TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY PROGRAM FOR COMMERCIAL AND INDUSTRIAL EQUIPMENT: EFFICIENCY STANDARDS FOR COMMERCIAL HEATING, AIR-CONDITIONING, AND WATER-HEATING EQUIPMENT

Including Water-cooled and Evaporatively-cooled Air Conditioners, Water-source Variable Refrigerant Flow Systems, Single Package Vertical Air Conditioners, and Single Package Vertical Heat Pumps, and Air Conditioners and Condensing Units Serving Computer Rooms

May 2, 2011

U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Building Technologies Program
Appliances and Commercial Equipment Standards
Washington, DC 20585

This Document was prepared for the Department of Energy
by the staff members of
Navigant Consulting, Inc.,
Lawrence Berkeley National Laboratory,
And
Pacific Northwest National Laboratory

CHAPTER 1. INTRODUCTION

TABLE OF CONTENTS

1.1 PURPOSE OF THE DOCUMENT 1-1

1.2 PROCESS FOR AMENDED ENERGY CONSERVATION STANDARDS FOR ASHRAE EQUIPMENT 1-1

1.3 STRUCTURE OF THIS DOCUMENT 1-2

1.1 PURPOSE OF THE DOCUMENT

This technical support document (TSD) is a stand-alone report that provides the technical analysis and results supporting the information presented in the Notice of Data Availability (NODA) for ASHRAE Standard 90.1-2010 equipment.

1.2 PROCESS FOR AMENDED ENERGY CONSERVATION STANDARDS FOR ASHRAE EQUIPMENT

Title III of the Energy Policy and Conservation Act (EPCA), Pub. L. 94-163, as amended, sets forth a variety of provisions concerning energy efficiency. Part C[1] of Title III created the energy conservation program for "Certain Industrial Equipment." (42 U.S.C. 6311-6317) Of particular relevance for this rulemaking is 42 U.S.C 6313(a)(6) which directs DOE, in the event that ASHRAE Standard 90.1 is amended for certain types of commercial and industrial equipment, to adopt that efficiency level unless clear and convincing evidence supports a determination that adopting a more stringent level would produce significant additional energy savings and is technologically feasible and economically justified.

On October 29, 2010, American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) officially released the American National Standards Institute (ANSI)/ASHRAE/Illuminating Engineering Society of North America (IESNA) Standard 90.1-2010 (hereinafter referred to as ASHRAE Standard 90.1-2010), which addressed efficiency levels for certain categories of commercial heating, ventilating and air-conditioning (HVAC) and water heating equipment covered by the Energy Policy and Conservation Act (EPCA). The new Standard 90.1 revised the efficiency levels of the existing ASHRAE Standard 90.1-2007 for certain equipment, such as water-cooled and evaporatively-cooled air conditioning and heating equipment and water-source variable refrigerant flow (VRF) systems with a cooling capacity less than 17,000 Btu/h. The standard also created new energy efficiency levels for water-source VRF systems with a cooling capacity greater than or equal to 135,000 Btu/h and for air conditioners and condensing units serving computer rooms, which were previously uncovered by DOE's energy conservation standards..

The Energy Independence and Security Act of 2007 (EISA 2007) further amended EPCA by setting definitions and minimum energy conservation standards for single package vertical air conditioners (SPVACs) and single package vertical heat pumps (SPVHPs). EISA 2007 also amended EPCA to include a provision specifically for these equipment classes (and no others), which required DOE to review the most recently published ASHRAE Standard 90.1 in

[1] This Part was subsequently redesignated as Part A-1 for editorial reasons after Part C of Title III of EPCA was repealed by Pub. L. 109-58.

accordance with the procedures established for ASHRAE products under paragraph 42 U.S.C. 63131(a)(6). (42 U.S.C. 6313(a)(10)(B))

The NODA that this TSD accompanies is the first step in fulfilling DOE's obligations as set forth by the language in EPCA and its amendments. The NODA identifies the equipment for which the current ASHRAE Standard 90.1 amended its efficiency levels and presents the analysis of the potential energy savings at those levels as well as more stringent levels. In addition, the NODA presents the analysis of the potential energy savings from adopting more stringent energy conservation standards for SPVACs and SPVHPs as required by 42 U.S.C. 6313(a)(10)(B). This TSD provides a detailed description of the analyses performed in support of the NODA.

1.3 STRUCTURE OF THIS DOCUMENT

This NODA TSD outlines the analytical approaches used in this rulemaking. The TSD consists of 4 chapters:

Chapter 1 Introduction: Provides an overview of process to amend energy conservation standards for ASHRAE equipment and outlines the structure of the document.

Chapter 2 Market Assessment: Characterizes the market for water-cooled and evaporatively-cooled air conditioners, water-source variable refrigerant flow systems, single package vertical air conditioners and heat pumps, and air conditioners and condensing units serving computer rooms.

Chapter 3 Energy Use Characterization: Discusses the process used for generating energy use estimates for water-cooled and evaporatively-cooled air conditioners, single package vertical air conditioners, and single package vertical heat pumps at the current standard levels and at potential amended standard levels.

Chapter 4 National Energy Savings Analysis: Discusses the methodology and inputs for estimating the potential energy savings of various potential amended standard levels.

CHAPTER 2. MARKET ASSESSMENT

TABLE OF CONTENTS

2.1 BACKGROUND 2-1
- 2.1.1 Water-cooled and Evaporatively-cooled Air Conditioners 2-1
- 2.1.2 Single Package Vertical Air Conditioners and Heat Pumps 2-2
- 2.1.3 Variable Refrigerant Flow Commercial Package Air Conditioning and Heating Equipment 2-3
- 2.1.4 Air Conditioners and Condensing Units Serving Computer Rooms 2-4
- 2.1.5 Federal Energy Conservation Standards 2-5
- 2.1.6 ASHRAE Standard 90.1-2010 Efficiency Levels 2-8

2.2 MARKET ASSESSMENT 2-11
- 2.2.1 Trade Associations 2-11
- 2.2.2 Manufacturers 2-12
- 2.2.3 Market Performance Data 2-13

LIST OF TABLES

Table 2.1.1 Current Federal Energy Conservation Standards for Commercial Package Air Conditioning and Heating Equipment Classes with Increased Standard Levels in ASHRAE Standard 90.1-2010 2-7

Table 2.1.2 Federal Energy Conservation Standards for Single Package Vertical Air Conditioners 2-7

Table 2.1.3 Equipment Classes With Updated Efficiency Levels in ASHRAE Standard 90.1-2010 2-8

Table 2.2.1 Manufacturers of the Commercial Equipment Included in this Rulemaking 2-12

Table 2.2.2 CEC Computer Room Air Conditioners Minimum Efficiency Levels 2-20

LIST OF FIGURES

Figure 2.2.1 EER Histogram of Small Water-cooled Air Conditioners 2-15

Figure 2.2.2 EER Histogram of Large Water-cooled Air Conditioners 2-15

Figure 2.2.3 EER Histogram of Very Large Water-cooled Air Conditioners 2-16

Figure 2.2.4 EER Histogram of SPVACs <65,000 Btu/h 2-18

Figure 2.2.5 EER Histogram of SPVHPs 2-18

Figure 2.2.6 COP Histogram of SPVHPs 2-19

2.1 BACKGROUND

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) released an updated version of the American National Standards Institute (ANSI)/ASHRAE/Illuminating Engineering Society of North America (IESNA) Standard 90.1 (hereinafter referred to as ASHRAE Standard 90.1-2010) on October 29, 2010. ASHRAE Standard 90.1-2010 included increased efficiency levels for water-cooled and evaporatively-cooled commercial package air conditioners (triggering DOE review of the minimum standards for these equipment classes), and created a new set of equipment classes for variable refrigerant flow (VRF) products and for air conditioners and condensing units serving computer rooms. ASHRAE Standard 90.1-2010 also updated the standards for certain classes of water-source VRF commercial package air conditioning and heating equipment in comparison to the existing Federal standards that would apply, thereby triggering DOE review of the standards for those equipment classes.

In addition, DOE is required by EPCA to review the most recently published ASHRAE Standard 90.1 with respect to single package vertical air conditioners and single package vertical heat pumps in accordance with the procedures for ASHRAE equipment established under paragraph 42 U.S.C. 6313(a)(6). (42 U.S.C. 6313(a)(10)(B)) Therefore, although ASHRAE Standard 90.1-2010 did not increase the efficiency levels for single package vertical air conditioners and heat pumps, DOE is reviewing the minimum standards for these equipment classes under the requirements of 42 U.S.C. 6313(a)(10)(B).

2.1.1 Water-cooled and Evaporatively-cooled Air Conditioners

Water-cooled and evaporatively-cooled air conditioners are part of a subset of commercial package air conditioning and heating equipment. EPCA defines a "commercial package air conditioning and heating equipment" as an "air-cooled, water-cooled, evaporatively-cooled, or water-source (not including ground water-source) electrically operated, unitary central air conditioners and central air conditioning heat pumps for commercial application." (42 U.S.C. 6311(8)(A))

Air conditioners use a refrigeration cycle to cool an indoor space by moving heat from the cold location to a hotter location by means of evaporating and condensing a fluid, typically a refrigerant. An air conditioner typically has four major components: a compressor, condensing coil, expansion valve, and an evaporator coil. The compressor turns the refrigerant from a low pressure gas into a high pressure gas, which raises the temperature of the gas. At the next step, the condensing coil convects the heat from the hot refrigerant, which condenses into a liquid, still at a high temperature and high pressure. This liquid refrigerant then goes through an expansion valve that lowers its pressure and temperature before entering the evaporator coil. The evaporator

coil cools the indoor air by transferring heat from the indoor air to the low temperature refrigerant.

Commercial-size water-cooled and evaporatively-cooled air conditioners cool commercial facilities and utilize water instead of ambient air (as is used in air-cooled equipment) to cool the condensing coil. In the case of a water-cooled air conditioner, the condensing coil is submerged in circulating water; whereas in the case of evaporatively-cooled air conditioner, the condensing coil is sprayed with water that evaporates as air passes over the coil. Both systems utilize the high heat capacity of water to optimize the heat transfer from the refrigerant in the condensing coil. Water-cooled air conditioners can be used effectively in any type of environment, while evaporatively-cooled air conditioners are most effective in hot-dry climate regions (i.e., the southwestern United States).

Although EPCA initially set the same standard levels for water-cooled and evaporatively-cooled air conditioners, ASHRAE Standard 90.1-2010 specifies different standard levels for each. EPCA and ASHRAE Standard 90.1 both further divide this equipment into four categories based on cooling capacity ranges: <65,000 Btu/h, ≥65,000 and <135,000 Btu/h, ≥135,000 and <240,000 Btu/h, and ≥240,000 and < 760,000 Btu/h.[a] EPCA identifies equipment with cooling capacities of <135,000 Btu/h, ≥135,000 and <240,000 Btu/h, ≥240,000 and <760,000 Btu/h as "small," "large," and "very large," respectively. (42 U.S.C. 6311(8)(B)-(D)) EPCA and ASHRAE Standard 90.1 also divide these products further based on whether they have electric resistance or no heating or any other kind of heating.

2.1.2 Single Package Vertical Air Conditioners and Heat Pumps

Single package vertical air conditioners and heat pumps are also a subset of commercial package air conditioning and heating equipment as defined by EPCA. EPCA further defines single package vertical air conditioners as "air-cooled commercial package air conditioning and heating equipment that---

(1) Is factory-assembled as a single package that—

(i) Has major components that are arranged vertically;

(ii) Is an encased combination of cooling and optional heating components; and

(iii) Is intended for exterior mounting on, adjacent interior to, or through an outside wall;

(2) Is powered by a single-or 3-phase current;

(3) May contain 1 or more separate indoor grilles, outdoor louvers, various ventilation options, indoor free air discharges, ductwork, well plenum, or sleeves; and

[a] ASHRAE Standard 90.1 does not specify an upper limit on the cooling capacity for the largest capacity equipment class (i.e., ≥240,000 Btu/h). However, EPCA limits the size of very large commercial package air conditioning and heating equipment to cooling capacities below 760,000 Btu/h.

(4) Has heating components that may include electrical resistance, steam, hot water, or gas, but may not include reverse cycle refrigeration as a heating means." (42 U.S.C. 6311(23))

EPCA also defines single package vertical heat pump as "a single package vertical air conditioner that (1) uses reverse cycle refrigeration as its primary heat source; and (2) may include secondary supplemental heating by means of electrical resistance, steam, hot water, or gas." (42 U.S.C. 6311(24)) ASHRAE Standard 90.1-2010 also defines both of these terms in the same way.

Single Package Vertical Air Conditioners (SPVACs) and Single Package Vertical Heat Pumps (SPVHPs) are mainly used for cooling and heating classrooms, modular buildings, telecommunication shelters, and portable buildings. Although this equipment is typically sized in cooling capacities similar to products used in residential applications, they are subject to different operational cycles and operating hours than are typically encountered in residential applications. The types of buildings in which SPVACs and SPVHPs are installed all have high internal loads stemming from a high number of occupants and heat sources when the building is in use. Also, since these buildings are usually high density buildings, floor space is at a premium; thus, having the components for these units arranged in a vertical fashion allows them to be placed in closets or mounted through the wall in order to minimize the amount of floor space occupied by the equipment.

EPCA and ASHRAE Standard 90.1 both divide SPVACs and SPVHPs into 3 size categories based on cooling capacity: <65,000 Btu/h, ≥65,000 Btu/h and < 135,000 Btu/h, and ≥135,000 and <240,000 Btu/h.

2.1.3 Variable Refrigerant Flow Commercial Package Air Conditioning and Heating Equipment

Variable refrigerant flow systems are a subset of commercial package air conditioning and heating equipment that is newly defined in ASHRAE 90.1-2010. Neither EPCA nor DOE's regulations in the Code of Federal Regulations define variable refrigerant flow systems. ASHRAE Standard 90.1-2010 defines a variable refrigerant flow system as "an engineered direct expansion (DX) multi-split system incorporating at least one variable capacity compressor distributing refrigerant through a piping network to multiple indoor fan coil units each capable of individual zone temperature control, through integral zone temperature control devices and common communications network. Variable refrigerant flow utilizes three or more steps of control, on common, interconnecting piping."

VRF systems are most commonly used in hotels, schools, and office buildings where different zones have different heating and cooling load requirements depending on occupancy and time of day. VRF systems have one outdoor condensing unit that is connected to multiple indoor evaporator coils, as opposed to the single evaporator coil typically found in conventional air conditioners and heat pumps. Each evaporator coil in a VRF system can be individually controlled, and VRF systems are capable of monitoring and adjusting the refrigerant flow to each evaporator to meet the requirements of heating and cooling loads in specific zones. Some VRF heat pumps have a heat recovery option, which allows the system to move heat within a building via a third refrigerant line that connects indoor evaporator coils. The heat recovery feature allows a zone requiring heat to be warmed using the heat extracted from a zone requiring cooling, and vice versa. However, if all zones need to be heated at the same time, then the heat would need to be provided by other means.

Water-source VRF systems utilize a condensing unit that transfers heat to or from circulating water depending on whether the system is in cooling or heating mode. These systems allow the condensing unit of the system to be placed indoors, such as in a mechanical closet or a basement. Having the condensing unit indoors decreases the amount of refrigerant piping to the individual evaporator coils, which is especially useful for equipment installed in high rise office buildings.

ASHRAE 90.1-2010 divides air-cooled VRF systems into 4 size categories: <65,000 Btu/h, ≥65,000 and <135,000 Btu/h, ≥135,000 and <240,000 Btu/h, and ≥240,000 and < 760,000 Btu/h.[b] ASHRAE 90.1-2010 also divides water-source VRF systems into 3 size categories, <65,000 Btu/h, ≥65,000 and <135,000 Btu/h, and ≥135,000. For both air-cooled and water-source VRF systems, ASHRAE also further divides the equipment classes with a cooling capacity greater than 65,000 Btu/h based on whether or not a heat recovery system is present.

2.1.4 Air Conditioners and Condensing Units Serving Computer Rooms

"Air conditioners and condensing units serving computer rooms" is a new equipment class established in ASHRAE Standard 90.1-2010. ASHRAE Standard 90.1-2010 specifies the efficiency metric for this equipment class as sensible coefficient of performance (SCOP) as measured by ASHRAE 127-2007, *Method of Testing for Rating Computer and Data Processing Room Unitary Air Conditioners*. ASHRAE Standard 90.1-2010 does not contain a definition for "air conditioners and condensing units serving computer rooms," but does define a "computer room" as "a room whose primary function is to house equipment for the processing and storage

[b] ASHRAE Standard 90.1 does not specify an upper limit on the cooling capacity for the largest capacity equipment class (i.e., ≥240,000 Btu/h). However, EPCA limits the size of very large commercial package air conditioning and heating equipment to cooling capacities below 760,000 Btu/h.

of electronic data and that had a design electronic data equipment power density exceeding 20 watts/ft^2 of conditioned floor area."

Cooling computer rooms, server rooms, and data centers presents unique challenges because these areas contain valuable equipment that are sensitive to small changes in temperature and humidity. Too much humidity can lead to water condensing on electronic equipment, and too little humidity may cause static discharges. Computer equipment are also constantly producing dynamic, high density heating loads, which means that the air conditioning also would need to be running constantly and needs to be able to cool any "hot spots." Server rooms and data centers are typically located in the center of buildings away from windows and often have limited floor space, which limits the size and positioning of the air conditioner and causes issues related to removing the heat from the computer room.

Because of these challenges air conditioners serving computer rooms have different design requirements than standard air conditioners, even though they use the same process and components as conventional air conditioners (i.e., a refrigeration cycle with a compressor, condensing coil, expansion valve, and evaporator coil). Air conditioners serving computer rooms have to maintain a precise temperature, usually 72 °F or 75 °F, and maintain a specific relative humidity (usually between 40 and 55 percent) so in addition to cooling, these equipment have to be capable of both humidifying and dehumidifying the air. These air conditioners are often called "precision air conditioners" because of this control requirement. These units can be installed in various configurations, including floor mounted, ceiling mounted, or portable units for moving around the room. The condensing units can be cooled by air, water, or a glycol-water mixture.

ASHRAE Standard 90.1-2010 first divides air conditioners and condensing units serving computer rooms into 5 classes depending on cooling mechanism: air-cooled, water-cooled, water-cooled with a fluid economizer, glycol-cooled (rated at 40% propylene glycol), and glycol-cooled with a fluid economizer. ASHRAE Standard 90.1-2010 further divides these classes into 3 size categories (<65,000 Btu/h, ≥65,000 and <240,000 Btu/h, and ≥240,000 Btu/h) and orientation (upflow and downflow) to make up a total of 30 unique efficiency levels for this equipment class.

2.1.5 Federal Energy Conservation Standards

On January 12, 2001, DOE published in the *Federal Register* a final rule promulgating the current standards for 5 equipment classes of small (i.e., cooling capacity <135,000 Btu/h) and large (i.e., cooling capacity ≥135,000 Btu/h and <240,000 Btu/h) water-cooled and evaporatively-cooled air conditioners. 66 FR 3336. This final rule adopted the energy conservation standards set by ASHRAE Standard 90.1-1999. On July 22, 2009, DOE published in the *Federal Register* a final rule setting the standards for very large water-cooled and

evaporatively-cooled equipment with a cooling capacity ≥240,000 and <760,000 Btu/h. 74 FR 36312. In the July final rule, DOE adopted the standard levels for those products specified by ASHRAE Standard 90.1-2007.

The existing energy conservation standards for all classes of SPVACs and SPVHPs were established by the Energy Independence and Security Act of 2007 (EISA 2007) amendments to EPCA. These standards were codified by DOE in a Technical Amendment published in the Federal Register on March 23, 2009. 74 FR 12058. ASHRAE Standard 90.1-2010 specifies efficiency levels for SPVACs and SPVHPs that are the same as the energy conservation standards promulgated by EISA 2007.

As noted previously, variable refrigerant flow systems are new classes of equipment in ASHRAE Standard 90.1-2010. However, these equipment classes are currently covered under the more broad federal equipment classes of commercial package air conditioning and heating equipment. ASHRAE Standard 90.1-2010 set its efficiency levels for all classes of VRF systems equal to the federal energy conservation standards for commercial package air conditioning and heating equipment, except for the equipment class of water-source VRF heat pumps with a cooling capacity <17,000 Btu/h. Therefore, with the exception of water-source VRF heat pumps with a cooling capacity <17,000 Btu/h, DOE was not required to perform an analysis of those equipment classes. In addition, ASHRAE Standard 90.1-2010 includes efficiency levels for water-source VRF heat pumps with cooling capacity ≥135,000 Btu/h, which are not currently regulated by federal energy conservation standards. The current federal energy conservation standard for water-source heat pumps was set by the January 2001 final rule, which adopted the ASHRAE Standard 90.1-1999 levels. 66 FR 3336. The Energy Policy Act of 2005 (EPACT 2005) set the current federal standard for the other classes of commercial package air conditioners and heating equipment with the exception of air-cooled heat pumps with a cooling capacity less than 65,000 Btu/h, which were included in EISA 2007.

Table 2.1.1 shows the current federal energy conservation levels for equipment classes where ASHRAE Standard 90.1-2010 increased the standard levels in comparison to the federal levels. Table 2.1.2 shows the current federal energy conservation levels for single package vertical air conditioners, which DOE is required to review according to EPCA, as amended by EISA 2007.

