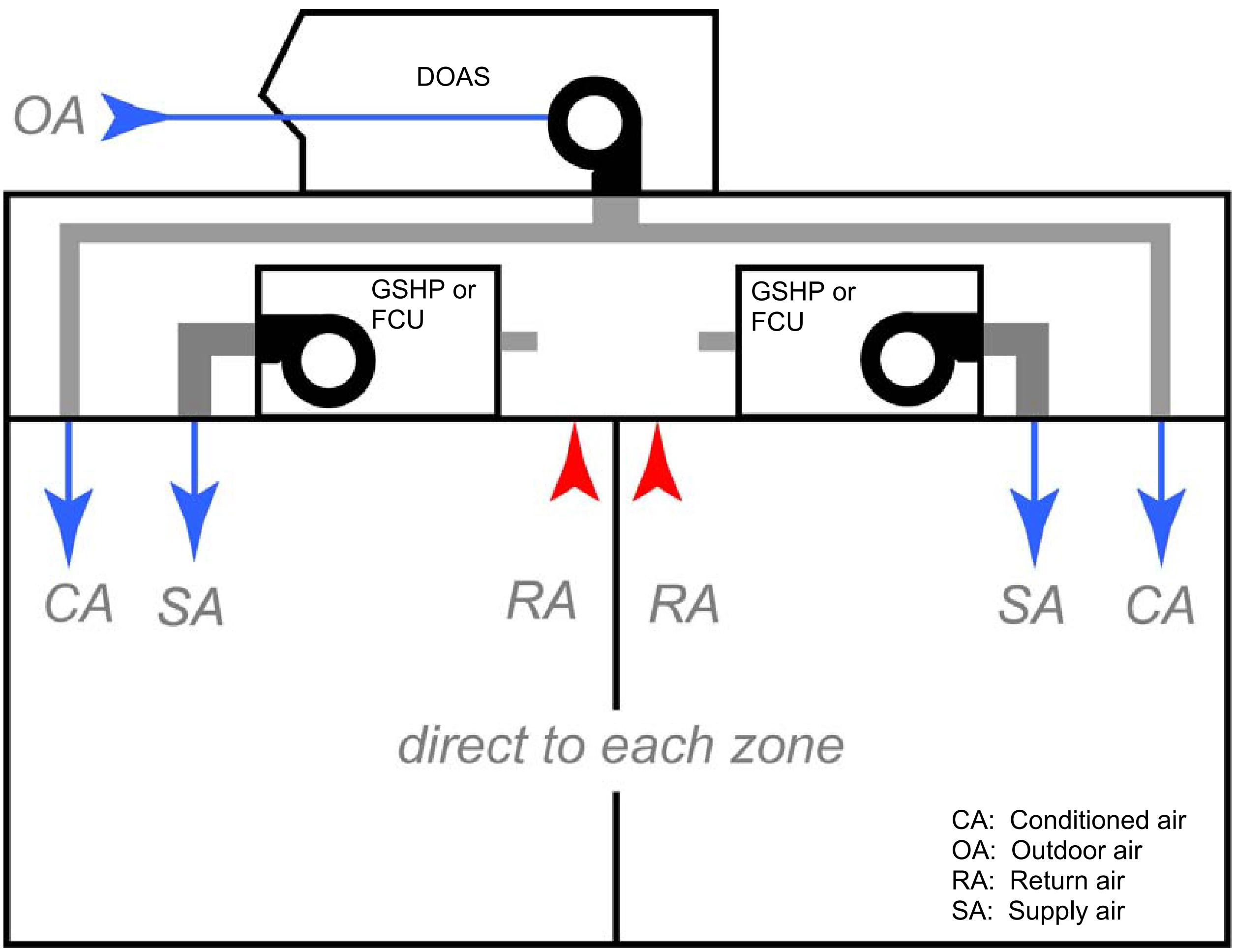


Figure 3–46 DOAS configuration for GSHP and FCU system
(Credit: John Murphy/Trane)

3.4.4.3 Ground Source Heat Pump System

In this low-energy model variation, each zone served by the DOAS (classrooms, corridors, library/media center, lobbies, mechanical rooms, offices, and restrooms) also had a two-speed GSHP. The primary school had 22 separate heat pumps; the secondary school had 42. The heat pumps represented best-in-class efficiency levels, with a cooling COP of 6.45, a heating COP of 4 (with supplemental electric resistance heat), and 50% efficient constant speed fans that cycled with the load (0.25 in. w.c. pressure drop).

The heat pumps rejected energy to a single plant loop that was served by a 90% efficient variable-speed pump with 1,195,627 Pa of head and a loop temperature set point of 69.8°F. A ground heat exchanger was on the loop (see Appendix E for details). The heat rejection loop included a boiler to help maintain loop temperature during the winter. The boiler on the loop was a 90% efficient natural gas-fired condensing boiler.

3.4.4.4 Fan Coil Unit System

In this low-energy model variation, each zone served by the DOAS (classrooms, corridors, library/media center, lobbies, mechanical rooms, offices, and restrooms) also had a four-pipe FCU. The FCU consisted of a water heating coil, a water cooling coil, and a 50% efficient constant speed fan that cycled with load (0.25 in. w.c. pressure drop).

The fan coils were connected to a hot water loop and a chilled water loop. The hot water loop was served by a 90% efficient variable-speed pump (119,563 Pa of head) and a 90% efficient natural gas-fired condensing boiler. The chilled water loop was served by a 90% efficient variable-speed pump (149,453 Pa of head) and a 6.1 COP water-cooled chiller. The condenser loop for the chiller was served by a 90% efficient variable-speed pump (134,508 Pa of head) and a variable-speed cooling tower. The chilled water loop also included a counterflow heat exchanger that allowed the cooling tower to provide water-side economizing.

3.4.4.5 Variable Air Volume Cooling, Baseboard Heating System

In this low-energy model variation, each zone served by the DOAS (classrooms, corridors, library/media center, lobbies, mechanical rooms, offices, and restrooms) was cooled by a separate VAV air system and heated with in-zone radiant heat. This HVAC option provided the central maintenance capability of a traditional VAV-reheat system (as the baseline had), but eliminated the wasteful reheat energy. In this configuration, a dual-duct VAV terminal unit was used to separately control ventilation and cooling air. One side of the terminal unit was connected to the DOAS (DOAS deck) and provided the necessary ventilation air. The other side was connected to the VAV air system (cold deck) and provided cooling to the zone. The cold deck side of the terminal unit was open when a zone called for cooling and closed when no cooling was required. Ventilation air continued to be provided as required; the dual-duct VAV terminal unit had independent control over each deck. Heating was provided via hot water baseboard radiant heaters. Figure 3–47 shows this HVAC system configuration (the heating is depicted as in-floor radiant heat although it was modeled as baseboard radiant heaters).

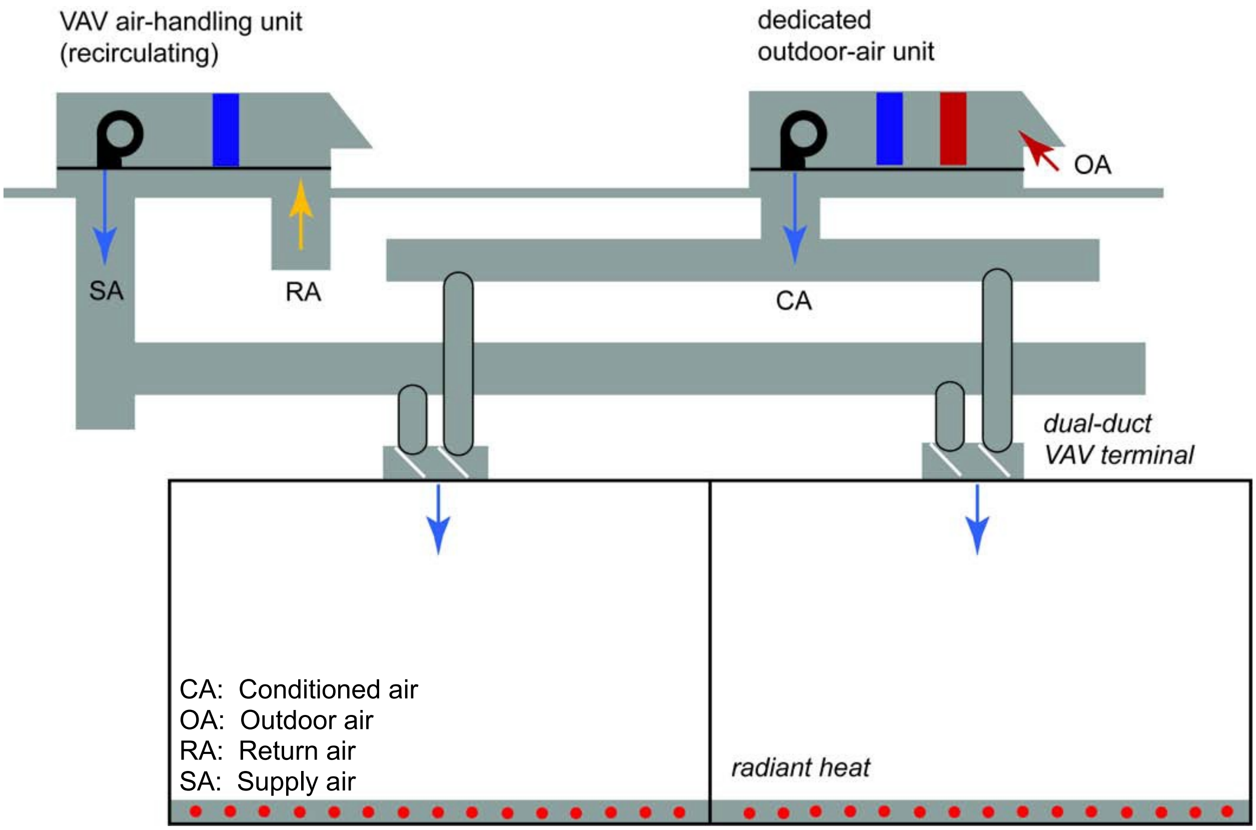


Figure 3–47 VAV cooling, baseboard heating HVAC system configuration
(Credit: John Murphy/Trane)

The DOAS had heating and cooling coils; the VAV air handling unit contained cooling coils only. These coils were connected to a hot water loop (heating coils) and a chilled water loop (cooling coils). The hot water loop was served by a 90% efficient variable-speed pump (119,563 Pa of head) and a 90% efficient natural gas-fired condensing boiler. The chilled water loop was served by a 90% efficient variable-speed pump (149,453 Pa of head) and a 2.93 COP air-cooled chiller.

3.4.5 Service Water Heating

The SWH in both the primary and secondary school low-energy models were exactly as the baseline, except that the water heaters were 90% efficient instead of 80% efficient and the circulation pump in the secondary school was 90% efficient instead of 80% efficient.

3.4.6 Refrigeration

The refrigeration objects were the same in the low-energy models as in the baseline models (see Section 3.3.6 and Appendix F for more information).

3.4.7 Daylight Modeling

The daylight modeling for the AEDG-K12 was performed using Radiance (Ward 1994) and DAYSIM (Walkenhorst et al. 2002) to develop zone-by-zone hourly lighting schedules. The goal was to create representative electric lighting schedules that would mimic how a daylight responsive electric lighting control system would respond given the daylighting design studied here. This schedule accurately accounted for the energy savings observed as a result of that daylighting system. The target daylight illuminance was 500 lux (~46 footcandles [fc]) and the lighting controls were modeled as continuous dimming from 0%–100%, using a closed loop control scheme. The calculation grid was placed 30 in. above the finished floor with 2 ft on-center spacing and a 2-ft wall offset. Only the daylight apertures were modeled for daylight penetration (the view windows were modeled as opaque); this gives a "worst case" daylighting scenario, essentially presuming that the view window glare control devices (e.g., blinds and shades) were deployed year round. All daylight apertures (except those in the north-facing classroom) had fixed louver systems that provided aggressive cutoff of direct solar beam radiation (specific cutoffs defined in the following sections), and a single daylight fenestration-to-floor area ratio was modeled that was within the range specified in the AEDG-K12 for most climate zones. The assumed room surface properties were:

- A 90% ceiling reflectance
- A 60% wall reflectance
- A 35% floor reflectance
- Glazing with 80% VLT, and 100% specular transmission (i.e. no diffusion).

Separate models were generated for the spaces in which daylighting is recommended in the AEDG-K12. These space types are:

- South-facing classroom
- North-facing classroom
- Gymnasium
- Cafeteria
- Typical office (south-facing).

The daylight models for this guide were created in Trimble SketchUp (www.sketchup.com), but any three-dimensional computer-aided design modeling tool could be used, provided an export to Radiance function is available. DAYSIM created a settings file (.rif) to control the "rad" executive control program, which managed all the Radiance simulation parameters. The pertinent entries in the .rif files for these simulations are shown in Table 3–39.

Table 3–39 Radiance Simulation Parameters

Parameter	Value
Quality	Medium
Detail	Medium
Variability	High
Indirect (ambient bounces)	4
Penumbras	True

Annual simulations were performed using DAYSIM/Radiance for each model and climate zone. The daylight illuminance was averaged and blended with dimming set point (500 lux, ~46 fc) and occupancy schedule. This ultimately generated a lighting schedule for each space for EnergyPlus. The internal daylighting calculation in EnergyPlus was disabled, and the Radiance-computed lighting schedule was followed for the electric lighting use in the annual whole-building energy simulation.

Additional details about the space type models, along with renderings of these models, are discussed in the following sections.

3.4.7.1 South-Facing Classroom

Additional model details for the south-facing classroom include:

- The overhang was located 2 in. below the daylight window sill, and projects 2 ft from the south façade. The overhangs visible light reflectance was 50%.
- The daylight louver slats provided full direct solar cutoff for solar altitude angles above 17 degrees (see Figure 3–49).
- The view (lower) windows were not modeled.

An isometric rendering of the south-facing classroom model can be seen in Figure 3–48 and a section view can be seen in Figure 3–49.

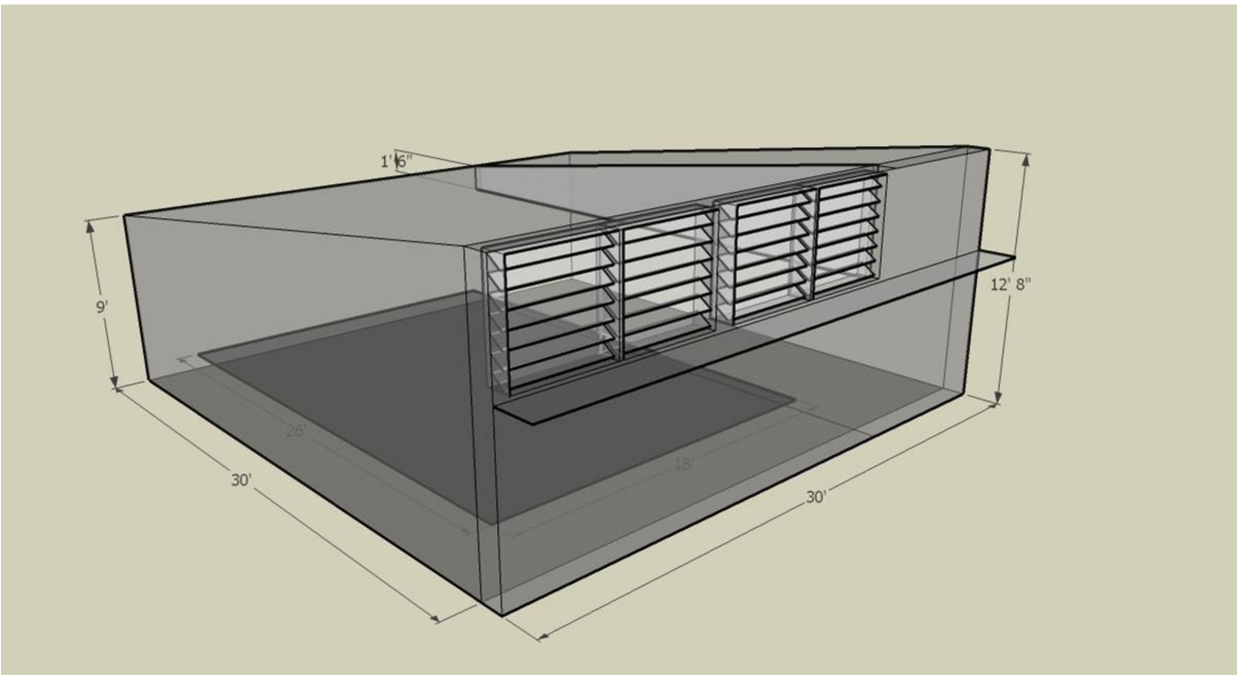


Figure 3–48 South-facing classroom – view from southwest
(Credit: Mike Nicklas/Innovative Design, Inc.)

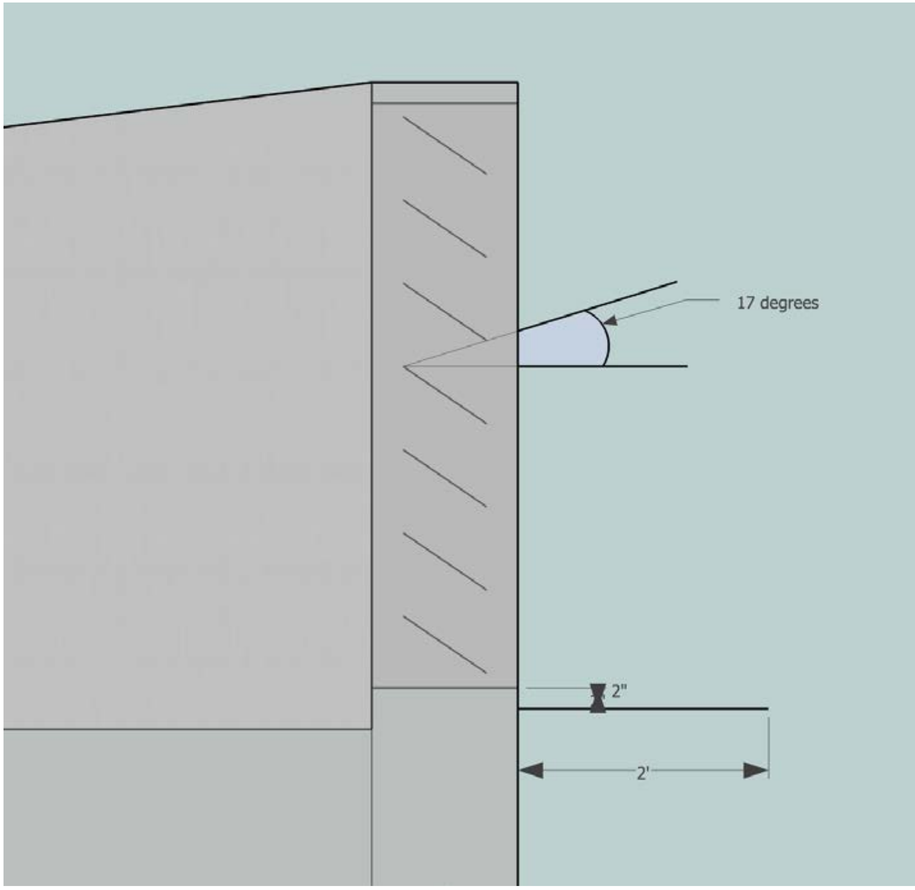


Figure 3–49 South-facing classroom – section view
(Credit: Mike Nicklas/Innovative Design, Inc.)

3.4.7.2 North-Facing Classroom

The north-facing classroom had no overhangs or louvers. This is due to the fact that direct sun on north facades in North American latitudes is not a problem during the extent of the school year. An isometric rendering of the model can be seen in Figure 3–50.

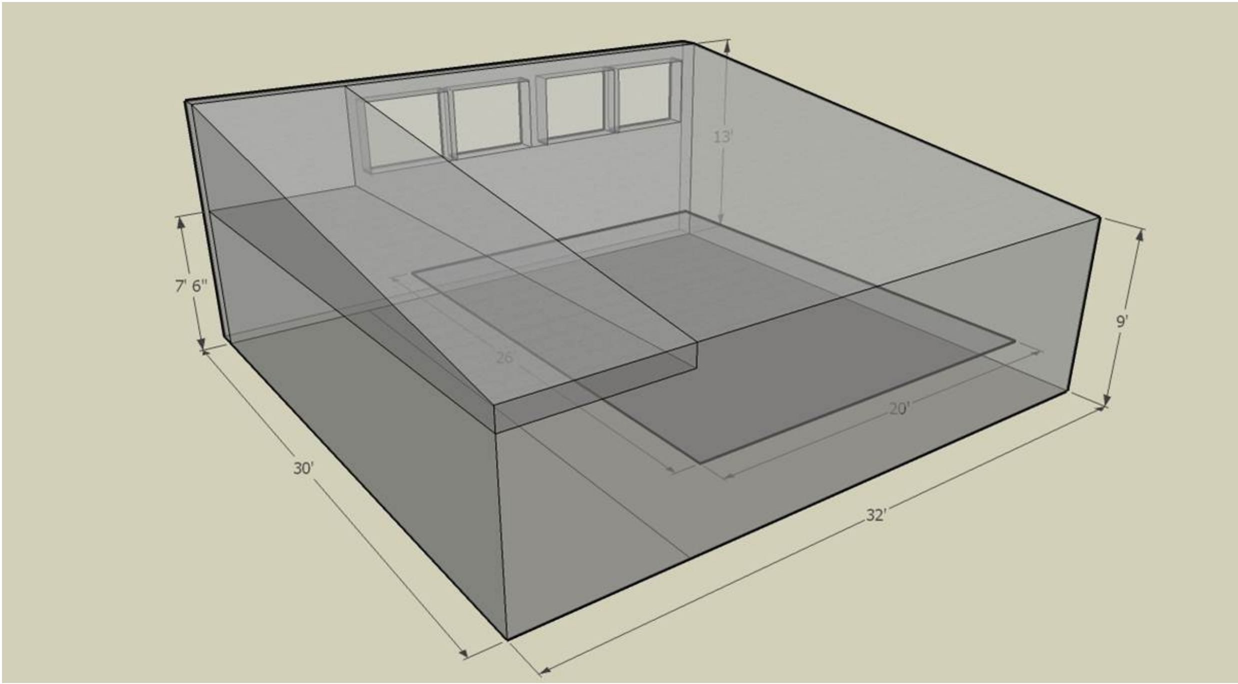


Figure 3–50 North-facing classroom – view from southwest
(Credit: Mike Nicklas/Innovative Design, Inc.)

3.4.7.3 Gym With South-Facing Roof Monitors

An isometric rendering of the gym with south-facing roof monitors model can be seen in Figure 3–51 and additional details about the roof monitors can be seen in Figure 3–52 and Figure 3–53. The ceiling baffles were designed to provide 21 degrees of direct beam solar cutoff.

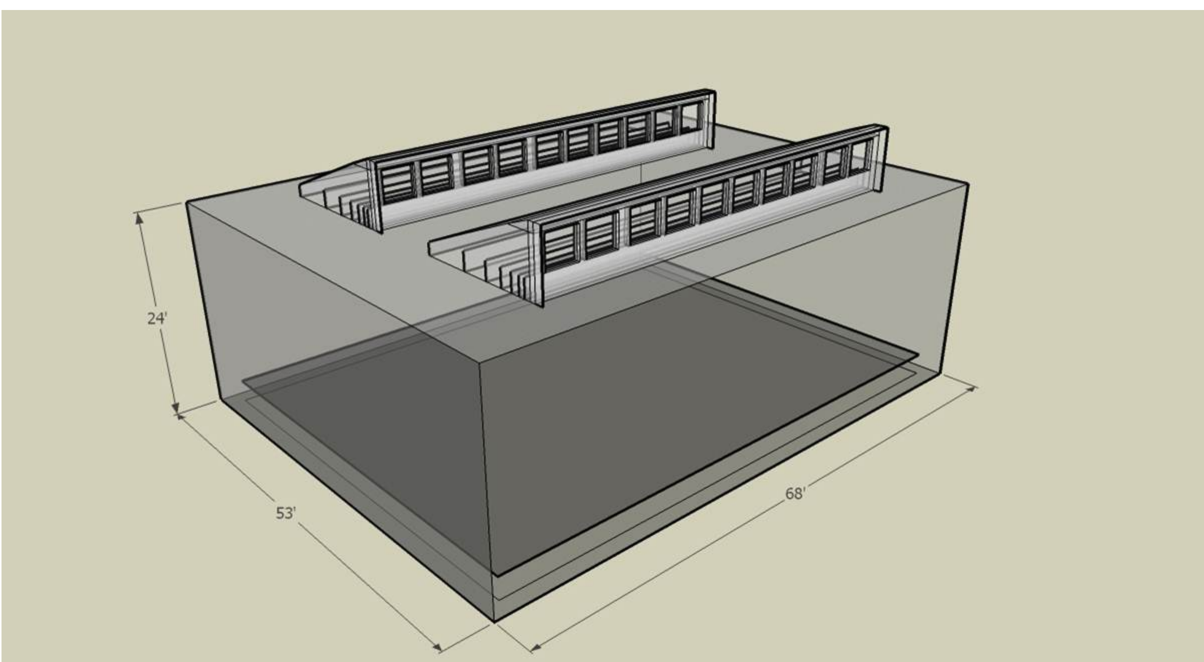


Figure 3–51 Gym with south-facing roof monitors – view from southwest
(Credit: Mike Nicklas/Innovative Design, Inc.)

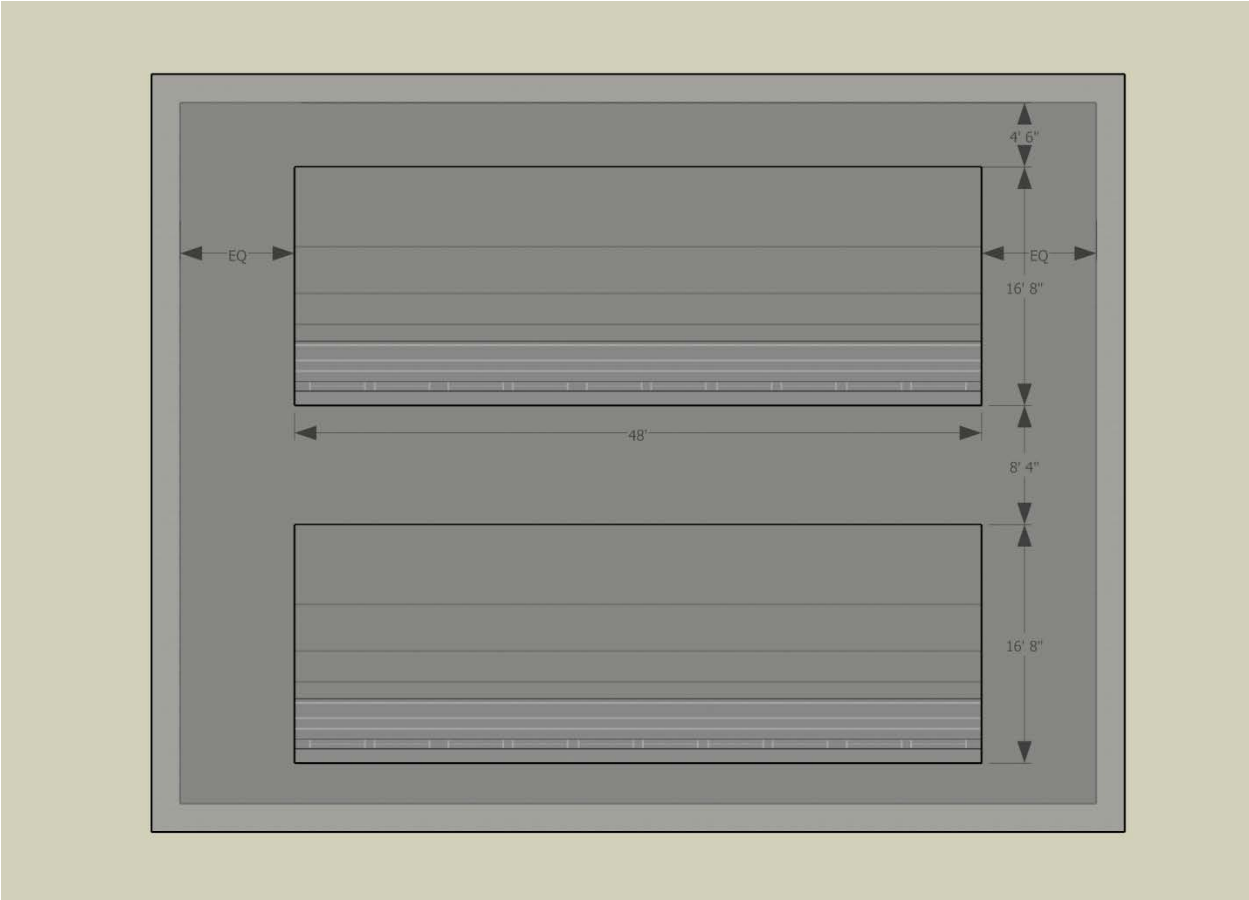


Figure 3–52 Gym with south-facing roof monitors – reflected ceiling plan
(Credit: Mike Nicklas/Innovative Design, Inc.)

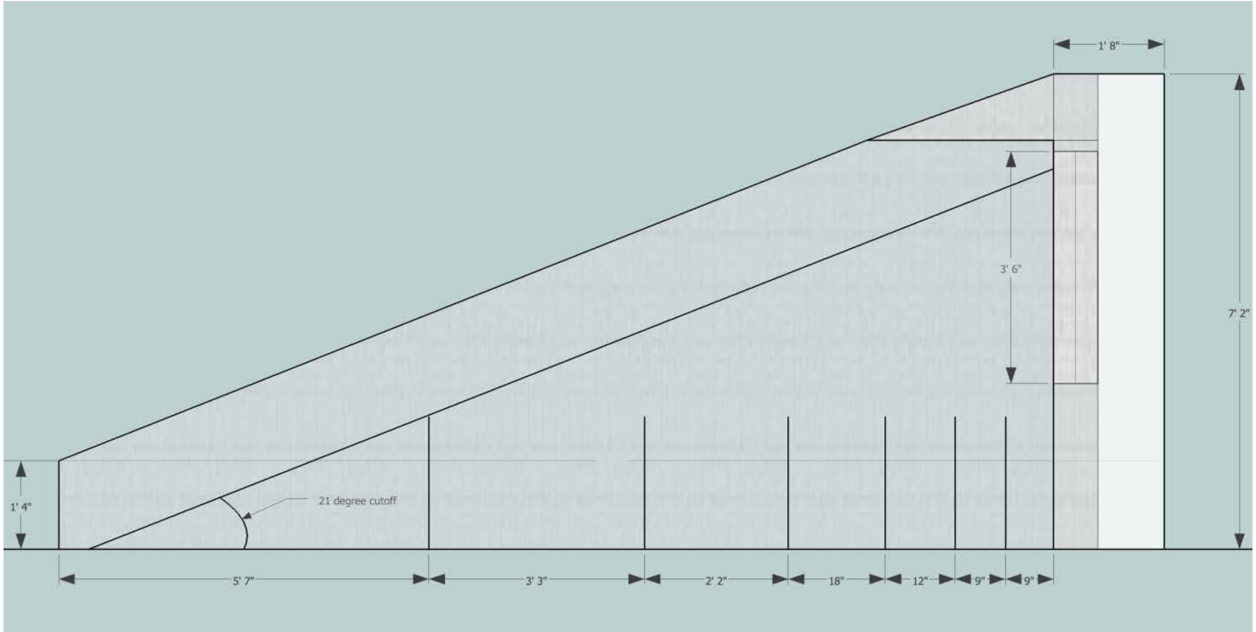


Figure 3–53 Gym with south-facing roof monitors – section view
(Credit: Mike Nicklas/Innovative Design, Inc.)

3.4.7.4 Cafeteria With South-Facing Roof Monitors

An isometric rendering of the cafeteria with south-facing roof monitors model can be seen in Figure 3–54 and additional details about the roof monitors can be seen in Figure 3–55 and Figure 3–56. The deep roof monitors provide 100% direct solar beam cutoff throughout the year.

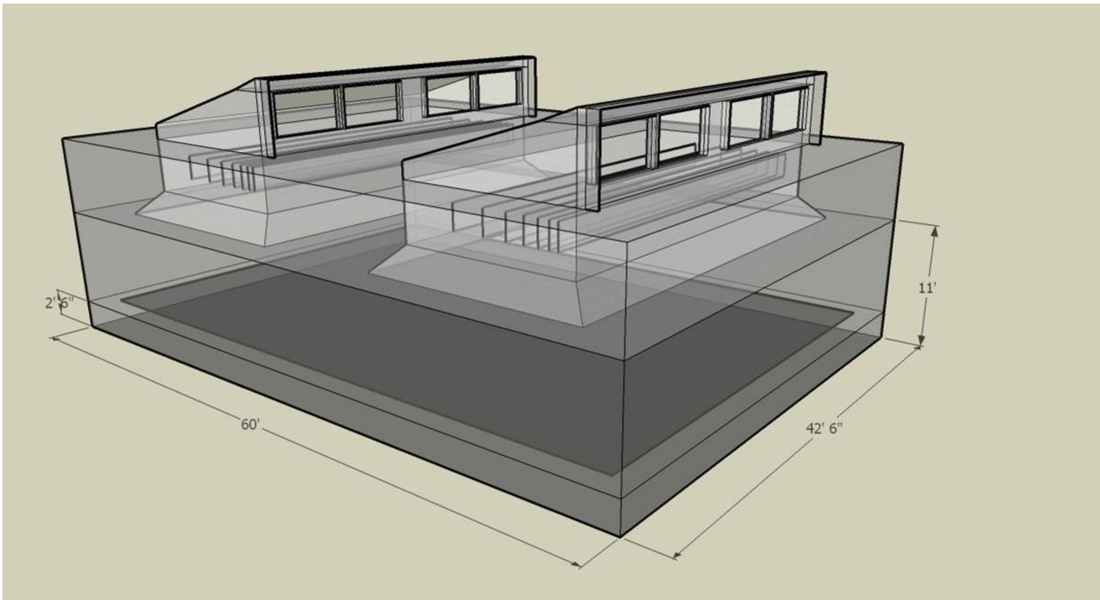


Figure 3–54 Cafeterias with south-facing roof monitors – view from southwest
(Credit: Mike Nicklas/Innovative Design, Inc.)

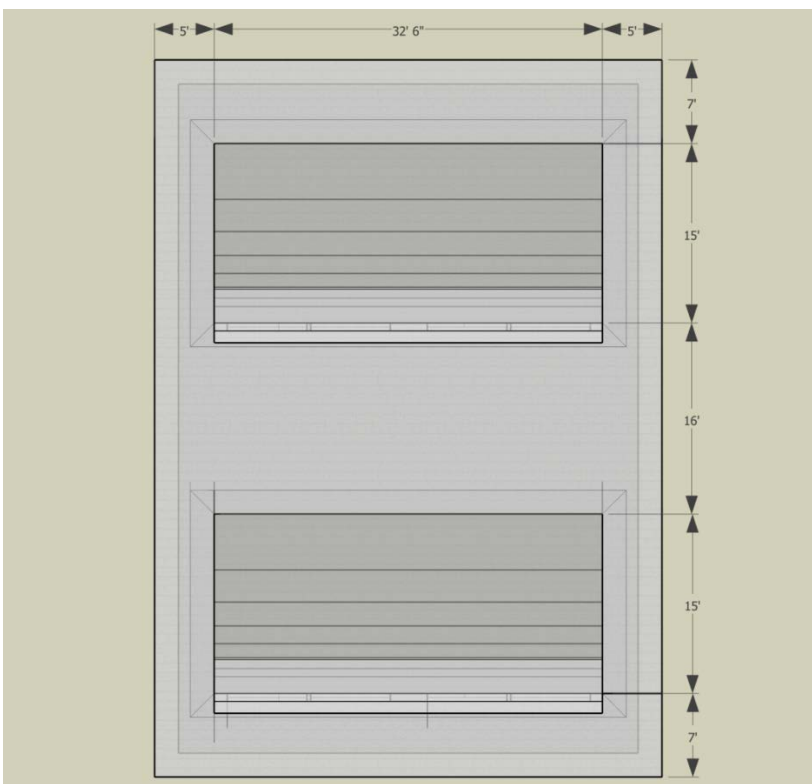


Figure 3–55 Cafeterias with south-facing roof monitors – reflected ceiling plan
(Credit: Mike Nicklas/Innovative Design, Inc.)

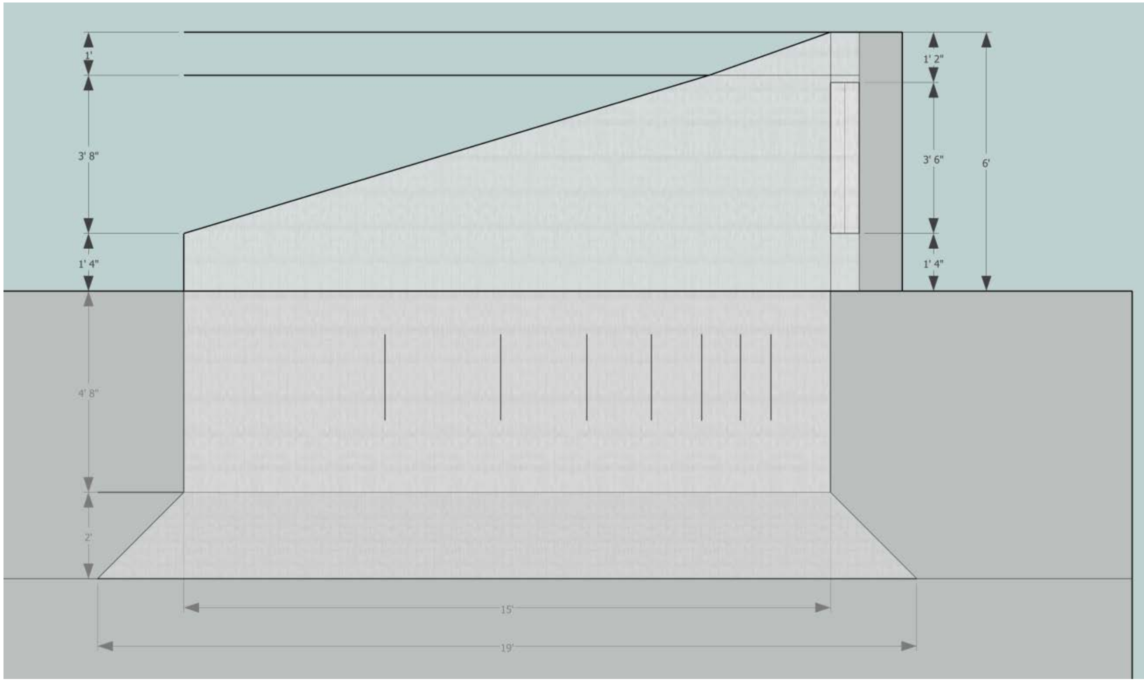


Figure 3–56 Cafeterias with south-facing roof monitors – section view
(Credit: Mike Nicklas/Innovative Design, Inc.)

3.4.7.5 Typical Office (South-Facing)

Additional model details for the typical south-facing office include:

- The overhang was located 3¼ in. below the daylight window sill and projected 12 in. from the south façade. The visible light reflectance was 50%.
- The daylight louver slats provided full direct solar cutoff for solar altitude angles above 7 degrees (see Figure 3–58).
- The view (lower) window was modeled as an opaque surface.

An isometric rendering of the typical south-facing office model can be seen in Figure 3–57, and a section view of the model can be seen in Figure 3–58.

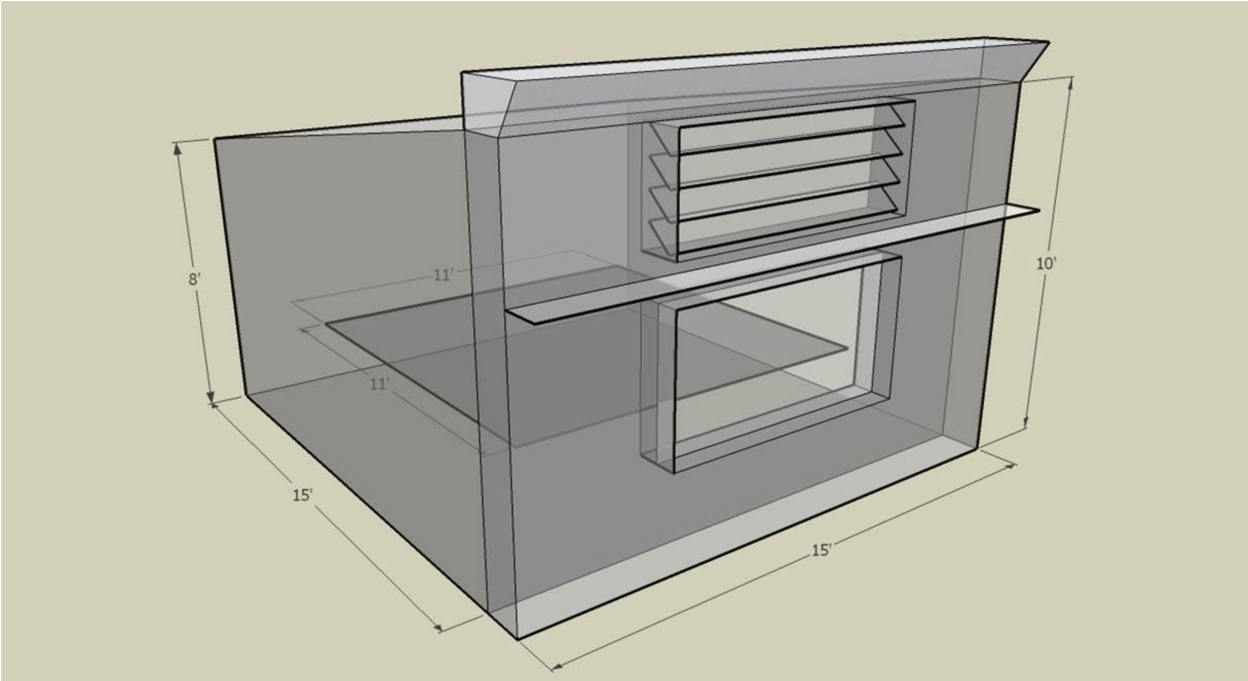


Figure 3–57 Typical office (south-facing) – view from southwest
(Credit: Mike Nicklas/Innovative Design, Inc.)

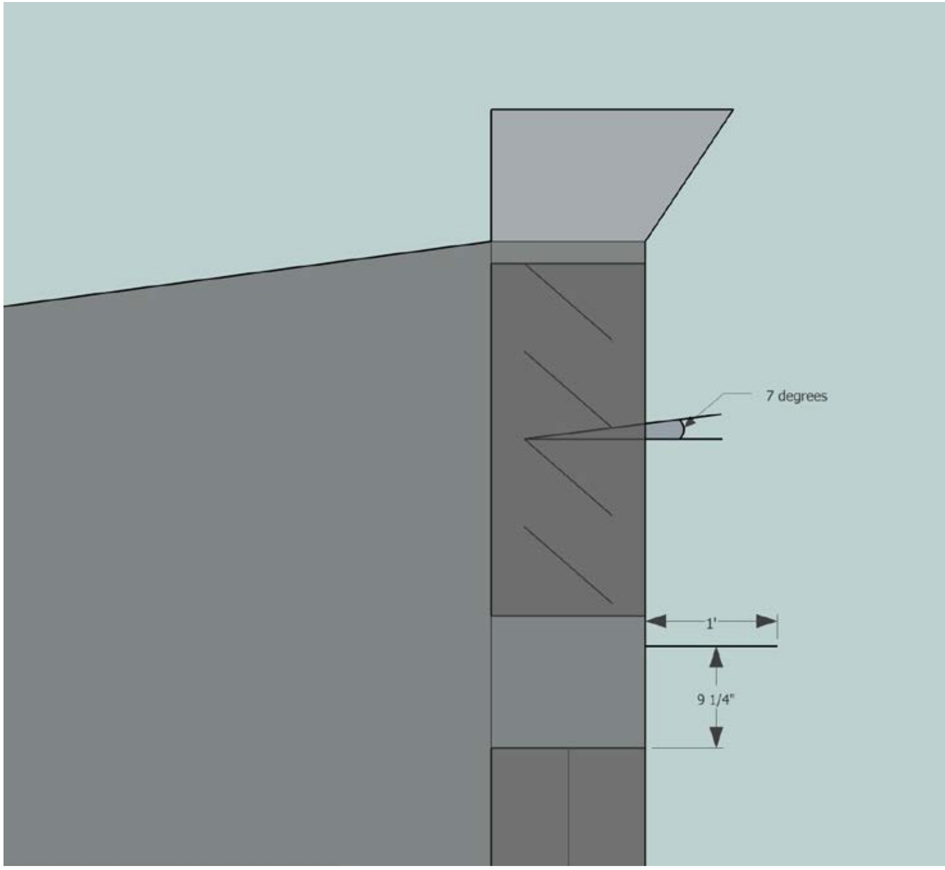


Figure 3–58 Typical office (south-facing) – section view
(Credit: Mike Nicklas/Innovative Design, Inc.)

4. Energy Targets

Careful goal setting is required to design and construct high-performance buildings. The goal of the AEDG-K12 was a building that consumed 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 should be set as a best practice. This target is a single number that defines a building's energy performance. The lower the number, the more energy efficient the building. The AEDG-K12 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-K12 are applicable to most K-12 schools with typical programs and use profiles. The AEDG-K12 energy targets were designed to simplify the process of setting whole-building absolute energy use targets.

The prescriptive path in the AEDG-K12 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 not related to energy performance). Specifying AEDG-K12 whole-building absolute energy targets can eliminate most of the analysis that may otherwise be required to specify energy performance goals, because they embody the knowledge required to set practical, aggressive energy performance targets. One can specify an absolute energy target using the AEDG-K12 energy target tables and then focus analysis efforts toward achieving industry best practice energy performance rather than trying to define 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-K12 were developed in accordance with the following approach:

1. Start with the primary and secondary school DOE Commercial Reference Building models (Deru et al. 2010); these models are minimally compliant with Standard 90.1-2004 (ASHRAE 2004b).
2. Update the models according to the AEDG-K12 PC's expert guidance. Pay special attention to aspects that are not prescribed by Standard 90.1-2004, including schedules and unregulated plug and process loads. The goal is to develop a model that accurately captures typical (common practice) whole-building energy use for K-12 schools. 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 16 climate zones that fully represent the variations in the eight DOE climate zones (Figure 3–2). Benchmark the results against available sector data and solicit input from the PC. Make any necessary corrections to the model inputs and resimulate. 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 committee 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 and Table 4–2. The results in these tables represent 50% savings over the baseline models, which were compliant with Standard 90.1-2004 (ASHRAE 2004b). The PC members confirmed that these results were in line with their expectations for 50% savings.

Table 4–1 Primary School Energy Targets

Climate Zone	Plug/Process (kBtu/ft²yr)	Lighting (kBtu/ft²yr)	HVAC (kBtu/ft²yr)	Total (kBtu/ft²yr)
1A	11	6	20	37
2A			20	37
2B			20	37
3A			15	32
3B:CA			8	25
3B			14	31
3C			10	27
4A			19	36
4B			15	32
4C			15	32
5A			22	39
5B			17	34
6A			27	44
6B			22	39
7			30	47
8			45	62

Table 4–2 Secondary School Energy Targets

Climate Zone	Plug/Process (kBtu/ft²yr)	Lighting (kBtu/ft²yr)	HVAC (kBtu/ft²yr)	Total (kBtu/ft²yr)
1A	8	7	21	36
2A			21	36
2B			21	36
3A			18	33
3B:CA			10	25
3B			17	32
3C			13	28
4A			22	37
4B			18	33
4C			19	34
5A			25	40
5B			21	36
6A			31	46
6B			26	41
7			34	49
8			48	63

Whole-building absolute targets are supplemented with key end use energy targets (plug and process loads, 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 K-12 school building; they can also inform end use energy budgets. Programmatic requirements are relatively constant for a given school type (primary or secondary); accordingly, the AEDG-K12 whole-building and end use energy targets are likely to apply reasonably well to most K-12 school building projects. The AEDG-K12 energy targets do not take into account the energy use of specialty space types such as indoor swimming pools, wet laboratories (e.g., chemistry), dirty dry laboratories (e.g., woodworking and auto shops), or other 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-K12 targets to determine an area-weighted, whole-building energy use target that correctly reflects all energy uses.