Table 2.1.1 Current Federal Energy Conservation Standards for Commercial Package Air Conditioning and Heating Equipment Classes with Increased Standard Levels in ASHRAE Standard 90.1-2010

Equipment Type	Cooling Capacity	Subcategory	Federal Standard
Small Commercial Package Air Conditioning Equipment, Water-cooled and Evaporatively-cooled	≥65,000 Btu/h and <135,000 Btu/h	Electric Resistance or no heating	11.5 EER
		All other	11.3 EER
Large Commercial Package Air Conditioning and Heating Equipment, Water-cooled and Evaporatively-cooled	≥135,000 Btu/h and <240,000 Btu/h	Electric Resistance or no heating	11.0 EER
		All other	11.0 EER
Very Large Commercial Package Air Conditioning and Heating Equipment, Water-cooled and Evaporatively-cooled	≥240,000 Btu/h and <760,000 Btu/h	Electric Resistance or no heating	11.0 EER
		All other	10.8 EER
Small Commercial Package Air Conditioning and Heating Equipment, Water-source*	<17,000 Btu/h	HP	11.2 EER 4.2 COP
Large Commercial Package Air Conditioning and Heating Equipment, Water-source*	>135,000 Btu/h	HP	None

* This product class includes VRF systems, for which ASHRAE Standard 90.1-2010 updated its standard levels.

Table 2.1.2 Federal Energy Conservation Standards for Single Package Vertical Air Conditioners

Equipment Type	Cooling Capacity	Subcategories	Federal Minimum Energy Conservation Standards
Single Package Vertical Air Conditioners	<65,000 Btu/h	Single Phase	9.0 EER
		Three-Phase	
Single Package Vertical Air Conditioners	≥65,000 and <135,000Btu/h	-	8.9 EER
Single Package Vertical Air Conditioners	≥135,000 and <240,000Btu/h	-	8.6 EER
Single Package Vertical Heat Pumps	<65,000 Btu/h	Single Phase	9.0 EER 3.0 COP
		Three-Phase	
Single Package Vertical Heat Pumps	≥65,000 and <135,000Btu/h	-	8.9 EER 3.0 COP
Single Package Vertical Heat Pumps	≥135,000 and <240,000Btu/h	-	8.6 EER 2.9 COP

2.1.6 ASHRAE Standard 90.1-2010 Efficiency Levels

The previous version of ASHRAE Standard 90.1 (ASHRAE Standard 90.1-2007) specified the efficiency levels for water-cooled and evaporatively-cooled air conditioners as part of a single equipment class including both types of equipment. In ASHRAE Standard 90.1-2010, ASHRAE specified different efficiency levels for water-cooled air conditioners and evaporatively-cooled air conditioners, while retaining the same cooling capacity divisions separating the equipment classes. For the water-cooled and evaporatively-cooled equipment class with a cooling capacity between 65,000 Btu/h and 135,000 Btu/h, ASHRAE divides the class into two more classes based on whether the system has no heating or electric resistance heating or any other type of heating, similar to the other size categories. ASHRAE also created new equipment classes for variable refrigerant flow systems and raised the efficiency level above the federal standard for those with a cooling capacity less than 17,000 Btu/h and with a cooling capacity greater than or equal to 135,000 Btu/h (for which no federal standard exists). ASHRAE also created new equipment classes for air conditioners and condensing units serving computer rooms. Table 2.1.3 below shows the ASHRAE Standard 90.1-2010 efficiency level for the updated equipment classes along with the currently applicable Federal minimum efficiency standards for comparison.

Table 2.1.3 Equipment Classes With Updated Efficiency Levels in ASHRAE Standard 90.1-2010

ASHRAE Equipment Type	Cooling Capacity	Subcategories		ASHRAE Standard 90.1-2010	Federal Minimum Energy Conservation Standards
Water-cooled Air Conditioner	≥65,000 and <135,000Btu/h	Electric Resistance or No Heating	Split System and Single Package	12.1 EER (as of 6/1/11)	11.5 EER
		All Others	Split System and Single Package	11.9 EER (as of 6/1/11)	11.3 EER
	≥135,000 and <240,000Btu/h	Electric Resistance or No Heating	Split System and Single Package	12.5 EER (as of 6/1/11)	11.0 EER
		All Others	Split System and Single Package	12.3 EER (as of 6/1/11)	
	≥240,000 and <760,000Btu/h	Electric Resistance or No Heating	Split System and Single Package	12.4 EER (as of 6/1/11)	11.0 EER
		All Others	Split System and Single Package	12.2 EER (as of 6/1/11)	10.8 EER

ASHRAE Equipment Type	Cooling Capacity	Subcategories		ASHRAE Standard 90.1-2010	Federal Minimum Energy Conservation Standards
Evaporatively-cooled Air Conditioner	≥65,000 and <135,000Btu/h	Electric Resistance or No Heating	Split System and Single Package	12.1 EER (as of 6/1/11)	11.5 EER
		All Others	Split System and Single Package	11.9 EER (as of 6/1/11)	11.3 EER
	≥135,000 and <240,000Btu/h	Electric Resistance or No Heating	Split System and Single Package	12.0 EER (as of 6/1/11)	11.0 EER
		All Others	Split System and Single Package	11.8 EER (as of 6/1/11)	
	≥240,000 and <760,000Btu/h	Electric Resistance or No Heating	Split System and Single Package	11.9 EER (as of 6/1/11)	11.0 EER
		All Others	Split System and Single Package	12.2 EER * (as of 6/1/11)	10.8 EER
Variable Refrigerant Flow, Water-source	<17,000 Btu/h	All heating types	Multi-split system	12.0 EER 4.2 COP	11.2 EER 4.2 COP
			Multi-split system with Heat Recovery	11.8 EER 4.2 COP	11.2 EER 4.2 COP
	≥135,000 Btu/h	All heating types	Multi-split system	10.0 EER 3.9 COP	None
			Multi-split system with Heat Recovery	9.8 EER 3.9 COP	
Air Conditioners Serving Computer Rooms, Air-Cooled	<65,000 Btu/h	-	Downflow	2.20 SCOP	None
			Upflow	2.09 SCOP	
	≥65,000 Btu/h and <240,000 Btu/h	-	Downflow	2.10 SCOP	
			Upflow	1.99 SCOP	
	≥240,000 Btu/h	-	Downflow	1.90 SCOP	
			Upflow	1.79 SCOP	
Air Conditioners Serving Computer Rooms, Water Cooled	<65,000 Btu/h	-	Downflow	2.60 SCOP	None
			Upflow	2.49 SCOP	

ASHRAE Equipment Type	Cooling Capacity	Subcategories		ASHRAE Standard 90.1-2010	Federal Minimum Energy Conservation Standards
	≥65,000 Btu/h and <240,000 Btu/h	-	Downflow	2.50 SCOP	
			Upflow	2.39 SCOP	
	≥240,000 Btu/h	-	Downflow	2.40 SCOP	
			Upflow	2.29 SCOP	
Air Conditioners Serving Computer Rooms, Water Cooled with fluid economizer	<65,000 Btu/h	-	Downflow	2.55 SCOP	None
			Upflow	2.44 SCOP	
	≥65,000 Btu/h and <240,000 Btu/h	-	Downflow	2.45 SCOP	
			Upflow	2.34 SCOP	
	≥240,000 Btu/h	-	Downflow	2.35 SCOP	
			Upflow	2.24 SCOP	
Air Conditioners Serving Computer Rooms, glycol-cooled	<65,000 Btu/h	-	Downflow	2.50 SCOP	None
			Upflow	2.39 SCOP	
	≥65,000 Btu/h and <240,000 Btu/h	-	Downflow	2.15 SCOP	
			Upflow	2.04 SCOP	
	≥240,000 Btu/h	-	Downflow	2.10 SCOP	
			Upflow	1.99 SCOP	
Air Conditioners Serving Computer Rooms, glycol-cooled with fluid economizer	<65,000 Btu/h	-	Downflow	2.45 SCOP	None
			Upflow	2.34 SCOP	
	≥65,000 Btu/h and <240,000 Btu/h	-	Downflow	2.10 SCOP	
			Upflow	1.99 SCOP	
	≥240,000 Btu/h	-	Downflow	2.05 SCOP	
			Upflow	1.94 SCOP	

*Given the historical approach of the ASHRAE committee to setting efficiency levels with for commercial air conditioning and heating equipment, this efficiency level appears to be a mistake in ASHRAE Standard 90.1-2010. DOE believes the intended level is 11.7 EER, and an addendum to lower the value to 11.7 EER is currently being considered by ASHRAE. Accordingly, DOE considered the value 11.7 EER as the ASHRAE Standard 90.1-2010 efficiency level in its potential energy savings analysis.

ASHRAE Standard 90.1-2010 raised the efficiency level in comparison to the current Federal minimum energy conservation standards for 6 water-cooled air conditioner equipment classes, 6 evaporatively-cooled air conditioner equipment classes, and 1 water-source VRF commercial air conditioner and heat pump equipment classes. In addition, ASHRAE Standard 90.1-2010 included efficiency levels for one water-source VRF commercial air conditioner and heat pump equipment class and for 15 classes of air conditioners serving computer rooms that were not previously covered by DOE's regulations. ASHRAE did not raise the efficiency level for any equipment classes of SPVACs and SPVHPs; however, DOE is required by EPCA (as amended by EISA 2007) to assess the potential for energy savings from more stringent energy conservation standards for these equipment classes. DOE assessed the current market and performed a potential energy savings analysis for each equipment class. The market assessment is described in the sections immediately below; while the energy use characterization and assessment of the potential energy savings are described in detail in chapters 3 and 4 of this TSD, respectively.

2.2 MARKET ASSESSMENT

The following market assessment identifies the manufacturer trade associations and domestic and international manufacturers of commercial water-cooled and evaporatively-cooled air conditioners, single package vertical air conditioners and heat pumps, variable refrigerant flow systems, and air conditioners and condensing units serving computer rooms. The market assessment also summarizes the relevant market performance data for each equipment class where such data was available.

2.2.1 Trade Associations

DOE researched various trade groups who represent manufacturers, distributors, and installers of the various types of equipment being analyzed this rulemaking. The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) is one of the largest trade associations for manufacturers of space heating and cooling equipment, representing over 90% of the residential and commercial air-conditioning, space-heating, water-heating, and commercial refrigeration equipment manufactured in the US.[1] AHRI also develops and publishes test procedures standards for residential and commercial heating, ventilation, and air conditioning (HVAC) equipment and coordinates with the International Organization for Standardization (ISO) to help harmonize the US standards with international standards, if feasible. AHRI also maintains the AHRI Directory of Certified Product Performance that lists all the products and equipment that have been certified by AHRI. AHRI keeps a separate directory for single package vertical air conditioners and single package vertical heat pumps. Water-cooled air conditioners can be found in the commercial unitary large equipment directory. There are no evaporatively-cooled air conditioners listed in the AHRI directory.

Heating, Airconditioning & Refrigeration Distributors International (HARDI) is a trade association that represents over 450 wholesale heating, ventilation, air conditioning, and refrigeration (HVACR) companies plus over 300 manufacturing associates and nearly 140 manufacturing representatives. HARDI estimates that 80% of the revenue of HVACR systems goes through its members.[2]

Air Conditioning Contractors of America (ACCA) is another trade association whose members include over 4,000 contractors and 60,000 professionals. ACCA provides contractors technical, legal, and market resources, helping to promote good practices and to keep buildings safe, clean, and affordable.[3]

2.2.2 Manufacturers

DOE reviewed the efficiency data for water-cooled and evaporatively-cooled air conditioners currently on the market by examining the AHRI Directory of Certified Product Performance[4] and the California Energy Commission (CEC) Appliance Efficiency Database.[5] To supplement the data in the AHRI and CEC databases, DOE gathered additional information from the websites of individual manufacturers of that equipment. For single package vertical air conditioners and heat pumps, DOE gathered market data from the AHRI directory as well as additional information from manufacturer's websites. Because the AHRI directory does not break out VRF systems separately in its database, DOE gathered data from manufacturers' websites for that equipment. DOE gathered data on air conditioners and condensing units serving computer rooms from the CEC website and from manufacturer's websites.

DOE identified eight manufacturers of water-cooled air conditioners, five manufacturers of evaporatively-cooled air conditioners, eight manufacturers of single package vertical air conditioners and heat pumps, and two manufactures of water-source variable refrigerant flow systems, and 7 manufacturers of air conditioners and condenser serving computer rooms. The manufacturers for each equipment class are listed in Table 2.2.1.

Table 2.2.1 Manufacturers of the Commercial Equipment Included in this Rulemaking

Water-Cooled Air Conditioner Manufacturers	Evaporatively-cooled Air Conditioner Manufacturers	Single Package Vertical Air Conditioner and Heat Pump Manufacturers	Water-source Variable Refrigerant Flow System Manufacturers	Air Conditioners and Condensers Serving Computer Room Manufacturers
Aaon, Inc.	Aaon, Inc.	Allied Air Enterprises	Daikin Industries, Ltd.	Airedale (Modine)
Allied Thermal Systems	Beutler Corp.	Bard Manufacturing Company	Mitsubishi Electric	American Power Conversion
Carrier Corp.	EP Investments, Inc.	Enviromaster International		CES Group, Inc (Nordyne)
Lennox International	Trane Inc.	Friedrich Air		Emerson Network

		Conditioning Co.		Power
RSI Co.	York International Corp.	GE Appliances & Lighting		CompuAire
Thermoplus Air, Inc.		Marvair, division of Airxcel, Inc.		Data Aire, Inc.
Trane Inc.		National Coil Company		Stulz Air Technology Systems
York International Corp.		National Comfort Products		

2.2.3 Market Performance Data

For each equipment class analyzed, DOE began by gathering market data to characterize the efficiency and performance of models currently on the market. As noted earlier, DOE gathered information from the AHRI directory of certified product performance, as well as the CEC appliance database. DOE also examined individual manufacturer websites and literature to compile a complete database of models for each equipment class.

For the analysis, DOE only examined the water-cooled and evaporatively-cooled air conditioner equipment classes with cooling capacities greater than 65,000 Btu/h because ASHRAE Standard 90.1-2010 did not change the efficiency levels for the commercial equipment classes with a cooling capacity under 65,000 Btu/h.

Using the AHRI and CEC directories as a starting point and augmenting the data with information from manufacturer websites, DOE compiled a database of water-cooled air conditioner models with efficiency data available and separated them into the appropriate equipment classes based on cooling capacity: small (i.e., <135,000 Btu/h), large (i.e., ≥135,000 Btu/h and <240,000 Btu/h), and very large (i.e., ≥240,000 Btu/h and <760,000 Btu/h).

DOE found no evaporatively-cooled air conditioners in the AHRI Directory of Certified Product Performance and found few evaporatively-cooled air conditioners from manufacturers' websites. DOE compiled a database of evaporatively-cooled air conditioner models with efficiency data available, and found no models that would fall into the small and large equipment classes. Accordingly, all evaporatively-cooled models identified were in the very large equipment class.

DOE compiled a database of SPVACs and SPVHPs from the AHRI directory and separated them into three equipment classes based on cooling capacity (<65,000 Btu/h; ≥65,000 Btu/h and <135,000 Btu/h; and ≥135,000 Btu/h and <240,000 Btu/h). DOE did not identify any SPVAC models that would fall into the largest cooling capacity (i.e., ≥135,000 Btu/h and <240,000 Btu/h) and did not find any SPVHP models that would fall into either of the two largest cooling capacity equipment classes (i.e., ≥65,000 Btu/h and <135,000 Btu/h; and

≥135,000 Btu/h and <240,000 Btu/h). The majority of SPVAC and SPVHP models fell in the smallest cooling capacity equipment classes (i.e., <65,000 Btu/h).

DOE also compiled a database from manufacturers' websites of water-source VRF heat pumps with a cooling capacity greater than or equal to 135,000 Btu/h. However, DOE found no water-source VRF heat pumps with a cooling capacity less than 17,000 Btu/h on the market.

Lastly, for air conditioners and condensing units serving computer rooms, DOE compiled a database of available models using information from the CEC directory and from manufacturers' websites. DOE then divided the computer room air conditioner models into 15 equipment classes, by net sensible cooling capacity (<65,000 Btu/h, ≥65,000 Btu/h and <240,000 Btu/h, and ≥240,000 Btu/h) and by cooling type (air-cooled, water-cooled, water-cooled with a fluid economizer, glycol-cooled, and glycol-cooled with a fluid economizer). DOE further divided each equipment class by orientation (i.e., whether it is upflow or downflow).

2.2.3.1 Water-Cooled Air Conditioners

Small water-cooled Air Conditioners. Small water-cooled air conditioners have a cooling capacity greater than or equal to 65,000 Btu/h and less than 135,000 Btu/h and have their condensing coil completely submerged in water. Small water-cooled air conditioners are part of the water-cooled and evaporatively-cooled air conditioners equipment class, whose Federal energy conservation standard is 11.5 EER for systems with electric resistance or no heating and 11.3 EER for systems that use any other type of heating (66 FR 3336; 10 CFR 431.97). ASHRAE Standard 90.1-2010 changes the efficiency rating to 12.1 for systems with electric resistance or no heating and 11.9 for systems that use any other type of heating. DOE analyzed the distribution of energy efficiency ratios (EERs) for these products as well as the minimum, maximum, and average cooling input capacities and EER values. The average EER value for this equipment class is 13.9. Of the models identified by DOE, two (13 percent of the total models) have EERs rated below the ASHRAE Standard 90.1-2010 levels.

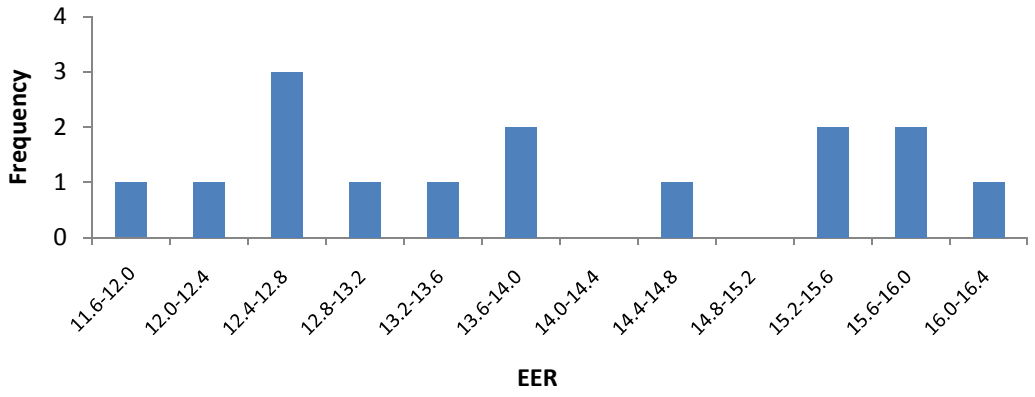


Figure 2.2.1 EER Histogram of Small Water-cooled Air Conditioners

Large water-cooled air conditioners. Large water-cooled air conditioners have a cooling capacity greater than or equal to 135,000 Btu/h and less than 240,000 Btu/h and have their condensing coil completely submerged in water. Large water-cooled air conditioners are part of the water-cooled and evaporatively-cooled air conditioners equipment class, whose Federal energy conservation standard is 11.0 EER regardless of what kind of heating is used (66 FR 3336; 10 CFR 431.97). ASHRAE Standard 90.1-2010 changes the efficiency rating to 12.5 for systems with electric resistance or no heating and 12.3 for systems that use any other type of heating. DOE analyzed the distribution of efficiencies for these products. The average EER for these units was 13.1. DOE identified 6 models (43 percent of the total models in this equipment class) that would fall below the ASHRAE Standard 90.1-2010 levels for this equipment class.

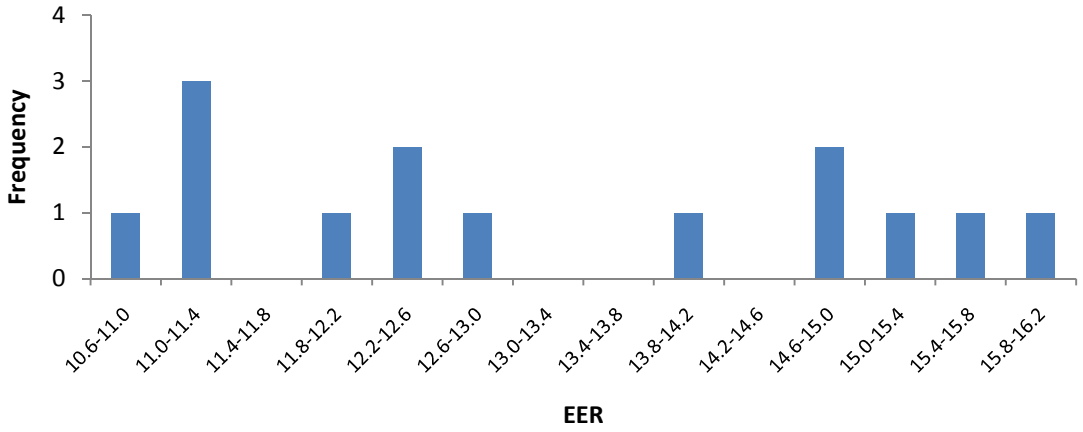


Figure 2.2.2 EER Histogram of Large Water-cooled Air Conditioners

Very large water-cooled air conditioners. Very large water-cooled air conditioners have a cooling capacity greater than or equal to 240,000 Btu/h and less than 760,000 Btu/h, and have their condensing coil completely submerged in water. Very large water-cooled air conditioners are part of the water-cooled and evaporatively-cooled air conditioners equipment

class, whose Federal energy conservation standard is 11.0 EER for units with electric resistance or no heating and 10.8 for units with all other kinds of heating (74 FR 36312; 10 CFR 431.97). ASHRAE Standard 90.1-2010 changes the efficiency rating to 12.5 for systems with electric resistance or no heating and 12.3 for systems that use any other type of heating. DOE analyzed the distribution of efficiencies for these products. The average EER rating for these units is 13.0. DOE identified 12 models (34 percent of the total models identified) that would fall below the ASHRAE Standard 90.1-2010 efficiency level for this equipment class.