5. Evaluation Results

This section contains the PC-approved energy efficiency recommendations for the AEDG-K12. The energy savings that result from applying these recommendations are presented as well. End use comparison figures are provided; the end use data are also presented in tabular format.

The recommendations in the AEDG-K12 represent a way to achieve 50% energy savings over Standard 90.1-2004 in a typical K-12 school. 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-K12 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.

5.1 Recommendation Tables for 50% Energy Savings

This section provides the recommendation tables that are presented in the AEDG-K12. 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 as well as the interior reflectance values are provided. For the AEDG-K12, daylighting strategies are presented for classrooms, cafeterias, and gymnasiums. Each strategy includes several options and variations depending on climate and orientation. These daylighting strategies are designed to provide the recommended illuminance for the space over most occupied daytime hours. Interior lighting recommendations, including LPD, lamp efficacy, ballast specification, controls, and daylighting system integration; as well as exterior LPDs and controls, are presented. Plug and process load (including commercial kitchen equipment) recommendations are provided. SWH efficiency recommendations are provided for electric and gas water heaters, as well as instantaneous or natural gas-fired water storage tank units. Many types of HVAC systems could be used in K-12 schools, but the AEDG-K12 provides recommendations for each of the following three system types:

- GSHP with a DOAS for ventilation
- FCU with a chiller, boiler, and DOAS for ventilation
- Multizone, VAV air handling unit with a chiller, a DOAS for ventilation, and perimeter radiant heat.

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, along with economizer use recommendations (where applicable) for each HVAC system type.

The recommendation tables for the AEDG-K12 (ASHRAE et al. 2011a) are shown in Table 5–1 and Table 5–2.

Table 5–1 AEDG-K12 Recommendations: Climate Zones 1–4

Item		Component	Climate Zone 1 Recommendations	Climate Zone 2 Recommendations	Climate Zone 3 Recommendations	Climate Zone 4 Recommendations
Envelope	Roofs	Insulation entirely above deck	R-20.0 c.i.	R-25.0 c.i.		R-30.0 c.i.
		Attic and other	R-38.0			R-49.0
		Metal building	R-10.0 + R-19.0 filled cavity			R-19.0 + R-11.0 Ls
		Solar reflectance index (SRI)	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.			
		Wood framed and other	R-13.0	R-13.0 + R-3.8 c.i.		R-13.0 + R-7.5 c.i.
		Metal building	R-0.0 + R-9.8 c.i.		R-0.0 + R-13.0 c.i.	R-0.0 + R-19.0 c.i.
		Below grade walls	Comply with 90.1		R-7.5 c.i. (comply with 90.1 in climate zone 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-19.0	R-30.0	R-38.0
		Wood framed and other				
	Slabs	Unheated	Comply with 90.1			
		Heated	R-7.5 c.i.	R-10 for 24 in.	R-15 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 building entrance	Comply with 90.1		> 10,000 ft^2 only	Yes
	View fenestration	Thermal transmittance	Nonmetal framing = 0.56	Nonmetal framing = 0.45	Nonmetal framing = 0.41	Nonmetal framing = 0.38
			Metal framing = 0.65		Metal framing = 0.60	Metal framing = 0.44
		Fenestration-to-floor area ratio	E or W orientation = 5% maximum			
			N or S orientation = 7% maximum			
		SHGC	E or W orientation = 0.25			E or W orientation = 0.40
			N orientation = 0.62			
			S orientation = 0.25	S orientation = 0.5	S orientation = 0.75	
		Exterior sun control	S orientation only = PF-0.5			
	Daylighting fenestration	VLT	See Table 5-5 in the AEDG-K12 for appropriate VLT values			
		Interior/exterior sun control (S orientation only)	S orientation = no glare during school hours			

Item		Component	Climate Zone 1 Recommendations	Climate Zone 2 Recommendations	Climate Zone 3 Recommendations	Climate Zone 4 Recommendations
Lighting/daylighting	Daylighting	Classrooms, resource rooms, cafeteria, gym, and multipurpose rooms.	Daylight 100% of floor area for 2/3 of school hours			
		Administrative areas	Daylight perimeter floor area (within 15 ft) for 2/3 of school hours			
	Interior finishes	Interior surface average reflectance for daylighted rooms	Ceilings = 80%; wall surfaces = 70%			
	Interior lighting	LPD	Whole building = 0.7 W/ft²			
			Gyms, multipurpose rooms = 1.0 W/ft²			
			Classrooms, art rooms, kitchens, libraries, media centers = 0.8 W/ft²			
			Cafeterias, lobbies = 0.7 W/ft²			
			Offices = 0.6 W/ft²			
			Auditoriums, restrooms = 0.5 W/ft²			
			Corridors, mechanical rooms = 0.4 W/ft²			
		Light source lamp efficacy (mean lumens per Watt)	T8 and T5 > 2 ft = 92; T8 and T5 < 2 ft = 85; all other > 50			
		T8 ballasts	Nondimming = NEMA premium instant start; dimming = premium program start			
		T5/T5 high output ballasts	Electronic program start			
		CFL and HID ballasts	Electronic			
		Dimming controls daylight harvesting	Dim all fixtures in daylit zones			
		Lighting controls	Manual ON, auto/timed OFF in all areas as possible			
	Exterior lighting	Façade and landscape lighting	LPD = 0.075 W/ft² in LZ3 and LZ4; LPD = 0.05 W/ft² in LZ2; Controls = auto OFF between 12:00 a.m. and 6:00 a.m.			
		Parking lots and drives	LPD = 0.1 W/ft² in LZ3 and LZ4; LPD = 0.06 W/ft² in LZ2; Controls = auto reduce to 25% (12:00 a.m. to 6:00 a.m.)			
		Walkways, plazas, and special feature areas	LPD = 0.16 W/ft² LZ3 and LZ4; LPD = 0.14 W/ft² in LZ2; Controls = auto reduce to 25% (12:00 a.m. to 6:00 a.m.)			
		All other exterior lighting	LPD = follow 90.1-2010; controls = auto reduce to 25% (12:00 a.m. to 6:00 a.m.)			
Plug and process	Equipment choices	Laptop computers	Minimum 2/3 of total computers			
		ENERGY STAR equipment	All computers, equipment, and appliances			
		Vending machines	De-lamp and specify best in class efficiency			
	Controls	Computer power control	Network control with power saving modes and control OFF during unoccupied hours			
		Power outlet control	Controllable power outlets with auto OFF during unoccupied hours for classrooms, office, library/media spaces. All plug-in equipment not requiring continuous operation to use controllable outlets			

<table>
<thead>
<tr><th colspan="2">Item</th><th>Component</th><th>Climate Zone 1 Recommendations</th><th>Climate Zone 2 Recommendations</th><th>Climate Zone 3 Recommendations</th><th>Climate Zone 4 Recommendations</th></tr>
</thead>
<tbody>
<tr><td></td><td></td><td>Policies</td><td colspan="4">Implement at least one:
- District/school policy on allowed equipment
- School energy teams</td></tr>
<tr><td rowspan="3">Kitchen</td><td rowspan="3">Kitchen equipment</td><td>Cooking equipment</td><td colspan="4">ENERGY STAR or California rebate-qualified equipment</td></tr>
<tr><td>Walk-in refrigeration equipment</td><td colspan="4">6 in. insulation on low-temp walk-in equipment, insulated floor, LED lighting, floating-head pressure controls, liquid pressure amplifier, sub-cooled liquid refrigerant, evaporative condenser</td></tr>
<tr><td>Exhaust hoods</td><td colspan="4">Side panels, larger overhangs, rear seal at appliances, proximity hoods, VAV demand-based exhaust</td></tr>
<tr><td rowspan="6">SWH</td><td rowspan="6">SWH</td><td>Gas water heater (condensing)</td><td colspan="4">95% efficiency</td></tr>
<tr><td>Electric water heater
(< 12 kW, > 20 gal)</td><td colspan="4">EF > 0.99 – 0.0012 × volume</td></tr>
<tr><td>Point-of-use heater selection</td><td colspan="4">0.81 EF or 81% Et</td></tr>
<tr><td>Electric heat pump water heater</td><td colspan="4">COP 3.0 (interior heat source)</td></tr>
<tr><td>Solar water heating</td><td colspan="4">30% solar hot water fraction when life cycle cost effective</td></tr>
<tr><td>Pipe insulation
(d < 1.5 in. / d ≥ 1.5 in.)</td><td colspan="4">1 in./1.5 in.</td></tr>
<tr><td rowspan="14">HVAC</td><td rowspan="9">GSHP system with DOAS</td><td>GSHP cooling efficiency</td><td colspan="4">17.1 EER</td></tr>
<tr><td>GSHP heating efficiency</td><td colspan="4">3.6 COP</td></tr>
<tr><td>GSHP compressor capacity control</td><td colspan="4">Two stage or variable speed</td></tr>
<tr><td>Water circulation pumps</td><td colspan="4">VFD and NEMA premium efficiency</td></tr>
<tr><td>Cooling tower/fluid cooler</td><td colspan="4">VFD on fans</td></tr>
<tr><td>Boiler efficiency</td><td colspan="4">90% Ec</td></tr>
<tr><td>Maximum fan power</td><td colspan="4">0.4 W/cfm</td></tr>
<tr><td>Exhaust-air energy recovery in DOAS</td><td colspan="2">A (humid) zones: 60% enthalpy reduction
B (dry) zones: 60% dry-bulb temperature reduction</td><td colspan="2">A (humid) zones: 60% enthalpy reduction
B (dry) zones: 60% dry-bulb temperature reduction
C (marine) zones: 60% enthalpy reduction</td></tr>
<tr><td>DOAS ventilation control</td><td colspan="4">DCV with VFD</td></tr>
<tr><td rowspan="5">Fan-coil system with DOAS</td><td>Water-cooled chiller efficiency</td><td colspan="4">Comply with 90.1</td></tr>
<tr><td>Water circulation pumps</td><td colspan="4">VFD and NEMA premium efficiency</td></tr>
<tr><td>Boiler efficiency</td><td colspan="4">90% Ec</td></tr>
<tr><td>Maximum fan power</td><td colspan="4">0.4 W/cfm</td></tr>
<tr><td>FCU fans</td><td colspan="4">Multiple speed</td></tr>
</tbody>
</table>

Item		Component	Climate Zone 1 Recommendations	Climate Zone 2 Recommendations	Climate Zone 3 Recommendations	Climate Zone 4 Recommendations
		Economizer	Comply with 90.1			
		Exhaust-air energy recovery in DOAS	A (humid) zones: 60% enthalpy reduction B (dry) zones: 60% dry-bulb temperature reduction		A (humid) zones: 60% enthalpy reduction B (dry) zones: 60% dry-bulb temperature reduction C (marine) zones: 60% enthalpy reduction	
		DOAS ventilation control	DCV with VFD			
	VAV air-handling system with DOAS	Air-cooled chiller efficiency	10.0 EER, 12.75 IPLV			
		Water-cooled chiller efficiency	Comply with 90.1			
		Water-circulation pumps	VFD and NEMA premium efficiency			
		Boiler efficiency	90% Ec			
		Maximum fan power	0.8 W/cfm			
		Economizer	Comply with 90.1			
		Exhaust-air energy recovery in DOAS	A (humid) zones: 60% enthalpy reduction B (dry) zones: 60% dry-bulb temperature reduction		A (humid) zones: 60% enthalpy reduction B (dry) zones: 60% dry-bulb temperature reduction C (marine) zones: 60% enthalpy reduction	
		DOAS ventilation control	DCV with VFD			
	Ducts and dampers	OA damper	Motorized damper			
		Duct seal class	Seal Class A			
		Insulation level	R-6			
QA	M&V/ benchmarking	Electrical submetering	Separately meter lighting, HVAC, general 120 V, renewables, and whole building. Begin submetering early to address issues during warranty period			
		Benchmarking	Benchmark monthly energy use and provide training on benchmarking			

Table 5–2 AEDG-K12 Recommendations: Climate Zones 5–8

<table>
<tr><th colspan="2">Item</th><th>Component</th><th>Climate Zone 5 Recommendations</th><th>Climate Zone 6 Recommendations</th><th>Climate Zone 7 Recommendations</th><th>Climate Zone 8 Recommendations</th></tr>
<tr><td rowspan="27">Envelope</td><td rowspan="4">Roofs</td><td>Insulation entirely above deck</td><td colspan="2">R-30.0 c.i.</td><td colspan="2">R-35.0 c.i.</td></tr>
<tr><td>Attic and other</td><td colspan="2">R-49.0</td><td colspan="2">R-60.0</td></tr>
<tr><td>Metal building</td><td colspan="2">R-25.0 + R-11.0 Ls</td><td>R-30.0 + R-11.0 Ls</td><td>R-25.0 + R-11.0 + R-11.0 Ls</td></tr>
<tr><td>SRI</td><td colspan="4">Comply with 90.1</td></tr>
<tr><td rowspan="5">Walls</td><td>Mass (HC > 7 Btu/ft²)</td><td>R-13.3 c.i.</td><td colspan="3">R-19.5 c.i.</td></tr>
<tr><td>Steel framed</td><td>R-13.0 + R-15.6 c.i.</td><td colspan="3">R-13.0 + R-18.8 c.i.</td></tr>
<tr><td>Wood framed and other</td><td>R-13.0 + R-10.0 c.i.</td><td>R-13.0 + R-12.5 c.i.</td><td>R-13.0 + R-15.0 c.i.</td><td>R-13.0 + R-18.8 c.i.</td></tr>
<tr><td>Metal building</td><td colspan="2">R-0.0 + R-19.0 c.i.</td><td>R-0.0 + R-22.1 c.i.</td><td>R-0.0 + R-25.0 c.i.</td></tr>
<tr><td>Below-grade walls</td><td>R-7.5 c.i.</td><td>R-10.0 c.i.</td><td colspan="2">R-15.0 c.i.</td></tr>
<tr><td rowspan="3">Floors</td><td>Mass</td><td>R-14.6 c.i.</td><td>R-16.7 c.i.</td><td>R-20.9 c.i.</td><td>R-23.0 c.i.</td></tr>
<tr><td>Steel framed</td><td colspan="2" rowspan="2">R-38.0</td><td rowspan="2">R-49.0</td><td rowspan="2">R-60.0</td></tr>
<tr><td>Wood framed and other</td></tr>
<tr><td rowspan="2">Slabs</td><td>Unheated</td><td>Comply with 90.1</td><td>R-10 for 24 in.</td><td colspan="2">R-20 for 24 in.</td></tr>
<tr><td>Heated</td><td>R-20 for 24 in.</td><td>R-20 for 48 in.</td><td>R-25 for 48 in.</td><td>R-20 full slab</td></tr>
<tr><td rowspan="2">Doors</td><td>Swinging</td><td colspan="4" rowspan="2">U-0.50</td></tr>
<tr><td>Nonswinging</td></tr>
<tr><td>Vestibules</td><td>At building entrance</td><td colspan="4">Yes</td></tr>
<tr><td rowspan="8">View fenestration</td><td rowspan="2">Thermal transmittance</td><td colspan="2">Nonmetal framing = 0.35</td><td>Nonmetal framing = 0.33</td><td>Nonmetal framing = 0.25</td></tr>
<tr><td>Metal framing = 0.44</td><td>Metal framing = 0.42</td><td colspan="2">Metal framing = 0.34</td></tr>
<tr><td rowspan="2">Fenestration-to-floor area ratio</td><td colspan="4">E or W orientation = 5% maximum</td></tr>
<tr><td colspan="4">N or S orientation = 7% maximum</td></tr>
<tr><td rowspan="3">SHGC</td><td colspan="2">E or W orientation = 0.42</td><td colspan="2">E or W orientation = 0.45</td></tr>
<tr><td colspan="4">N orientation = 0.62</td></tr>
<tr><td colspan="4">S orientation = 0.75</td></tr>
<tr><td>Exterior sun control</td><td colspan="4">S orientation only = PF-0.5</td></tr>
<tr><td rowspan="2">Daylighting fenestration</td><td>VLT</td><td colspan="4">See Table 5-5 in the AEDG-K12 for appropriate VLT values</td></tr>
<tr><td>Interior/exterior sun control</td><td colspan="4">S orientation = no glare during school hours</td></tr>
<tr><td></td><td>Daylighting</td><td>Classrooms, resource rooms, cafeteria, gym, and multipurpose rooms.</td><td colspan="4">Daylight 100% of floor area for 2/3 of school hours</td></tr>
</table>

Item		Component	Climate Zone 5 Recommendations	Climate Zone 6 Recommendations	Climate Zone 7 Recommendations	Climate Zone 8 Recommendations
Lighting/daylighting		Administrative areas	Daylight perimeter floor area (within 15 feet) for 2/3 of school hours			
	Interior finishes	Interior surface average reflectance for daylighted rooms	Ceilings = 80%; wall surfaces = 70%			
	Interior lighting	LPD	Whole building = 0.7 W/ft²			
			Gyms, multipurpose rooms = 1.0 W/ft²			
			Classrooms, art rooms, kitchens, libraries, media centers = 0.8 W/ft²			
			Cafeterias, lobbies = 0.7 W/ft²			
			Offices = 0.6 W/ft²			
			Auditoriums, restrooms = 0.5 W/ft²			
			Corridors, mechanical rooms = 0.4 W/ft²			
		Light source lamp efficacy (mean lumens per watt)	T8 and T5 > 2 ft = 92; T8 and T5 < 2 ft = 85; all other > 50			
		T8 ballasts	Nondimming = NEMA premium instant start; dimming = premium program start			
		T5/T5 high output ballasts	Electronic program start			
		CFL and HID ballasts	Electronic			
		Dimming controls daylight harvesting	Dim all fixtures in daylit zones			
		Lighting controls	Manual ON, auto/timed OFF in all areas as possible			
	Exterior lighting	Façade and landscape lighting	LPD = 0.075 W/ft² in LZ3&4; LPD = 0.05 W/ft² in LZ2; Controls = auto OFF between 12:00 a.m. and 6:00 a.m.			
		Parking lots and drives	LPD = 0.1 W/ft² in LZ3 & 4; LPD = 0.06 W/ft² in LZ2; Controls = auto reduce to 25% (12:00 a.m. to 6:00 a.m.)			
		Walkways, plazas, and special feature areas	LPD = 0.16 W/ft² LZ3 and LZ4; LPD = 0.14 W/ft² in LZ2; Controls = auto reduce to 25% (12:00 a.m. to 6:00 a.m.)			
		All other exterior lighting	LPD = follow 90.1-2010; controls = auto reduce to 25% (12:00 a.m. to 6:00 a.m.)			
Plug and process	Equipment choices	Laptop computers	Minimum 2/3 of total computers			
		ENERGY STAR equipment	All computers, equipment, and appliances			
		Vending machines	De-lamp and specify best in class efficiency			
	Controls	Computer power control	Network control with power saving modes and control OFF during unoccupied hours			
		Power outlet control	Controllable power outlets with auto OFF during unoccupied hours for classrooms, office, library/media spaces. All plug-in equipment not requiring continuous operation to use controllable outlets			
		Policies	Implement at least one: - District/school policy on allowed equipment			

<table>
<tr><th colspan="2">Item</th><th>Component</th><th>Climate Zone 5 Recommendations</th><th>Climate Zone 6 Recommendations</th><th>Climate Zone 7 Recommendations</th><th>Climate Zone 8 Recommendations</th></tr>
<tr><td></td><td></td><td></td><td colspan="4">- School energy teams</td></tr>
<tr><td rowspan="3">Kitchen</td><td rowspan="3">Kitchen equipment</td><td>Cooking equipment</td><td colspan="4">ENERGY STAR or California rebate-qualified equipment</td></tr>
<tr><td>Walk-in refrigeration equipment</td><td colspan="4">6 in. insulation on low-temp walk-in equipment, insulated floor, LED lighting, floating-head pressure controls, liquid pressure amplifier, sub-cooled liquid refrigerant, evaporative condenser</td></tr>
<tr><td>Exhaust hoods</td><td colspan="4">Side panels, larger overhangs, rear seal at appliances, proximity hoods, VAV demand-based exhaust</td></tr>
<tr><td rowspan="6">SWH</td><td rowspan="6">SWH</td><td>Gas water heater (condensing)</td><td colspan="4">95% efficiency</td></tr>
<tr><td>Electric water heater
(< 12 kW, > 20 gal)</td><td colspan="4">EF > 0.99 – 0.0012 × volume</td></tr>
<tr><td>Point-of-use heater selection</td><td colspan="4">0.81 EF or 81% Et</td></tr>
<tr><td>Electric heat pump water heater</td><td colspan="4">COP 3.0 (interior heat source)</td></tr>
<tr><td>Solar water heating</td><td colspan="4">30% solar hot water fraction when life cycle cost effective</td></tr>
<tr><td>Pipe insulation
(d < 1.5 in. / d ≥ 1.5 in.)</td><td colspan="4">1 in. / 1.5 in.</td></tr>
<tr><td rowspan="14">HVAC</td><td rowspan="10">GSHP system with DOAS</td><td>GSHP cooling efficiency</td><td colspan="4">17.1 EER</td></tr>
<tr><td>GSHP heating efficiency</td><td colspan="4">3.6 COP</td></tr>
<tr><td>GSHP compressor capacity control</td><td colspan="4">Two stage or variable speed</td></tr>
<tr><td>Water-circulation pumps</td><td colspan="4">VFD and NEMA premium efficiency</td></tr>
<tr><td>Cooling tower/fluid cooler</td><td colspan="4">VFD on fans</td></tr>
<tr><td>Boiler efficiency</td><td colspan="4">90% Ec</td></tr>
<tr><td>Maximum fan power</td><td colspan="4">0.4 W/cfm</td></tr>
<tr><td>Exhaust-air energy recovery in DOAS</td><td>A (humid) zones: 60% enthalpy reduction
B (dry) zones: 60% dry-bulb temperature reduction
C (marine) zones: 60% enthalpy reduction</td><td colspan="2">A (humid) zones: 60% enthalpy reduction
B (dry) zones: 60% dry-bulb temperature reduction</td><td>60% dry-bulb temperature reduction</td></tr>
<tr><td>DOAS ventilation control</td><td colspan="4">DCV with VFD</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="4">Fan-coil system with DOAS</td><td>Water-cooled chiller efficiency</td><td colspan="4">Comply with 90.1</td></tr>
<tr><td>Water-circulation pumps</td><td colspan="4">VFD and NEMA premium efficiency</td></tr>
<tr><td>Boiler efficiency</td><td colspan="4">90% Ec</td></tr>
<tr><td>Maximum fan power</td><td colspan="4">0.4 W/cfm</td></tr>
</table>

Item		Component	Climate Zone 5 Recommendations	Climate Zone 6 Recommendations	Climate Zone 7 Recommendations	Climate Zone 8 Recommendations
		FCU fans	Multiple speed			
		Economizer	Comply with 90.1			
		Exhaust-air energy recovery in DOAS	A (humid) zones: 60% enthalpy reduction B (dry) zones: 60% dry-bulb temperature reduction C (marine) zones: 60% enthalpy reduction	A (humid) zones: 60% enthalpy reduction B (dry) zones: 60% dry-bulb temperature reduction		60% dry-bulb temperature reduction
		DOAS ventilation control	DCV with VFD			
	VAV air-handling system with DOAS	Air-cooled chiller efficiency	10.0 EER, 12.75 IPLV			
		Water-cooled chiller efficiency	Comply with 90.1			
		Water-circulation pumps	VFD and NEMA premium efficiency			
		Boiler efficiency	90% Ec			
		Maximum fan power	0.8 W/cfm			
		Economizer	Comply with 90.1			
		Exhaust-air energy recovery in DOAS	A (humid) zones: 60% enthalpy reduction B (dry) zones: 60% dry-bulb temperature reduction C (marine) zones: 60% enthalpy reduction	A (humid) zones: 60% enthalpy reduction B (dry) zones: 60% dry-bulb temperature reduction		60% dry-bulb temperature reduction
		DOAS ventilation control	DCV with VFD			
	Ducts and dampers	OA damper	Motorized damper			
		Duct seal class	Seal Class A			
		Insulation level	R-6			
QA	M&V/ benchmarking	Electrical submetering	Separately meter lighting, HVAC, general 120V, renewables, and whole building. Begin submetering early to address issues during warranty period			
		Benchmarking	Benchmark monthly energy use and provide training on benchmarking			

5.2 Energy Savings Results

When the AEDG-K12 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	Primary School			Secondary School		
		VAV DOAS	FCU DOAS	GSHP DOAS	VAV DOAS	FCU DOAS	GSHP DOAS
1A	Miami, Florida	58.0%	67.9%	56.5%	56.5%	64.8%	55.4%
2A	Houston, Texas	59.7%	68.0%	60.6%	58.2%	65.2%	58.8%
2B	Phoenix, Arizona	62.2%	69.6%	63.1%	59.1%	66.7%	60.6%
3A	Atlanta, Georgia	55.2%	62.5%	57.4%	55.1%	61.4%	56.4%
3B:CA	Los Angeles, California	51.1%	58.4%	54.6%	51.7%	57.8%	53.5%
3B	Las Vegas, Nevada	56.1%	63.6%	58.4%	55.1%	62.8%	57.3%
3C	San Francisco, California	53.3%	58.7%	58.3%	54.4%	59.2%	57.6%
4A	Baltimore, Maryland	56.9%	62.7%	60.1%	57.5%	62.5%	59.5%
4B	Albuquerque, New Mexico	56.4%	61.6%	59.8%	56.9%	61.6%	58.9%
4C	Seattle, Washington	54.8%	59.2%	59.9%	56.5%	60.1%	59.7%
5A	Chicago, Illinois	57.2%	62.1%	60.9%	58.0%	62.1%	60.4%
5B	Denver, Colorado	56.3%	60.7%	60.9%	57.4%	61.1%	60.1%
6A	Minneapolis, Minnesota	58.9%	62.9%	63.2%	59.6%	62.9%	62.3%
6B	Helena, Montana	57.6%	61.1%	63.1%	58.7%	61.6%	62.1%
7	Duluth, Minnesota	59.2%	62.1%	64.5%	59.8%	62.2%	63.3%
8	Fairbanks, Alaska	55.3%	57.5%	62.8%	55.4%	57.2%	60.5%

Energy savings are relative to the Standard 90.1-2004 (ASHRAE 2004b) baseline energy use, and include plug loads in the energy use of the baseline and low-energy models. The analysis shows that the recommendations in the AEDG-K12 meet or exceed the goal of 50% energy savings and that this goal can be met with a range of HVAC system types. Energy savings by school type does not vary significantly from one climate zone to another.