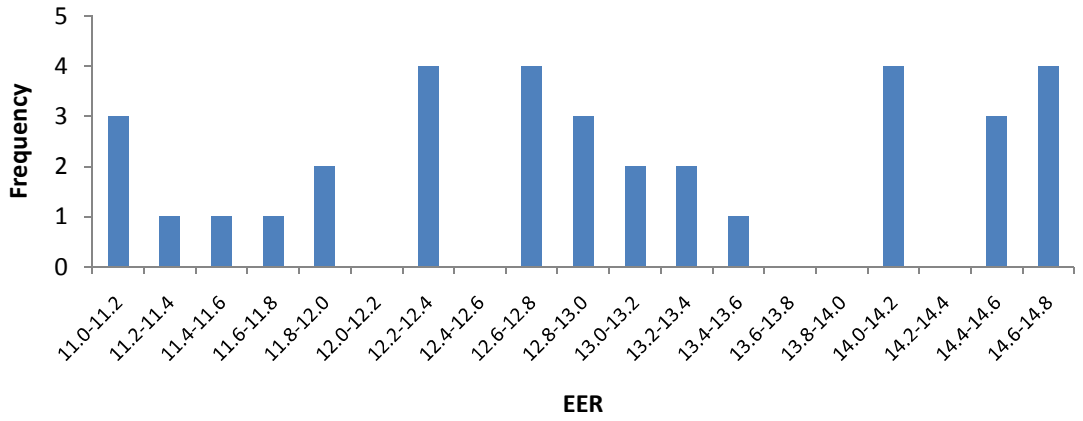


Figure 2.2.3 EER Histogram of Very Large Water-cooled Air Conditioners

2.2.3.2 Evaporatively-Cooled Air Conditioners

Small evaporatively-cooled air conditioners. Small evaporatively-cooled air conditioners have a cooling capacity greater than or equal to 65,000 Btu/h and less than 135,000 Btu/h. Small evaporatively-cooled air conditioners are covered as part of the water-cooled and evaporatively-cooled air conditioners equipment class, whose Federal energy conservation standard is 11.5 EER for systems with electric resistance or no heating and 11.3 EER for systems that use any other type of heating (66 FR 3336; 10 CFR 431.97). ASHRAE Standard 90.1-2010 changes the efficiency rating to 12.1 EER for systems with electric resistance or no heating and 11.9 EER for systems that use any other type of heating. DOE did not find any models on the market that would be classified as small evaporatively-cooled air conditioners.

Large evaporatively-cooled air conditioners. Large evaporatively-cooled air conditioners have a cooling capacity greater than or equal to 135,000 Btu/h and less than 240,000 Btu/h. Large evaporatively-cooled air conditioners are covered as part of the water-cooled and evaporatively-cooled air conditioners equipment class, whose Federal energy conservation standard is 11.0 EER regardless of what type of heating is used (66 FR 3336; 10 CFR 431.97). ASHRAE Standard 90.1-2010 changes the efficiency rating to 12.0 EER for systems with electric resistance or no heating and 11.8 EER for systems that use any other type

of heating. DOE also did not find any models on the market that would be classified as large evaporatively-cooled air conditioners.

Very large evaporatively-cooled air conditioners. Very large evaporatively-cooled air conditioners have an input capacity greater than or equal to 240,000 Btu/h and less than 760,000 Btu/h. Very large evaporatively-cooled air conditioners are covered as part of the water-cooled and evaporatively-cooled air conditioners equipment class, whose Federal energy conservation standard is 11.0 EER for systems with electric resistance or no heating and 10.8 EER for systems that use any other type of heating (74 FR 36312; 10 CFR 431.97). ASHRAE Standard 90.1-2010 changes the efficiency rating to 12.0 EER for systems with electric resistance or no heating and 11.8 EER for systems that use any other type of heating. During the market research, DOE identified several models from manufacturers that would be classified as very large evaporatively-cooled air conditioners. However, the efficiency rating for these models was not readily available, and DOE was unable to obtain it. Although DOE could not obtain efficiency information from manufacturer literature, DOE did develop an estimate of the potential energy savings for very large evaporatively-cooled air conditioners. See chapter 4 of this TSD for details on DOE's potential energy savings analysis.

2.2.3.3 Single Package Vertical Air Conditioners and Heat Pumps

Single package vertical air conditioners. EISA 2007 divided single package vertical air conditioners into three equipment classes and set the efficiency level for each class. SPVACs with a cooling capacity <65,000 Btu/h have a federal conservation standard of 9.0 EER. SPVACs with a cooling capacity ≥65,000 Btu/h and <135,000 Btu/h have a federal conservation standard of 8.9 EER. SPVACs with a cooling capacity ≥135,000 Btu/h and <240,000 Btu/h have a federal conservation standard of 8.6 EER (10 CFR 431.97). DOE found 364 SPVACs listed in the AHRI database. Of the models listed, 359 have an input capacity less than 65,000 Btu/h and only 5 have a cooling capacity greater than or equal to 65,000 Btu/h. DOE did not find any large SPVACs (with a cooling capacity greater than or equal to 135,000 Btu/h and less than 240,000 Btu/h). There were 108 models (30 percent of the total models) with a cooling capacity less than 65,000 Btu/h that are minimally compliant with the current federal energy conservation standards. The 5 models with a input capacity greater than 65,000 Btu/h had an average EER value of 9.7 with a minimum EER of 9.5 and a maximum EER of 10.0. All of these models are compliant with the federal standard of 8.9 for this equipment class.

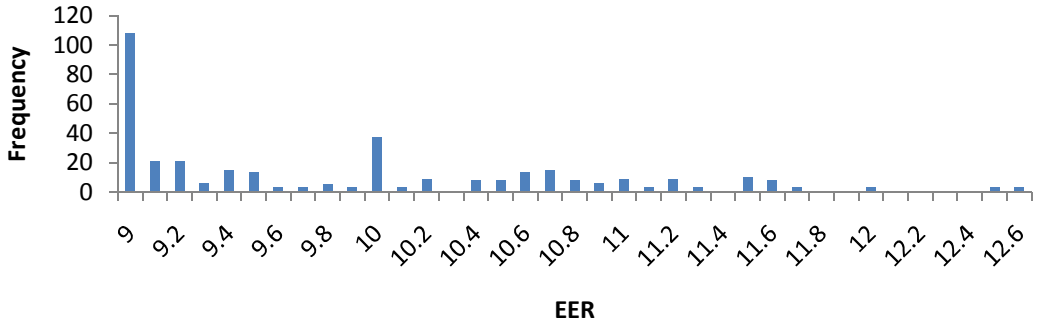


Figure 2.2.4 EER Histogram of SPVACs <65,000 Btu/h

Single package vertical heat pumps. EISA 2007 divided single package vertical heat pumps into three equipment classes and set the efficiency level for each class. SPVHPs with a cooling capacity <65,000 Btu/h have federal conservation standard of 9.0 EER and 3.0 coefficient of performance (COP). SPVHPs with a cooling capacity ≥65,000 Btu/h and <135,000 Btu/h have a federal conservation standard of 8.9 EER and 3.0 COP. SPVHPs with a cooling capacity ≥135,000 Btu/h and <240,000 Btu/h have a federal conservation standard of 8.6 EER and 2.9 COP (10 CFR 431.97). DOE found 245 SPVHP models listed in the AHRI directory. All of them have a cooling capacity less than 65,000 Btu/h. Of the models identified, 64 (26 percent of the total) are minimally compliant with the current federal EER standard and 135 (55 percent of the total) are minimally compliant with the federal COP standard.

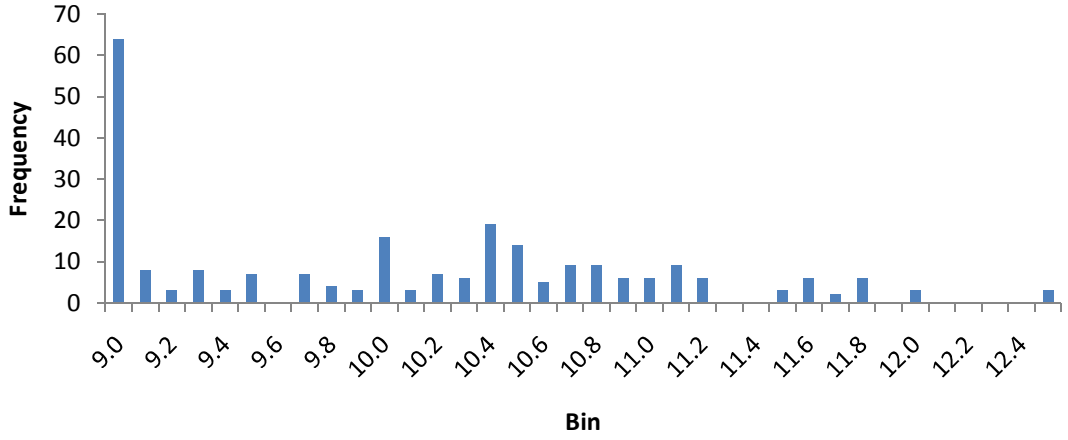


Figure 2.2.5 EER Histogram of SPVHPs

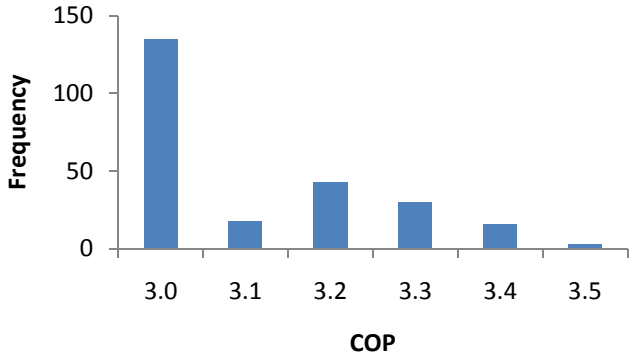


Figure 2.2.6 COP Histogram of SPVHPs

2.2.3.4 Variable Refrigerant Flow Water-source Heat Pumps

Water-source VRF heat pumps with a cooling capacity less than 17,000 Btu/h have a federal energy conservation standard of 11.2 EER and 4.2 COP. ASHRAE Standard 90.1-2010 changes the efficiency rating for water cooled VRF systems with a cooling capacity less than 17,000 Btu/h to 12.0 EER and 4.2 COP for those systems with no heat recovery technology and to 11.8 EER and 4.2 COP for those systems with heat recovery technology. DOE surveyed the market to find VRF water-source heat pumps with cooling capacities below 17,000 Btu/h, and did not find any on the market.

Water-source VRF heat pumps with a cooling capacity greater than or equal to 135,000 Btu/h currently do not have a federal energy conservation standard. ASHRAE is also adding new efficiency standards for those systems with a cooling capacity greater than or equal to 135,000 Btu/h to 10.0 EER and 3.9 COP for systems without heat recovery devices and 9.8 EER and 3.9 COP for systems with heat recovery devices. From two manufacturers' websites, DOE found 19 models with no heat recovery option and 9 models with a heat recovery add-on for a total of 28 unique units. Manufacturers only reported EER and COP information for 8 of these units. For the remaining of the units, DOE contacted the relevant manufacturer but could not obtain EER or COP ratings.

2.2.3.5 Air Conditioners and Condensing Units Serving Computer Rooms

Prior to ASHRAE Standard 90.1-2010, air conditioners and condensing units serving computer rooms were not considered covered equipment under EPCA, so there are currently no federal energy conservation standards for these equipment. As a result, several manufacturers do not report efficiency information. However, the CEC regulates the minimum efficiency of

computer room air conditioners, requiring units installed in the state of California to meet a minimum EER rating as listed in Table 2.2.2.

Table 2.2.2 CEC Computer Room Air Conditioners Minimum Efficiency Levels

CEC Equipment Type	Cooling Capacity (Btu/h)	Minimum Efficiency Level
Air-cooled computer room air conditioners	< 65,000	11.0 EER
	≥ 65,000 and < 135,000	10.4 EER
	≥ 135,000 and < 240,000	10.2 EER
Water-cooled, Glycol-cooled, and Evaporatively-cooled Computer Air Conditioners	< 65,000	11.1 EER
	≥ 65,000 and < 135,000	10.5 EER
	≥ 135,000 and < 240,000	10.0 EER

As noted previously, the CEC also maintains a directory of "computer room air conditioners" in its appliance efficiency database. DOE searched the CEC database for air conditioners and condensing units serving computer rooms and supplemented that data with information from literature found on manufacturer websites. In total, DOE found over 1500 models of air conditioners and condensing units serving computer rooms, many of which were derivatives of the same basic unit. For example, a basic unit could have the option of an upflow or downflow configuration and the option of adding a fluid economizer; thus from this basic unit, 4 different models are possible.

The CEC database includes the rated EER of each model listed. Although this information provides a measure of equipment efficiency, DOE notes that ASHRAE Standard 90.1-2010 adopts an updated version of ASHRAE Standard 127 (i.e., ASHRAE Standard 127-2007), which changes the efficiency metric from EER to SCOP. CEC requires manufacturers to use the 2001 version of ASHRAE 127, which tests for the EER and not SCOP. In addition, the standard rating conditions were changed between the 2001 and 2007 editions of the ASHRAE 127 test procedure, which adds to the difficulty of obtaining information about product efficiency as rated using the new SCOP rating metric. A footnote to Table D1 in Appendix D of ASHRAE Standard 127-2007 contains a "rule-of-thumb" formula that approximates the SCOP value using the old EER rating. Using this simple rule of thumb gives a rough approximation of SCOP and a basic idea of how SCOP values compare to EER, but is not a substitute for efficiency data obtained from direct application of the test method. As a result, DOE was unable to acquire reliable SCOP data for computer rooms and air conditioners serving computer rooms.

REFERENCES

1 Air-Conditioning, Heating, and Refrigeration Institute Website. *About Us.* 2011. (Last accessed April 28, 2011.) <www.ahrinet.org/about+us.aspx>

2 Heating, Airconditioning & Refrigeration Distributors International Website. *About HARDI*. 2011. (Last accessed April 28, 2011.) <www.hardinet.org/aws/HARDI/pt/sp/about>

3 Air Conditioning Contractors of America Website. *About ACCA.* 2011. (Last accessed April 28,2011.) <www.acca.org/acca>

4 AHRI Directory. *Directory of Certified Product Performance*. 2011. (Last accessed April 28, 2011.) <www.ahridirectory.org>

5 California Energy Commission Website. *Appliance Efficiency Database*. 2011. (Last accessed April 28, 2011.) <www.appliances.energy.ca.gov/QuickSearch.aspx>

CHAPTER 3 ENERGY USE CHARACTERIZATION

TABLE OF CONTENTS

3.1 INTRODUCTION 3-1
3.2 ENERGY USE ANALYSIS BY EQUIPMENT TYPE 3-1
3.2.1 Water-Cooled Air Conditioners 3-1
3.2.1.1 Water-Cooled Condenser Performance 3-2
3.2.1.2 Supply Water Temperature 3-4
3.2.1.3 Supply Fan Power 3-5
3.2.1.4 Water-Cooled Condenser-Only Cooling Coefficient of Performance vs. Energy Efficiency Ratio Relationship 3-6
3.2.1.5 Baseline Annual Energy Use/Ton for Climates—Water-Cooled 3-7
3.2.1.6 Energy Use Estimates for Baseline and Higher-Efficiency Water-Cooled Air Conditioner Equipment by Equipment Class 3-8
3.2.2 Evaporatively Cooled Air Conditioners 3-10
3.2.2.1 Baseline Annual Energy Use/Ton for Climates—Evaporatively Cooled 3-11
3.2.2.2 Energy Use Estimates for Baseline and Higher Efficiency Evaporatively Cooled Air Conditioners by Equipment Class 3-12
3.2.3 Single-Package Vertical Air Conditioners and Heat Pumps 3-12
3.2.3.1 Fan and Condenser Power Assumptions: Single-Package Vertical Air Conditioners 3-13
3.2.3.2 Single-Package Vertical Heat Pump Analysis 3-16

LIST OF TABLES

Table 3.2.1 Normalized Energy Use Ton by Climate for Water-Cooled Air Conditioners, 11.0 EER 3-8
Table 3.2.2 Water-Cooled Air Conditioner Representative Capacities by Product Class 3-9
Table 3.2.3 Normalized Energy Use Ton by Climate for Evaporatively-Cooled Air Conditioners, 11.0 EER 3-11
Table 3.2.4 Evaporatively Cooled Air Conditioner Representative Capacities by Product Class 3-12
Table 3.2.5 Normalized Energy Use Ton by Climate for SPVAC, Baseline (9.0 EER) 3-14
Table 3.2.6 Blower Power Adjustments for ECM Motor 3-15
Table 3.2.7 Normalized Energy Use Ton by Climate for SPVHP, Baseline (9.0 EER/3.0 COP) 3-17

LIST OF FIGURES

Figure 3.2.1 Comparison of Floor-Space Weighting Factors by Region. Small and Medium Office Buildings versus All Buildings. 3-7

CHAPTER 3. ENERGY USE CHARACTERIZATION

3.1 INTRODUCTION

The national energy savings analysis described in chapter 4 of the technical support document (TSD) requires determination of the energy savings consumers would realize from the establishment of standards at the levels set forth in American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2010 for specific classes of equipment analyzed as well as for more energy efficient standards.

This chapter describes the energy use analysis for both water-cooled and evaporatively cooled commercial packaged air conditioners as well as single package vertical air conditioners and heat pumps. These equipment types are described in separate subsections of this chapter that detail the analysis and the determination of baseline annual per unit energy consumption (UEC) estimates for specific product classes within each of the three product types examined. This chapter also describes the development of UEC estimates for more efficient equipment, up to the max-tech levels defined in chapter 4 of this TSD.

For each of these equipment types, the Federal standard is expressed in terms of an efficiency metric or metrics: energy efficiency ratio (EER) for cooling efficiency, coefficient of performance (COP) for heating efficiency. For each equipment class, this chapter describes how an estimate of the UEC is developed corresponding to different rated efficiencies.

3.2 ENERGY USE ANALYSIS BY EQUIPMENT TYPE

3.2.1 Water-Cooled Air Conditioners

The analysis to assess the per unit energy savings of water-cooled air conditioners began with a review of the existing market as well as the review of historical shipments data provided by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) and discussed in chapter 4 of the TSD. The review of the market suggested that most water-cooled air conditioner units on the market are designed for installation inside of commercial buildings (as opposed to on building rooftops), and the shipments data suggested that in recent years shipments were dominated by larger equipment (greater than 240,000 British thermal units per hour (Btu/h) capacity), with a trend toward relatively few shipments of smaller capacity units. Because of this, the U.S. Department of Energy (DOE) analysis of energy savings focused on typical applications for equipment in the 240,000 Btu/h or greater class. Review of manufacturer's literature suggested that a common application is floor-by-floor cooling in a multi-story building.[1]

To estimate the energy use of water-cooled air conditioners in this application, DOE used annual hourly simulation data developed from computer simulations of a prototypical commercial office building. The prototype building model was a 3-story, 53,600 ft^2 commercial

office building developed as part of DOE's commercial reference building models.[a] This building model, referred to as a "medium office," has each floor served by a separate packaged air conditioning unit. The hourly data used for this analysis was previously developed from simulations using this model and the DOE EnergyPlus building simulation software, and reflected building simulations in 15 climate locations in the United States.[b] Each climate location used is representative of climate in 1 of 15 climate regions that have been developed in DOE's Building Energy Codes Program and subsequently used in the development of the commercial reference building models. Characteristics of the DOE reference medium office building model used in this analysis are provided in appendix 7A.

The medium office reference building model used packaged variable air volume (VAV) rooftop cooling units, one unit serving each floor of the building, and the hourly thermal load and supply fan air volume data used for this analysis reflects this. DOE determined that the hourly cooling thermal loads from modeling of this type of equipment would be representative of hourly loads for systems served by larger water-cooled equipment also providing floor-by-floor cooling and serving multiple building thermal zones with a VAV air distribution network. Thus, these loads would be accurate for the analysis of water-cooled air conditioners in this application. EnergyPlus does not have an equipment component model developed around a water-cooled air conditioner used in this application. EnergyPlus does have equipment models of water-source heat pumps, but these equipment models do not appear to provide for variable volume air flow. For this reason, DOE used the previously developed hourly cooling thermal load, hourly air flow, and hourly air temperature data for the air-cooled packaged rooftop equipment used in the medium office reference building model as a starting point for its analysis.

To process the hourly data into annual equipment energy consumption for water-cooled air conditioners for baseline level equipment, DOE developed a spreadsheet model of the equipment performance of a water-cooled air conditioner using actual manufacturer's performance data for an existing 25-ton water-cooled air conditioner.[2] Cooling capacity and condenser power consumption curve fits to this data were developed using polynomial relationships and the independent variables recommended for modeling of cooling efficiency for water-source heat pumps in EnergyPlus with minor variations. Discussion of the modeling of the water-cooled condenser and supply fan power follows.

3.2.1.1 Water-Cooled Condenser Performance

EnergyPlus provides two methods of modeling equipment performance of water-source heat pumps. The method used for this work is referred to as the "equation-fit model." The equation-fit model uses non-dimensional equations developed from curve-fits to manufacturer's

---

[a] The commercial reference building models are available on DOE's Office of Energy Efficiency and Renewable Energy website as Energy Plus input files at: <http://www1.eere.energy.gov/buildings/commercial_initiative/new_construction.html>. Documentation of the model development is provided in Deru, M., *et al*..U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. (NREL/TP-5500-46861) (2011).

[b] Hourly simulations results for medium office reference building model were developed at Pacific Northwest National Laboratory and provided for support of the ASHRAE 90.1 Mechanical Subcommittee in April 2009. Simulation results used reflect code requirements for buildings designed to ANSI/ASHRAE/IESNA 90.1-2004.

performance data to predict the condenser performance in cooling (and heating mode). Least squares regression is used to generate a set of performance coefficients from catalog performance data at various conditions for the particular equipment modeled. Then the respective coefficients from the least squares regressions are used in the model to simulate the heat pump performance in the EnergyPlus software. The variables EnergyPlus uses to describe the water-cooled condenser performance are the entering air wet bulb and dry bulb temperature, the condenser water inlet temperature, the entering air volumetric flow rate, and the condenser water flow rate. Each of these variables is made non-dimensional by first dividing by corresponding values for each variable at a defined reference condition. Two minor variations from the implementation in EnergyPlus included the use of inch-pound (IP) units in developing the DOE performance curves and the selection of reference temperature conditions that correspond precisely to the DOE rating conditions. The governing equations for the cooling performance are as follows:

$$\frac{Q_{total}}{Q_{total_ref}} = A_1 + A_2 \times \left(\frac{T_{wb}}{T_{wb_ref}}\right) + A_3 \times \left(\frac{T_{w,in}}{T_{w,in_ref}}\right) + A_4 \times \left(\frac{\dot{V}_{air}}{\dot{V}_{air_ref}}\right) + A_5 \times \left(\frac{\dot{V}_{w}}{\dot{V}_{w_ref}}\right) \qquad \textbf{Eq. 3.2.1}$$

$$\frac{Q_{sen}}{Q_{sens_ref}} = B_1 + +B_2 \times \left(\frac{T_{db}}{T_{db_ref}}\right) + B_3 \times \left(\frac{T_{wb}}{T_{wb_ref}}\right) + B_4 \times \left(\frac{T_{w,in}}{T_{w,in_ref}}\right) + B_5 \times \left(\frac{\dot{V}_{air}}{\dot{V}_{air_ref}}\right) + B_6 \times \left(\frac{\dot{V}_{w}}{\dot{V}_{w_ref}}\right) \qquad \textbf{Eq. 3.2.2}$$

$$\frac{Power}{Power_{ref}} = C_1 + C_2 \times \left(\frac{T_{wb}}{T_{wb_ref}}\right) + C_3 \times \left(\frac{T_{w}}{T_{w-ref}}\right) + C_4 \times \left(\frac{\dot{V}_{air}}{\dot{V}_{air_ref}}\right) + C_5 \times \left(\frac{\dot{V}_{w}}{\dot{V}_{w_ref}}\right) \qquad \textbf{Eq. 3.2.3}$$

Where:

$A_1 - C_5 =$	equation fit coefficients for the cooling mode,
$Q_{total} =$	cooling capacity (Btu/h),
$Q_{total_ref} =$	cooling capacity at reference condition (Btu/h),
$Q_{sens} =$	sensible cooling capacity (Btu/h),
$Q_{sens_ref} =$	sensible cooling capacity at reference condition (Btu/h),
$Power =$	condenser power (W),
$Power_{ref} =$	condenser power at reference condition (W),
$T_{wb} =$	entering air wet bulb temperature (Rankine (°R)),
$T_{wb\text{-}ref} =$	entering air wet bulb temperature at reference temperature (°R),
$T_{db} =$	entering air dry bulb temperature (°R),
$T_{db\text{-}ref} =$	entering air dry bulb temperature at reference temperature (°R),
$T_{w} =$	entering water temperature (°R),
$T_{w\text{-}ref} =$	entering water temperature at reference temperature (°R),
$V_{air} =$	volumetric air flow rate (cubic feet per minute (cfm)),
$V_{air\text{-}ref} =$	volumetric air flow rate at reference (gallons per minute (gpm)),
$V_{w} =$	volumetric water flow rate (cfm), and
$V_{w\text{-}ref} =$	volumetric water flow rate at reference (gpm).

The equations above are based on steady state full-load operation at the rating (reference) conditions and off-rating conditions. To account for operation at part-load and non-steady-state operation, part-load performance modifier curves for air-source air conditioners—and that were used in the EnergyPlus medium office reference building model—were also used for this

analysis. Because these part-load modifier curves reflect the effects of compressor cycling at part-load for air-cooled systems, it was determined that they should be representative of the compressor cycling impacts for water-cooled air conditioners as well.

The part-load modifier curves are of the following equation form:

$$CoolPLFFPLR = C_1 + C_2 \times PLR \qquad \textbf{Eq. 3.2.4}$$

Where:

CoolPLFFPLR = cooling power part-load factor modifier,
PLR = ratio of cooling load to cooling capacity under the conditions of interest, and
C_1 and C_2 = equation fit coefficients for the part-load performance curves.

C_1 and C_2 values of 0.771 and 0.229, respectively, were used based on the part-load modifier curves in the reference building simulations and for this analysis.

The steady state power input is then adjusted according to the following equation:

$$Power_{Hourly} = Power \times \frac{PLR}{CoolPLFFPLR} \qquad \textbf{Eq. 3.2.5}$$

Where:

$Power_{Hourly}$ = hourly average power in response to hourly cooling load,
Power = steady state power at conditions as defined in equation 3.2.3,
PLR = part-load ratio as defined in equation 3.2.4, and
CoolPLFFPLR = part-load modifier as defined in equation 3.2.4.

For each climate zone, the original system air volumes were sized based on design day runs and the maximum hourly supply air for each system was used as the basis for the system air volumes and reference volumetric flow rate. The peak cooling loads were adjusted for rated conditions and used to determine the equipment nominal capacity for each system. This is also the cooling capacity at reference condition. No hourly condenser-water flow rates were available, and for the modeling purpose the condenser water flow rate at all hours was assumed to be at the reference (rated) condition. Thus, the condenser water flow rate did not affect the performance curves in the analysis.

3.2.1.2 Supply Water Temperature

The performance equations developed in this spreadsheet model separately account for the water-cooled gross cooling capacity and power consumption as a function of entering air conditions and supply water temperature and flow rate. To function, the spreadsheet model requires an hourly entering water temperature and entering water flow rate. For this analysis, a simple cooling tower supply water temperature model was developed based on a defined control profile with minimum 70 °F return water temperature and using a 7 °F approach temperature. Thus, the return water temperature from the cooling tower is calculated as

$$T_w = \min\left[T_{wb,o} + 7\,, 70\right] + 459.67 \qquad \textbf{Eq. 3.2.6}$$

Where:

T_w = Building supply water temperature from cooling tower (°R), and
$T_{wb,o}$ = Outdoor air wet bulb temperature (°F).

The supply water temperature from the cooling tower is thus estimated at 7 °F above the current wet bulb temperature during most cooling hours. Condenser water flow rates were assumed to be equivalent to the nominal rating condition water flow rates for all cooling hours.

Using these inputs and performance curves, it was possible to calculate the hourly condenser energy consumption of each of the three water-cooled air conditioner units for this building model.

3.2.1.3 Supply Fan Power

In addition, DOE's spreadsheet model calculated the fan energy consumption for the equipment. Fan energy for each system at design conditions (peak fan capacity) was estimated using the following assumptions.

$$Power_{fan,max} = \frac{\Delta P \times Q}{6350 \times n_f \times n_m \times 0.746} \qquad \textbf{Eq. 3.2.7}$$

Where:

$Power_{fan,max}$ = design fan power (kW),
ΔP = total fan static pressure (in. H_20),
Q = design supply air flow rate (cfm),
n_f = fan efficiency, and
n_m = motor and drive efficiency.

A design total fan static pressure of 4.35 in. H_2O, fan efficiency of 0.65, and motor efficiency of 0.9 were used, providing for a design fan system power of 0.87 W/cfm at design conditions. The total fan static pressure was judged likely to be less than that used in the reference building design (4.35 in. H_2O versus 5.35 in. H_2O) based on the determination that the total supply and return path pressure drop would be less with water cooled units installed inside the building as compared to packaged units installed on rooftops due to the length of the duct runs.

Because this was a VAV system with varying hourly air flow rate, the fan power was adjusted hourly using a fan power part-load curve used for the DOE reference building VAV system. The fan power curve provides the relationship between fan system power and system air flow rate, which varied hourly for the VAV system. The fan power versus flow rate relationship is of the form used in EnergyPlus:

$$PLF_{fan} = C_1 + C_2 \times FF + C_3 \times FF^2 + C_4 \times FF^3 + C_5 \times FF^3 \qquad \textbf{Eq. 3.2.8}$$

Where:

PLF_{fan} = a part-load factor multiplier equal to the ratio of system fan power to design fan power,
FF = fraction of system design air flow rate, and
$C1 - C5$ = equation coefficients for the VAV fan power curve.

The coefficients C_1 through C_5 used for this curve are those from the reference building model and are shown below.

$C_1 = 0.040759894$
$C_2 = 0.08804497$
$C_3 = -0.07292612$
$C_4 = 0.943739823$
$C_5 = 0$

3.2.1.4 Water-Cooled Condenser-Only Cooling Coefficient of Performance vs. Energy Efficiency Ratio Relationship

For analysis of energy use at the base efficiency (EER) level, DOE developed estimates for the condenser-only efficiency (condenser-only cooling COP) for the water-cooled air conditioner based on the nominal rating conditions for an 11 EER unit. Condenser-only cooling COP at rating conditions is an input to the EnergyPlus simulation model. This parameter can be calculated by backing out the estimated fan power at nominal rating conditions from the rated energy consumption while accounting for the effect of fan heat. This is done by calculating the condenser-only cooling COP according the equation below:

$$COP_{CU_Cool} = \frac{\frac{EER}{3.413} + R}{1 - R} \qquad \textbf{Eq. 3.2.9}$$

Where:

EER = EER rating of the equipment being modeled,
R = ratio of supply fan power to total equipment power at the AHRI rating condition, and
COP_{CU_Cool} = condensing-only cooling COP at rated conditions.

The parameter R can be estimated from available manufacturer fan power data at the external static rating condition and a known air flow rate. Generally, however, the air flow rate at rating is not provided in the manufacturer's literature. DOE used an R of 0.164 based on review of available data for a large evaporatively cooled air conditioner and assuming a supply air flow rate of 350 cfm/ton.[2] For an 11.0 EER unit that DOE modeled directly, the calculated condenser-only COP corresponding to an 11.0 EER unit was 4.052.

3.2.1.5 Baseline Annual Energy Use/Ton for Climates—Water-Cooled

For each of the 15 climates, DOE used the spreadsheet model to calculate the hourly condenser energy use and supply fan energy use for each of the three water-cooled air conditioner units in the reference medium office building model and summed the results to provide annual energy use estimates for condenser and for supply fan separately. DOE also calculated the cooling capacity for each unit and summed these for the whole building. Dividing the energy use figures for both condenser and supply fan by the rated cooling capacity provides a normalized energy-use-per-ton figure for each end use at the baseline efficiency level. These climate-specific results, along with the climate weighting factors used are shown in Table 3.2.1. The climate weighting factors are developed from construction statistics for commercial office floor space for small and for medium sized office buildings (likely to use commercial packaged air conditioning equipment regardless of system size) for the period from 2003 to 2007.[3] For each building type weights were first calculated for the building class and then averaged. Figure 3.2.1 shows the floor space weighting factors for this analysis compared with that of all 16 DOE reference buildings types with construction floor space tallied in the study.

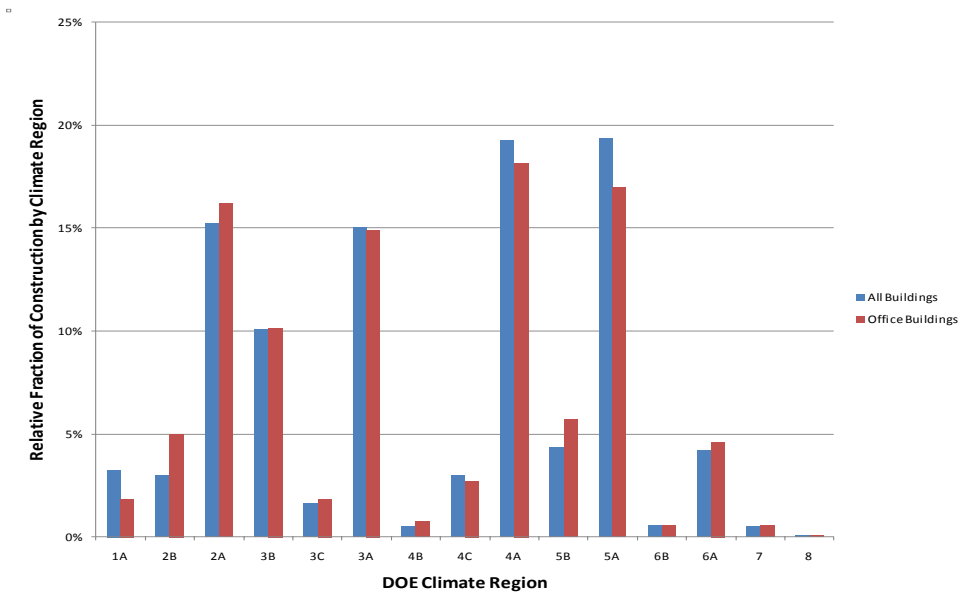


Figure 3.2.1 Comparison of Floor-Space Weighting Factors by Region. Small and Medium Office Buildings versus All Buildings.

In addition, Table 3.2.1 shows a parameter called the "full load equivalent operating hours" (FLEOH), which is calculated as the annual cooling load served divided by the system cooling capacity. In this case the FLEOH shown is the result from weighting of the FLEOH calculated for each individual air conditioning unit by the relative capacity of that equipment to the total capacity of all equipment serving the reference building model. While not used in DOE's energy calculation, FLEOH values provide a useful reference point to compare with other energy calculations methods.

Table 3.2.1 Normalized Energy Use Ton by Climate for Water-Cooled Air Conditioners, 11.0 EER

Climate Zone	Representative Climate Location	Construction Wt.	Annual Condenser Energy *kWh/ton*	Annual Fan Energy *kWh/ton*	Annual System Energy *kWh/Ton*	FLEOH
1A	Miami, Fl	1.82%	1999	257	2256	2718
2A	Houston, TX	16.20%	1440	215	1654	1966
2B	Phoenix, AZ	4.99%	1446	354	1800	2052
3A	Memphis, TN	14.91%	1051	204	1255	1440
3B	El Paso, TX	10.15%	973	284	1258	1413
3C	San Francisco, CA	1.82%	497	273	770	736
4A	Baltimore, MD	18.18%	824	216	1040	1135
4B	Albuquerque, NM	0.72%	776	357	1133	1154
4C	Salem, OR	2.71%	517	247	764	736
5A	Chicago, IL	16.96%	674	215	889	926
5B	Boise, ID	5.70%	542	283	825	807
6A	Burlington, VT	0.56%	545	230	775	759
6B	Helena, MT	4.62%	446	360	807	682
7	Duluth, MN	0.56%	352	249	600	496
8	Fairbanks, AK	0.10%	259	436	696	398
National		100.00%	947	242	1189	1319

kWh = kilowatt-hours

3.2.1.6 Energy Use Estimates for Baseline and Higher-Efficiency Water-Cooled Air Conditioner Equipment by Equipment Class.

National average estimates of the energy use for efficiencies other than those directly modeled in the spreadsheet tool were developed based by first scaling the national average condenser energy use per ton from the spreadsheet simulation of 11.0 EER equipment shown in Table 3.2.1 by the condenser-only cooling COP corresponding to the higher EER equipment. The condenser-only cooling COP is developed based on equation 3.2.9 for higher EER values. To that result is added the baseline fan energy consumption/ton values, and the sum is then multiplied by the selected representative tonnage for each equipment class; or in equation form,

$$UEC_{EER} = CAP \times [CondUEC_n \times \frac{COP_{CU_Cool_Modeled}}{COP_{CU_Cool_EER}} + FanUEC_n] \qquad \textbf{Eq. 3.2.10}$$

Where:

CAP = nominal equipment capacity in cooling tons,
UEC_{EER} = unit energy consumption at the specific EER level being evaluated,
$CondUEC_n$ = normalized condenser energy consumption from the modeling, kWh/ton – national basis,
$COP_{CU_Cool_Modeled}$ = the cooling condenser-only COP used in the spreadsheet equipment model,

$COP_{CU_Cooled\ EER}$ = the cooling condenser-only COP corresponding to the specific EER level being evaluated, and

$FanUEC_n$ = normalized condenser energy consumption from the modeling, kWh/ton – national.

Thus, for example, to estimate the annual energy consumption of a 35 ton water-cooled air conditioner at an EER of 12.4, the initial step is to calculate a condenser-only COP_{EER} using equation 3.2.9. For an EER of 12.4, the ASHRAE 90.1-2010 level for this product class, this corresponds to a COP of 4.543. UEC is then calculated as

$$UEC_{12.4\ EER} = 35\ tons\ \times [947\ kWh/ton \times \frac{4.052}{4.543} + 242\ kWh/ton] \qquad \textbf{Eq. 3.2.11}$$

A representative capacity for each product class was selected as shown in Table 3.2.2 based on the approximate average capacity of the units available in the market as identified in DOE's market analysis.

Table 3.2.2 Water-Cooled Air Conditioner Representative Capacities by Product Class

Product Class	Representative Cooling Capacity
Water-Cooled Air Conditioner, ≥65,000 and <135,000 Btu/h, Electric Resistance Heating or No Heating	8 tons
Water-Cooled Air Conditioner, ≥65,000 and <135,000 Btu/h, All Other Heating	8 tons
Water-Cooled Air Conditioner, ≥135,000 and <240,000 Btu/h, Electric Resistance Heating or No Heating	15 tons
Water-Cooled Air Conditioner, ≥135,000 and <240,000 Btu/h, All Other Heating	15 tons
Water-Cooled Air Conditioner, ≥240,000 Btu/h, Electric Resistance Heating or No Heating	35 tons
Water-Cooled Air Conditioner, ≥240,000 Btu/h, All Other Heating	35 tons

For this analysis, the annual supply fan power was not adjusted for different efficiency levels. A more detailed analysis of the engineering of higher efficiency water-cooled air conditioners might show that some improvement can come from the reduction of supply fan power. One path to reducing fan power in rooftop equipment is believed to have been through larger case designs and consequently lower internal fan pressure drop. However, based on the assumption that these units are typically installed in mechanical rooms as opposed to rooftops, increased size may come at the expense of installation cost and available (rentable) floor space. It is noted that for a given EER level, assuming that improvements to the fan efficiency are used to reach that level, there would be less improvement to the condenser performance and less energy savings from the condenser portion of the packaged air conditioning system.

The resulting UEC values for each class of water-cooled air conditioner are provided in chapter 4 of the TSD based on selected efficiency levels analyzed for the national energy savings analysis.

3.2.2 Evaporatively Cooled Air Conditioners

The analysis to assess the per unit energy use of evaporatively cooled air conditioners began with review of the existing market (see chapter 2 of the TSD). DOE did not identify any current models of evaporatively cooled air conditioners less than 240,000 Btu/h cooling capacity. The review of the market suggested that the evaporatively-cooled equipment models currently available appear to be designed as packaged rooftop cooling units. Based on the available models identified, DOE estimated that the average capacity was 40 tons. Because of this, DOE's analysis of energy savings focused on typical applications for this very large equipment class. Because of the large size, DOE believes that a common application would also be packaged VAV system serving a building. To assess energy use for evaporatively cooled equipment, DOE modified the 3-story office reference building model used for the water-cooled equipment discussed previously to serve as the simulation model for the very large evaporatively cooled air conditioner equipment class.

The EnergyPlus simulation tool can model evaporatively cooled unitary air conditioners directly, with only minor modifications from the air-cooled unitary air conditioner equipment models that were used in the original DOE medium office reference building model. EnergyPlus offers two alternatives for modeling evaporatively cooled air conditioners. One is to use performance curves that characterize the steady state efficiency as a function of ambient wet bulb temperature and coil entering air dry bulb temperature (in contrast to the performance curves for air-cooled equipment, which use ambient dry bulb temperature and coil entering air dry bulb temperature). DOE was not able to derive separate performance curves for evaporatively cooled equipment as neither compressor nor overall condenser power data at different operating conditions was available in the manufacturer literature reviewed. Therefore, DOE utilized the second approach provided for in EnergyPlus, which is to use performance curves for air-cooled equipment that are a function of condenser entering air dry bulb conditions, but provide for a evaporative condenser using a evaporative condenser effectiveness parameter that reduces the condenser coil entering air conditions to below the ambient air temperature according to the equation below:

$$T_{C,i} = (T_{wb,o} + (1 - Eff) \times (T_{db,o} - T_{wb,o}) \qquad \textbf{Eq. 3.2.12}$$

Where:

$T_{c,i}$ = temperature of the air entering the condenser coil (°F),
$T_{wb,o}$ = wet-bulb temperature of the outdoor air (°F),
$T_{db,o}$ = dry-bulb temperature of the outdoor air (°F), and
Eff = evaporative condenser effectiveness.

DOE modified the medium office reference building model to use this latter modeling approach and defined an evaporatively cooled condenser for each of the three packaged VAV systems in the model. An evaporative condenser with an effectiveness of 0.9, equivalent to the default value in EnergyPlus, was used.

DOE developed estimates for the condenser-only cooling COP based on the nominal rating conditions. This was done by backing out the estimated fan power at nominal rating conditions and separately accounting for the impact of fan heat using equation 3.2.9 as discussed for water-cooled equipment. The fan power ratio parameter *R* was estimated from review of available manufacturer fan power data for an evaporatively-cooled rooftop air conditioner. DOE estimated an *R* of 0.137 based on review of available data for a large evaporatively cooled air conditioner and assuming a supply air flow rate of 350 cfm/ton of net cooling capacity.[4] For an 11.0 EER unit that DOE modeled directly, the calculated condenser-only COP was then estimated at 3.893. DOE used the fan power performance curves and peak fan power assumptions from the original reference medium office building model.

3.2.2.1 Baseline Annual Energy Use/Ton for Climates—Evaporatively Cooled

DOE performed simulations in the 15 climates identified previously using the 11.0 EER evaporatively cooled air conditioners. Equipment was sized using design day sizing. DOE extracted the cooling capacity, annual equipment condenser energy consumption, and blower energy consumption for each evaporatively cooled air conditioner equipment simulated. The annual energy consumption values were then normalized by dividing by the equipment capacity in cooling tons. The sum of the resulting condenser energy per cooling ton and blower energy per cooling ton represents the annual energy consumption per cooling ton for equipment at that 11 EER efficiency level. These climate-specific results, along with the climate weights are shown in Table 3.2.3.