The simulation results are presented in Table 5–4 through Table 5–15, broken out by low-energy model HVAC system type (see Section 3.4.4 for details about the different HVAC system types).

5.2.1 Ground-Source Heat Pump System

Table 5–4 Primary School GSHP System Simulation Results, Climate Zones 1A–4A

	End Use	1A	2A	2B	3A	3B:CA	3B	3C	4A
kBtu/ft²yr	Interior equipment (electric)	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
	Interior equipment (gas)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	Interior lighting (electric)	5.3	5.4	5.2	5.5	5.3	5.2	5.4	5.5
	Exterior lighting (electric)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Heating (electric)	0.0	0.2	0.2	0.4	0.1	0.4	0.4	0.8
	Heating (gas)	0.0	0.9	0.6	1.8	0.3	0.9	1.0	3.3
	Cooling (electric)	5.2	3.3	3.0	1.9	1.1	2.3	0.3	1.3
	Fans (electric)	2.0	2.0	2.0	2.0	2.0	2.0	2.8	2.0
	Pumps (electric)	5.6	3.9	3.3	3.1	1.4	2.6	0.8	2.9
	SWH (gas)	0.8	1.1	1.0	1.3	1.3	1.1	1.5	1.5
	Refrigeration (electric)	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1
	Total	29.5	27.2	25.8	26.4	21.8	24.9	22.6	27.8
Percent savings (%)		56.5	60.6	63.1	57.4	54.6	58.4	58.3	60.1

Table 5–5 Primary School GSHP System Simulation Results, Climate Zones 4B–8

	End Use	4B	4C	5A	5B	6A	6B	7	8
kBtu/ft²yr	Interior equipment (electric)	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
	Interior equipment (gas)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	Interior lighting (electric)	5.3	5.9	5.6	5.5	5.7	5.6	5.7	6.0
	Exterior lighting (electric)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Heating (electric)	0.6	0.9	1.2	1.0	1.6	1.8	2.0	5.8
	Heating (gas)	2.0	3.1	4.7	3.1	6.6	5.2	8.2	16.6
	Cooling (electric)	1.1	0.2	1.0	0.7	0.7	0.3	0.2	0.1
	Fans (electric)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.1
	Pumps (electric)	1.8	1.3	3.1	1.6	3.0	1.6	2.4	2.7
	SWH (gas)	1.5	1.6	1.7	1.7	1.9	1.9	2.1	2.3
	Refrigeration (electric)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	Total	24.7	25.4	29.6	25.9	31.8	28.7	32.9	45.9
Percent savings (%)		59.8	59.9	60.9	60.9	63.2	63.1	64.5	62.8

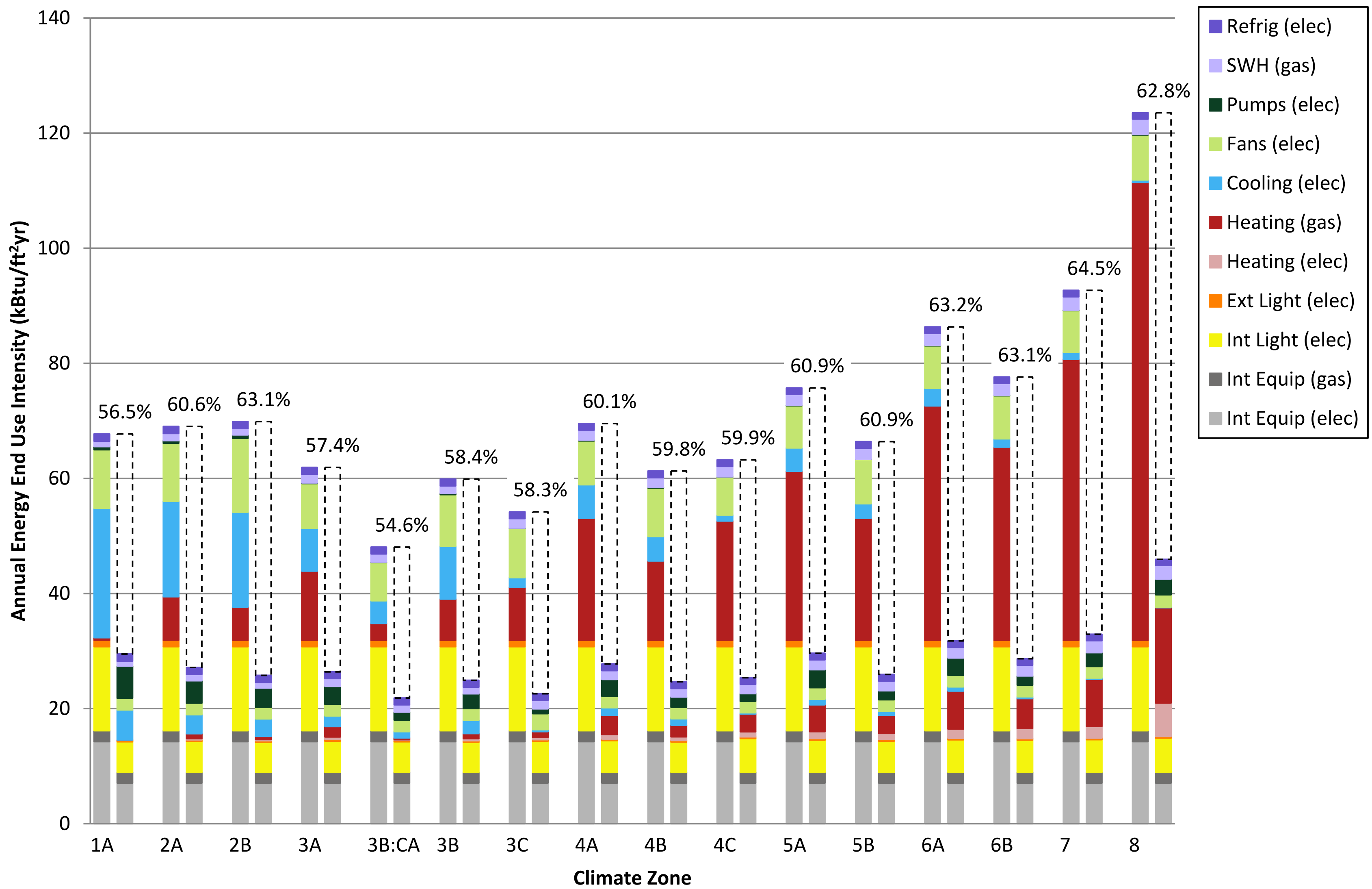


Figure 5–1 Primary school GSHP system simulation results

Table 5–6 Secondary School GSHP System Simulation Results, Climate Zones 1A–4A

	End Use	1A	2A	2B	3A	3B:CA	3B	3C	4A
kBtu/ft²yr	Interior equipment (electric)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	Interior equipment (gas)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Interior lighting (electric)	5.4	5.5	5.3	5.5	5.4	5.3	5.5	5.6
	Exterior lighting (electric)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Heating (electric)	0.0	0.1	0.1	0.2	0.0	0.1	0.1	0.4
	Heating (gas)	0.1	1.2	0.8	2.4	0.5	1.2	1.7	4.6
	Cooling (electric)	5.8	3.9	3.9	2.4	1.3	3.1	0.5	1.7
	Fans (electric)	5.0	4.9	4.9	4.9	4.3	4.9	4.6	4.7
	Pumps (electric)	4.4	3.2	2.7	2.5	1.3	2.2	0.8	2.2
	SWH (gas)	0.7	1.0	0.9	1.2	1.2	1.0	1.4	1.4
	Refrigeration (electric)	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
	Total	30.1	28.3	27.2	27.9	22.7	26.4	23.2	29.2
Percent savings (%)		55.4	58.8	60.6	56.4	53.5	57.3	57.6	59.5

Table 5–7 Secondary School GSHP System Simulation Results, Climate Zones 4B–8

	End Use	4B	4C	5A	5B	6A	6B	7	8
kBtu/ft²yr	Interior equipment (electric)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	Interior equipment (gas)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Interior lighting (electric)	5.3	5.9	5.7	5.5	5.7	5.6	5.7	6.0
	Exterior lighting (electric)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9
	Heating (electric)	0.2	0.4	0.7	0.4	0.9	0.8	1.2	3.5
	Heating (gas)	2.6	4.4	6.5	4.2	9.1	7.1	11.3	22.8
	Cooling (electric)	1.6	0.4	1.2	1.0	1.0	0.5	0.4	0.2
	Fans (electric)	5.1	4.4	4.6	5.1	4.6	4.8	4.5	4.6
	Pumps (electric)	1.5	1.0	2.2	1.2	2.1	1.1	1.5	1.7
	SWH (gas)	1.4	1.5	1.6	1.6	1.7	1.7	1.9	2.2
	Refrigeration (electric)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Total	26.3	26.6	31.1	27.6	33.7	30.3	35.1	49.5
Percent savings (%)		58.9	59.7	60.4	60.1	62.3	62.1	63.3	60.5

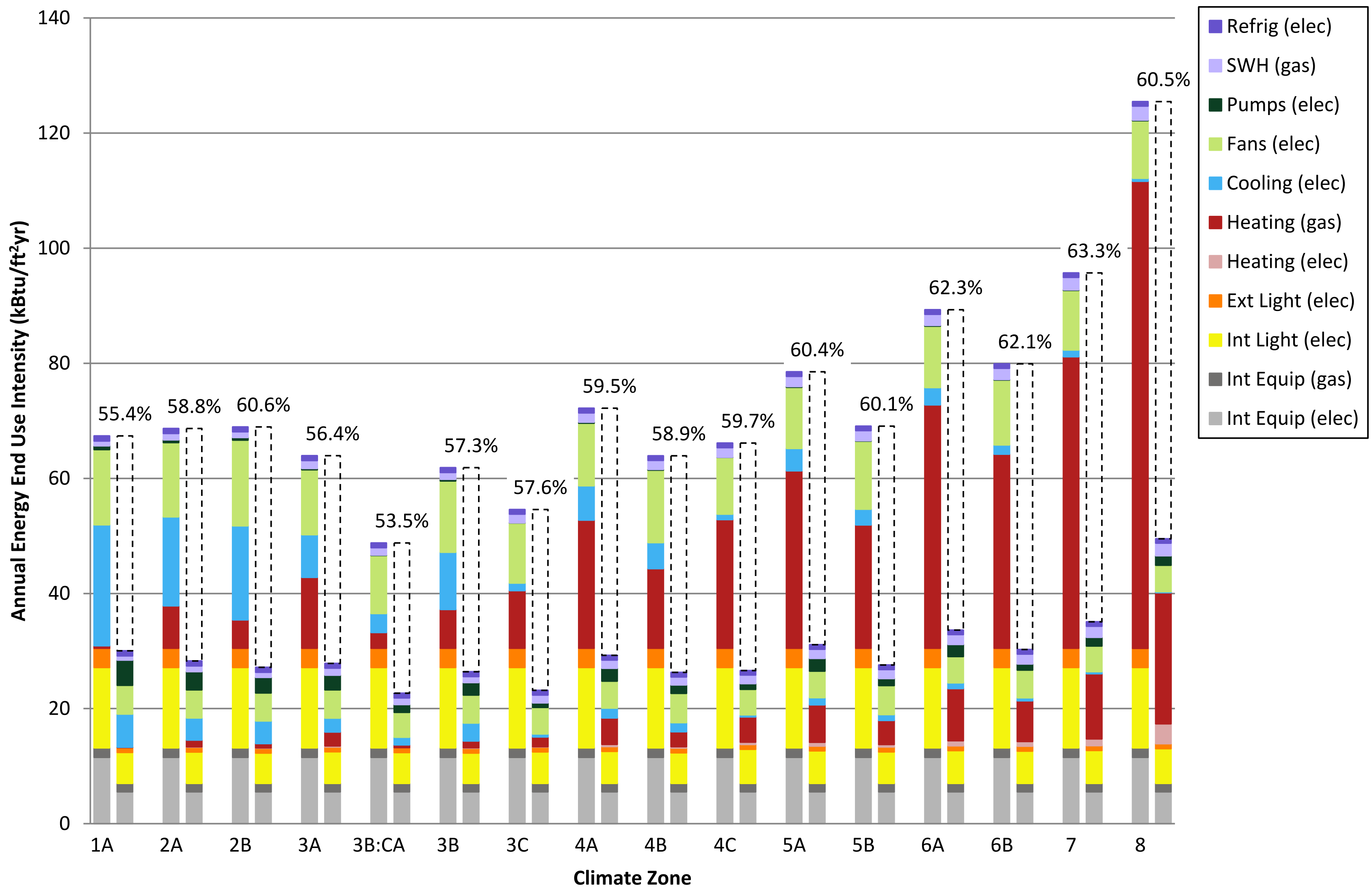


Figure 5–2 Secondary school GSHP system simulation results

5.2.2 Fan Coil System

Table 5–8 Primary School FCU System Simulation Results, Climate Zones 1A–4A

	End Use	1A	2A	2B	3A	3B:CA	3B	3C	4A
kBtu/ft²yr	Interior equipment (electric)	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
	Interior equipment (gas)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	Interior lighting (electric)	5.3	5.4	5.2	5.5	5.3	5.2	5.4	5.5
	Exterior lighting (electric)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heating (gas)	0.0	1.5	1.3	3.3	0.6	2.1	2.2	6.0
	Cooling (electric)	2.2	1.3	1.1	0.6	0.3	0.7	0.1	0.4
	Fans (electric)	2.2	2.1	2.1	2.1	2.0	2.0	2.8	2.0
	Pumps (electric)	0.6	0.3	0.2	0.2	0.1	0.1	0.0	0.1
	SWH (gas)	0.8	1.1	1.0	1.3	1.3	1.1	1.5	1.5
	Refrigeration (electric)	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1
	Total	21.7	22.1	21.2	23.2	20.0	21.8	22.4	25.9
Percent savings (%)		67.9	68.0	69.6	62.5	58.4	63.6	58.7	62.7

Table 5–9 Primary School FCU System Simulation Results, Climate Zones 4B–8

	End Use	4B	4C	5A	5B	6A	6B	7	8
kBtu/ft²yr	Interior equipment (electric)	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
	Interior equipment (gas)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	Interior lighting (electric)	5.3	5.9	5.6	5.5	5.7	5.6	5.7	6.0
	Exterior lighting (electric)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heating (gas)	4.0	5.9	8.7	6.3	11.9	10.3	14.9	31.8
	Cooling (electric)	0.3	0.0	0.3	0.2	0.2	0.1	0.1	0.0
	Fans (electric)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.1
	Pumps (electric)	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0
	SWH (gas)	1.5	1.6	1.7	1.7	1.9	1.9	2.1	2.3
	Refrigeration (electric)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	Total	23.5	25.8	28.7	26.1	32.0	30.2	35.1	52.5
Percent savings (%)		61.6	59.2	62.1	60.7	62.9	61.1	62.1	57.5

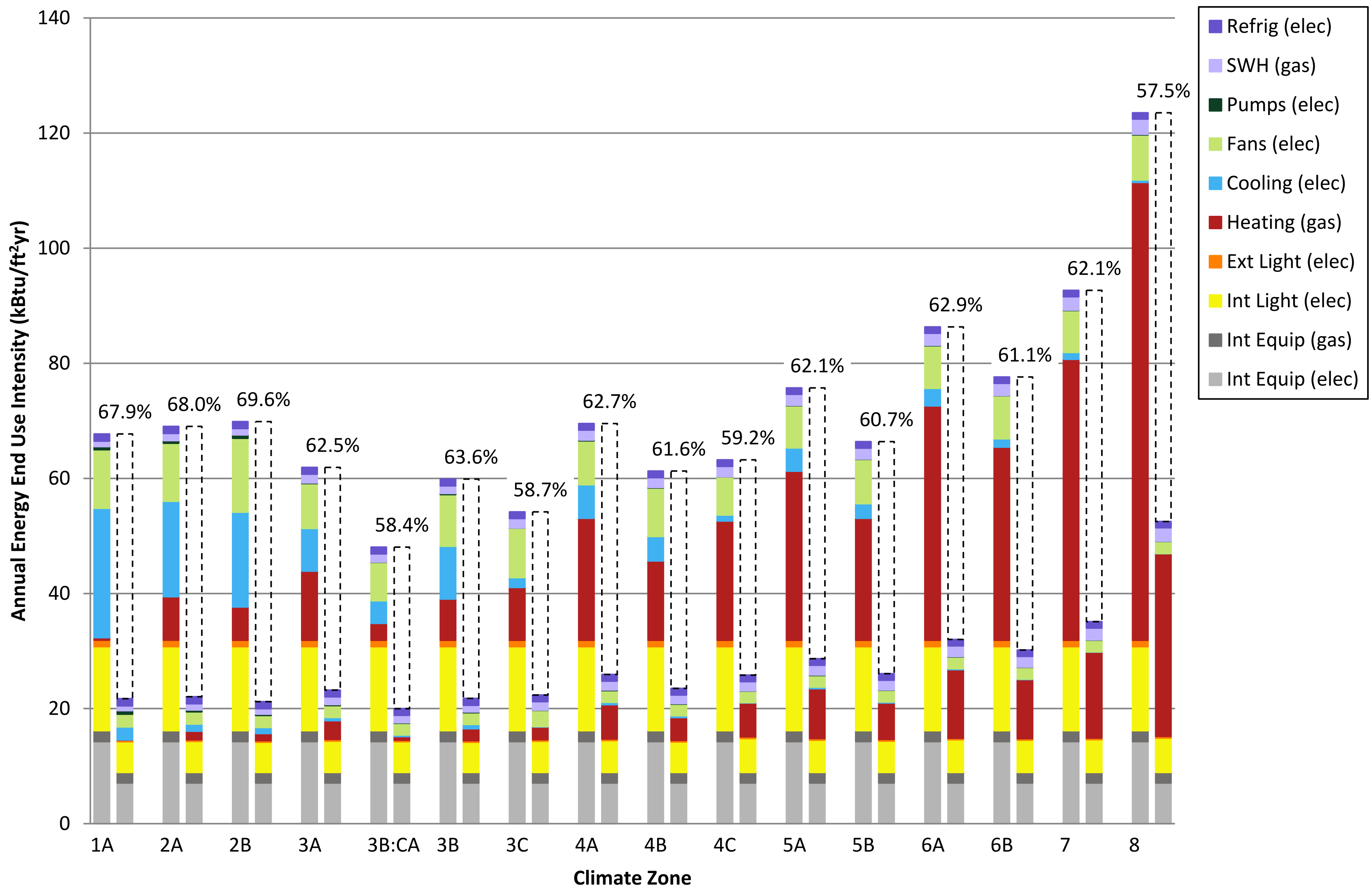


Figure 5–3 Primary school FCU system simulation results

Table 5–10 Secondary School FCU System Simulation Results, Climate Zones 1A–4A

	End Use	1A	2A	2B	3A	3B:CA	3B	3C	4A
kBtu/ft²yr	Interior equipment (electric)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	Interior equipment (gas)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Interior lighting (electric)	5.4	5.5	5.3	5.5	5.4	5.3	5.5	5.6
	Exterior lighting (electric)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heating (gas)	0.1	1.4	0.9	3.0	0.5	1.5	2.0	5.9
	Cooling (electric)	3.1	2.0	2.0	1.1	0.4	1.5	0.2	0.7
	Fans (electric)	5.2	5.0	4.9	5.0	4.3	4.9	4.6	4.7
	Pumps (electric)	0.5	0.3	0.3	0.2	0.1	0.2	0.1	0.2
	SWH (gas)	0.7	1.0	0.9	1.2	1.2	1.0	1.4	1.4
	Refrigeration (electric)	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
	Total	23.7	23.9	22.9	24.7	20.6	23.0	22.3	27.1
Percent savings (%)		64.8	65.2	66.7	61.4	57.8	62.8	59.2	62.5

Table 5–11 Secondary School FCU System Simulation Results, Climate Zones 4B–8

	End Use	4B	4C	5A	5B	6A	6B	7	8
kBtu/ft²yr	Interior equipment (electric)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	Interior equipment (gas)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Interior lighting (electric)	5.3	5.9	5.7	5.5	5.7	5.6	5.7	6.0
	Exterior lighting (electric)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9
	Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heating (gas)	3.3	5.7	8.7	5.6	12.0	9.6	15.2	32.2
	Cooling (electric)	0.7	0.1	0.5	0.4	0.3	0.2	0.1	0.0
	Fans (electric)	5.1	4.4	4.6	5.1	4.6	4.8	4.5	4.6
	Pumps (electric)	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	SWH (gas)	1.4	1.5	1.6	1.6	1.7	1.7	1.9	2.2
	Refrigeration (electric)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Total	24.6	26.4	29.8	26.9	33.1	30.7	36.2	53.7
Percent savings (%)		61.6	60.1	62.1	61.1	62.9	61.6	62.2	57.2