Table 3.2.3 Normalized Energy Use Ton by Climate for Evaporatively-Cooled Air Conditioners, 11.0 EER

Climate Zone	Representative Climate Location	Construction Wt.	Annual Condenser Energy *kWh/ton*	Annual Fan Energy *kWh/ton*	Annual System Energy *kWh/Ton*
1A	Miami, Fl	1.82%	1683	380	2068
2A	Houston, TX	16.20%	1293	329	1626
2B	Phoenix, AZ	4.99%	1117	431	1551
3A	Memphis, TN	14.91%	979	305	1287
3B	El Paso, TX	10.15%	873	420	1295
3C	San Francisco, CA	1.82%	420	343	764
4A	Baltimore, MD	18.18%	782	318	1101
4B	Albuquerque, NM	0.72%	620	405	1027
4C	Salem, OR	2.71%	426	332	759
5A	Chicago, IL	16.96%	569	313	883
5B	Boise, ID	5.70%	448	374	823
6A	Burlington, VT	0.56%	473	340	814
6B	Helena, MT	4.62%	335	356	692
7	Duluth, MN	0.56%	318	374	693
8	Fairbanks, AK	0.10%	186	383	569
Nat		100.00%	838	341	1189

3.2.2.2 Energy Use Estimates for Baseline and Higher Efficiency Evaporatively Cooled Air Conditioners by Equipment Class.

Energy use energy consumptions for representative evaporatively cooled equipment sizes corresponding to each product class were developed as was done for water-cooled air conditioners. A representative capacity for each product class was selected, as shown in Table 3.2.4, based on the approximate average capacity of the units available in the market as identified in DOE's market analysis.

Table 3.2.4 Evaporatively Cooled Air Conditioner Representative Capacities by Product Class

Product Class	Representative Cooling Capacity
Evaporatively Cooled Air Conditioner, ≥240,000 Btu/h, Electric Resistance Heating or No Heating	40 tons
Evaporatively Cooled Air Conditioner, ≥240,000 Btu/h, All Other Heating	40 tons

The national average energy consumption per ton figures from Table 3.2.3 were then multiplied by the selected equipment capacities for the evaporatively cooled equipment class analyzed to establish the UEC values for the evaporatively cooled equipment classes at an 11 EER level.

To assess the annual energy consumption at the other efficiency levels analyzed, DOE developed estimates of the condenser-only cooling COP for each other efficiency level using equation 3.2.9. To establish annual energy consumption metrics for the higher efficiency levels, DOE used equation 3.2.10, adjusting the baseline annual condenser energy consumption for each climate by the ratio of the baseline condenser-only cooling COP at 11 EER to the condenser-only cooling COP at the efficiency levels analyzed. The annual fan energy consumption estimates were held constant at the baseline level for all higher standards. The UEC for each efficiency level analyzed is the sum of the annual condenser energy consumption and the annual fan energy consumption.

The resulting UEC values for each class of water-cooled air conditioner are provided in chapter 4 of the TSD based on selected efficiency levels analyzed for the national energy savings analysis.

3.2.3 Single-Package Vertical Air Conditioners and Heat Pumps

Based on previous discussions with industry, it is estimated that approximately 60 percent of the SPVU market goes to educational facilities, the majority of which is for space conditioning of modular classroom buildings. Another approximately 20 percent of the market may go to providing cooling for telecommunications and electronic enclosures. The remainder is used in a wide variety of commercial buildings including office and lodging, and is expected to serve more niche applications, such as modular offices buildings, within those market segments.

For its initial estimate of energy savings for single-package vertical air conditioners (SPVACs) and single-package vertical heat pumps (SPVHPs), DOE focused its analysis on the education market and in particular modular classrooms. To estimate the energy use of SPVACs

and SPVHPs in educational facilities, DOE developed a modular classroom building model for use with the EnergyPlus software. Characteristics of the modular classroom building model used in this analysis are provided in appendix 7A.

The modular classroom was based on a double-wide modular building design with 1,568 ft^2 of floor area (56 by 28 ft). Wood-frame construction, consistent with known modular classroom design, was used. Envelope performance characteristics were established using the requirements in ANSI/ASHRAE/IESNA 90.1-2004 to approximate a mix of existing stock and new construction.[5] Schedules and load profiles were taken from classroom space building zones in the DOE primary school reference building models.[c] Internal loads were based on direct equipment power (watts per square foot) and occupancy figures for the DOE primary school reference building model. Lighting power requirements were based on ASHRAE 90.1-2004, which was selected to be representative of a mix of existing classroom lighting power in the building stock and in recent construction. Because of the small size of the SPVAC equipment, an economizer was not assumed in the model, consistent with current and historical requirements found in ASHRAE 90.1. DOE notes that local jurisdictions may have building codes for education buildings that differ from ASHRAE 90.1 in this respect, but it has not examined this at the state or local code level for this analysis.

DOE simulated this building in each of the 15 climates discussed for water-cooled air conditioners and evaporatively cooled air conditioners. Simulations were done for the buildings with SPVAC equipment and electric resistance heating, and then separately for the same buildings with SPVHP equipment. DOE used the current Federal standard efficiencies of 9.0 EER for SPVAC equipment and 9.0 EER and 3.0 COP for SPVHP equipment in the less than 65,000 Btu/h size range.

3.2.3.1 Fan and Condenser Power Assumptions: Single-Package Vertical Air Conditioners

Fan power at the baseline efficiency levels was based on manufacturer's reported fan power consumption data for a 3.5 ton SPVAC.[6] From the manufacturer's literature, at 208/230 Volts, the reported motor current draw was 3.3 amps. From this, DOE estimated the fan power to be 686 watts or 0.49 watts/cfm at the manufacturer's defined external static pressure of 0.3 in. H_2O. Based on DOE's market analysis, all SPVAC and SPVHP equipment at the baseline efficiency levels used permanent split capacitor (PSC) blower motors. From the data reviewed, DOE established the baseline fan power ratio (R), as used in equation 3.2.9, was 0.15 for this equipment. Using equation 3.2.9 to develop the condenser-only cooling COP from this value of R for a baseline 9.0 COP unit yields a condenser-only cooling COP of 3.279.

For modeling the supply fan energy consumption, DOE used a combined fan and fan motor efficiency of 0.313, corresponding to a fan motor efficiency of 0.54 and a fan efficiency of 0.58. Rearranging the variables in equation 3.2.7 for fan power, DOE estimated that the total fan static pressure corresponding to the 0.49 watts/cfm identified from the product literature would be 1.3 inches. DOE used these supply fan and fan motor efficiencies and total static pressure

---

[c] The commercial reference building models are available on DOE's website as EnergyPlus input files at: <http://www1.eere.energy.gov/buildings/commercial_initiative/new_construction.html>.

estimate as inputs to the EnergyPlus modeling of the baseline unit. For modeling of baseline equipment fan power, these values provide for the estimate of total supply fan power for units installed in the field.

DOE first performed simulations for SPVAC equipment at a baseline 9.0 EER. From the annual simulation results for SPVAC equipment, DOE extracted the condenser energy use for cooling, the blower energy use, and equipment capacity. From these, DOE developed the annual cooling energy per ton and annual blower energy per ton for the baseline efficiency simulated. These per-ton values were then added together and then multiplied by the average cooling capacity estimated for SPVU in the less than 65,000 Btu/h capacity range to arrive at the baseline UEC for SPVAC. This average unit capacity was estimated at 3 tons. Table 3.2.5 shows the annual energy use per ton data for the baseline SPVAC equipment by climate region and at a national levels based on construction wts. Weighting factors for each climate are based on average of overall weighting factors for primary and for secondary school buildings by climate zone based on square feet of construction of these building types from 2003–2007.[3]

Table 3.2.5 Normalized Energy Use Ton by Climate for SPVAC, Baseline (9.0 EER)

Zone	Construction Wt.	Annual Condenser Cooling Energy *kWh/ton*	Annual Fan Energy *kWh/ton*	Annual System Energy *kWh/ton*
1A	1.46%	2868	761	3630
2A	15.99%	2088	729	2817
2B	2.56%	2351	893	3244
3A	18.48%	1557	740	2297
3B	8.24%	2000	1074	3074
3C	1.02%	986	878	1865
4A	18.94%	1085	757	1842
4B	0.61%	1597	1102	2699
4C	2.19%	967	849	1817
5A	20.85%	802	788	1590
5B	4.31%	1166	1135	2301
6A	0.80%	740	781	1521
6B	3.80%	940	1153	2094
7	0.64%	301	849	1151
8	0.10%	372	1241	1613
Nat	100.00%	1397	823	2220

To estimate the UEC for higher efficiency SPVAC levels, DOE recognized that the available market data indicated that higher EER equipment were much more likely to use electronically commutated motor (ECM) blower motors and have resulting lower blower motor power. DOE analyzed available products on the market and classified them into units with PSC and units with ECM motors. Based on examination of SPVAC and SPVHP models less than 65,000 Btu/h, DOE developed estimates of the likelihood of an SPVAC or SPVHP unit having an ECM motor at each efficiency level. Based on the data available, DOE estimated the fraction of units with ECM motor at selected efficiency levels as shown in Table 3.2.6 based on review of manufacturer's literature for equipment at various efficiency levels.

DOE estimated the blower motor power for units using ECM motors at 0.37 W/cfm based on a 71 percent efficiency ECM blower motor, or 75.8 percent of the fan power estimated for the baseline unit with a PSC blower motor. Using the estimated fraction of units at each efficiency levels with ECM and PSC motors, DOE developed an adjustment factor for the fan energy/ton (k_{fan}) which it applied to the fan energy/ton figures from the baseline simulations. In this estimate of national energy savings potential, DOE did not analyze the potential for fan energy savings from variable speed operation with ECM blower motors.

For the analysis of UEC at higher efficiency levels, DOE scaled the baseline condenser cooling energy/ton by the condenser-only cooling COP calculated for higher efficiency levels using equation 3.2.9. DOE scaled the fan energy/ton by the k_{fan} factors for SPVAC as shown in Table 3.2.6.

Table 3.2.6 Blower Power Adjustments for ECM Motor

EER	Estimated Fraction of SPVAC Market with ECM Blower	Estimated Fraction of SPVHP Market with ECM Blower	Relative Blower Power Compared to Modeled 9.0 EER Unit SPVAC (k_{fan})	Relative Blower Power Compared to Modeled 9.0 EER Unit SPVAC (k_{fan})
9.0 (Baseline)*	0	0	1.000	1.000
9.5	0.25	0.25	0.939	0.939
10	0.5	0.5	0.879	0.879
11	0.66	1	0.840	0.758
12	1	1	0.758	0.758

*PSC motor assumed in baseline simulation.

The condenser energy per ton and blower energy per ton at each efficiency level analyzed were then added together and the result multiplied by the 3-ton average capacity to develop SPVAC UEC for each higher efficiency level analyzed, or in equation form,

$$UEC_{EER} = CAP \times [CondUEC_n \times \frac{COP_{CU_Cool_Modeled}}{COP_{CU_Cool_EER}} + k_{fan_EER} \times FanUEC_n] \quad \textbf{Eq. 3.2.13}$$

Where:

CAP = nominal equipment capacity in cooling tons,
UEC_{EER} = unit energy consumption at the specific EER level being evaluated,
$CondUEC_n$ = normalized condenser energy consumption from the modeling, kWh/ton – national basis,
$COP_{CU_Cool_Modeled}$ = the cooling condenser-only COP used in the simulation model,
$COP_{CU_Cool_EER}$ = the cooling condenser-only COP corresponding to the specific EER level being evaluated,
k_{fan_eer} = fan power multiplier (k_{fan}) for each efficiency level for SPVAC, and

$FanUEC_n$ = normalized condenser energy consumption from the modeling, kWh/ton – national basis.

3.2.3.2 Single-Package Vertical Heat Pump Analysis

The analysis method for SPVHP was carried out in a similar fashion as was done for SPVAC; however, the analysis for SPVHP also included the heating energy from the simulation results. As with most heat pumps, SPVHP equipment uses electric resistance backup heat to supplement the compressor heating capability as needed. For SPVHP analysis, DOE modified the modular classroom building model to use a heat pump with electric resistance backup heating. In addition to the annual condenser energy for cooling and fan energy that were extracted from the simulation results for SPVAC, DOE extracted the condenser heating energy and the backup electric resistance heating energy. Each of these energy consumption values was normalized on a per-cooling ton basis as was done for SPVAC analysis.

For each SPVHP heating efficiency analyzed, the condenser heating energy use per ton was adjusted using an estimate of the heating-only condenser COP at the rating condition for that efficiency level. The calculation of the heating-only condenser COP is based on the fan power ratio parameter (R) and the rated high temperature heating COP at 47 °F. The equation relating these parameters is

$$COP_{CUHeat} = \frac{COP_{Heat} - R}{1 - R} \qquad \textbf{Eq. 3.2.14}$$

Where:

COP_{Heat} = Heating COP rating of the equipment being modeled,
R = ratio of supply fan power to total equipment power at the AHRI rating condition, and
COP_{CU_Heat} = condensing-only heating COP at rated conditions.

From the SPVHP simulation results at the baseline 9.0 EER and 3.0 COP levels, DOE extracted the compressor cooling energy, blower energy, compressor heating energy, backup electric resistance heating energy, and the cooling capacity and from these developed per ton energy consumption figures for each of these four electric loads. The results by climate and for the nation are shown in Table 3.2.7. These per-ton energy figures summed and multiplied by the nominal capacity provide the UEC for SPVHP at the modeled EER and COP assuming the fan power levels modeled for baseline equipment.

Table 3.2.7 Normalized Energy Use Ton by Climate for SPVHP, Baseline (9.0 EER/3.0 COP)

Zone	Construction Wt.	Annual Condenser Cooling Energy *kWh/ton*	Annual Condenser Heating Energy *kWh/ton*	Annual Supplemental Heating Energy *kWh/ton*	Annual Fan Energy *kWh/ton*	Annual System Energy *kWh/ton*
1A	1.46%	2871	16	3	761	3650
2A	15.99%	2090	306	100	727	3222
2B	2.56%	2352	90	11	889	3342
3A	18.48%	1557	672	385	737	3350
3B	8.24%	2002	410	118	1070	3600
3C	1.02%	989	663	196	869	2717
4A	18.94%	1084	1275	1223	752	4334
4B	0.61%	1597	1007	709	1095	4409
4C	2.19%	969	1101	319	840	3229
5A	20.85%	802	1664	2509	783	5757
5B	4.31%	1166	1574	1826	1129	5695
6A	0.80%	738	1502	5179	775	8193
6B	3.80%	941	1469	4773	1147	8329
7	0.64%	303	1450	5769	845	8367
8	0.10%	372	857	13595	1238	16062
Nat.	100.00%	1397	981	1218	819	4414

To estimate the annual energy consumption for SPVHP at higher efficiency levels and different combinations of EER and COP, DOE modified the approach used for SPVAC to incorporate changes in the annual condenser heating energy for higher COP equipment. In addition to the adjustments for cooling and fan energy discussed for SPVAC, DOE scaled the annual condenser heating energy by the condenser-only heating COP calculated for each higher efficiency level in accordance with equation 3.2.14. DOE did not adjust the supplemental heating energy as it would not be affected by changes in heating COP rating. The equation for calculating annual energy consumption at efficiency levels other than those modeled is shown below.

$$UEC_{EER,COP} = CAP \times [CondUEC_{cool,n} \times \frac{COP_{CU_Cool_Modeled}}{COP_{CU_Cool_EER}} + CondUEC_{heat,n} \times \frac{COP_{CU_Heat_Modeled}}{COP_{CU_Heat_COP}} + UEC_{Heat_Supp,n} + k_{fan_EER} \times FanUEC_n] \quad \textbf{Eq. 3.2.15}$$

Where:

CAP = nominal equipment capacity in cooling tons,

$UEC_{EER,COP}$ = unit energy consumption at the specific EER and COP level being evaluated,

$CondUEC_{Cool,n}$ = normalized condenser cooling energy consumption from the modeling, kWh/ton – national basis,

$CondUEC_{Heat,n}$ = normalized condenser heating energy consumption from the modeling, kWh/ton – national basis,

$COP_{CU_Cool_Modeled}$ = the cooling condenser-only COP used in the spreadsheet equipment model,

$COP_{CU_Cool,EER}$ = the cooling condenser-only COP corresponding to the specific EER level being evaluated,

$COP_{CU_Heat_Modeled}$ = the heating condenser-only COP used in the spreadsheet equipment model,

$COP_{CU_Heat_COP}$ = the heating condenser-only COP corresponding to the specific COP level being evaluated,

$UEC_{Heat_Supp,n}$ = normalized condenser energy consumption from the modeling, kWh/ton – national,

k_{fan_eer} = fan power multiplier (k_{fan}) for each higher EER level from Table 3.2.6 for SPVHP, and

$FanUEC_n$ = normalized condenser energy consumption from the modeling, kWh/ton – national.

The resulting UEC values for each class of SPVHP are provided in chapter 4 of the TSD based on selected EER and COP efficiency levels analyzed for the national energy savings analysis.

REFERENCES

1. Carrier Corporation. *OMNIZONE™ Indoor Self-Contained Systems*. Farmington, CT. (Last accessed April 2011.) <http://xpedio.carrier.com/idc/groups/public/documents/marketing/04-850275-25.pdf>

2. Carrier Corporation. *Carrier Product Data Remote Air-Cooled and Water-Cooled Indoor Self- contained Systems and Water Source Heat Pumps*. 50BV-4PD.pdf. (Last accessed March 2011.) <http://www.commercial.carrier.com/commercial/hvac/carrier/0,3068,CLI1_DIV12_ETI12690_MID4412,00.html>

3. Jarnagin RE, and GK Bandyopadhyay. 2010. *Weighting Factors for the Commercial Building Prototypes Used in the Development of ANSI/ASHRAE/IESNA Standard 90.1-2010*. Pacific Northwest National Laboratory: Richland, WA. PNNL-19116. <http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19116.pdf>

4. Trane. *Packaged IntelliPak™ Rooftop Systems 20 to 130 tons*. Product catalog for Packaged Rooftop Air Conditioners IntellipakTM – S*HL,S*HK. (Last accessed April 2011.) <http://www.trane.com/COMMERCIAL/DNA/View.aspx?i=1102>

5. ASHRAE. 2004. *ANSI/ASHRAE/IESNA Standard 90.1-2004, Energy Standard for Buildings Except Low-Rise Residential Buildings*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

6. Bard Manufacturing Company, Inc. *Bard Product Specifications*. BARD WA-Series Product Data. S3208.pdf (Last accessed January 2011.) <http://www.bardhvac.com/tech_cntr_specs.shtml>

CHAPTER 4. NATIONAL ENERGY SAVINGS ANALYSIS

TABLE OF CONTENTS

4.1 INTRODUCTION 4-1
4.2 NATIONAL ENERGY SAVINGS CALCULATION 4-2
4.3 INPUTS TO THE NES CALCULATION 4-5
4.3.1 Shipments 4-5
4.3.2 Unit Electricity Consumption 4-12
4.3.3 Product Lifetime 4-22
4.3.4 Site-to-Source Energy Conversion Factors 4-22
4.3.5 Effective Dates and Analysis Period 4-24
4.4 NES RESULTS 4-25

LIST OF TABLES

Table 4.3.1 Historical Water-Cooled Commercial Air Conditioner Shipments 4-6
Table 4.3.2 Historical Water-Cooled Commercial Air Conditioner Shipments 4-7
Table 4.3.3 Projected Commercial Water-Cooled Air Conditioner Shipments 4-8
Table 4.3.4 Projected SPVU Shipments 4-9
Table 4.3.5 Shipments Used in the Analysis: Historical Trend Scenario 4-11
Table 4.3.6 UECs: Small Water Cooled Equipment with Electric Resistance or No Heat (8 ton representative capacity) 4-12
Table 4.3.7 UECs: Small Water Cooled Equipment with Other Heat (8 ton representative capacity) 4-12
Table 4.3.8 UECs: Large Water Cooled Equipment with Electric Resistance or No Heat (15 ton representative capacity) 4-13
Table 4.3.9 UECs: Large Water Cooled Equipment with Other Heat (15 ton representative capacity) 4-13
Table 4.3.10 UECs: Very Large Water Cooled Equipment with Electric Resistance or No Heat (35 ton representative capacity) 4-13
Table 4.3.11 UECs: Very Large Water Cooled Equipment with Other Heat (35 ton representative capacity) 4-13
Table 4.3.12 UECs: Very Large Evaporatively Cooled Equipment with Electric Resistance or No Heat (40 ton representative capacity) 4-14
Table 4.3.13 UECs: Very Large Evaporatively Cooled Equipment with Other Heat (40 ton representative capacity) 4-14
Table 4.3.14 UECs: SPVAC 1-Phase <65,000 Btu/h (3 ton representative capacity) 4-15
Table 4.3.15 UECs: SPVAC 3-Phase <65,000 Btu/h (3 ton representative capacity) 4-15
Table 4.3.16 UECs: SPVHP 1-Phase <65,000 Btu/h (3 ton representative capacity) 4-15
Table 4.3.17 UECs: SPVHP 3-Phase <65,000 Btu/h (3 ton representative capacity) 4-15
Table 4.3.18 Efficiency Distributions and Market Weighted-Average UECs: Small Water Cooled Equipment with Electric Resistance or No Heat 4-18
Table 4.3.19 Efficiency Distributions and Market Weighted-Average UECs: Small Water Cooled Equipment with Other Heat 4-18

Table 4.3.20 Efficiency Distributions and Market Weighted-Average UECs: Large Water Cooled Equipment with Electric Resistance or No Heat 4-18
Table 4.3.21 Efficiency Distributions and Market Weighted-Average UECs: Large Water Cooled Equipment with Other Heat 4-19
Table 4.3.22 Efficiency Distributions and Market Weighted-Average UECs: Very Large Water Cooled Equipment with Electric Resistance or No Heat 4-19
Table 4.3.23 Efficiency Distributions and Market Weighted-Average UECs: Very Large Water Cooled Equipment with Other Heat 4-19
Table 4.3.24 Efficiency Distributions and Market Weighted-Average UECs: Very Large Evaporatively Cooled Equipment with Electric Resistance or No Heat 4-20
Table 4.3.25 Efficiency Distributions and Market Weighted-Average UECs: Very Large Evaporatively Cooled Equipment with Other Heat 4-20
Table 4.3.26 Efficiency Distributions and Market Weighted-Average UECs: Small Single-Phase SPVAC 4-21
Table 4.3.27 Efficiency Distributions and Market Weighted-Average UECs: Small Three-Phase SPVAC 4-21
Table 4.3.28 Efficiency Distributions and Market Weighted-Average UECs: Small Single-Phase SPVHP 4-21
Table 4.3.29 Efficiency Distributions and Market Weighted-Average UECs: Small Three-Phase SPVHP 4-22
Table 4.3.30 Site-to-Source Conversion Factors 4-23
Table 4.4.1 National Energy Savings for Water and Evaporatively Cooled Products (Quads, 2013–2042 or 2014-2043): Based on Historical Trends 4-25
Table 4.4.2 National Energy Savings for Water and Evaporatively Cooled Products (Quads, 2013–2042 or 2014-2043): Shipments Fixed to 2009 4-25
Table 4.4.3 National Energy Savings for SPVUs (Quads, 2017-2046) 4-27

LIST OF FIGURES

Figure 4.2.1 Flow Diagram of National Energy Savings Calculation 4-3
Figure 4.3.1 Projection of Commercial Water-Cooled AC Shipments 4-7
Figure 4.3.2 Relationship between EER and COP for 1-Phase SPVHPs 4-16
Figure 4.3.3 Relationship between EER and COP for 3-Phase SPVHPs 4-16
Figure 4.4.1 National Energy Savings for Water and Evaporatively Cooled Products by Product Class: Historical Trends 4-26
Figure 4.4.2 National Energy Savings for Water and Evaporatively Cooled Products by Product Class: Shipments Fixed to 2009 4-26
Figure 4.4.3 National Energy Savings for SPVUs by Product Class 4-27

4.1 INTRODUCTION

This chapter describes the national energy savings (NES) analysis for water- and evaporatively-cooled products as well as SPVUs. Each subsection of this chapter discusses each of these product categories in separate sections.