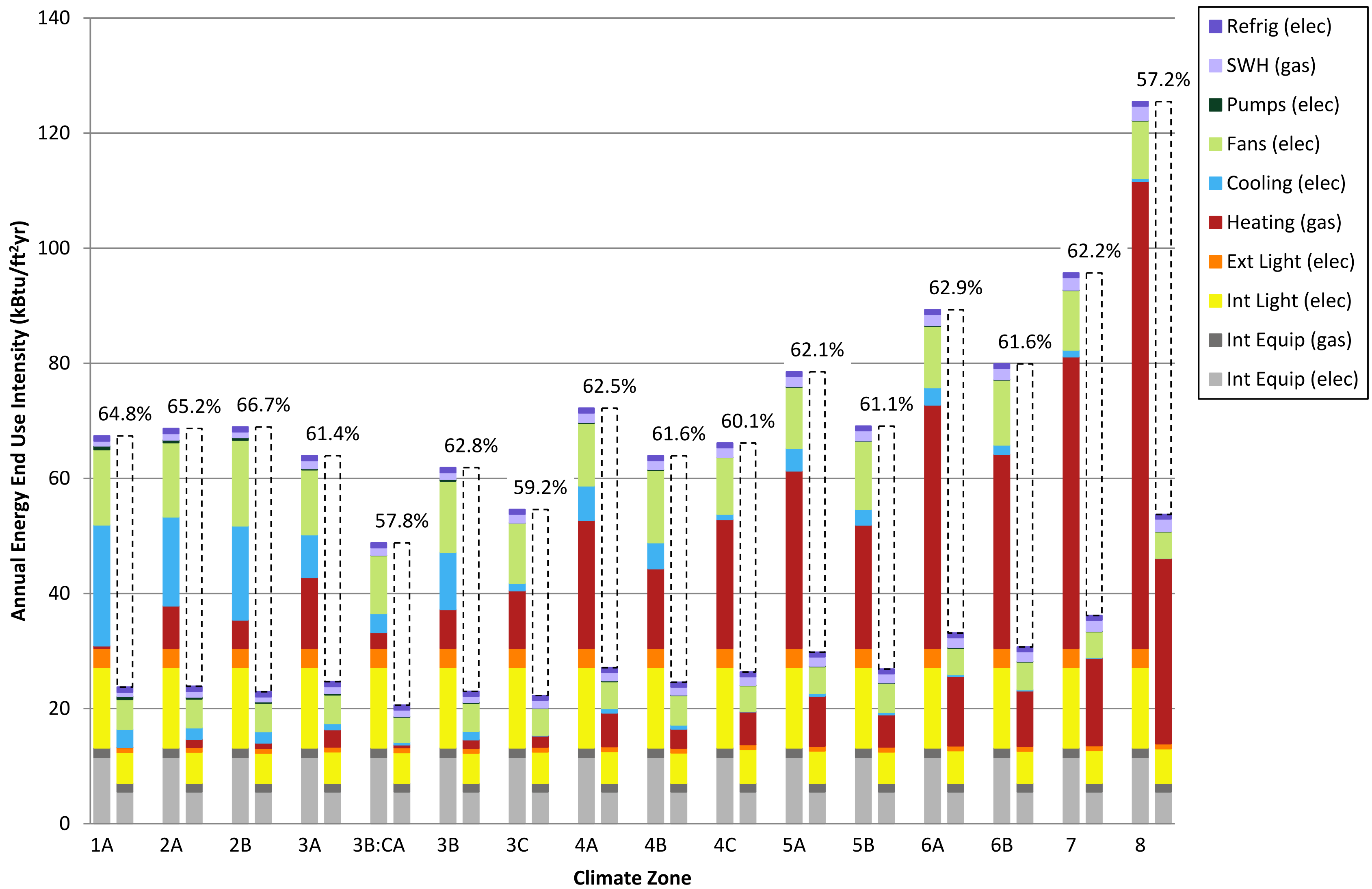


Figure 5–4 Secondary School FCU System Simulation Results

5.2.3 Variable Air Volume Cooling, Baseboard Heating System

Table 5–12 Primary School VAV System Simulation Results, Climate Zones 1A–4A

End Use		1A	2A	2B	3A	3B:CA	3B	3C	4A
kBtu/ft²yr	Interior equipment (electric)	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
	Interior equipment (gas)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	Interior lighting (electric)	5.3	5.4	5.2	5.5	5.3	5.2	5.4	5.5
	Exterior lighting (electric)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heating (gas)	0.1	1.5	1.3	3.3	0.6	2.1	2.2	6.1
	Cooling (electric)	8.8	6.6	5.6	4.6	3.3	4.5	2.4	3.8
	Fans (electric)	2.9	2.8	2.9	2.7	2.6	2.8	3.4	2.6
	Pumps (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SWH (gas)	0.8	1.1	1.0	1.3	1.3	1.1	1.5	1.5
	Refrigeration (electric)	1.2	1.2	1.2	1.2	1.2	1.2	1.1	1.1
	Total	28.4	27.8	26.4	27.8	23.5	26.3	25.3	30.0
Percent savings (%)		58.0	59.7	62.2	55.2	51.1	56.1	53.3	56.9

Table 5–13 Primary School VAV System Simulation Results, Climate Zones 4B–8

End Use		4B	4C	5A	5B	6A	6B	7	8
kBtu/ft²yr	Interior equipment (electric)	7.1	7.1	7.1	7.1	7.1	7.1	7.1	7.1
	Interior equipment (gas)	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
	Interior lighting (electric)	5.3	5.9	5.6	5.5	5.7	5.6	5.7	6.0
	Exterior lighting (electric)	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
	Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heating (gas)	4.1	6.0	8.8	6.5	12.1	10.5	15.2	32.1
	Cooling (electric)	2.8	2.2	3.4	2.4	3.0	2.1	2.1	1.9
	Fans (electric)	2.7	2.6	2.6	2.7	2.6	2.6	2.5	2.5
	Pumps (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SWH (gas)	1.5	1.6	1.7	1.7	1.9	1.9	2.1	2.3
	Refrigeration (electric)	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	Total	26.7	28.6	32.4	29.0	35.5	32.9	37.8	55.2
Percent savings (%)		56.4	54.8	57.2	56.3	58.9	57.6	59.2	55.3

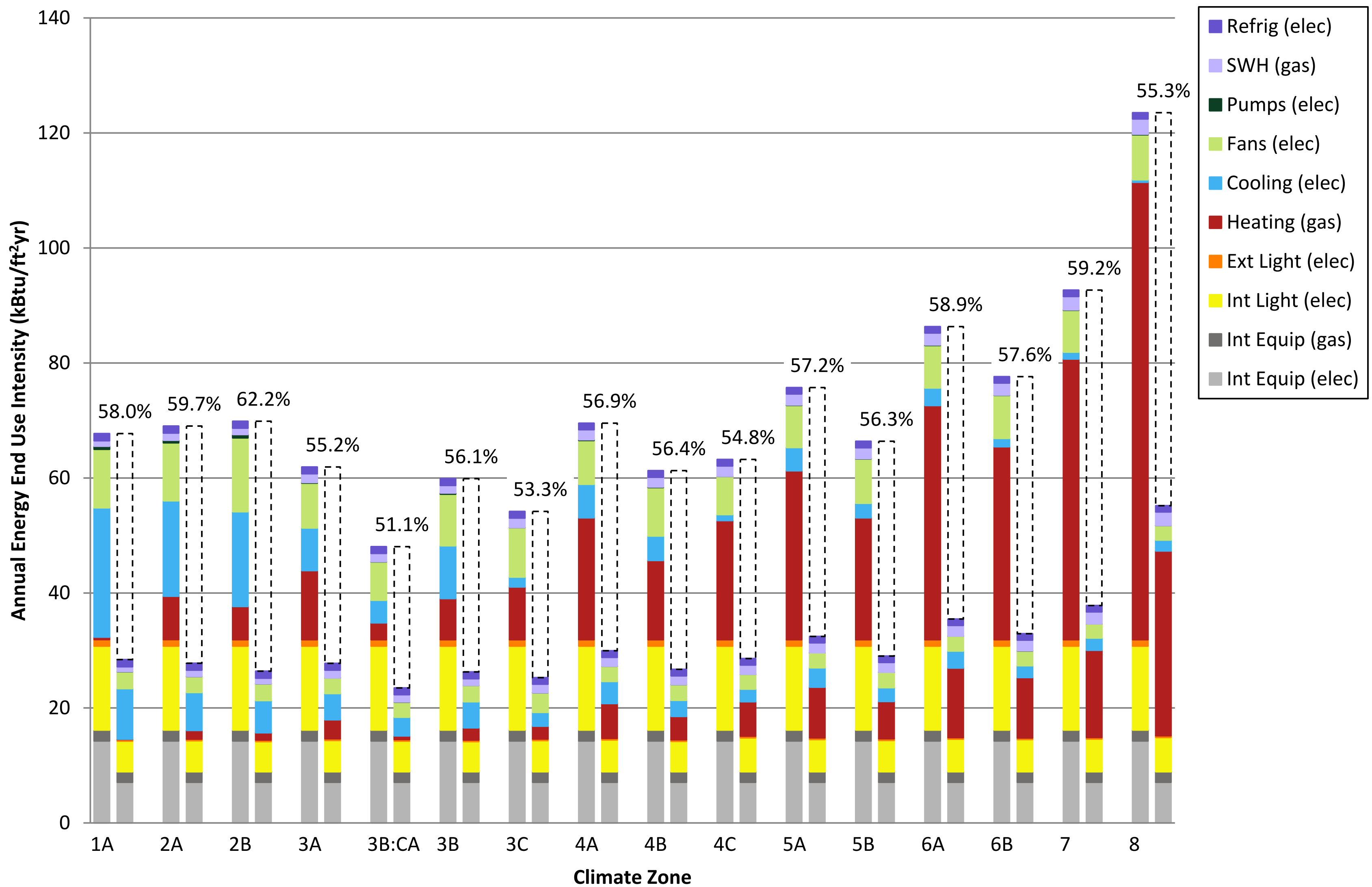


Figure 5–5 Primary school VAV system simulation results

Table 5–14 Secondary School VAV System Simulation Results, Climate Zones 1A–4A

	End Use	1A	2A	2B	3A	3B:CA	3B	3C	4A
kBtu/ft²yr	Interior equipment (electric)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	Interior equipment (gas)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Interior lighting (electric)	5.4	5.5	5.3	5.5	5.4	5.3	5.5	5.6
	Exterior lighting (electric)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heating (gas)	0.1	1.4	0.9	3.1	0.5	1.5	2.0	5.9
	Cooling (electric)	8.4	6.4	6.3	4.5	2.9	5.2	2.2	3.7
	Fans (electric)	6.0	5.8	6.1	5.7	4.9	6.0	5.3	5.3
	Pumps (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SWH (gas)	0.7	1.0	0.9	1.2	1.2	1.0	1.4	1.4
	Refrigeration (electric)	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
	Total	29.3	28.7	28.2	28.7	23.6	27.7	24.9	30.6
Percent savings (%)		56.5	58.2	59.1	55.1	51.7	55.1	54.4	57.5

Table 5–15 Secondary School VAV System Simulation Results, Climate Zones 4B–8

	End Use	4B	4C	5A	5B	6A	6B	7	8
kBtu/ft²yr	Interior equipment (electric)	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
	Interior equipment (gas)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
	Interior lighting (electric)	5.3	5.9	5.7	5.5	5.7	5.6	5.7	6.0
	Exterior lighting (electric)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.9
	Heating (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Heating (gas)	3.4	5.7	8.8	5.7	12.2	9.8	15.4	32.4
	Cooling (electric)	3.0	2.0	3.1	2.4	2.8	1.9	1.9	1.7
	Fans (electric)	5.9	5.0	5.2	5.7	5.1	5.3	4.9	5.0
	Pumps (electric)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	SWH (gas)	1.4	1.5	1.6	1.6	1.7	1.7	1.9	2.2
	Refrigeration (electric)	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Total	27.6	28.8	33.0	29.4	36.1	33.0	38.5	55.9
Percent savings (%)		56.9	56.5	58.0	57.4	59.6	58.7	59.8	55.4

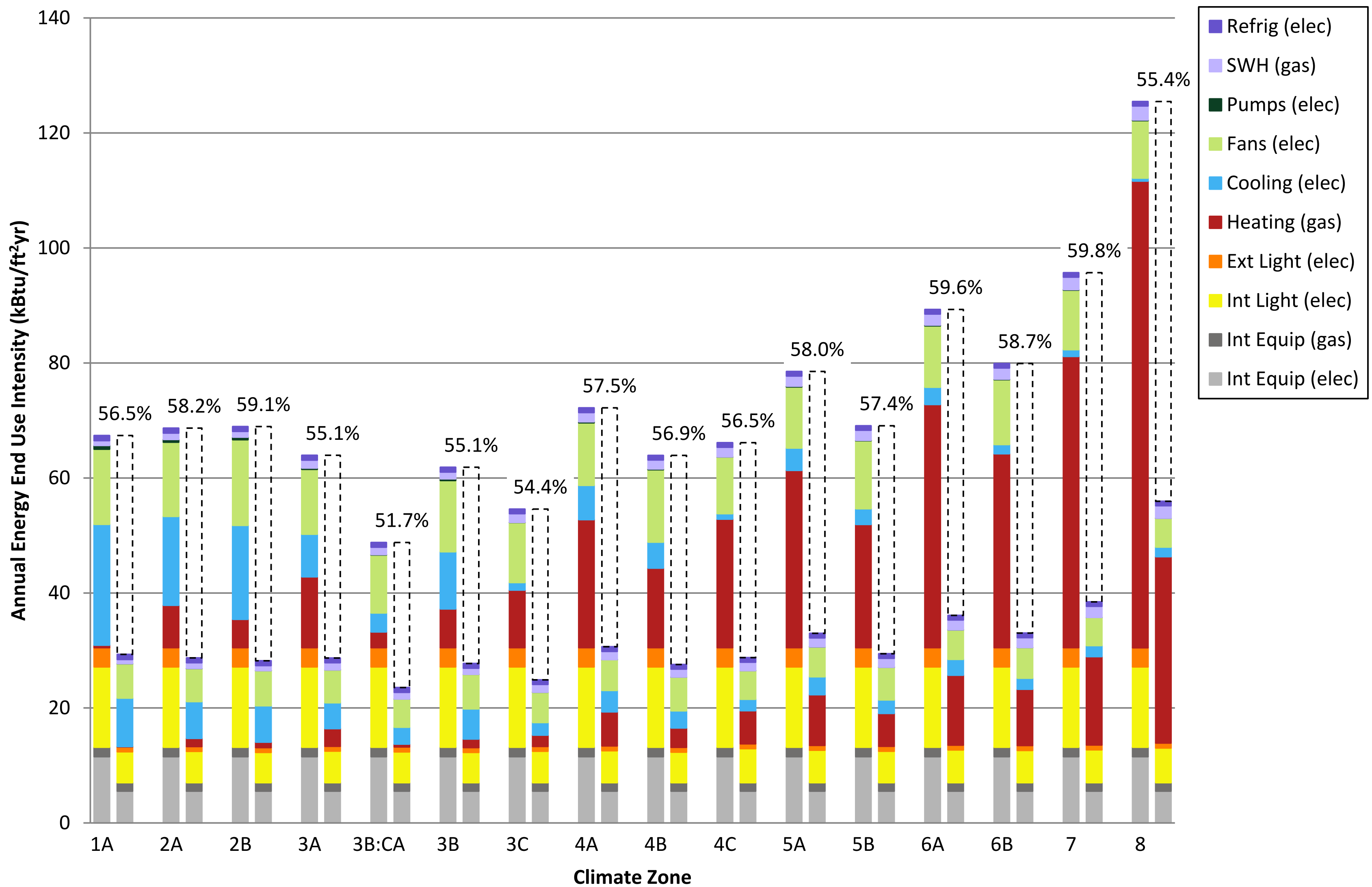


Figure 5–6 Secondary School VAV System Simulation Results

6. Conclusion

This TSD describes the process and methodology used to develop the AEDG-K12, which provides recommendations for achieving 50% whole-building energy savings in K-12 school facilities over levels achieved by following Standard 90.1-2004. The AEDG-K12 was developed in collaboration with ASHRAE, AIA, IES, USGBC, and DOE. It includes:

- User-friendly design assistance and recommendations to design, architectural, and engineering firms to help achieve energy savings
- Prescriptive recommendations by climate zone for designing the building envelope, fenestration lighting systems (including electrical lights and daylighting), HVAC systems, building automation and controls, OA treatment, and SWH
- Additional savings recommendations for alternative HVAC systems and renewable energy systems that are not necessary for 50% savings

NREL's primary tasks in the development of the AEDG-K12 were to provide the analysis and modeling support to verify energy savings and to develop recommendations that meet the 50% savings goal. The purpose of the building energy simulation analysis presented in this TSD is to assess and quantify the energy savings potential of the climate-specific energy efficiency recommendations in the AEDG-K12. This TSD also provides the technical details that were used to determine energy savings, including model inputs and assumptions. The specific objectives of this TSD were to:

- Document the process and schedule used for developing the AEDG-K12.
- Document prototypical K-12 school characteristics.
- Document the EnergyPlus modeling assumptions used to establish 50% energy savings.
- Document the baseline and low-energy EnergyPlus K-12 school models.
- Demonstrate that the recommendations result in 50% or greater energy savings by climate zone.

The AEDG-K12 does not provide detailed documentation for developing recommendations or energy savings details. This TSD was developed separately to document the process used to develop the AEDG-K12 and the analysis and energy modeling performed to support that development.

The AEDG-K12 is 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. In many ways, the AEDG-K12 is a simple interface to a complex analysis performed using EnergyPlus. The combination 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 K-12 school applications strengthen the business case for taking advantage of energy efficiency opportunities.

The 50% energy savings target of the AEDG-K12 represents a step toward achieving net-zero K-12 school facilities. Net-zero energy facilities are buildings that draw equal (or less) energy annually from outside sources than they generate onsite from renewable energy sources. The ultimate goal of the AEDG partner organizations is to achieve net-zero energy buildings, and the AEDG-K12 represents an important step in reaching this goal.

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Appendix A. Scoping Document

Purpose

To significantly transform the marketplace with speed and scale by providing user-friendly, “how-to” design guidance and efficiency recommendations to owners, builders, energy modelers, and designers of K-12 schools in order to achieve energy savings of 50% over ASHRAE Standard 90.1-2004. To install skills and knowledge in practitioners that can be used in a wide variety of buildings.

Background

The ASHRAE Advanced Energy Design Guides (AEDGs) are a series of publications designed to provide recommendations for achieving energy savings over the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-1999. Designers, while complying with minimum energy code requirements, often lack the opportunity or have sufficient design fees to pursue innovative, energy efficient concepts in the design of schools. The 50% AEDG for K-12 schools 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. In a departure from 30% AEDG work, the intent of this work is not to replace energy modeling entirely, but to supplement the recommendations of the guide with user-friendly modeling tools to help owners and designers predict project-specific energy savings achievable through design recommendations implementation.

Goal

To provide owners and designers of K-12 school buildings 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 eight ASHRAE climate zones covered by the guide. The list of representative cities for each climate zone will be consistent with that for the 30% AEDG for K-12 schools.
- 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 K-12 school buildings 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 K-12 schools.

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; see Table A1 in Appendix A for an example of this approach. 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 school 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 – we will require that all recommended products 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 and cost inputs.
- Focus will be given to illustrate 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 K-12 schools, 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 K-12 schools. Energy savings will be measured against "baseline" or "reference" buildings for each climate that are minimally code-compliant with respect to ASHRAE Standard 90.1-2004.

For the purposes of this 50% AEDG, we define a K-12 school as having the following common space types:

- Administrative and office areas
- Classrooms, hallways, and restrooms
- Gymnasiums with locker rooms and showers
- Assembly spaces with either flat or tiered seating
- Food preparation spaces
- Libraries

The AEDG-K12 will not consider atypical specialty spaces such as indoor pools, wet labs (e.g., chemistry), “dirty” dry labs (e.g., woodworking and auto shops), or other unique spaces with extraordinary heat or pollution generation.

The 50% AEDG for K-12 schools will apply to all sizes and classifications (elementary, middle and high schools) of new construction K-12 school buildings. Recommendations will be based on two different prototype designs: a ~74,500 ft² primary school and a ~210,000 ft² secondary school. Single zone “vignette” models will be created to analyze key space types such as north- and south-facing classrooms. Whole-building models adapted from the prototype designs and vignette models will be equipped with HVAC systems designed to meet minimum ventilation requirements and maintain ASHRAE comfort standards year-round. Ventilation and other internal load requirements will be reduced during summer months due to reduced building occupancy.

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 computing and kitchen process loads
- Commissioning

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

- Steam heating
- Modular classrooms
- Vehicle and other maintenance areas
- Domestic water well pumping
- Sewage disposal

The guide is not intended to substitute for rating systems or references that address the full range of sustainable issues in schools, 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 school 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

K-12 Advanced Energy Design Guide - 50% Energy Savings
Project Committee Meeting 1 Agenda

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

Wednesday, December 1, 2010, 8:00AM – 5:00PM
Thursday, December 2, 2010, 8:00AM – 2:00PM

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 Wednesday 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 high performance schools
- Bring calendars for next spring/summer
- 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
- Form working groups and section assignments

Agenda

Wednesday, December 1, 2010

1	Welcome/review agenda	Pless	8:00
2	Introductions • Give name/affiliation and experience working with high performance schools • Be ready to share the energy efficiency strategies that you have used in high performance schools (what do you think it takes to get to 50% energy savings)	All	8:15
3	AEDG-K12 overview • Organization of AEDG series • Committee makeup structure/partnering organization • Scoping document formation • Reference case determination	Colliver (NREL to provide slides)	9:15

4	Review and questions on scoping document • Context of the other AEDGs • Goals and objectives of the AEDG-K12 • 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)	Colliver (NREL to provide slides)	9:30
5	Break	All	10:00
6	AEDG-K12 development schedule Future meeting schedule • Bring your calendars for next spring/summer	Pratt/Pless	10:15
7	Outline of AEDG-K12 • 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	Lunch	All	12:00
9	Energy modeling • Analysis engine and modeling background • Baseline building discussion • Preliminary modeling results • Plans for modeling going forward	Bonnema/Leach	1:00
10	Break	All	3:00
11	How to use model results to develop the AEDG-K12? What additional modeling can we do?	All	3:15

Thursday, December 2, 2010

1	Group breakout • Lighting/daylighting • Architecture, envelope, and integrated design • HVAC • O&M, commissioning (important!)	Groups	8:00
2	Break	All	10:15
3	Group breakout	Groups	10:45
4	Working lunch (discuss case studies) • Bring case studies to share	All	12:00
5	Review • Group breakout sessions • Action items for next meeting	All	1:00
8	Adjourn	All	2:00

B.2 Meeting 2

K-12 Advanced Energy Design Guide - 50% Energy Savings
Project Committee Meeting 2 Agenda

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

Thursday, February 10, 2011, 8:00AM – 5:00PM
Friday, February 11, 2011, 8:00AM – 2:00PM

Continental breakfast will be served each morning at 7:45 at NREL. On Thursday, please meet in the hotel lobby at 7:15 to be checked in by NREL security. A shuttle will depart the hotel at 7:30 each morning. 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

- Complete action items from 1/10/11 conference call
- Review low-energy schools material (sent out with agenda)

Meeting objectives

- Everyone should have all the information they need to complete the first draft by February 21.

Agenda

Thursday, February 10, 2011

1	Welcome/review agenda	Pless	8:00
2	RSF tour	All	8:15
3	Review action items from 1/10/11 conference call	All	8:45
4	Section updates • Forward – Ryles • Integrated design – Kobet, Ornektekin, Ryles • Lighting – Kohring, McSpadden • Daylighting – Nicklas, Kohring, McSpadden (also give daylighting conference call update) • HVAC – Murphy, Jefferson, Seibert • Opaque envelope – McBride • Fenestration – Nicklas • Plug loads – Seibert, Ornektekin	All	9:00
5	Break	All	10:00
6	Discuss M&V for schools and how to handle it in the AEDG-K12	All	10:15
7	Discuss plan for Chapter 3 (performance option) • Determine outline for the chapter, who will contribute • What will be covered in the chapter	All	10:45
8	Lunch	All	12:00

9	Review low-energy schools material • Paul Hutton slides • NZEB schools round table • Case studies	All	1:00
10	Recommendation table review • Any changes to the structure? • Plan on including recommendation table by climate zone in the first draft of the AEDG-K12	Leach	1:30
11	Modeling update • Low-energy model review	Bonnema	1:45
12	Group breakout • Lighting/daylighting • Architecture, envelope, and integrated design • HVAC • O&M, commissioning	All	2:15

Friday, February 11, 2011

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

B.3 Meeting 3

K-12 Advanced Energy Design Guide - 50% Energy Savings
Project Committee Meeting 3 Agenda

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

Monday, March 14, 2011, 8:00AM – 5:00PM
Tuesday, March 15, 2011, 8:00AM – 2:00PM

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 Wednesday night. Lunches will be brought in by ASHRAE.

Pre meeting action items

- Review comments assigned to each member and prepare responses to discuss at the meeting
- Conduct detailed review of the first draft
- Bring your calendars to schedule conference calls
- Bring case studies that you would like to include in the AEDG-K12

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 April 25.
- Conference call week of March 28 to discuss progress
- "Final" deadline week of April 11
- Conference call early in the week of and April 18 to verify any additional tweaking
- Draft posted April 25

Agenda

Monday, March 14, 2011

1	Welcome/review agenda • Next meeting in Atlanta May 25-26 • Schedule conference call for week of March 28 • Schedule conference call for early week of April 18	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 • School and technology case studies	Pless	9:30
5	Break	All	10:00
6	Review recommendation table as a group	Pless/Bonnema	10:15
7	Discuss simulation results	Bonnema	10:45

8	Additions to the draft • Can we add sample RFP/RFQ wording to chapter 2? • How-to tip on thermally broken and or non-aluminum window frames? • Daylighting/lighting section needs to mesh better • Add more plug load information Others?	Bonnema/All	11:15
9	Lunch	All	12:00
10	Review general draft remarks and determine responses • Overall observations • Problems based on first look? • Major holes in draft?	Pratt	1:00
11	Break	All	3:00
12	Break into chapter groups to address specific remarks and work on solutions to remarks	All	3:15
13	Break for the day	All	5:00

Tuesday, March 15, 2011

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

B.4 Meeting 4

K-12 Advanced Energy Design Guide – 50% Energy Savings
Project Committee Meeting 4 Agenda

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

Wednesday, May 25, 2011, 8:00AM – 5:00PM
Thursday, May 26, 2011, 8:00AM – 2:00PM

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 7:00 am for breakfast. We will identify a place to have dinner as a group on Wednesday night. Lunches will be brought in by ASHRAE.

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-K12

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 internal 95% draft completed by June 3, 2011

Agenda

Wednesday, May 25, 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	Old action items review and update	Etheredge	8:45
5	Case studies • More whole building case studies • Technology examples (daylighting, HVAC, others?)	Pless	9:15
6	Break	All	9:45
7	Final energy modeling results	Bonnema	10:00
8	Review general draft remarks and determine responses • Overall observations • Problems based on first look?	Pratt	10:30

	• Major holes in draft?		
9	Lunch	All	12:00
10	Break into chapter groups to address specific remarks and work on solutions to remarks	All	1:00
11	Break	All	3:00
12	Break into chapter groups to address specific remarks and work on solutions to remarks	All	3:15
13	Break for the day	All	5:00

Thursday, May 26, 2011

1	Review final schedule for completion of the document • See schedule below • Schedule conference call times	Pratt	8:00
2	Galley proof review process	Pratt	9:00
3	Break	All	10:00
4	Break into chapter groups to address specific remarks and work on solutions to remarks	All	10:15
5	Meeting summary review • Define the work that will need to be done • Define the timing for getting everything done	All	11:00
6	Lunch	All	12:00
7	Break into chapter groups to address specific remarks and work on solutions to remarks	All	1:00
8	Adjourn	All	2:00

Appendix C. Responses to the AEDG-K12 Draft Review Remarks

C.1 First Peer Review Draft

SUMMARY RESPONSE TO
PEER REVIEW REMARKS AND RECOMMENDATIONS
RECEIVED ON
TECHNICAL REVIEW DRAFT OF
50% ADVANCED ENERGY DESIGN GUIDE FOR
K-12 SCHOOL BUILDINGS

April 25, 2011

On February 21, the Project Committee for the 50% Advanced Energy Design Guide for K-12 School Buildings (AEDG-K12) issued a Technical Review Draft of the document Advanced Energy Design Guide for K-12 School Buildings. Following the review period of February 21 through March 4, 2011, the AEDG-K12 Project Committee met on March 13-14 to review the remarks and recommendations received.

The committee received over 300 remarks and review recommendations from 17 reviewers representing AIA, IES, USGBC and the ASHRAE membership at large. The following documents the Project Committee's summary response to those remarks and recommendations. Although many of the suggestions dealt with details presented in the draft, this summary includes responses only to significant technical recommendations, especially those in which there was disagreement with what had been written or omitted. The specific and detailed suggestions and remarks were reviewed and digested by the Project Committee in preparing the next draft of the AEDG-K12. The review remarks received fall into the following six categories.

1. General Remarks and Recommendations

- The intent of the prescriptive recommendations in this guide is to provide a list of measures to achieve at least 50% energy savings over Standard 90.1-2004. We emphasize that the AEDG-K12 presents a way, but not the only way to achieve 50% energy savings, so not all possible strategies will be included, especially specialty items. A balanced, multi-option approach is recommended.
- Energy use is considered the independent variable with cost effectiveness (i.e. simple payback or life cycle costing) as a dependent (or resulting) variable. While some of the products or recommendations may be considered premium; all recommended equipment, systems, and technology specified in the document are commercially available from multiple manufacturers.
- Per the direction of the AEDG Steering Committee, the 50% goal is based on site energy use and uses Standard 90.1-2004 as the baseline measurement. This will be consistent for all the AEDG guides in the 50% series. A high level comparison to other versions of 90.1 will be included, time and resources permitting.
- Criteria used in the advanced case prescriptive recommendations will be no less stringent than Standard 90.1-2010.
- The AEDGs are intended for new construction and major renovations, not retrofits and existing buildings. Other documents being developed for existing buildings would be more appropriate to discuss energy efficiency retrofits.

- This guide is intended to provide guidance for the design of an energy efficient building without compromising the indoor environmental quality or violating ASHRAE Standard 55 or Standard 62.1. However, the PC agrees that additional information on IEQ/IAQ and references to the ASHRAE IAQ guide are needed. This information has been added in multiple locations in the AEDG-K12. The PC also notes that this guide is not intended to provide comprehensive guidance on IAQ and that other resources will be needed for that purpose.
- Language, figures, graphics and tables have been modified as needed for clarity and to more clearly reflect industry and ASHRAE standard terms.
- References have been added, corrected, updated, or eliminated as needed throughout the AEDG-K12. The placement of references is an editorial decision determined by publications staff.

2. Foreword and Introduction (Chapter 1)

- Additional discussion will be added to the Foreword regarding the impact of IEQ issues in energy design on the learning environment.
- A new section will be added to Chapter 1 to emphasize the need to address all facets of school building design including comfort, IAQ, acoustics, and the learning environment.

3. Integrated Design Process (Chapter 2)

- Additional emphasis on the need for buy-in from the school board in order to achieve successful implementation of a building's design will be added. Budget considerations will also be included.
- Chapter 2 will be modified to have a stronger emphasis on Integrated Design concepts rather than commissioning. Additional commissioning information will be added as an Appendix.

4. Performance Targets and Case Studies (Chapter 3)

- The climate zone map from Chapter 4 will either be referenced or repeated in Chapter 3.
- Lighting LPD levels have been adjusted. Design information on how to reach those levels will be included in the chapter 5 lighting how to tips.

5. Recommendations by Climate Zone (Chapter 4)

- Fenestration descriptions have been changed to metal and non-metal framed.

6. How-to Implement Recommendations (Chapter 5)

a) Envelope

- The project committee will develop a table of vertical fenestration descriptions that describe the physical characteristics of fenestration alternatives that meet the SHGC, VLT, and/or U-Factor recommendations in the AEDG-K12. This information is still in development and may not be available for the 90% review document.

b) Daylighting/Lighting

- A graph will be added to show the impacts of different colored window wells.
- Glazing systems that use fiber-fill solutions will be included as an option for areas where there is excessive outdoor ambient noise.

- Lighting level values will be corrected and will be adjusted so as to be consistent between the daylighting and lighting sections and to match the Chapter 4 recommendation tables
- While the Project Committee agrees that induction lighting can be more cost efficient from a total cost of ownership standpoint, it is not more energy efficient than HID therefore it is not included in the AEDG-K12.

c) Plug Loads/Kitchens

- These sections will be expanded and modified for clarity.

d) HVAC and SWH

- Information on operating set points will be added to the zone temperature control discussion.
- Information on variable-speed compressors in HV1 (system description) will reworded so as not to appear to be an afterthought.
- Some information is intentionally repeated in HV5 (Chilled Water Systems) and HV7 (Condenser Water Systems) as these are two different systems.
- The information in HV13 will be merged with HV4 (DOAS).
- The discussion on air side economizers in HV14 (Economizer) will be revised to be more specific to the system types recommended in this guide.
- The text in HV15 (Demand Controlled Ventilation) will be revised to caution about sensor accuracy and calibration and to discuss centralized vs. distributed sensing. While set point limit information in HV15 is used in the context of carbon dioxide-based DCV, the text will also be modified to "address IAQ" rather than to "maintain acceptable IAQ."
- A discussion on the temperature reset strategy for heating dominated climates will be added to HV16 (System Level Control Strategies).
- Filter specifications are covered in HV23 (Filters) and reference to HV23 will be added to HV1, HV2, and HV3 (system descriptions).
- HV23 (Filters) will be rewritten to address air-cleaning in general and will make reference to the requirements of ASHRAE 62.1 and the recommendations in the ASHRAE IAQ Guide. The text will match ASHRAE 62.1 and NAFA recommendations
- While specific recommendations regarding acoustics are beyond the scope of this guide, HV27 (Noise Control) will be rewritten based on recommendations from the Acoustical Society of America to include cautionary language on noise.
- The intent of the schematics in Figure 5-23 (DOAS Configurations) is to depict airflow paths rather than to show all components of the equipment. The figure will be modified to just show the fans.
- The discussion on Thermal Energy Storage was inadvertently left out of the draft and will be re-included.
- The discussion on heat pump water heaters will be removed as these are not being recommended in this guide.

e) Quality Assurance & Commissioning

- Additional how-to tips on operation and training issues will be added.

f) Additional Bonus Savings

- A how-to tip will be added to discuss the use of the IAQ Procedure.

- The information in HV28 (Operable Windows) has been merged with the Natural Ventilation how-to tip which will be further updated for accuracy and clarity.

C.2 Second Peer Review Draft

SUMMARY RESPONSE TO
PEER REVIEW REMARKS AND RECOMMENDATIONS
RECEIVED ON
TECHNICAL REVIEW DRAFT OF
50% ADVANCED ENERGY DESIGN GUIDE FOR
K-12 SCHOOL BUILDINGS

October 26, 2011

On April 28, 2011, the Project Committee for the 50% Advanced Energy Design Guide for K-12 School Buildings (AEDG-K12) issued a Technical Review Draft of the document Advanced Energy Design Guide for K-12 School Buildings. Following the review period of April 28-May 13, 2011, the AEDG-K12 Project Committee met on May 25, 2011 to review the remarks and recommendations received.

The committee received 375 remarks and review recommendations from 12 reviewers representing AIA, IES, USGBC and the ASHRAE membership at large. The following documents the Project Committee's summary response to those remarks and recommendations. Although many of the suggestions dealt with details presented in the draft, this summary includes responses only to significant technical recommendations, especially those in which there was disagreement with what had been written or omitted. The specific and detailed suggestions and remarks were reviewed and digested by the Project Committee in preparing the next draft of the AEDG-K12. The review remarks received fall into the following six categories.

1. General Remarks and Recommendations
    - The intent of the prescriptive recommendations in this guide is to provide a list of measures to achieve at least 50% energy savings over Standard 90.1-2004. We emphasize that the AEDG-K12 presents a way, but not the only way to achieve 50% energy savings, so not all possible strategies will be included, especially specialty items. A balanced, multi-option approach is recommended.
    - Energy modeling results will be published in a following Technical Support Document.
    - Payback consideration is outside the scope of the document.
    - Example pictures have been expanded.
    - All editorial errors have been corrected.
2. Foreword and Introduction (Chapter 1)
    - Text was modified to improve clarity in the body or in tables.
3. Integrated Design Process (Chapter 2)
    - Text was modified for editorial corrections or to improve clarity in the body, in lists or in tables.
    - Checklists showing typical processes for integrated design were incorporated in the AEDG-K12.
    - Variables for low-energy solutions the Integrated Design team should consider were expanded.
    - References were added including O&M training resources.

4. Performance Targets and Case Studies (Chapter 3)
    - Text was modified for editorial corrections or to improve clarity in the body of the document, in lists or in tables. This includes renaming tables 3-1, 3-2, 3-3 and 3-4 to more clearly reflect their intention. Information to which version of 90.1 should be used was more clearly defined in the AEDG-K12.
    - Specific guidance on how U and SHGC values are measured has been noted in the AEDG-K12.
5. Strategies and Recommendations by Climate Zone (Chapter 4)
    - Water-cooled chillers and water-side economizers were added to the Chapter 4 tables.
    - Transpired solar collectors and evaporative coolers were added to the Additional Bonus Savings section of the AEDG-K12.
    - A single-path (mixed-air) VAV system may certainly be another way to achieve the 50% savings threshold, but it was not modeled as part of this guide.
    - Text was modified for editorial corrections or to improve clarity in the body of the document or in tables. U-Factors per climate zone in the view fenestration category have been corrected.
    - The committee believes the efficacy numbers provided in the recommendation tables will not restrict a designer's decision on the type of efficient lamps to use, but should only suggest the lamps chosen meet certain efficiency levels.
    - The lighting section in the recommendation tables follows the criteria of ASHRAE 90.1.
    - Performance stage lighting is a specialty space consideration that is outside the scope of this guide.
6. How-to Implement Recommendations (Chapter 5)
    - Language relating to certification of various types of HVAC equipment was added to the AEDG-K12.
    - Content on controlling daylighting in multi-purpose rooms was added. However the Project Committee would like to note that the criteria for the lighting design of multi-use spaces considers the primary function of the space and not necessarily all of its possible uses.
    - The specific lighting/daylighting design for specialty spaces such as performance stages, art studios, costume shops, scenery shops, make-up and dressing rooms is outside the scope of this guide.
    - All references, tables, figures and graphics have been updated or revised for clarity or correction. Table 5-4 was modified to improve readability. References to other documents and studies have been updated or included as necessary.
    - Text has been modified for editorial and technical correction as well as improving clarity in the body of the document. The PC has removed the statement that manual on/automatic off occupancy sensors provide the greatest energy savings.
    - Consideration of the structural performance of fenestration products in coastal areas was added to the AEDG-K12.
    - Specific guidance on how VLT values are measured has been noted in the AEDG-K12.
    - The PC recognizes that dark out rooms will provide better contrast on the viewing screen but inhibits the student's ability to take notes. The AEDG-K12's recommended light

levels for liquid crystal display use is a logical compromise and works in both daylit and non-daylit spaces. Language will be added to the AEDG-K12 noting that designers be aware that teachers will prefer the student seating areas be well lit while viewing videos.

- The AEDG-K12 will note that automatic multilevel daylight switching will be used only for those rooms that have been daylit.
- The PC agrees that LEDs will probably be the preferred source 5 years from now; however energy savings can be achieved through more cost effective technologies.
- EL 9 was changed from Multi-Level Switching to Multi-Level Switching or Dimming
- While using advanced teaching technologies a minimum of two lighting scenes was suggested in the AEDG-K12 for classrooms.
- EnergyPlus modeling results will be published in a following Technical Support Document.
- DOAS system configurations were chosen based on energy use, ventilation distribution and first cost. The advantages and drawbacks of various DOAS system configurations are discussed in other documents and articles referenced in Chapter 5.
- Language discouraging the use of inefficient motors for small pumps in GSHP systems has been added.
- A caution about the energy performance of digital scroll compressors was added to the AEDG-K12.
- Content on the installation of carbon dioxide sensors and their control of ventilation was revised to more closely reflect the guidance provided in the 62.1 User's Manual.
- HV33 on the IAQ Procedure from ASHRAE 62.1 was modified to include additional recommendations for managing contaminants.
- A section on Electrical Distribution Systems to discuss transformer efficiency has been added to the how-to-tips.
- Language on solar air heating has been added to the Additional Bonus Savings section of the AEDG-K12.

Appendix D. Schedule Tabular Data

Table D–1 Library/Media Center Occupancy Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.00	0.30	0.60	0.60	0.30	0.30	0.60	0.60	0.30	0.30	0.00	0.00	0.00	0.00	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–2 Primary School General Occupancy Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.20	0.20	0.30	0.30	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–3 Primary School Cafeteria Occupancy Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.15	0.05	0.05	0.05	0.70	0.70	0.05	0.05	0.15	0.15	0.15	0.00	0.00	0.00	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–4 Primary School Gym Occupancy Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.00	0.15	0.15	0.15	0.15	0.15	0.15	0.00	0.15	0.15	0.15	0.05	0.05	0.05	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–5 Primary School Office Occupancy Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.00	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.00	0.00	0.00	0.00	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.25	0.25	0.25	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–6 Secondary School General Occupancy Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.00	0.50	0.45	0.45	0.20	0.20	0.45	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–7 Secondary School Cafeteria Occupancy Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.15	0.00	0.00	0.00	0.95	0.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–8 Secondary School Gym Occupancy Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.04	0.04	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–9 Secondary School Office Occupancy Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.40	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.15	0.00	0.00	0.00	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.40	0.40	0.40	0.40	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–10 Secondary School Auditorium Occupancy Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–11 Secondary School Auxiliary Gym Occupancy Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.06	0.06	0.06	0.06	0.06	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–12 Primary School Infiltration Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
Gym Weekdays	1.00	1.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	1.00
Other Spaces Weekdays	1.00	1.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00
All Spaces Summer Weekdays	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
All Spaces All Other Days	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table D–13 Secondary School Infiltration Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
Gym/Auditorium Weekdays	1.00	1.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	1.00
Gym/Auditorium Summer Weekdays	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Other Spaces Weekdays	1.00	1.00	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00
Other Spaces Summer Weekdays	1.00	1.00	1.00	1.00	0.50	0.50	0.50	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
All Spaces All Other Days	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table D–14 Heating Set Point Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
Gym/auditorium weekdays	60.0	60.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	60.0	60.0
Secondary school gym/ auditorium summer weekdays	60.0	60.0	60.0	60.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
School weekdays	60.0	60.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	71.0	60.0	60.0	60.0	60.0	60.0
Summer weekdays	60.0	60.0	60.0	60.0	71.0	71.0	71.0	71.0	71.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Other days	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0

Table D–15 Cooling Set Point Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
Gym/auditorium weekdays	81.0	81.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	81.0	81.0
Secondary school gym/ auditorium summer weekdays	81.0	81.0	81.0	81.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0
School weekdays	81.0	81.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	74.0	81.0	81.0	81.0	81.0	81.0
Summer weekdays	81.0	81.0	81.0	81.0	74.0	74.0	74.0	74.0	74.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0
Other days	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0	81.0

Table D–16 Secondary School Elevator Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.00	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–17 Baseline Lighting Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.20	0.20	0.40	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.70	0.70	0.70	0.50	0.50	0.20	0.20
Summer weekdays	0.20	0.20	0.20	0.20	0.50	0.50	0.50	0.50	0.50	0.50	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Other days	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

Table D–18 Primary School Baseline Electric Equipment Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.40	0.40	0.40	0.40	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Summer weekdays	0.40	0.40	0.40	0.40	0.40	0.60	0.60	0.60	0.60	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Other days	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

Table D–19 Primary School Baseline Kitchen Electric Equipment Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.27	0.33	0.47	0.84	0.75	0.50	0.72	0.91	1.00	0.41	0.34	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Summer weekdays	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
Other days	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27

Table D–20 Primary School Baseline Kitchen Gas Equipment Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.03	0.03	1.00	1.00	0.33	0.07	1.00	1.00	1.00	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Summer weekdays	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Other days	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Table D–21 Secondary School Baseline Electric Equipment Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.50	0.50	0.50	0.50	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Summer weekdays	0.50	0.50	0.50	0.50	0.65	0.65	0.65	0.65	0.65	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Other days	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

Table D–22 Secondary School Baseline Kitchen Electric Equipment Schedule

Schedule	Hour																		
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.40	0.40	0.87	1.00	0.78	0.78	0.78	1.00	1.00	0.61	0.47	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Summer weekdays	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
Other days	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40

Table D–23 Secondary School Baseline Kitchen Gas Equipment Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.18	0.18	0.92	0.76	0.38	0.38	0.85	1.00	1.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Summer weekdays	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Other days	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Table D–24 General SWH Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.05	0.05	0.05	0.10	0.34	0.60	0.63	0.72	0.79	0.83	0.61	0.65	0.10	0.10	0.19	0.25	0.22	0.22	0.12
Summer weekdays	0.05	0.05	0.05	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.19	0.25	0.22	0.22	0.12
Other days	0.03	0.03	0.03	0.03	0.05	0.05	0.05	0.05	0.05	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

Table D–25 Secondary School Shower SWH Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.00	0.00	0.00	0.60	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	1.00	1.00	1.00	0.00	0.00	0.00	0.00
Summer weekdays	0.00	0.00	0.00	0.00	0.30	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
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	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D–26 Primary School Low-Energy Electric Equipment Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.15	0.15	0.15	0.15	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Summer weekdays	0.15	0.15	0.15	0.15	0.15	0.60	0.60	0.60	0.60	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Other days	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15

Table D–27 Primary School Low-Energy Kitchen Electric Equipment Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.29	0.35	0.45	0.85	0.78	0.55	0.70	0.89	1.00	0.45	0.36	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Summer weekdays	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
Other days	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29

Table D–28 Primary School Low-Energy Kitchen Gas Equipment Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.04	0.04	1.00	1.00	0.32	0.06	1.00	1.00	1.00	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Summer weekdays	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Other days	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04

Table D–29 Secondary School Low-Energy Electric Equipment Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.25	0.25	0.25	0.25	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Summer weekdays	0.25	0.25	0.25	0.25	0.65	0.65	0.65	0.65	0.65	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Other days	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Table D–30 Secondary School Low-Energy Kitchen Electric Equipment Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.38	0.38	0.86	1.00	0.77	0.77	0.77	1.00	1.00	0.60	0.46	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Summer weekdays	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Other days	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38

Table D–31 Secondary School Low-Energy Kitchen Gas Equipment Schedule

Schedule	Hour																	
	1-5	6	7	8	9	10	11	12	13	14	15	16	18	19	20	21	22	23	24
School weekdays	0.22	0.22	0.99	0.79	0.40	0.40	0.86	1.00	1.00	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Summer weekdays	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Other days	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02