Water and Evaporatively Cooled Products

The NES for water- and evaporatively-cooled products considers the ASHRAE standard level as well as several higher efficiency standard levels. The effective date of a standard depends upon the standard selected and the product class. For purposes of this analysis, the Department assumed the effective date of such a standard would be 2013 (for small products under the ASHRAE standard), 2014 (for large and very large products under the ASHRAE standard), or 2017 (for all products under standards higher than ASHRAE).

The Department analyzed the National Energy Savings (NES) of amended energy conservation standards for the following eight product classes of commercial water and evaporatively cooled air conditioning equipment: (1) small water-cooled with electric resistance or no heating (65-135 kBtu/h), (2) small water-cooled with other heating (65-135 kBtu/h), (3) large water-cooled with electric resistance or no heating (135-240 kBtu/h), (4) large water-cooled with other heating (135-240 kBtu/h), (5) very large water-cooled with electric resistance or no heating (240-760 kBtu/h), (6) very large water-cooled with other heating (240-760 kBtu/h), (7) very large evaporatively cooled with electric resistance or no heating (240-760 kBtu/h), and (8) very large evaporatively cooled with other heating (240-760 kBtu/h).

The Department examined various standard levels for each class of equipment, including the ASHRAE Standard 90.1 2010 efficiency level, the maxtech level (the highest efficiency level of equipment currently on the market), and several levels between. The baseline for each level is the current federal energy conservation standard.

SPVUs

The NES for SPVUs considers several levels of efficiency standards higher than the existing federal conservation standard, and up to the maxtech level. For the purposes of this analysis, the Department assumed the effective date of such a standard would be 2017 (all efficiency levels are higher than ASHRAE standards).

The Department analyzed the NES of amended energy conservation standards for the following four classes of commercial SPVUs: (1) single phase SPVACs under 65,000 Btu/h, (2) three phase SPVACs under 65,000 Btu/h, (3) single phase SPVHPs under 65,000 Btu/h, and (4) three phase SPVHPs under 65,000 Btu/h.

4.2 NATIONAL ENERGY SAVINGS CALCULATION

Water and Evaporatively Cooled Products

Figure 4.2.1 illustrates the inputs, intermediate values, and outputs of the NES calculation. The NES is the difference between the national energy consumption in the base case (i.e., the case without amended energy conservation standards) and the standards case (i.e., the case with amended energy conservation standards). The Department developed a spreadsheet model to calculate the NES from air conditioning equipment standards for eight product classes of interest to this analysis.

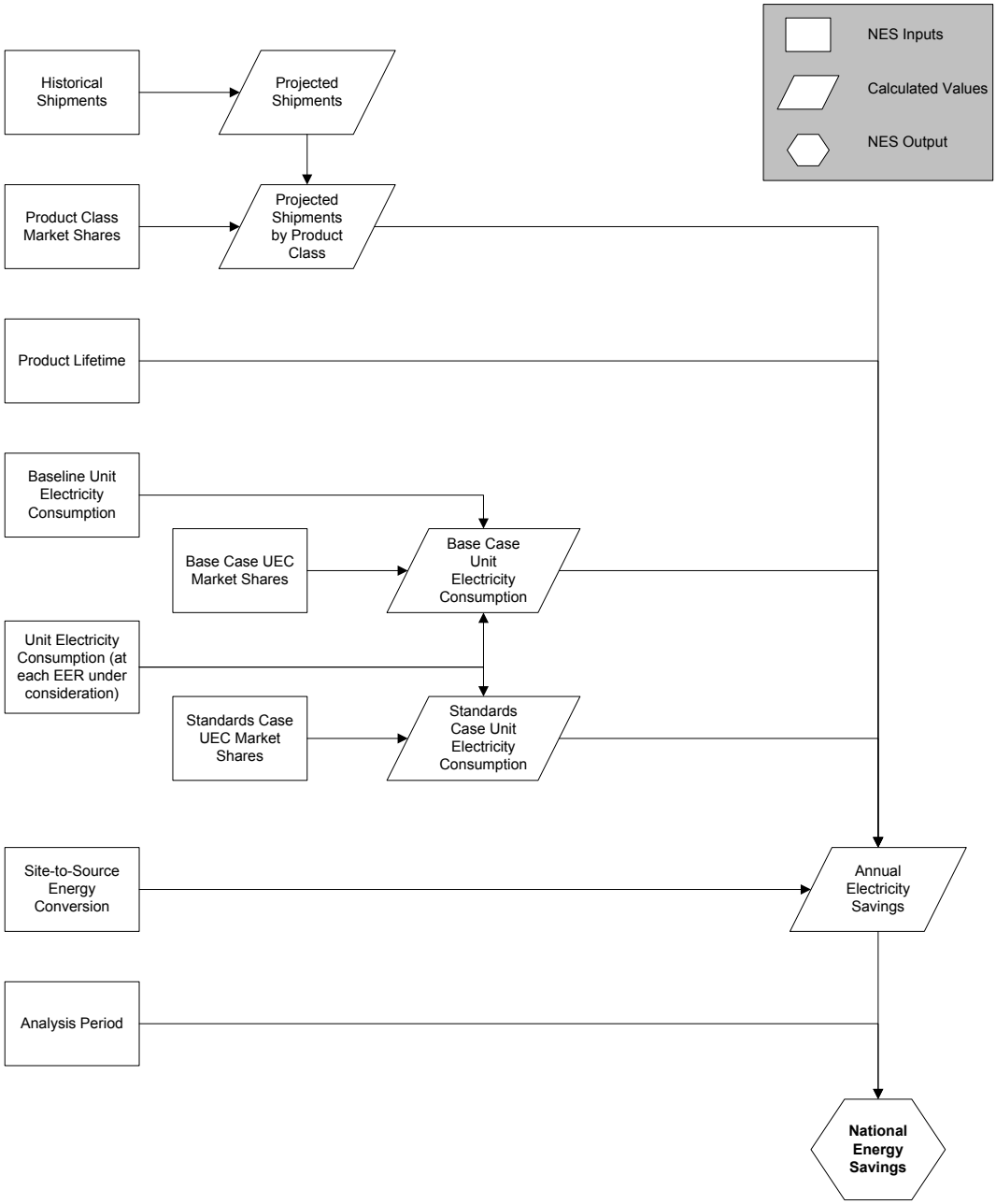


Figure 4.2.1 Flow Diagram of National Energy Savings Calculation

For each product class and standards case, DOE calculated the total energy savings using a stock accounting method. Using historical shipments provided by AHRI, DOE forecasted shipments into the future using two scenarios: (1) based on historical trend, and (2) fixed to 2009 levels. The number of new shipments in any given year is assumed to remain in the commercial building stock for a total of 15 years (the assumed lifetime of the product), at which point that entire year's shipments disappears from existing stock. In this way, the total stock, or number of surviving units, in any given year is the sum of that year's shipments plus the shipments from the previous 14 years.

The annual base total energy use in any given year is the sum product of the shipments for that year and the previous 14 years and the market weighted average base UEC[a] in each relevant year (multiplied by a site to source conversion factor).

$$Annual\ Base\ Total\ Energy\ Use_{year=n} = \sum_{year=n-14}^{n} Shipments_{year} \times Base\ UEC_{year}$$

As currently modeled, the base UEC remains constant throughout time. As a result, in the calculation above, $Base\ UEC_{year}$could be moved outside the summation terms as $Base\ UEC$.

The annual standards case total energy use in any given year is the sum product of the shipments for that year and the previous 14 years and the market weighted average standards case UEC[b] in each relevant year (multiplied by a site to source conversion factor).

$$Annual\ Standards\ Case\ Total\ Energy\ Use_{year=n} = \sum_{year=n-14}^{n} Shipments_{year} \times Standards\ UEC_{year}$$

Prior to the analysis period, the standards case UEC is equal to the Base UEC, as standards have not yet become effective. Therefore, in the earlier part of the analysis period, energy savings accrue from only the newer units in the building stock. Later in the analysis period, all units in the building stock will have the lower standards UEC (as they were all shipped within the analysis period) and will be providing energy savings.

The annual energy savings is the difference between the base case total energy use and the standards case total energy use.

$$Annual\ Energy\ Savings_{year=n} = Annual\ Base\ Total\ Energy\ Use_{year=n} - Annual\ Standards\ Case\ Total\ Energy\ Use_{year=n}$$

DOE calculated the cumulative energy savings over the analysis period by summing the annual energy savings for each year in the analysis period. The analysis period differs by product, as discussed in the next section.

[a] As will be discussed later, the market weighted average base UEC is based on the distribution of efficiencies under the current federal standards (base case). It includes products both meeting and exceeding the current federal minimum efficiency. It is *not* the UEC for a product at a specified EER.

[b] The market weighted average standards UEC is based on the distribution of efficiencies under a given amended federal standards scenario. It may include products both meeting and exceeding the given amended federal standards level (with the exception of the Max Tech scenario, in which it is assumed that no product exceeds the amended federal standards level). It is *not* the UEC for a product at a specified EER.

$$Cumulative\ Energy\ Savings = \sum_{year=x}^{x+29} Annual\ Energy\ Savings_{year}$$

For the ASHRAE standard, the cumulative energy savings are presented as above. For higher efficiency levels, the Department calculates cumulative energy savings as net of ASHRAE standard energy savings, as that is the presumed default.

$$\begin{aligned} Net\ Cumulative\ Energy\ Savings_{higher\ efficiency\ standard} \\ = Cumulative\ Energy\ Savings_{higher\ efficiency\ standard} \\ - Cumulative\ Energy\ Savings_{ASHRAE\ standard} \end{aligned}$$

SPVUs

The NES calculation for the four classes of SPVUs of interest to this rulemaking follows the same method described above for water- and evaporatively-cooled equipment, with two exceptions. The first is that because this analysis is not based on the ASHRAE standard, the cumulative energy savings for all efficiency levels are presented as gross energy savings (not net of any standard such as ASHRAE). The second is that for SPVHPs, energy saving for heating based on COP are taken into account:

$$\begin{aligned} Annual\ Base\ Total\ Energy\ Use_{year=n} \\ = \sum_{year=n-14}^{n} Shipments_{year} \times (Base\ UEC_{year} + Base\ UEC_heat_{year}) \end{aligned}$$

$$\begin{aligned} Annual\ Standards\ Case\ Total\ Energy\ Use_{year=n} \\ = \sum_{year=n-14}^{n} Shipments_{year} \times (Standards\ UEC_{year} + Standards\ UEC_heat_{year}) \end{aligned}$$

4.3 INPUTS TO THE NES CALCULATION

The following sections discuss and document the inputs to the calculation of the NES.

4.3.1 Shipments

4.3.1.1 Historical Shipments

Water and Evaporatively Cooled Products

The Department obtained historical water-cooled commercial air conditioner shipment data from AHRI. While AHRI provided shipments in the categories small, large, and very large, it is important to note that AHRI tracks large up to 249 kBtu/h, while the federal standards limit

the large category to 240 kBtu/h. Throughout this analysis, DOE used AHRI data to represent the large category. Table 4.3.1 shows historical shipments from 1989 through 2009.

Table 4.3.1 Historical Water-Cooled Commercial Air Conditioner Shipments

Year	Small AC (65-134.9 kBtu/h)	Large AC (135-249 kBtu/h)	Very Large AC (250 & Over kBtu/h)
1989	1,437	793	1,622
1990	1,503	779	1,211
1991	1,107	621	908
1992	1,068	537	720
1993	985	520	668
1994	922	504	815
1995	1,121	493	805
1996	1,217	652	1,020
1997	989	522	1,216
1998	795	623	1,886
1999	874	477	898
2000	1,478	1,621	1,170
2001	606	409	762
2002	502	355	1,227
2003	390	287	740
2004	447	291	711
2005	177	188	861
2006	316	278	1,231
2007	359	317	1,231
2008	282	311	1,390
2009	152	182	585

Source: AHRI.

SPVUs

The Department relied upon SPVU shipment data from the Energy Efficiency Standards for Certain Commercial and Industrial Equipment: Efficiency Standards for Commercial Heating, Air Conditioning, and Water Heating Equipment Technical Support Document, Including: Packaged Terminal Air Conditioners and Packaged Terminal Heat Pumps, Small Commercial Packaged Boilers, Three-Phase Air Conditioners and Heat Pumps <65,000 Btu/h, Single-Package Vertical Air Conditioners and Single-Package Vertical Heat Pumps<65,000 Btu/h, March 2, 2006. In this document, the Department provided 2005 shipments based on ARI estimates, as shown in Table 4.3.2.

Table 4.3.2 Historical Water-Cooled Commercial Air Conditioner Shipments

Year	SPVAC < 65,000 Btu/h, single-phase	SPVHP < 65,000 Btu/h, single-phase	SPVAC < 65,000 Btu/h, three-phase	SPVHP < 65,000 Btu/h, three-phase
2005	31,976	13,125	14,301	6,129

Source: ARI Estimate.

4.3.1.2 Projected Shipments

Water and Evaporatively Cooled Products

The Department estimated future shipments using the historical data provided by AHRI. The small and large AC categories show an exponential trend, yielding very few shipments in the future. (Note that the data points for year 2000 were removed as outliers to facilitate identifying historical trends.) The very large AC shipments show no trend, although a linear fit shows a slowly decreasing forecast. Figure 4.3.1 shows the extrapolations, and Table 4.3.3 shows projected shipments for 2010 through 2043.

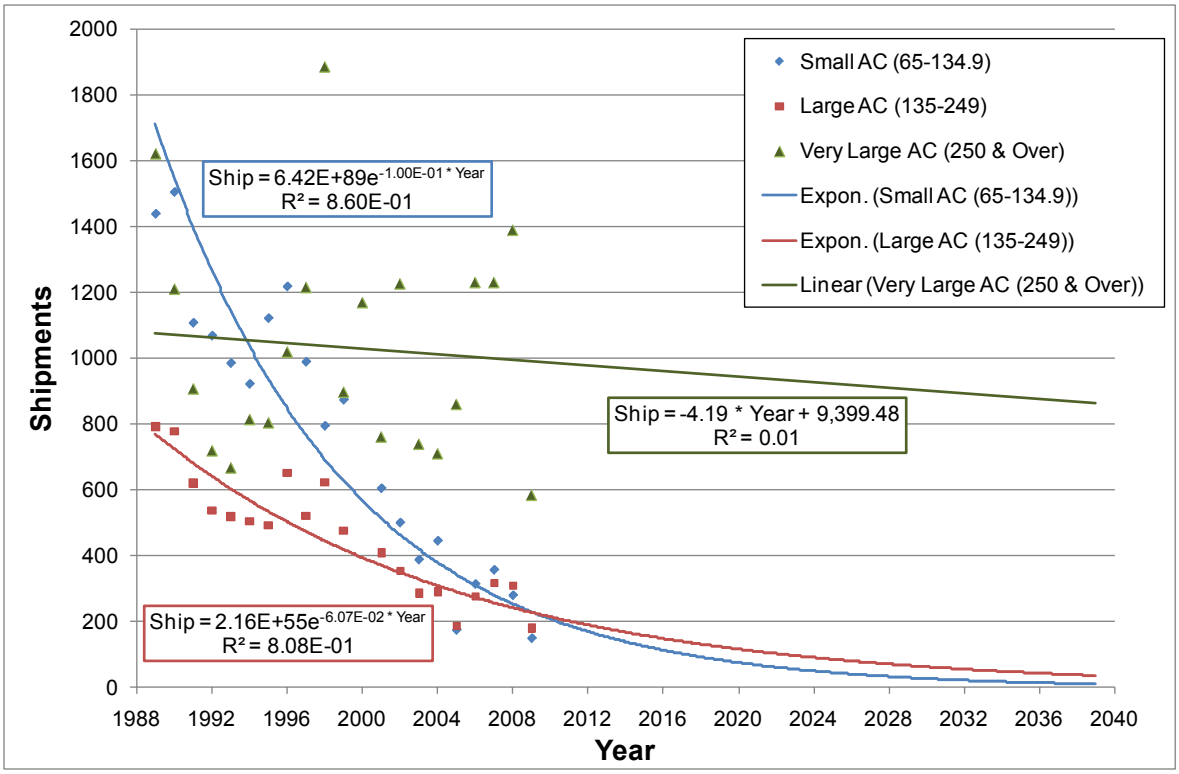


Figure 4.3.1 Projection of Commercial Water-Cooled AC Shipments

Table 4.3.3 Projected Commercial Water-Cooled Air Conditioner Shipments

Year	Small AC (65-134.9 kBtu/h)	Large AC (135-249 kBtu/h)	Very Large AC (350 & Over kBtu/h)
2010	208	215	986
2011	189	203	982
2012	171	191	978
2013	154	179	974
2014	140	169	970
2015	126	159	965
2016	114	150	961
2017	103	141	957
2018	93	132	953
2019	85	125	949
2020	76	117	944
2021	69	110	940
2022	63	104	936
2023	57	98	932
2024	51	92	928
2025	46	87	923
2026	42	81	919
2027	38	77	915
2028	34	72	911
2029	31	68	907
2030	28	64	903
2031	25	60	898
2032	23	57	894
2033	21	53	890
2034	19	50	886
2035	17	47	882
2036	15	44	877
2037	14	42	873
2038	13	39	869
2039	11	37	865
2040	10	35	861
2041	9	33	856
2042	8	31	852
2043	8	29	848

SPVUs

The Department projected shipments of SPVUs according to the average growth rate of 2.18 percent noted in the 2006 TSD. This was based on analysis of ARI data for commercial unitary AC products 65,000 Btu/h to 240,000 Btu/h for DOE's commercial unitary AC and HP rulemaking. Table 4.3.4 shows the projected SPVU shipments.

Table 4.3.4 Projected SPVU Shipments

Year	SPVAC < 65,000 Btu/h, single-phase	SPVHP < 65,000 Btu/h, single-phase	SPVAC < 65,000 Btu/h, three-phase	SPVHP < 65,000 Btu/h, three-phase
2006	32,673	13,411	14,613	6,263
2007	33,385	13,703	14,931	6,399
2008	34,113	14,002	15,257	6,539
2009	34,857	14,307	15,589	6,681
2010	35,617	14,619	15,929	6,827
2011	36,393	14,938	16,277	6,976
2012	37,187	15,264	16,631	7,128
2013	37,997	15,596	16,994	7,283
2014	38,826	15,936	17,364	7,442
2015	39,672	16,284	17,743	7,604
2016	40,537	16,639	18,130	7,770
2017	41,420	17,002	18,525	7,939
2018	42,323	17,372	18,929	8,112
2019	43,246	17,751	19,341	8,289
2020	44,189	18,138	19,763	8,470
2021	45,152	18,533	20,194	8,655
2022	46,136	18,937	20,634	8,843
2023	47,142	19,350	21,084	9,036
2024	48,170	19,772	21,544	9,233
2025	49,220	20,203	22,013	9,434
2026	50,293	20,643	22,493	9,640
2027	51,389	21,094	22,984	9,850
2028	52,510	21,553	23,485	10,065
2029	53,654	22,023	23,997	10,284
2030	54,824	22,503	24,520	10,508
2031	56,019	22,994	25,054	10,737
2032	57,240	23,495	25,600	10,972
2033	58,488	24,007	26,158	11,211
2034	59,763	24,531	26,729	11,455
2035	61,066	25,065	27,311	11,705
2036	62,397	25,612	27,907	11,960
2037	63,758	26,170	28,515	12,221
2038	65,148	26,741	29,137	12,487
2039	66,568	27,324	29,772	12,759
2040	68,019	27,919	30,421	13,038
2041	69,502	28,528	31,084	13,322
2042	71,017	29,150	31,762	13,612
2043	72,565	29,785	32,454	13,909
2044	74,147	30,435	33,162	14,212
2045	75,764	31,098	33,885	14,522
2046	77,415	31,776	34,623	14,839

The Department also used the 2.18 percent growth rate to project backwards from 2005 to estimate shipments that would still be in the product stock during the NES analysis period.

4.3.1.3 Product Class Market Shares and Projected Shipments by Product Class

Water and Evaporatively Cooled Products

The Department could not identify data that would allow the shipments provided by AHRI to be separated into products with electrical resistance or no heating, and those with other types of heating. However, the Department believes that most small and large water-cooled equipment do not provide heating, and as a result assigned 90% of shipments in those categories to the no-heating class, and 10% to the other heating class. For very large equipment, the Department believes that most equipment are roof-top units that are combined with gas furnaces, and as a result assigned 10% of very large shipments to the no-heating class and 10% to the other heating class.

The Department identified nine models of very large evaporatively-cooled equipment, but no shipment data were available. For this product class, the Department used the ratio of very large evaporative to water cooled models on the market (9:35) and applied this to the water cooled shipments to estimate evaporatively cooled shipments. The same fraction as for very large water cooled equipment was used to separate units into the heating categories.

DOE used two shipment scenarios in the analysis: one using the trends identified from historical data, and another with future shipments fixed to the 2009 value. Table 4.3.5 shows the shipments used for all the product classes in this analysis using the historical shipment scenario. This is based on the AHRI historical data, the forecasted shipments, and the attribution of the shipments to the specific product classes. No table is provided for the shipment scenario in which future shipments are fixed to the 2009 level.

Table 4.3.5 Shipments Used in the Analysis: Historical Trend Scenario

Year	Small Water E/N 65-135	Small Water O 65-135	Large Water E/N 135-240	Large Water O 135-240	VL Water E/N 240-760	VL Water O 240-760	VL Evap E/N 240-760	VL Evap O 240-760
1999	787	87	429	48	90	808	23	208
2000	1,330	148	1,459	162	117	1,053	30	271
2001	545	61	368	41	76	686	20	176
2002	452	50	320	35	123	1,104	32	284
2003	351	39	258	29	74	666	19	171
2004	402	45	262	29	71	640	18	165
2005	159	18	169	19	86	775	22	199
2006	284	32	250	28	123	1,108	32	285
2007	323	36	285	32	123	1,108	32	285
2008	254	28	280	31	139	1,251	36	322
2009	137	15	164	18	59	526	15	135
2010	187	21	194	21	99	887	25	228
2011	170	19	183	20	98	884	25	227
2012	154	17	172	19	98	880	25	226
2013	139	15	161	18	97	877	25	226
2014	126	14	152	17	97	873	25	224
2015	113	13	143	16	97	868	25	223
2016	103	11	135	15	96	865	25	222
2017	93	10	127	14	96	861	25	221
2018	84	9	119	13	95	858	24	221
2019	77	8	113	12	95	854	24	220
2020	68	8	105	12	94	850	24	219
2021	62	7	99	11	94	846	24	218
2022	57	6	94	10	94	842	24	217
2023	51	6	88	10	93	839	24	216
2024	46	5	83	9	93	835	24	215
2025	41	5	78	9	92	831	24	214
2026	38	4	73	8	92	827	24	213
2027	34	4	69	8	92	823	24	212
2028	31	3	65	7	91	820	23	211
2029	28	3	61	7	91	816	23	210
2030	25	3	58	6	90	813	23	209
2031	23	2	54	6	90	808	23	208
2032	21	2	51	6	89	805	23	207
2033	19	2	48	5	89	801	23	206
2034	17	2	45	5	89	797	23	205
2035	15	2	42	5	88	794	23	204
2036	14	1	40	4	88	789	23	203
2037	13	1	38	4	87	786	22	202
2038	12	1	35	4	87	782	22	201
2039	10	1	33	4	87	778	22	200
2040	9	1	32	3	86	775	22	199
2041	8	1	30	3	86	770	22	198
2042	7	1	28	3	85	767	22	197
2043	7	1	26	3	85	763	22	196

SPVUs

For SPVUs, the projected shipments shown in the previous section represent the extent of disaggregation necessary for the product classes of interest to this rulemaking.

4.3.2 Unit Electricity Consumption

4.3.2.1 Unit Electricity Consumption per EER

Water and Evaporatively Cooled Products

For each of the eight product classes, the Department identified a single representative capacity based on the approximate average capacity of models identified in the AHRI directory and through reviews of manufacturer websites. The UEC data are shown in Table 4.3.6 through Table 4.3.13. The UECs are from the energy use analysis (Chapter 3) and represent the energy use of a product at a specified EER.

Table 4.3.6 UECs: Small Water Cooled Equipment with Electric Resistance or No Heat (8 ton representative capacity)

Efficiency Level	EER	UEC
Baseline	11.5	9,199
ASHRAE Standard	12.1	8,855
13 EER	13.0	8,396
14 EER	14.0	7,953
15 EER	15.0	7,566
Max Tech	16.4	7,101

Table 4.3.7 UECs: Small Water Cooled Equipment with Other Heat (8 ton representative capacity)

Efficiency Level	EER	UEC
Baseline	11.3	9,322
ASHRAE Standard	11.9	8,966
13 EER	13.0	8,396
14 EER	14.0	7,953
15 EER	15.0	7,566
Max Tech	16.4	7,101

Table 4.3.8 UECs: Large Water Cooled Equipment with Electric Resistance or No Heat (15 ton representative capacity)

Efficiency Level	EER	UEC
Baseline	11.0	17,838
ASHRAE Standard	12.5	16,206
13 EER	13.0	15,743
14 EER	14.0	14,911
15 EER	15.0	14,186
Max Tech	16.1	13,490

Table 4.3.9 UECs: Large Water Cooled Equipment with Other Heat (15 ton representative capacity)

Efficiency Level	EER	UEC
Baseline	11.0	17,838
ASHRAE Standard	12.3	16,402
13 EER	13.0	15,743
14 EER	14.0	14,911
15 EER	15.0	14,186
Max Tech	16.1	13,490

Table 4.3.10 UECs: Very Large Water Cooled Equipment with Electric Resistance or No Heat (35 ton representative capacity)

Efficiency Level	EER	UEC
Baseline	11.0	41,621
ASHRAE Standard	12.4	38,041
13 EER	13.0	36,733
14 EER	14.0	34,793
Max Tech	14.8	33,422

Table 4.3.11 UECs: Very Large Water Cooled Equipment with Other Heat (35 ton representative capacity)

Efficiency Level	EER	UEC
Baseline	10.8	42,205
ASHRAE Standard	12.2	38,504
13 EER	13.0	36,733
14 EER	14.0	34,793
Max Tech	14.8	33,422

Table 4.3.12 UECs: Very Large Evaporatively Cooled Equipment with Electric Resistance or No Heat (40 ton representative capacity)

Efficiency Level	EER	UEC
Baseline	11.0	47,171
ASHRAE Standard	11.9	44,732
12.5 EER	12.5	43,294
Max Tech	13.1	41,983

Table 4.3.13 UECs: Very Large Evaporatively Cooled Equipment with Other Heat (40 ton representative capacity)

Efficiency Level	EER	UEC
Baseline	10.8	47,766
ASHRAE Standard	11.7	45,243
12.5 EER	12.5	43,294
Max Tech	13.1	41,983

SPVUs

For each of the four SPVU product classes, the Department identified a single representative capacity (3 ton) based on the approximate average capacity of models identified in the AHRI directory. The UEC data are shown in Table 4.3.14 through Table 4.3.17. The UECs are from the energy use analysis and represent the energy use of a product at a specified EER.

For SPVHPs, the Department determined heating UECs for the heating COPs that correspond to the EER of each efficiency level examined. Heating COPs in the AHRI directory range from 3.0 to 3.5. However, the relationship between EER and COP is not exceptionally clear. Using the linear relationships shown in Figure 4.3.2 and Figure 4.3.3, the heating COPs used in this analysis range from 3.00 to 3.36.

Table 4.3.14 UECs: SPVAC 1-Phase <65,000 Btu/h (3 ton representative capacity)

Efficiency Level	EER	UEC
Baseline	9.0	6,660
9.5 EER	9.5	6,301
10 EER	10.0	5,962
11 EER	11.0	5,537
12 EER	12.0	5,057
Max Tech	12.6	4,911

Table 4.3.15 UECs: SPVAC 3-Phase <65,000 Btu/h (3 ton representative capacity)

Efficiency Level	EER	UEC
Baseline	9.0	6,660
9.5 EER	9.5	6,301
10 EER	10.0	5,962
11 EER	11.0	5,537
12 EER	12.0	5,057
Max Tech	12.6	4,911

Table 4.3.16 UECs: SPVHP 1-Phase <65,000 Btu/h (3 ton representative capacity)

Efficiency Level	EER	UEC	Heating COP	Heating UEC
Baseline	9.0	6,648	3.01	6,280
9.5 EER	9.5	6,290	3.06	6,234
10 EER	10.0	5,952	3.11	6,189
11 EER	11.0	5,325	3.21	6,105
12 EER	12.0	5,048	3.31	6,026
Max Tech	12.5	4,925	3.36	5,988

Table 4.3.17 UECs: SPVHP 3-Phase <65,000 Btu/h (3 ton representative capacity)

Efficiency Level	EER	UEC	Heating COP	Heating UEC
Baseline	9.0	6,648	3.00	6,281
9.5 EER	9.5	6,290	3.05	6,240
10 EER	10.0	5,952	3.09	6,201
11 EER	11.0	5,325	3.18	6,126
12 EER	12.0	5,048	3.27	6,055
Max Tech	12.5	4,925	3.32	6,021

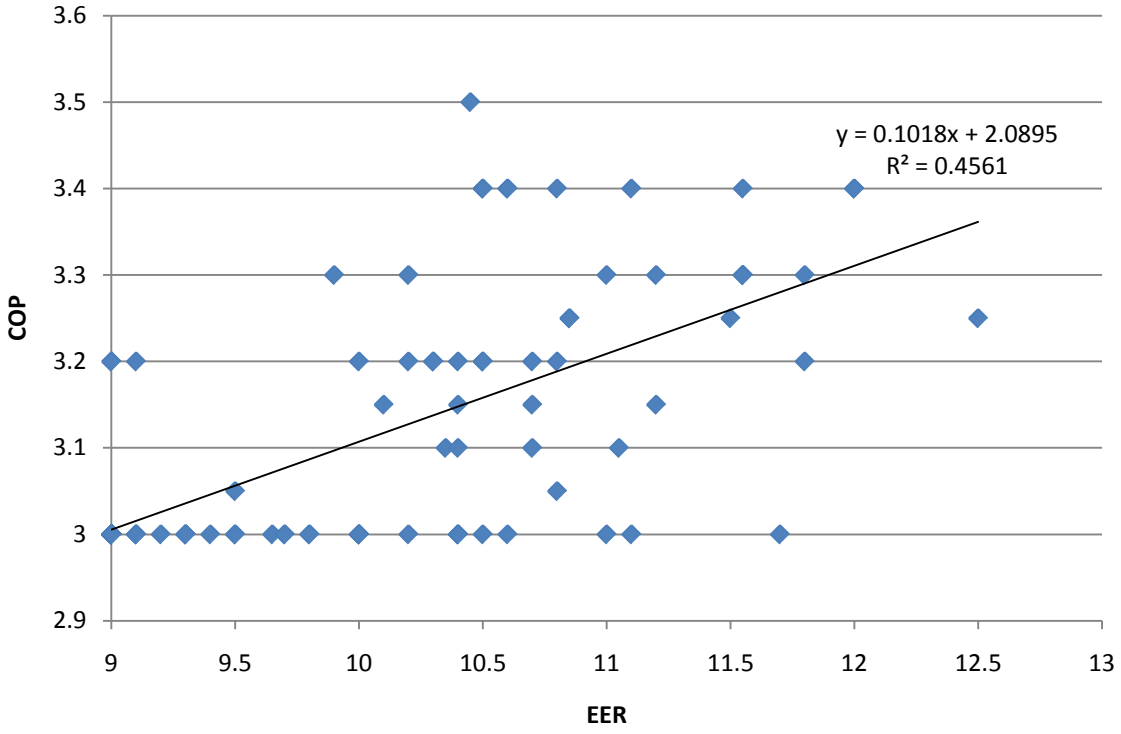


Figure 4.3.2 Relationship between EER and COP for 1-Phase SPVHPs

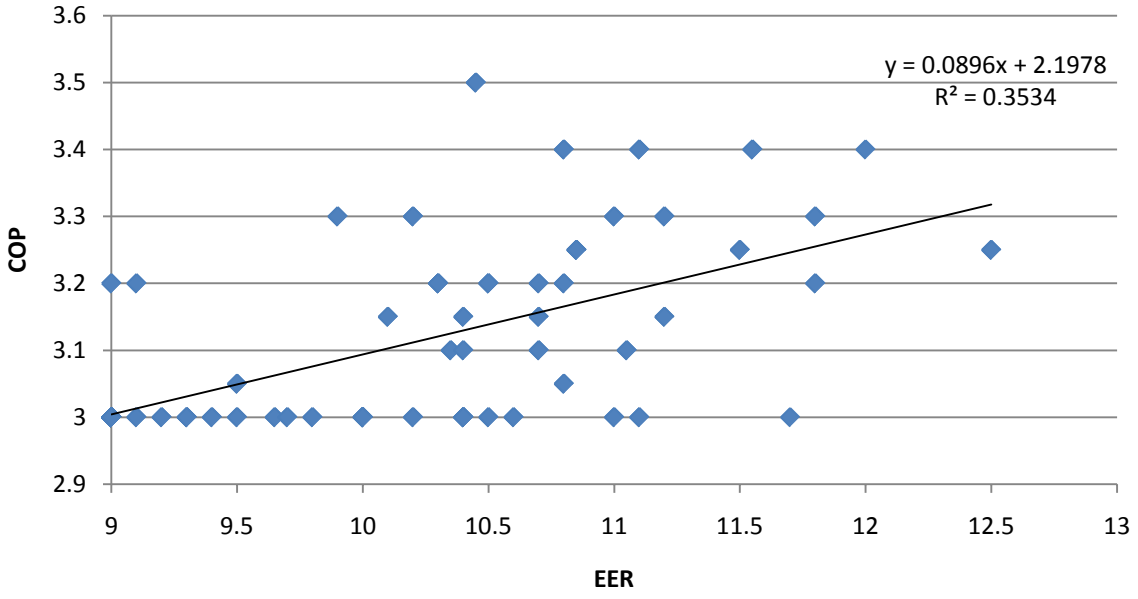


Figure 4.3.3 Relationship between EER and COP for 3-Phase SPVHPs

4.3.2.2 Base Case and Standards Case Market Shares and Market Weighted Average UEC

The UECs associated with the base case and standards case scenarios – or market weighted average UECs – are dependent on the market shares of products at each efficiency level and the UECs for products at each efficiency level (shown in the previous section). In the NES, the market shares are based on model distributions as a proxy for shipment distributions.

Water and Evaporatively Cooled Products

The Department did not have available data on shipments by efficiency level, so it relied on the AHRI certified products directory as well as reviews of manufacturer websites to identify models of water-cooled commercial AC products. The Department then created base case efficiency distributions based on these models. The AHRI certified directory does not list evaporatively-cooled equipment, and the models found on manufacturer websites had limited efficiency information. As a result, the Department created base case efficiency distributions based on very large air-cooled equipment in the AHRI directory. These distributions were bumped up 1.0 EER based on the approximate difference between the federal standards for these equipment categories.

When creating base case efficiency distributions for both water and evaporatively cooled products, the Department binned models into efficiency levels in a manner that created a market weighted-average EER approximately equal to the full distribution EER. The Department assumed that this base case market share remained the same throughout the analysis period.

For each of the efficiency levels or standards cases analyzed within a given equipment class, the Department used a "rollup" scenario to establish the market shares by efficiency level for the year that standards become effective (as well as subsequent years). Information available to DOE suggests that the efficiencies of equipment in the base case that did not meet the standard level under consideration would roll up to meet the standard level. In addition, available information suggests that all equipment efficiencies in the base case that were above the standard level under consideration would not be affected.

DOE calculated the market-weighted average UEC values for each standards scenario using the distribution of efficiencies as well as the capacity-weighted average UECs for each EER being analyzed. The market-weighted average UEC value represents the average energy use of the total units shipped under a specified amended standard level. DOE used the market weighted average UEC values to calculate the annual energy use of the equipment class at a given amended standard level. For each standards case scenario:

$$Mkt\ Wtd\ Avg\ UEC = \sum_{Level=Baseline}^{Max\ Tech} Market\ Share_{Level} \times Capacity\ Wtd\ Avg\ UEC_{Level}$$

Table 4.3.18 through Table 4.3.25 shows the distribution of efficiencies within the base case and the rollup scenarios to establish the distribution of efficiencies in the standards cases for each equipment class. In addition, the market weighted average UEC (based on the rollup

distribution) is shown for each standard case under consideration. Efficiency distributions do not change over time except from base case to standards case on the relevant effective date.

Table 4.3.18 Efficiency Distributions and Market Weighted-Average UECs: Small Water Cooled Equipment with Electric Resistance or No Heat

Standard Scenario	EER						Market Weighted Average UEC
	11.5 (11.5-11.8)	**12.1** (11.9-12.5)	**13** (12.6-13.4)	**14** (13.5-14.4)	**15** (14.5-15.6)	**16.4** (15.7-16.4)	
Base Case	7%	27%	13%	13%	20%	20%	8,088
ASHRAE Standard		34%	13%	13%	20%	20%	8,065
13 EER			47%	13%	20%	20%	7,912
14 EER				60%	20%	20%	7,705
15 EER					80%	20%	7,473
Max Tech						100%	7,101

Table 4.3.19 Efficiency Distributions and Market Weighted-Average UECs: Small Water Cooled Equipment with Other Heat

Standard Scenario	EER						Market Weighted Average UEC
	11.3 (11.3-11.7)	**11.9** (11.8-12.5)	**13** (12.6-13.4)	**14** (13.5-14.4)	**15** (14.5-15.6)	**16.4** (15.7-16.4)	
Base Case	7%	27%	13%	13%	20%	20%	8,126
ASHRAE Standard		34%	13%	13%	20%	20%	8,102
13 EER			47%	13%	20%	20%	7,912
14 EER				60%	20%	20%	7,705
15 EER					80%	20%	7,473
Max Tech						100%	7,101

Table 4.3.20 Efficiency Distributions and Market Weighted-Average UECs: Large Water Cooled Equipment with Electric Resistance or No Heat

Standard Scenario	EER						Market Weighted Average UEC
	11.0 (11.0-11.5)	**12.5** (11.6-12.7)	**13** (12.8-13.4)	**14** (13.5-14.4)	**15** (14.5-15.5)	**16.1** (15.6-16.1)	
Base Case	29%	21%	7%	7%	29%	7%	15,776
ASHRAE Standard		50%	7%	7%	29%	7%	15,309
13 EER			57%	7%	29%	7%	15,078
14 EER				64%	29%	7%	14,602
15 EER					93%	7%	14,137
Max Tech						100%	13,490

Table 4.3.21 Efficiency Distributions and Market Weighted-Average UECs: Large Water Cooled Equipment with Other Heat

Standard Scenario	EER						Market Weighted Average UEC
	11.0 (11.0-11.4)	**12.3** (11.5-12.6)	**13** (12.7-13.4)	**14** (13.5-14.4)	**15** (14.5-15.5)	**16.1** (15.6-16.1)	
Base Case	29%	21%	7%	7%	29%	7%	15,818
ASHRAE Standard		50%	7%	7%	29%	7%	15,407
13 EER			57%	7%	29%	7%	15,078
14 EER				64%	29%	7%	14,602
15 EER					93%	7%	14,137
Max Tech						100%	13,490

Table 4.3.22 Efficiency Distributions and Market Weighted-Average UECs: Very Large Water Cooled Equipment with Electric Resistance or No Heat

Standard Scenario	EER					Market Weighted Average UEC
	11.0 (11-11.69)	**12.4** (11.7-12.69)	**13** (12.7-13.49)	**14** (13.5-14.39)	**14.8** (14.4-14.89)	
Base Case	17%	20%	29%	14%	20%	36,893
ASHRAE Standard		37%	29%	14%	20%	36,279
13 EER			66%	14%	20%	35,794
14 EER				80%	20%	34,518
Max Tech					100%	33,422

Table 4.3.23 Efficiency Distributions and Market Weighted-Average UECs: Very Large Water Cooled Equipment with Other Heat

Standard Scenario	EER					Market Weighted Average UEC
	10.8 (10.8-11.59)	**12.2** (11.6-12.69)	**13** (12.7-13.49)	**14** (13.5-14.39)	**14.8** (14.4-14.89)	
Base Case	14%	23%	29%	14%	20%	36,980
ASHRAE Standard		37%	29%	14%	20%	36,452
13 EER			66%	14%	20%	35,794
14 EER				80%	20%	34,518
Max Tech					100%	33,422

Table 4.3.24 Efficiency Distributions and Market Weighted-Average UECs: Very Large Evaporatively Cooled Equipment with Electric Resistance or No Heat

Standard Scenario	EER				Market Weighted Average UEC
	11.0 (11.0-11.3)	**11.9** (11.4-12.1)	**12.5** (12.2-12.7)	**13.1** (12.8-13.1)	
Base Case	65%	27%	6%	2%	46,166
ASHRAE Standard		92%	6%	2%	44,584
12.5 EER			98%	2%	43,265
Max Tech				100%	41,983

Table 4.3.25 Efficiency Distributions and Market Weighted-Average UECs: Very Large Evaporatively Cooled Equipment with Other Heat

Standard Scenario	EER				Market Weighted Average UEC
	10.8 (10.8-11.2)	**11.7** (11.3-12.0)	**12.5** (12.1-12.7)	**13.1** (12.8-13.1)	
Base Case	56%	35%	7%	2%	46,436
ASHRAE Standard		91%	7%	2%	45,033
12.5 EER			98%	2%	43,265
Max Tech				100%	41,983

SPVUs

The Department did not have data on shipments of SPVUs by efficiency level, so it relied on the AHRI certified products directory to identify models of SPVUs and develop efficiency distributions for the base case based on these models. The Department assumed that this base case market share remained the same throughout the analysis period.

For each of the efficiency levels or standards cases analyzed, the Department used a "rollup" scenario as described for Water and Evaporatively Cooled Equipment. The Department also calculated the market weighted-average UEC in the same way as shown above.