Appendix E. EnergyPlus Ground Heat Exchanger Object

E.1 Primary School

```
GroundHeatExchanger:Vertical,
  Primary School,  !- Name
  Inlet Node,  !- Inlet Node Name
  Outlet Node,  !- Outlet Node Name
  0.0346,  !- Maximum Flow Rate (m3/s)
  100,  !- Number of Bore Holes
  91.44,  !- Bore Hole Length (m)
  0.1524,  !- Bore Hole Radius (m)
  1.731,  !- Ground Thermal Conductivity (W/m-K)
  2160000.000,  !- Ground Thermal Heat Capacity (J/m3-K)
  10.6,  !- Ground Temperature (C)
  0.0346,  !- Design Flow Rate (m3/s)
  0.7443,  !- Grout Thermal Conductivity (W/m-K)
  0.3895,  !- Pipe Thermal Conductivity (W/m-K)
  0.03675,  !- Pipe Out Diameter (m)
  0.01890,  !- U-Tube Distance (m)
  0.005,  !- Pipe Thickness (m)
  1,  !- Maximum Length of Simulation
  0.00167,  !- G-Function Reference Ratio
  76,  !- Number of Data Pairs of the G Function
  -15.1672784904,  !- G-Function Ln(T/Ts) Value 1
  -02.0161699703,  !- G-Function G Value 1
  -15.0312115825,  !- G-Function Ln(T/Ts) Value 2
  -01.9786268344,  !- G-Function G Value 2
  -14.8951446745,  !- G-Function Ln(T/Ts) Value 3
  -01.9384925746,  !- G-Function G Value 3
  -14.7590777665,  !- G-Function Ln(T/Ts) Value 4
  -01.8955154218,  !- G-Function G Value 4
  -14.6230108586,  !- G-Function Ln(T/Ts) Value 5
  -01.8494905807,  !- G-Function G Value 5
  -14.4869439506,  !- G-Function Ln(T/Ts) Value 6
  -01.8002436168,  !- G-Function G Value 6
  -14.3508770426,  !- G-Function Ln(T/Ts) Value 7
  -01.7476251040,  !- G-Function G Value 7
  -14.2148101347,  !- G-Function Ln(T/Ts) Value 8
  -01.6915092891,  !- G-Function G Value 8
  -14.0787432267,  !- G-Function Ln(T/Ts) Value 9
  -01.6317944375,  !- G-Function G Value 9
  -13.9426763187,  !- G-Function Ln(T/Ts) Value 10
  -01.5684038633,  !- G-Function G Value 10
  -13.8066094108,  !- G-Function Ln(T/Ts) Value 11
  -01.5012871299,  !- G-Function G Value 11
  -13.6705425028,  !- G-Function Ln(T/Ts) Value 12
  -01.4304211246,  !- G-Function G Value 12
  -13.5344755948,  !- G-Function Ln(T/Ts) Value 13
  -01.3558108471,  !- G-Function G Value 13
  -13.3984086869,  !- G-Function Ln(T/Ts) Value 14
  -01.2774898668,  !- G-Function G Value 14
  -13.2623417789,  !- G-Function Ln(T/Ts) Value 15
  -01.1955205287,  !- G-Function G Value 15
  -13.1262748709,  !- G-Function Ln(T/Ts) Value 16
  -01.1099941021,  !- G-Function G Value 16
  -12.9902079630,  !- G-Function Ln(T/Ts) Value 17
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-01.0210311586,  !- G-Function G Value 17
-12.8541410550,  !- G-Function Ln(T/Ts) Value 18
-00.9287824714,  !- G-Function G Value 18
-12.7180741470,  !- G-Function Ln(T/Ts) Value 19
-00.8334306271,  !- G-Function G Value 19
-12.5820072390,  !- G-Function Ln(T/Ts) Value 20
-00.7351923129,  !- G-Function G Value 20
-12.4459403311,  !- G-Function Ln(T/Ts) Value 21
-00.6343209413,  !- G-Function G Value 21
-12.3098734231,  !- G-Function Ln(T/Ts) Value 22
-00.5311089631,  !- G-Function G Value 22
-12.1738065151,  !- G-Function Ln(T/Ts) Value 23
-00.4258889989,  !- G-Function G Value 23
-12.0377396072,  !- G-Function Ln(T/Ts) Value 24
-00.3190328684,  !- G-Function G Value 24
-11.9016726992,  !- G-Function Ln(T/Ts) Value 25
-00.2109477420,  !- G-Function G Value 25
-11.7656057912,  !- G-Function Ln(T/Ts) Value 26
-00.1020689797,  !- G-Function G Value 26
-11.6295388833,  !- G-Function Ln(T/Ts) Value 27
00.0071503217,  !- G-Function G Value 27
-11.4934719753,  !- G-Function Ln(T/Ts) Value 28
00.1162525543,  !- G-Function G Value 28
-11.3574050673,  !- G-Function Ln(T/Ts) Value 29
00.2247906404,  !- G-Function G Value 29
-11.2213381594,  !- G-Function Ln(T/Ts) Value 30
00.3323436246,  !- G-Function G Value 30
-11.0852712514,  !- G-Function Ln(T/Ts) Value 31
00.4385314202,  !- G-Function G Value 31
-10.9492043434,  !- G-Function Ln(T/Ts) Value 32
00.5430273761,  !- G-Function G Value 32
-10.8131374355,  !- G-Function Ln(T/Ts) Value 33
00.6455675716,  !- G-Function G Value 33
-10.6770705275,  !- G-Function Ln(T/Ts) Value 34
00.7459561254,  !- G-Function G Value 34
-10.5410036195,  !- G-Function Ln(T/Ts) Value 35
00.8440662653,  !- G-Function G Value 35
-10.4049367116,  !- G-Function Ln(T/Ts) Value 36
00.9398373733,  !- G-Function G Value 36
-10.2688698036,  !- G-Function Ln(T/Ts) Value 37
01.0332686326,  !- G-Function G Value 37
-10.1328028956,  !- G-Function Ln(T/Ts) Value 38
01.1244101941,  !- G-Function G Value 38
-09.9967359877,  !- G-Function Ln(T/Ts) Value 39
01.2133529166,  !- G-Function G Value 39
-09.8606690797,  !- G-Function Ln(T/Ts) Value 40
01.3002177236,  !- G-Function G Value 40
-09.7246021717,  !- G-Function Ln(T/Ts) Value 41
01.3851454648,  !- G-Function G Value 41
-09.5885352637,  !- G-Function Ln(T/Ts) Value 42
01.4682879406,  !- G-Function G Value 42
-09.4524683558,  !- G-Function Ln(T/Ts) Value 43
01.5498004770,  !- G-Function G Value 43
-09.3164014478,  !- G-Function Ln(T/Ts) Value 44
01.6298361906,  !- G-Function G Value 44
-09.1803345398,  !- G-Function Ln(T/Ts) Value 45
01.7085418805,  !- G-Function G Value 45
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-09.0442676319,  !- G-Function Ln(T/Ts) Value 46
01.7860553519,  !- G-Function G Value 46
-08.9082007239,  !- G-Function Ln(T/Ts) Value 47
01.8625039066,  !- G-Function G Value 47
-08.7721338159,  !- G-Function Ln(T/Ts) Value 48
01.9380037225,  !- G-Function G Value 48
-08.6360669080,  !- G-Function Ln(T/Ts) Value 49
02.0126598642,  !- G-Function G Value 49
-08.5000000000,  !- G-Function Ln(T/Ts) Value 50
02.1681743762,  !- G-Function G Value 50
-07.8000000000,  !- G-Function Ln(T/Ts) Value 51
02.4686754092,  !- G-Function G Value 51
-07.2000000000,  !- G-Function Ln(T/Ts) Value 52
02.7656189434,  !- G-Function G Value 52
-06.5000000000,  !- G-Function Ln(T/Ts) Value 53
03.1242978688,  !- G-Function G Value 53
-05.9000000000,  !- G-Function Ln(T/Ts) Value 54
03.5015649724,  !- G-Function G Value 54
-05.2000000000,  !- G-Function Ln(T/Ts) Value 55
04.2026529773,  !- G-Function G Value 55
-04.5000000000,  !- G-Function Ln(T/Ts) Value 56
05.4857958796,  !- G-Function G Value 56
-03.9630000000,  !- G-Function Ln(T/Ts) Value 57
07.0051773905,  !- G-Function G Value 57
-03.2700000000,  !- G-Function Ln(T/Ts) Value 58
10.4207731493,  !- G-Function G Value 58
-02.8640000000,  !- G-Function Ln(T/Ts) Value 59
13.3280212513,  !- G-Function G Value 59
-02.5770000000,  !- G-Function Ln(T/Ts) Value 60
15.8654013089,  !- G-Function G Value 60
-02.1710000000,  !- G-Function Ln(T/Ts) Value 61
20.1371931751,  !- G-Function G Value 61
-01.8840000000,  !- G-Function Ln(T/Ts) Value 62
23.6566372811,  !- G-Function G Value 62
-01.1910000000,  !- G-Function Ln(T/Ts) Value 63
33.2878586365,  !- G-Function G Value 63
-00.4970000000,  !- G-Function Ln(T/Ts) Value 64
43.6787779612,  !- G-Function G Value 64
-00.2740000000,  !- G-Function Ln(T/Ts) Value 65
46.7331258988,  !- G-Function G Value 65
-00.0510000000,  !- G-Function Ln(T/Ts) Value 66
49.6253779886,  !- G-Function G Value 66
00.1960000000,  !- G-Function Ln(T/Ts) Value 67
52.4199303749,  !- G-Function G Value 67
00.4190000000,  !- G-Function Ln(T/Ts) Value 68
54.6399648005,  !- G-Function G Value 68
00.6420000000,  !- G-Function Ln(T/Ts) Value 69
56.5530675332,  !- G-Function G Value 69
00.8730000000,  !- G-Function Ln(T/Ts) Value 70
58.2199776625,  !- G-Function G Value 70
01.1120000000,  !- G-Function Ln(T/Ts) Value 71
59.6211288170,  !- G-Function G Value 71
01.3350000000,  !- G-Function Ln(T/Ts) Value 72
60.9229843177,  !- G-Function G Value 72
01.6790000000,  !- G-Function Ln(T/Ts) Value 73
62.1588573377,  !- G-Function G Value 73
02.0280000000,  !- G-Function Ln(T/Ts) Value 74
```

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  62.9441295016,  !- G-Function G Value 74
  02.2750000000,  !- G-Function Ln(T/Ts) Value 75
  63.3258904894,  !- G-Function G Value 75
  03.0030000000,  !- G-Function Ln(T/Ts) Value 76
  63.9669763718;  !- G-Function G Value 76
```

E.2 Secondary School

```
GroundHeatExchanger:Vertical,
  Secondary School,  !- Name
  Inlet Node,  !- Inlet Node Name
  Outlet Node,  !- Outlet Node Name
  0.097,  !- Maximum Flow Rate (m3/s)
  280,  !- Number of Bore Holes
  91.44,  !- Bore Hole Length (m)
  0.1524,  !- Bore Hole Radius (m)
  1.731,  !- Ground Thermal Conductivity (W/m-K)
  2160000.000,  !- Ground Thermal Heat Capacity (J/m3-K)
  10.6,  !- Ground Temperature (C)
  0.097,  !- Design Flow Rate (m3/s)
  0.7443,  !- Grout Thermal Conductivity (W/m-K)
  0.3895,  !- Pipe Thermal Conductivity (W/m-K)
  0.03675,  !- Pipe Out Diameter (m)
  0.01890,  !- U-Tube Distance (m)
  0.005,  !- Pipe Thickness (m)
  1,  !- Maximum Length of Simulation
  0.00167,  !- G-Function Reference Ratio
  76,  !- Number of Data Pairs of the G Function
  -15.1672784904,!- G-Function Ln(T/Ts) Value 1
  -02.0161699703,  !- G-Function G Value 1
  -15.0312115825,  !- G-Function Ln(T/Ts) Value 2
  -01.9786268344,  !- G-Function G Value 2
  -14.8951446745,  !- G-Function Ln(T/Ts) Value 3
  -01.9384925746,  !- G-Function G Value 3
  -14.7590777665,  !- G-Function Ln(T/Ts) Value 4
  -01.8955154218,  !- G-Function G Value 4
  -14.6230108586,  !- G-Function Ln(T/Ts) Value 5
  -01.8494905807,  !- G-Function G Value 5
  -14.4869439506,  !- G-Function Ln(T/Ts) Value 6
  -01.8002436168,  !- G-Function G Value 6
  -14.3508770426,  !- G-Function Ln(T/Ts) Value 7
  -01.7476251040,  !- G-Function G Value 7
  -14.2148101347,  !- G-Function Ln(T/Ts) Value 8
  -01.6915092891,  !- G-Function G Value 8
  -14.0787432267,  !- G-Function Ln(T/Ts) Value 9
  -01.6317944375,  !- G-Function G Value 9
  -13.9426763187,  !- G-Function Ln(T/Ts) Value 10
  -01.5684038633,  !- G-Function G Value 10
  -13.8066094108,  !- G-Function Ln(T/Ts) Value 11
  -01.5012871299,  !- G-Function G Value 11
  -13.6705425028,  !- G-Function Ln(T/Ts) Value 12
  -01.4304211246,  !- G-Function G Value 12
  -13.5344755948,  !- G-Function Ln(T/Ts) Value 13
  -01.3558108471,  !- G-Function G Value 13
  -13.3984086869,  !- G-Function Ln(T/Ts) Value 14
  -01.2774898668,  !- G-Function G Value 14
  -13.2623417789,  !- G-Function Ln(T/Ts) Value 15
  -01.1955205287,  !- G-Function G Value 15
```

```
-13.1262748709,  !- G-Function Ln(T/Ts) Value 16
-01.1099941021,  !- G-Function G Value 16
-12.9902079630,  !- G-Function Ln(T/Ts) Value 17
-01.0210311586,  !- G-Function G Value 17
-12.8541410550,  !- G-Function Ln(T/Ts) Value 18
-00.9287824714,  !- G-Function G Value 18
-12.7180741470,  !- G-Function Ln(T/Ts) Value 19
-00.8334306271,  !- G-Function G Value 19
-12.5820072390,  !- G-Function Ln(T/Ts) Value 20
-00.7351923129,  !- G-Function G Value 20
-12.4459403311,  !- G-Function Ln(T/Ts) Value 21
-00.6343209413,  !- G-Function G Value 21
-12.3098734231,  !- G-Function Ln(T/Ts) Value 22
-00.5311089631,  !- G-Function G Value 22
-12.1738065151,  !- G-Function Ln(T/Ts) Value 23
-00.4258889989,  !- G-Function G Value 23
-12.0377396072,  !- G-Function Ln(T/Ts) Value 24
-00.3190328684,  !- G-Function G Value 24
-11.9016726992,  !- G-Function Ln(T/Ts) Value 25
-00.2109477420,  !- G-Function G Value 25
-11.7656057912,  !- G-Function Ln(T/Ts) Value 26
-00.1020689797,  !- G-Function G Value 26
-11.6295388833,  !- G-Function Ln(T/Ts) Value 27
00.0071503217,  !- G-Function G Value 27
-11.4934719753,  !- G-Function Ln(T/Ts) Value 28
00.1162525543,  !- G-Function G Value 28
-11.3574050673,  !- G-Function Ln(T/Ts) Value 29
00.2247906404,  !- G-Function G Value 29
-11.2213381594,  !- G-Function Ln(T/Ts) Value 30
00.3323436246,  !- G-Function G Value 30
-11.0852712514,  !- G-Function Ln(T/Ts) Value 31
00.4385314202,  !- G-Function G Value 31
-10.9492043434,  !- G-Function Ln(T/Ts) Value 32
00.5430273761,  !- G-Function G Value 32
-10.8131374355,  !- G-Function Ln(T/Ts) Value 33
00.6455675716,  !- G-Function G Value 33
-10.6770705275,  !- G-Function Ln(T/Ts) Value 34
00.7459561254,  !- G-Function G Value 34
-10.5410036195,  !- G-Function Ln(T/Ts) Value 35
00.8440662653,  !- G-Function G Value 35
-10.4049367116,  !- G-Function Ln(T/Ts) Value 36
00.9398373733,  !- G-Function G Value 36
-10.2688698036,  !- G-Function Ln(T/Ts) Value 37
01.0332686326,  !- G-Function G Value 37
-10.1328028956,  !- G-Function Ln(T/Ts) Value 38
01.1244101941,  !- G-Function G Value 38
-09.9967359877,  !- G-Function Ln(T/Ts) Value 39
01.2133529166,  !- G-Function G Value 39
-09.8606690797,  !- G-Function Ln(T/Ts) Value 40
01.3002177236,  !- G-Function G Value 40
-09.7246021717,  !- G-Function Ln(T/Ts) Value 41
01.3851454648,  !- G-Function G Value 41
-09.5885352637,  !- G-Function Ln(T/Ts) Value 42
01.4682879406,  !- G-Function G Value 42
-09.4524683558,  !- G-Function Ln(T/Ts) Value 43
01.5498004770,  !- G-Function G Value 43
-09.3164014478,  !- G-Function Ln(T/Ts) Value 44
```

```
01.6298361906,  !- G-Function G Value 44
-09.1803345398,  !- G-Function Ln(T/Ts) Value 45
01.7085418805,  !- G-Function G Value 45
-09.0442676319,  !- G-Function Ln(T/Ts) Value 46
01.7860553519,  !- G-Function G Value 46
-08.9082007239,  !- G-Function Ln(T/Ts) Value 47
01.8625039066,  !- G-Function G Value 47
-08.7721338159,  !- G-Function Ln(T/Ts) Value 48
01.9380037225,  !- G-Function G Value 48
-08.6360669080,  !- G-Function Ln(T/Ts) Value 49
02.0126598642,  !- G-Function G Value 49
-08.5000000000,  !- G-Function Ln(T/Ts) Value 50
02.1681743762,  !- G-Function G Value 50
-07.8000000000,  !- G-Function Ln(T/Ts) Value 51
02.5066952841,  !- G-Function G Value 51
-07.2000000000,  !- G-Function Ln(T/Ts) Value 52
02.8034475994,  !- G-Function G Value 52
-06.5000000000,  !- G-Function Ln(T/Ts) Value 53
03.1632562498,  !- G-Function G Value 53
-05.9000000000,  !- G-Function Ln(T/Ts) Value 54
03.5442709075,  !- G-Function G Value 54
-05.2000000000,  !- G-Function Ln(T/Ts) Value 55
04.2662231357,  !- G-Function G Value 55
-04.5000000000,  !- G-Function Ln(T/Ts) Value 56
05.6210384264,  !- G-Function G Value 56
-03.9630000000,  !- G-Function Ln(T/Ts) Value 57
07.2604622271,  !- G-Function G Value 57
-03.2700000000,  !- G-Function Ln(T/Ts) Value 58
11.1078378913,  !- G-Function G Value 58
-02.8640000000,  !- G-Function Ln(T/Ts) Value 59
14.5375067269,  !- G-Function G Value 59
-02.5770000000,  !- G-Function Ln(T/Ts) Value 60
17.6400055107,  !- G-Function G Value 60
-02.1710000000,  !- G-Function Ln(T/Ts) Value 61
23.0836377491,  !- G-Function G Value 61
-01.8840000000,  !- G-Function Ln(T/Ts) Value 62
27.7675328765,  !- G-Function G Value 62
-01.1910000000,  !- G-Function Ln(T/Ts) Value 63
41.4639551757,  !- G-Function G Value 63
-00.4970000000,  !- G-Function Ln(T/Ts) Value 64
57.5142515470,  !- G-Function G Value 64
-00.2740000000,  !- G-Function Ln(T/Ts) Value 65
62.5046602524,  !- G-Function G Value 65
-00.0510000000,  !- G-Function Ln(T/Ts) Value 66
67.2609400647,  !- G-Function G Value 66
00.1960000000,  !- G-Function Ln(T/Ts) Value 67
72.0593131203,  !- G-Function G Value 67
00.4190000000,  !- G-Function Ln(T/Ts) Value 68
75.9170578720,  !- G-Function G Value 68
00.6420000000,  !- G-Function Ln(T/Ts) Value 69
79.2601624311,  !- G-Function G Value 69
00.8730000000,  !- G-Function Ln(T/Ts) Value 70
82.1724876065,  !- G-Function G Value 70
01.1120000000,  !- G-Function Ln(T/Ts) Value 71
84.6162411446,  !- G-Function G Value 71
01.3350000000,  !- G-Function Ln(T/Ts) Value 72
86.4523229065,  !- G-Function G Value 72
```

```
01.6790000000,  !- G-Function Ln(T/Ts) Value 73
88.4817393099,  !- G-Function G Value 73
02.0280000000,  !- G-Function Ln(T/Ts) Value 74
89.8299425367,  !- G-Function G Value 74
02.2750000000,  !- G-Function Ln(T/Ts) Value 75
90.4837956195,  !- G-Function G Value 75
03.0030000000,  !- G-Function Ln(T/Ts) Value 76
91.6069885624;  !- G-Function G Value 76
```

Appendix F. EnergyPlus Refrigeration Objects

F.1 Primary School

```
Refrigeration:Case,
  Kitchen_WalkInFreezer_Case:1,  !- Name
  ALWAYS_ON,  !- Availablility Schedule
  Kitchen,  !- Zone Name
  23.88,  !- Rated Ambient Temperature (C)
  55.0,  !- Rated Ambient Relative Humidity (%)
  734,  !- Rated Total Cooling Capacity per Unit length (W/m)
  0.1,  !- Rated Latent Heat Ratio
  0.4,  !- Rated Runtime Fraction
  3.66,  !- Case Length (m)
  -23,  !- Case Operating Temperature (C)
  CaseTemperatureMethod,  !- Latent Case Credit Curve Type
  Kitchen_WalkInFreezer_Case:1_LatentCaseCreditCurve,  !- Latent Case Credit Curve Name
  68.3,  !- Standard Case Fan Power per Unit Length (W/m)
  172.2,  !- Operating Case Fan Power per Unit Length (W/m)
  33,  !- Standard Case Lighting Power per Unit Length (W/m)
  28.1,  !- Installed Case Lighting Power per Unit Length (W/m)
  BLDG_LIGHT_SCH,  !- Case Lighting Schedule Name
  1,  !- Fraction Of Lighting Energy To Case
  0.0,  !- Case Anti-Sweat Heater Power per Unit Length (W/m)
  0.0,  !- Minimum Anti-Sweat Heater Power per Unit Length (W/m)
  None,  !- Anti-Sweat Heater Control Type (******)
  0.0,  !- Humidity At Zero Anti-Sweat Heater Energy (%)
  0.0,  !- Case Height (m)
  0.0,  !- Fraction of Anti-Sweat Heater Energy To Case ()
  547,  !- Case Defrost Power per Unit Length (W/m)
  Electric,  !- Case Defrost Type
  Kitchen_WalkInFreezer_Case:1_DefrostSchedule,  !- Case Defrost Schedule Name
  Kitchen_WalkInFreezer_Case:1_DefrostDripDownSchedule,  !- Case Defrost Drip-Down Schedule
  None,  !- Defrost Energy Correction Curve Type
  ,  !- Defrost Energy Correction Curve Name
  0.0,  !- Under Case HVAC Return Air Fraction ()
  Kitchen_WalkInFreezer_Case:1_RestockSchedule,  !- Refrigerated Case Restocking Schedule Name
  Kitchen_WalkInFreezer_Case:1_CaseCreditSchedule;  !- Case Credit Fraction Schedule Name

Curve:Cubic,
  Kitchen_WalkInFreezer_Case:1_LatentCaseCreditCurve,  !- Name
```

```
  0.0236,  !- Coefficient1 Constant
  0.0006,  !- Coefficient2 x
  0.0000,  !- Coefficient3 x**2
  0.0000,  !- Coefficient4 x**3
  -35.0,  !- Minimum Value of x
  20.0;  !- Maximum Value of x

Schedule:Compact,
  Kitchen_WalkInFreezer_Case:1_DefrostSchedule,  !- Name
  ON/OFF,  !- Schedule type
  Through:  12/31,  !- Complex field #1
  For:AllDays,  !- Complex field #2
  Interpolate:Yes,  !- Complex field #3
  Until:  11:00, 0,  !- Complex field #4
  Until:  11:20, 1,  !- Complex field #5
  Until:  23:00, 0,  !- Complex field #6
  Until:  23:20, 1,  !- Complex field #7
  Until:  24:00, 0;  !- Complex field #8

Schedule:Compact,
  Kitchen_WalkInFreezer_Case:1_DefrostDripDownSchedule,  !- Name
  ON/OFF,  !- Schedule type
  Through:  12/31,  !- Complex field #1
  For:AllDays,  !- Complex field #2
  Interpolate:Yes,  !- Complex field #3
  Until:  11:00, 0,  !- Complex field #4
  Until:  11:30, 1,  !- Complex field #5
  Until:  23:00, 0,  !- Complex field #6
  Until:  23:30, 1,  !- Complex field #7
  Until:  24:00, 0;  !- Complex field #8

Curve:Cubic,
  Kitchen_WalkInFreezer_Case:1_DefrostEnergyCorrectionCurve,  !- Name
  0.0236,  !- Coefficient1 Constant
  0.0006,  !- Coefficient2 x
  0.0000,  !- Coefficient3 x**2
  0.0000,  !- Coefficient4 x**3
  -35.0,  !- Minimum Value of x
  20.0;  !- Maximum Value of x

Schedule:Compact,
```

```
  Kitchen_WalkInFreezer_Case:1_RestockSchedule,  !- Name
  Any Number,  !- Schedule type
  Through:  12/31,  !- Complex field #1
  For:  Tuesday Friday,  !- Complex field #2
  Until:  4:00, 0.0,  !- Complex field #3
  Until:  5:00, 725.0,  !- Complex field #4
  Until:  6:00, 417.0,  !- Complex field #5
  Until:  7:00, 290.0,  !- Complex field #6
  Until:  24:00, 0.0,  !- Complex field #7
  For:  AllOtherDays,  !- Complex field #8
  Until:  4:00, 0.0,  !- Complex field #9
  Until:  5:00, 125.0,  !- Complex field #10
  Until:  6:00, 117.0,  !- Complex field #11
  Until:  7:00, 90.0,  !- Complex field #12
  Until:  19:00, 0.0,  !- Complex field #13
  Until:  20:00, 125.0,  !- Complex field #14
  Until:  21:00, 117.0,  !- Complex field #15
  Until:  22:00, 90.0,  !- Complex field #16
  Until:  24:00, 0.0;  !- Complex field #17

Schedule:Compact,
  Kitchen_WalkInFreezer_Case:1_CaseCreditSchedule,  !- Name
  Fraction,  !- Schedule type
  Through:  12/31,  !- Complex field #1
  For:AllDays,  !- Complex field #2
  Interpolate:No,  !- Complex field #3
  Until:  7:00, 0.2,  !- Complex field #4
  Until:  21:00, 0.4,  !- Complex field #5
  Until:  24:00, 0.2;  !- Complex field #6

Refrigeration:Case,
  Kitchen_SelfContainedDisplayCase_Case:2,  !- Name
  ALWAYS_ON,  !- Availablility Schedule
  Kitchen,  !- Zone Name
  23.88,  !- Rated Ambient Temperature (C)
  55.0,  !- Rated Ambient Relative Humidity (%)
  734,  !- Rated Total Cooling Capacity per Unit length (W/m)
  0.08,  !- Rated Latent Heat Ratio
  0.85,  !- Rated Runtime Fraction
  3.66,  !- Case Length (m)
  2,  !- Case Operating Temperature (C)
```

```
  CaseTemperatureMethod,  !- Latent Case Credit Curve Type
  Kitchen_SelfContainedDisplayCase_Case:2_LatentCaseCreditCurve,  !- Latent Case Credit Curve Name
  55,  !- Standard Case Fan Power per Unit Length (W/m)
  40.0,  !- Operating Case Fan Power per Unit Length (W/m)
  33,  !- Standard Case Lighting Power per Unit Length (W/m)
  75.0,  !- Installed Case Lighting Power per Unit Length (W/m)
  BLDG_LIGHT_SCH,  !- Case Lighting Schedule Name
  1,  !- Fraction Of Lighting Energy To Case
  0.0,  !- Case Anti-Sweat Heater Power per Unit Length (W/m)
  0.0,  !- Minimum Anti-Sweat Heater Power per Unit Length (W/m)
  None,  !- Anti-Sweat Heater Control Type (******)
  0.0,  !- Humidity At Zero Anti-Sweat Heater Energy (%)
  0.0,  !- Case Height (m)
  0.2,  !- Fraction of Anti-Sweat Heater Energy To Case ()
  0,  !- Case Defrost Power per Unit Length (W/m)
  None,  !- Case Defrost Type (*******)
  ,  !- Case Defrost Schedule Name
  ,  !- Case Defrost Drip-Down Schedule
  None,  !- Defrost Energy Correction Curve Type
  ,  !- Defrost Energy Correction Curve Name
  0.05,  !- Under Case HVAC Return Air Fraction ()
  Kitchen_SelfContainedDisplayCase_Case:2_RestockSchedule;  !- Refrigerated Case Restocking Schedule Name

Curve:Cubic,
  Kitchen_SelfContainedDisplayCase_Case:2_LatentCaseCreditCurve,  !- Name
  0.026526281,  !- Coefficient1 Constant
  0.001078032,  !- Coefficient2 x
  0.0000602558,  !- Coefficient3 x**2
  0.00000123732,  !- Coefficient4 x**3
  -35.0,  !- Minimum Value of x
  20.0;  !- Maximum Value of x

Curve:Cubic,
  Kitchen_SelfContainedDisplayCase_Case:2_DefrostEnergyCorrectionCurve,  !- Name
  0.0236,  !- Coefficient1 Constant
  0.0006,  !- Coefficient2 x
  0.0000,  !- Coefficient3 x**2
  0.0000,  !- Coefficient4 x**3
  -35.0,  !- Minimum Value of x
  20.0;  !- Maximum Value of x
```

```
Schedule:Compact,
  Kitchen_SelfContainedDisplayCase_Case:2_RestockSchedule,  !- Name
  Any Number,  !- Schedule type
  Through:  12/31,  !- Complex field #1
  For:AllDays,  !- Complex field #2
  Until:  6:00, 0.0,  !- Complex field #3
  Until:  7:00, 50.0,  !- Complex field #4
  Until:  9:00, 70.0,  !- Complex field #5
  Until:  10:00, 80.0,  !- Complex field #6
  Until:  11:00, 70.0,  !- Complex field #7
  Until:  13:00, 50.0,  !- Complex field #8
  Until:  14:00, 80.0,  !- Complex field #9
  Until:  15:00, 90.0,  !- Complex field #10
  Until:  16:00, 80.0,  !- Complex field #11
  Until:  24:00, 0.0;  !- Complex field #12

Refrigeration:CompressorRack,
  RACK1,  !- Name
  Outdoors,  !- Heat Rejection Location (Outdoors | Zone)
  1.5,  !- Design Compressor Rack COP (W/W)
  RACK1_CopFuncTempCurve,  !- Compressor Rack COP As Function Of Temperature Curve
  350,  !- Design Condenser Fan Power (W)
  RACK1_FanFuncTempCurve,  !- Condenser Fan Power Function of Temperature Curve Name
  AirCooled,  !- Condenser Type
  ,  !- Water-Cooled Condenser Inlet Node Name
  ,  !- Water-Cooled Condenser Outlet Node Name
  ,  !- Water-Cooled Loop Flow Type
  ,  !- Water-Cooled Condenser Outlet Temperature Schedule Name
  ,  !- Water-Cooled Condenser Design Flow Rate
  ,  !- Water-Cooled Condenser Maximum Flow Rate
  ,  !- Water-Cooled Condenser Maximum Water Outlet Temperature
  ,  !- Water-Cooled Condenser Minimum Water Inlet Temperature
  ,  !- Evaporative Condenser Availability Schedule Name
  ,  !- Evaporative Condenser Effectiveness
  ,  !- Evaporative Condenser Air Flow Rate
  ,  !- Basin Heater Capacity (W/K)
  ,  !- Basin Heater Setpoint Temperature (C)
  ,  !- Design Evaporative Condenser Water Pump Power
  ,  !- Evaporative Water Supply Tank Name
  RACK1_CondenserNode,  !- Condenser Air Inlet Node Name
  Refrigeration,  !- End-Use Subcategory
```

```
  Kitchen_WalkInFreezer_Case:1,  !- Refrigeration Case Name or CaseList Name
  ;  !- Heat Rejection Zone Name

Curve:Quadratic,
  RACK1_FanFuncTempCurve,  !- Name
  0.0,  !- Coefficient1 Constant
  0.0286,  !- Coefficient2 x
  0.0,  !- Coefficient3 x**2
  0.0,  !- Minimum Value of x
  35.0;  !- Maximum Value of x

Curve:Quadratic,
  RACK1_CopFuncTempCurve,  !- Name
  1.7603,  !- Coefficient1 Constant
  -0.0377,  !- Coefficient2 x
  0.0004,  !- Coefficient3 x**2
  10.0,  !- Minimum Value of x
  35.0;  !- Maximum Value of x

Refrigeration:CompressorRack,
  RACK2,  !- Name
  Outdoors,  !- Heat Rejection Location (Outdoors | Zone)
  3,  !- Design Compressor Rack COP (W/W)
  RACK2_CopFuncTempCurve,  !- Compressor Rack COP As Function Of Temperature Curve
  350,  !- Design Condenser Fan Power (W)
  ,  !- Condenser Fan Power Function of Temperature Curve Name
  AirCooled,  !- Condenser Type
  ,  !- Water-Cooled Condenser Inlet Node Name
  ,  !- Water-Cooled Condenser Outlet Node Name
  ,  !- Water-Cooled Loop Flow Type
  ,  !- Water-Cooled Condenser Outlet Temperature Schedule Name
  ,  !- Water-Cooled Condenser Design Flow Rate
  ,  !- Water-Cooled Condenser Maximum Flow Rate
  ,  !- Water-Cooled Condenser Maximum Water Outlet Temperature
  ,  !- Water-Cooled Condenser Minimum Water Inlet Temperature
  ,  !- Evaporative Condenser Availability Schedule Name
  ,  !- Evaporative Condenser Effectiveness
  ,  !- Evaporative Condenser Air Flow Rate
  ,  !- Basin Heater Capacity (W/K)
  ,  !- Basin Heater Setpoint Temperature (C)
  ,  !- Design Evaporative Condenser Water Pump Power
```

```
  ,  !- Evaporative Water Supply Tank Name
  RACK2_CondenserNode,  !- Condenser Air Inlet Node Name
  Refrigeration,  !- End-Use Subcategory
  Kitchen_SelfContainedDisplayCase_Case:2,  !- Refrigeration Case Name or CaseList Name
  ;  !- Heat Rejection Zone Name

Curve:Quadratic,
  RACK2_CopFuncTempCurve,  !- Name
  1.0,  !- Coefficient1 Constant
  0.0,  !- Coefficient2 x
  0.0,  !- Coefficient3 x**2
  0.0,  !- Minimum Value of x
  50.0;  !- Maximum Value of x
```

F.2 Secondary School

```
Refrigeration:Case,
  Kitchen_Flr_2_WalkInFreezer_Case:1,  !- Name
  ALWAYS_ON,  !- Availablility Schedule
  Kitchen_Flr_2,  !- Zone Name
  23.88,  !- Rated Ambient Temperature (C)
  55.0,  !- Rated Ambient Relative Humidity (%)
  734,  !- Rated Total Cooling Capacity per Unit length (W/m)
  0.1,  !- Rated Latent Heat Ratio
  0.4,  !- Rated Runtime Fraction
  7.32,  !- Case Length (m)
  -23,  !- Case Operating Temperature (C)
  CaseTemperatureMethod,  !- Latent Case Credit Curve Type
  Kitchen_Flr_2_WalkInFreezer_Case:1_LatentCaseCreditCurve,  !- Latent Case Credit Curve Name
  68.3,  !- Standard Case Fan Power per Unit Length (W/m)
  172.2,  !- Operating Case Fan Power per Unit Length (W/m)
  33,  !- Standard Case Lighting Power per Unit Length (W/m)
  28.1,  !- Installed Case Lighting Power per Unit Length (W/m)
  BLDG_LIGHT_SCH,  !- Case Lighting Schedule Name
  1,  !- Fraction Of Lighting Energy To Case
  0.0,  !- Case Anti-Sweat Heater Power per Unit Length (W/m)
  0.0,  !- Minimum Anti-Sweat Heater Power per Unit Length (W/m)
  None,  !- Anti-Sweat Heater Control Type (******)
  0.0,  !- Humidity At Zero Anti-Sweat Heater Energy (%)
  0.0,  !- Case Height (m)
  0.0,  !- Fraction of Anti-Sweat Heater Energy To Case ()
  410,  !- Case Defrost Power per Unit Length (W/m)
```

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  Electric,  !- Case Defrost Type
  Kitchen_Flr_2_WalkInFreezer_Case:1_DefrostSchedule,  !- Case Defrost Schedule Name
  Kitchen_Flr_2_WalkInFreezer_Case:1_DefrostDripDownSchedule,  !- Case Defrost Drip-Down Schedule
  None,  !- Defrost Energy Correction Curve Type
  ,  !- Defrost Energy Correction Curve Name
  0.0,  !- Under Case HVAC Return Air Fraction ()
  Kitchen_Flr_2_WalkInFreezer_Case:1_RestockSchedule,  !- Refrigerated Case Restocking Schedule Name
  Kitchen_Flr_2_WalkInFreezer_Case:1_CaseCreditSchedule;  !- Case Credit Fraction Schedule Name

Curve:Cubic,
  Kitchen_Flr_2_WalkInFreezer_Case:1_LatentCaseCreditCurve,  !- Name
  0.0236,  !- Coefficient1 Constant
  0.0006,  !- Coefficient2 x
  0.0000,  !- Coefficient3 x**2
  0.0000,  !- Coefficient4 x**3
  -35.0,  !- Minimum Value of x
  20.0;  !- Maximum Value of x

Schedule:Compact,
  Kitchen_Flr_2_WalkInFreezer_Case:1_DefrostSchedule,  !- Name
  ON/OFF,  !- Schedule type
  Through:  12/31,  !- Complex field #1
  For:AllDays,  !- Complex field #2
  Interpolate:Yes,  !- Complex field #3
  Until:  11:00, 0,  !- Complex field #4
  Until:  11:20, 1,  !- Complex field #5
  Until:  23:00, 0,  !- Complex field #6
  Until:  23:20, 1,  !- Complex field #7
  Until:  24:00, 0;  !- Complex field #8

Schedule:Compact,
  Kitchen_Flr_2_WalkInFreezer_Case:1_DefrostDripDownSchedule,  !- Name
  ON/OFF,  !- Schedule type
  Through:  12/31,  !- Complex field #1
  For:AllDays,  !- Complex field #2
  Interpolate:Yes,  !- Complex field #3
  Until:  11:00, 0,  !- Complex field #4
  Until:  11:30, 1,  !- Complex field #5
  Until:  23:00, 0,  !- Complex field #6
  Until:  23:30, 1,  !- Complex field #7
  Until:  24:00, 0;  !- Complex field #8
```

```
Curve:Cubic,
  Kitchen_Flr_2_WalkInFreezer_Case:1_DefrostEnergyCorrectionCurve,  !- Name
  0.0236,  !- Coefficient1 Constant
  0.0006,  !- Coefficient2 x
  0.0000,  !- Coefficient3 x**2
  0.0000,  !- Coefficient4 x**3
  -35.0,  !- Minimum Value of x
  20.0;  !- Maximum Value of x

Schedule:Compact,
  Kitchen_Flr_2_WalkInFreezer_Case:1_RestockSchedule,  !- Name
  Any Number,  !- Schedule type
  Through:  12/31,  !- Complex field #1
  For:  Tuesday Friday,  !- Complex field #2
  Until:  4:00, 0.0,  !- Complex field #3
  Until:  5:00, 725.0,  !- Complex field #4
  Until:  6:00, 417.0,  !- Complex field #5
  Until:  7:00, 290.0,  !- Complex field #6
  Until:  24:00, 0.0,  !- Complex field #7
  For:  AllOtherDays,  !- Complex field #8
  Until:  4:00, 0.0,  !- Complex field #9
  Until:  5:00, 125.0,  !- Complex field #10
  Until:  6:00, 117.0,  !- Complex field #11
  Until:  7:00, 90.0,  !- Complex field #12
  Until:  19:00, 0.0,  !- Complex field #13
  Until:  20:00, 125.0,  !- Complex field #14
  Until:  21:00, 117.0,  !- Complex field #15
  Until:  22:00, 90.0,  !- Complex field #16
  Until:  24:00, 0.0;  !- Complex field #17

Schedule:Compact,
  Kitchen_Flr_2_WalkInFreezer_Case:1_CaseCreditSchedule,  !- Name
  Fraction,  !- Schedule type
  Through:  12/31,  !- Complex field #1
  For:AllDays,  !- Complex field #2
  Interpolate:No,  !- Complex field #3
  Until:  7:00, 0.2,  !- Complex field #4
  Until:  21:00, 0.4,  !- Complex field #5
  Until:  24:00, 0.2;  !- Complex field #6
```

```
Refrigeration:Case,
  Kitchen_Flr_2_SelfContainedDisplayCase_Case:2,  !- Name
  ALWAYS_ON,  !- Availablility Schedule
  Kitchen_Flr_2,  !- Zone Name
  23.88,  !- Rated Ambient Temperature (C)
  55.0,  !- Rated Ambient Relative Humidity (%)
  734,  !- Rated Total Cooling Capacity per Unit length (W/m)
  0.08,  !- Rated Latent Heat Ratio
  0.85,  !- Rated Runtime Fraction
  7.32,  !- Case Length (m)
  2,  !- Case Operating Temperature (C)
  CaseTemperatureMethod,  !- Latent Case Credit Curve Type
  Kitchen_Flr_2_SelfContainedDisplayCase_Case:2_LatentCaseCreditCurve,  !- Latent Case Credit Curve Name
  55,  !- Standard Case Fan Power per Unit Length (W/m)
  40.0,  !- Operating Case Fan Power per Unit Length (W/m)
  33,  !- Standard Case Lighting Power per Unit Length (W/m)
  75.0,  !- Installed Case Lighting Power per Unit Length (W/m)
  BLDG_LIGHT_SCH,  !- Case Lighting Schedule Name
  1,  !- Fraction Of Lighting Energy To Case
  0.0,  !- Case Anti-Sweat Heater Power per Unit Length (W/m)
  0.0,  !- Minimum Anti-Sweat Heater Power per Unit Length (W/m)
  None,  !- Anti-Sweat Heater Control Type (******)
  0.0,  !- Humidity At Zero Anti-Sweat Heater Energy (%)
  0.0,  !- Case Height (m)
  0.2,  !- Fraction of Anti-Sweat Heater Energy To Case ()
  0,  !- Case Defrost Power per Unit Length (W/m)
  None,  !- Case Defrost Type (*******)
  ,  !- Case Defrost Schedule Name
  ,  !- Case Defrost Drip-Down Schedule
  None,  !- Defrost Energy Correction Curve Type
  ,  !- Defrost Energy Correction Curve Name
  0.05,  !- Under Case HVAC Return Air Fraction ()
  Kitchen_Flr_2_SelfContainedDisplayCase_Case:2_RestockSchedule;  !- Refrigerated Case Restocking Schedule
Name

Curve:Cubic,
  Kitchen_Flr_2_SelfContainedDisplayCase_Case:2_LatentCaseCreditCurve,  !- Name
  0.026526281,  !- Coefficient1 Constant
  0.001078032,  !- Coefficient2 x
  0.0000602558,  !- Coefficient3 x**2
  0.00000123732,  !- Coefficient4 x**3
```

```
  -35.0,  !- Minimum Value of x
  20.0;  !- Maximum Value of x

Curve:Cubic,
  Kitchen_Flr_2_SelfContainedDisplayCase_Case:2_DefrostEnergyCorrectionCurve,  !- Name
  0.0236,  !- Coefficient1 Constant
  0.0006,  !- Coefficient2 x
  0.0000,  !- Coefficient3 x**2
  0.0000,  !- Coefficient4 x**3
  -35.0,  !- Minimum Value of x
  20.0;  !- Maximum Value of x

Schedule:Compact,
  Kitchen_Flr_2_SelfContainedDisplayCase_Case:2_RestockSchedule,  !- Name
  Any Number,  !- Schedule type
  Through:  12/31,  !- Complex field #1
  For:AllDays,  !- Complex field #2
  Until:  6:00, 0.0,  !- Complex field #3
  Until:  7:00, 50.0,  !- Complex field #4
  Until:  9:00, 70.0,  !- Complex field #5
  Until:  10:00, 80.0,  !- Complex field #6
  Until:  11:00, 70.0,  !- Complex field #7
  Until:  13:00, 50.0,  !- Complex field #8
  Until:  14:00, 80.0,  !- Complex field #9
  Until:  15:00, 90.0,  !- Complex field #10
  Until:  16:00, 80.0,  !- Complex field #11
  Until:  24:00, 0.0;  !- Complex field #12

Refrigeration:CompressorRack,
  RACK1,  !- Name
  Outdoors,  !- Heat Rejection Location (Outdoors | Zone)
  1.5,  !- Design Compressor Rack COP (W/W)
  RACK1_CopFuncTempCurve,  !- Compressor Rack COP As Function Of Temperature Curve
  750,  !- Design Condenser Fan Power (W)
  RACK1_FanFuncTempCurve,  !- Condenser Fan Power Function of Temperature Curve Name
  AirCooled,  !- Condenser Type
  ,  !- Water-Cooled Condenser Inlet Node Name
  ,  !- Water-Cooled Condenser Outlet Node Name
  ,  !- Water-Cooled Loop Flow Type
  ,  !- Water-Cooled Condenser Outlet Temperature Schedule Name
  ,  !- Water-Cooled Condenser Design Flow Rate
```

```
  ,  !- Water-Cooled Condenser Maximum Flow Rate
  ,  !- Water-Cooled Condenser Maximum Water Outlet Temperature
  ,  !- Water-Cooled Condenser Minimum Water Inlet Temperature
  ,  !- Evaporative Condenser Availability Schedule Name
  ,  !- Evaporative Condenser Effectiveness
  ,  !- Evaporative Condenser Air Flow Rate
  ,  !- Basin Heater Capacity (W/K)
  ,  !- Basin Heater Setpoint Temperature (C)
  ,  !- Design Evaporative Condenser Water Pump Power
  ,  !- Evaporative Water Supply Tank Name
  RACK1_CondenserNode,  !- Condenser Air Inlet Node Name
  Refrigeration,  !- End-Use Subcategory
  Kitchen_Flr_2_WalkInFreezer_Case:1,  !- Refrigeration Case Name or CaseList Name
  ;  !- Heat Rejection Zone Name

Curve:Quadratic,
  RACK1_FanFuncTempCurve,  !- Name
  0.0,  !- Coefficient1 Constant
  0.0286,  !- Coefficient2 x
  0.0,  !- Coefficient3 x**2
  0.0,  !- Minimum Value of x
  35.0;  !- Maximum Value of x

Curve:Quadratic,
  RACK1_CopFuncTempCurve,  !- Name
  1.7603,  !- Coefficient1 Constant
  -0.0377,  !- Coefficient2 x
  0.0004,  !- Coefficient3 x**2
  10.0,  !- Minimum Value of x
  35.0;  !- Maximum Value of x

Refrigeration:CompressorRack,
  RACK2,  !- Name
  Outdoors,  !- Heat Rejection Location (Outdoors | Zone)
  3,  !- Design Compressor Rack COP (W/W)
  RACK2_CopFuncTempCurve,  !- Compressor Rack COP As Function Of Temperature Curve
  750,  !- Design Condenser Fan Power (W)
  ,  !- Condenser Fan Power Function of Temperature Curve Name
  AirCooled,  !- Condenser Type
  ,  !- Water-Cooled Condenser Inlet Node Name
  ,  !- Water-Cooled Condenser Outlet Node Name
```

```
  ,  !- Water-Cooled Loop Flow Type
  ,  !- Water-Cooled Condenser Outlet Temperature Schedule Name
  ,  !- Water-Cooled Condenser Design Flow Rate
  ,  !- Water-Cooled Condenser Maximum Flow Rate
  ,  !- Water-Cooled Condenser Maximum Water Outlet Temperature
  ,  !- Water-Cooled Condenser Minimum Water Inlet Temperature
  ,  !- Evaporative Condenser Availability Schedule Name
  ,  !- Evaporative Condenser Effectiveness
  ,  !- Evaporative Condenser Air Flow Rate
  ,  !- Basin Heater Capacity (W/K)
  ,  !- Basin Heater Setpoint Temperature (C)
  ,  !- Design Evaporative Condenser Water Pump Power
  ,  !- Evaporative Water Supply Tank Name
  RACK2_CondenserNode,  !- Condenser Air Inlet Node Name
  Refrigeration,  !- End-Use Subcategory
  Kitchen_Flr_2_SelfContainedDisplayCase_Case:2,  !- Refrigeration Case Name or CaseList Name
  ;  !- Heat Rejection Zone Name

Curve:Quadratic,
  RACK2_CopFuncTempCurve,  !- Name
  1.0,  !- Coefficient1 Constant
  0.0,  !- Coefficient2 x
  0.0,  !- Coefficient3 x**2
  0.0,  !- Minimum Value of x
  50.0;  !- Maximum Value of x
```