Table 4.3.26 through Table 4.3.29 shows the distribution of efficiencies within the base case and the rollup scenarios to establish the distribution of efficiencies in the standards cases for each equipment class. In addition, the market weighted average UEC (based on the rollup distribution) is shown for each standard case under consideration. Efficiency distributions do not change over time except from base case to standards case on the relevant effective date.

Table 4.3.26 Efficiency Distributions and Market Weighted-Average UECs: Small Single-Phase SPVAC

Standard Scenario	EER						Market Weighted Average UEC
	9.0 (9.0-9.29)	**9.5** (9.3-9.79)	**10** (9.8-10.49)	**11** (10.5-11.49)	**12** (11.5-12.29)	**12.6** (12.3-12.6)	
Base Case	52%	11%	15%	17%	4%	1%	6,239
9.5 EER		63%	15%	17%	4%	1%	6,054
10 EER			78%	17%	4%	1%	5,842
11 EER				95%	4%	1%	5,511
12 EER					99%	1%	5,055
Max Tech						100%	4,911

Table 4.3.27 Efficiency Distributions and Market Weighted-Average UECs: Small Three-Phase SPVAC

Standard Scenario	EER						Market Weighted Average UEC
	9.0 (9.0-9.29)	**9.5** (9.3-9.79)	**10** (9.8-10.49)	**11** (10.5-11.49)	**12** (11.5-12.29)	**12.6** (12.3-12.6)	
Base Case	34%	10%	21%	24%	9%	2%	6,023
9.5 EER		44%	21%	24%	9%	2%	5,901
10 EER			65%	24%	9%	2%	5,753
11 EER				89%	9%	2%	5,479
12 EER					98%	2%	5,053
Max Tech						100%	4,911

Table 4.3.28 Efficiency Distributions and Market Weighted-Average UECs: Small Single-Phase SPVHP

Standard Scenario	EER						Market Weighted Average Cooling UEC	Market Weighted Average Heating UEC
	9.0 (9.0-9.29)	**9.5** (9.3-9.79)	**10** (9.8-10.49)	**11** (10.5-11.49)	**12** (11.5-12.29)	**12.5** (12.3-12.5)		
Base Case	37%	10%	21%	21%	9%	1%	6,017	6,192
9.5 EER		47%	21%	21%	9%	1%	5,885	6,175
10 EER			69%	21%	9%	1%	5,725	6,154
11 EER				90%	9%	1%	5,295	6,096
12 EER					99%	1%	5,047	6,025
Max Tech						100%	4,925	5,988

Table 4.3.29 Efficiency Distributions and Market Weighted-Average UECs: Small Three-Phase SPVHP

Standard Scenario	EER						Market Weighted Average Cooling UEC	Market Weighted Average Heating UEC
	9.0 (9.0-9.29)	**9.5** (9.3-9.79)	**10** (9.8-10.49)	**11** (10.5-11.49)	**12** (11.5-12.29)	**12.5** (12.3-12.5)		
Base Case	26%	10%	28%	28%	7%	1%	5,909	6,191
9.5 EER		36%	28%	28%	7%	1%	5,818	6,181
10 EER			64%	28%	7%	1%	5,697	6,167
11 EER				92%	7%	1%	5,299	6,119
12 EER					99%	1%	5,046	6,054
Max Tech						100%	4,925	6,021

4.3.3 Product Lifetime

For both water-cooled and evaporatively-cooled products and SPVUs, DOE estimated the product lifetime from the advanced notice of proposed rulemaking on Energy Conservation Standards for Commercial Unitary Air Conditioners and Heat Pumps published in the Federal Register on July 29, 2004. 69 FR 45460. The product lifetime from the prior TSD was estimated to be a mean of 15.4 years. More recent sources confirm this estimate including the 2008 California Database for Energy Efficient Resources (15 years). For this preliminary analysis, DOE used a single-value lifetime of 15 years.

4.3.4 Site-to-Source Energy Conversion Factors

For both water and evaporatively cooled products and SPVUs, the Department calculated energy savings as site energy, which it then converted to source energy— the energy that electric power plants consume. As shown in Table 4.3.30, the Department used site-to-source energy conversion factors from the *AEO 2010*. The Department extrapolated the values in later years (after 2035) from their relative sources because the *AEO* does not forecast beyond 2035. To arrive at values for these later years, the Department used the forecast's trend from 2025 to 2035 to establish conversion factors in the years 2036 to 2045.

Table 4.3.30 Site-to-Source Conversion Factors

Year	Site-to-Source Conversion Factor (Btu/kWh)
2008	10,805
2009	10,876
2010	10,918
2011	10,877
2012	10,818
2013	10,812
2014	10,786
2015	10,727
2016	10,715
2017	10,694
2018	10,683
2019	10,666
2020	10,650
2021	10,643
2022	10,619
2023	10,599
2024	10,556
2025	10,543
2026	10,499
2027	10,475
2028	10,446
2029	10,422
2030	10,409
2031	10,390
2032	10,374
2033	10,354
2034	10,338
2035	10,318
2036	10,296
2037	10,274
2038	10,251
2039	10,229
2040	10,207
2041	10,185
2042	10,163
2043	10,141
2044	10,119
2045	10,098
2046	10,076

Source: EIA, *AEO 2010.*

4.3.5 Effective Dates and Analysis Period

Water and Evaporatively Cooled Products

For purposes of calculating the NES, the Department used an analysis period of 2013 (the assumed effective date of ASHRAE level standards for small products) or 2014 (the assumed effective date of ASHRAE level standards for large and very large products) through 2042 and 2043, respectively. This is the standard analysis period of 30 years. While the analysis period remains the same for standards higher than ASHRAE, energy savings do not begin accumulating until 2017 (the assumed effective date of higher than ASHRAE standards).

Generally, covered equipment to which a new or amended energy conservation standard applies must comply with the standard if such equipment is manufactured or imported on or after a specified date.

If DOE were to propose a rule prescribing energy conservation standards at the efficiency levels contained in ASHRAE Standard 90.1 2010, EPCA states that any such standards shall become effective on or after a date which is two or three years (depending on equipment size) after the effective date of the applicable minimum energy efficiency requirement in the amended ASHRAE standard (i.e., ASHRAE Standard 90.1 2010). (42 U.S.C. 6313(a)(6)(D)) For all water and evaporatively cooled equipment in this rulemaking, the effective date in ASHRAE Standard 90.1 2010 is June 1, 2011. Thus, if DOE decides to adopt the levels in ASHRAE Standard 90.1 2010, the rule would apply to small equipment (two product classes) manufactured on or after June 1, 2013, which is two years from the effective date specified in ASHRAE Standard 90.1 2010, and to large and very large equipment (six product classes) manufactured on or after June 1, 2014, which is three years from the effective date specified in ASHRAE Standard 90.1 2010.

If DOE were to propose a rule prescribing energy conservation standards higher than the efficiency levels contained in ASHRAE Standard 90.1 2010, EPCA states that any such standards "shall become effective for products manufactured on or after a date which is four years after the date such rule is published in the Federal Register." (42 U.S.C. 6313(a)(6)(D)) Thus, for products which DOE might adopt a level more stringent than the ASHRAE efficiency levels, the rule would apply to products manufactured on or after April 29, 2017, which is four years from the date of publication of the final rule that DOE must meet for higher than ASHRAE efficiency levels (30 months after publication of ASHRAE, which was October 29, 2010).

SPVUs

For purposes of calculating the NES for SPVUs, DOE used a 30-year analysis period of 2017-2046. As all efficiency levels being considered for SPVUs are higher than the ASHRAE efficiency levels, any rule adopted would apply to products manufactured on or after a date which is four years from the date of publication of the final rule adopting standards higher than the ASHRAE efficiency levels (30 months after publication of the revised ASHRAE Standard 90.1, which was October 29, 2010). Under this timeline, compliance with such more-stringent standards would be required no later than April 29, 2017.

4.4 NES RESULTS

Water and Evaporatively Cooled Products

Table 4.4.1, Table 4.4.2, Figure 4.4.1, and Figure 4.4.2 summarize the NES due to new energy conservation standards for the eight product classes examined. Results of the national energy savings analysis are provided for the two shipment case scenarios, Historical Trends and Fixed to 2009. Recall that all levels higher than ASHRAE are shown as net of ASHRAE savings.

Table 4.4.1 National Energy Savings for Water and Evaporatively Cooled Products (Quads, 2013–2042 or 2014-2043): Based on Historical Trends

Efficiency Level	Small Water E/N 65-135	Small Water O 65-135	Large Water E/N 135-240	Large Water O 135-240	VL Water E/N 240-760	VL Water O 240-760	VL Evap E/N 240-760	VL Evap O 240-760
ASHRAE Standard	0.000005	0.0000005	0.0001	0.00001	0.0002	0.002	0.0001	0.001
13/12.5 EER	0.00002	0.000002	0.00002	0.00001	0.0001	0.001	0.00008	0.001
14 EER	0.00004	0.000005	0.00013	0.00002	0.0005	0.005	-	-
15 EER	0.00007	0.000009	0.00024	0.00003	-	-	-	-
Max Tech	0.00012	0.000014	0.00039	0.00005	0.0008	0.008	0.00017	0.002

Table 4.4.2 National Energy Savings for Water and Evaporatively Cooled Products (Quads, 2013–2042 or 2014-2043): Shipments Fixed to 2009

Efficiency Level	Small Water E/N 65-135	Small Water O 65-135	Large Water E/N 135-240	Large Water O 135-240	VL Water E/N 240-760	VL Water O 240-760	VL Evap E/N 240-760	VL Evap O 240-760
ASHRAE Standard	0.000011	0.0000013	0.0003	0.00003	0.0001	0.001	0.0001	0.001
13/12.5 EER	0.00006	0.000008	0.00008	0.00001	0.0001	0.001	0.00005	0.001
14 EER	0.00014	0.000017	0.00032	0.00004	0.0003	0.003	-	-
15 EER	0.00024	0.000028	0.00056	0.00007	-	-	-	-
Max Tech	0.00039	0.000044	0.00089	0.00010	0.0005	0.005	0.00011	0.001

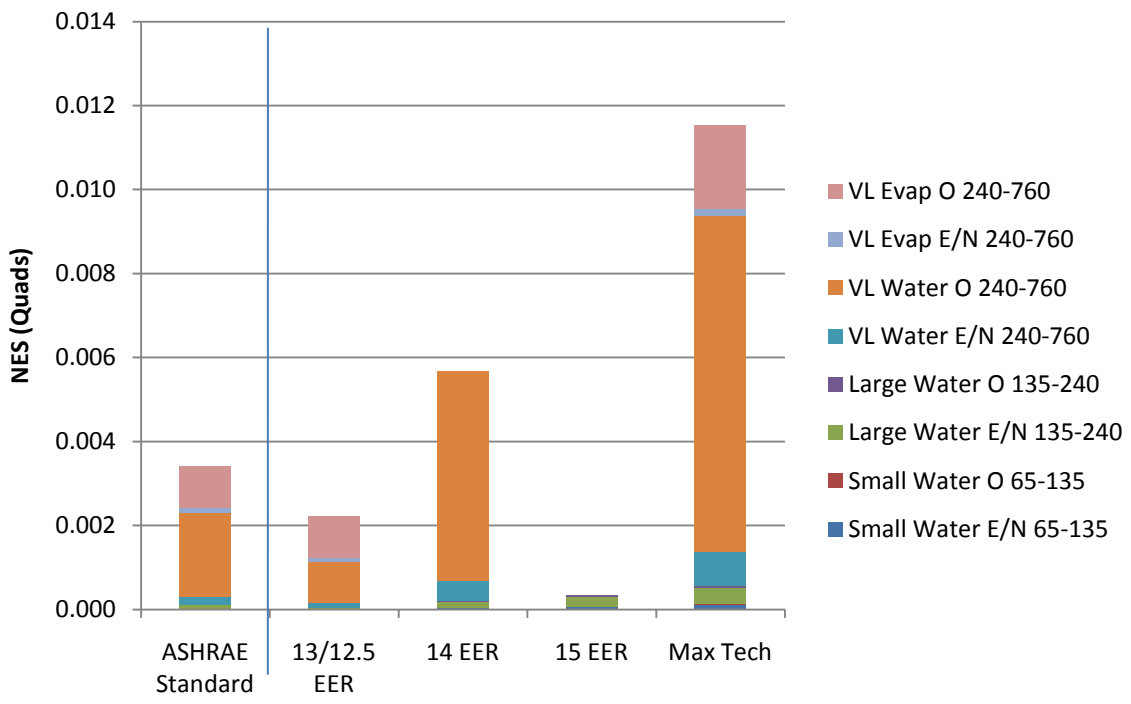


Figure 4.4.1 National Energy Savings for Water and Evaporatively Cooled Products by Product Class: Historical Trends

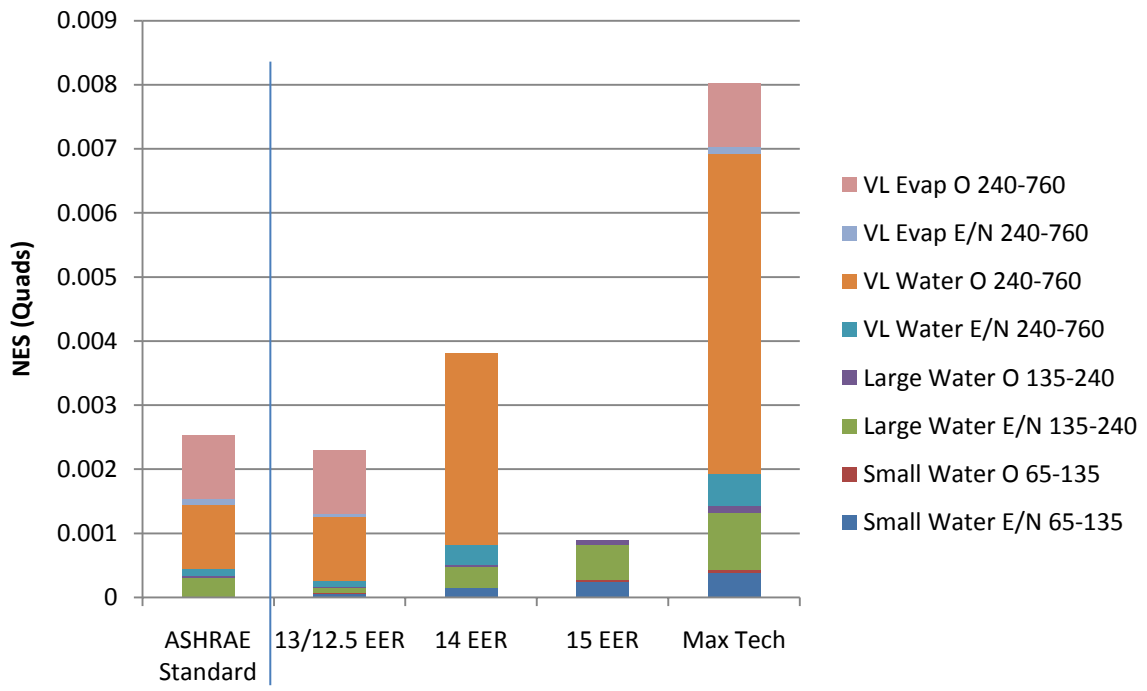


Figure 4.4.2 National Energy Savings for Water and Evaporatively Cooled Products by Product Class: Shipments Fixed to 2009

SPVUs

Table 4.4.3 and Figure 4.4.3 summarize the NES due to new energy conservation standards for the four product classes examined.

Table 4.4.3 National Energy Savings for SPVUs (Quads, 2017-2046)

Efficiency Level	SPVAC 1-phase < 65	SPVAC 3-phase < 65	SPVHP 1-phase < 65	SPVHP 3-phase < 65
9.5 EER	0.031	0.010	0.012	0.004
10 EER	0.076	0.023	0.026	0.009
11 EER	0.139	0.046	0.064	0.025
12 EER	0.226	0.083	0.089	0.037
Max Tech	0.253	0.095	0.101	0.042

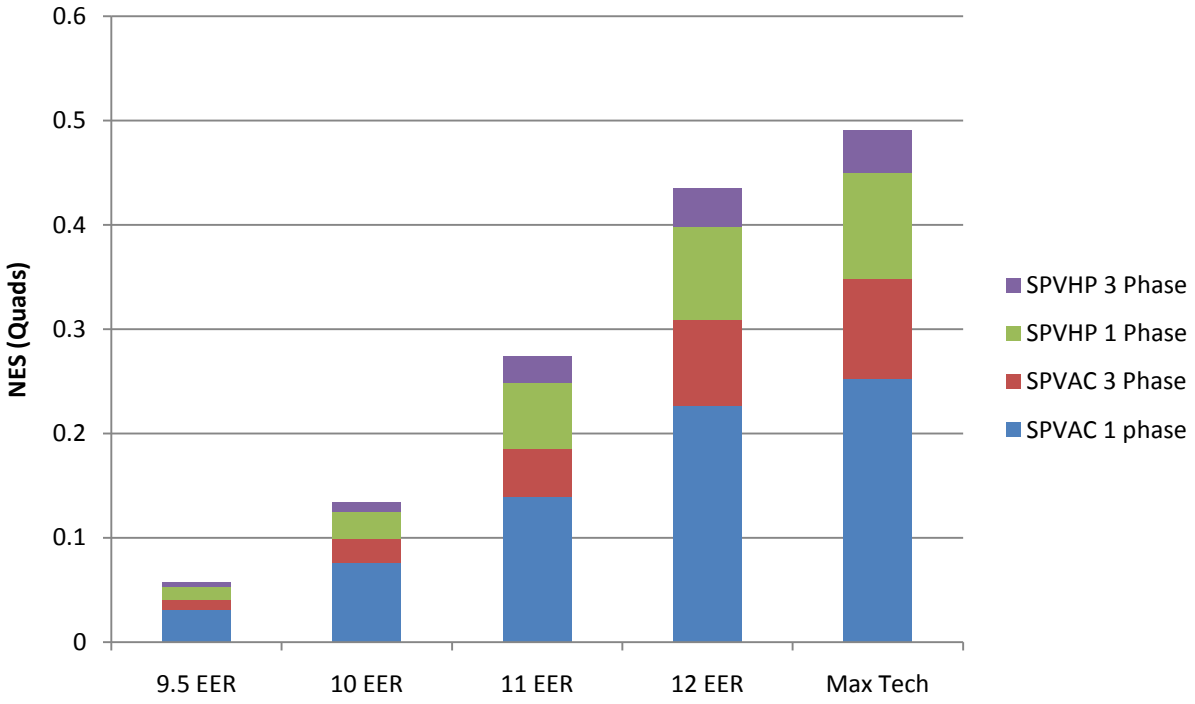


Figure 4.4.3 National Energy Savings for SPVUs by Product Class

REFERENCES

1 Air-Conditioning, Heating, and Refrigeration Institute, *Historical Shipment Data Commercial Air Conditioners Water Cooled*, 2011. Information provided by the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) to the U.S. Department of Energy, March 4, 2011.

2 U.S. Department of Energy, *Technical Support Document: Energy Efficiency Program for Commercial and Industrial Equipment: Efficiency Standards for Commercial Heating, Air-Conditioning, and Water Heating Equipment Including Packaged Terminal Air-Conditioners and Packaged Terminal Heat Pumps, Small Commercial Packaged Boiler, Three-Phase Air-Conditioners and Heat Pumps <65,000 Btu/h, and Single-Package Vertical Air Conditioners and Single-Package Vertical Heat Pumps < 65,000 Btu/h*, March 2006. Washington, DC.

3 California Public Utility Commission 2008. Database for Energy Efficient Resources. (Last accessed April 20, 2011.) <www.deeresources.com>

APPENDIX 3A. CHARACTERISTICS OF MEDIUM OFFICE REFERENCE BUILDING MODEL AND MODULAR CLASSROOM MODEL

TABLE OF CONTENTS

3A.1 Introduction 1
3A.2 Medium Office Reference Building Model Description 1
3A.3 Modular Classroom Building Model Description 9

LIST OF TABLES

Table 3A.2.1. Description of DOE Reference Medium Office Building Model 2
Table 3A.2.2. Key Schedules for DOE Reference Medium Office Building Model 8
Table 3A.3.1. Description of Modular Classroom Building Model 9
Table 3A.3.2. Key Schedules for Modular Classroom Building Model 13

APPENDIX 3A. CHARACTERISTICS OF MEDIUM OFFICE REFERENCE BUILDING MODEL AND MODULAR CLASSROOM MODEL

3A.1 INTRODUCTION

The analysis of baseline energy consumption for both water-cooled air conditioners and evaporatively cooled air conditioners discussed in chapter 3 were based on simulation data for DOE's medium office reference building model. This appendix provides key characteristics of the DOE medium office reference building model which formed the basis of this data. Further details and background may be found in the documentation and through review of the input files available at <http://www1.eere.energy.gov/buildings/commercial_initiative/new_construction.html>.

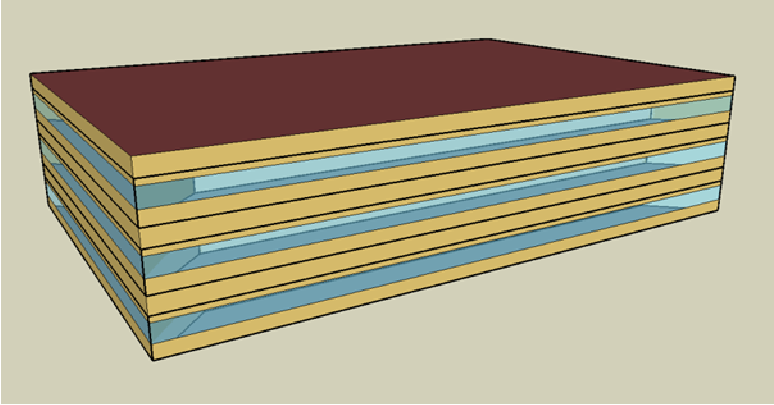
In addition, this appendix provides key characteristics for the modular classroom model used in the analysis of SPVAC and SPVHP energy usage.

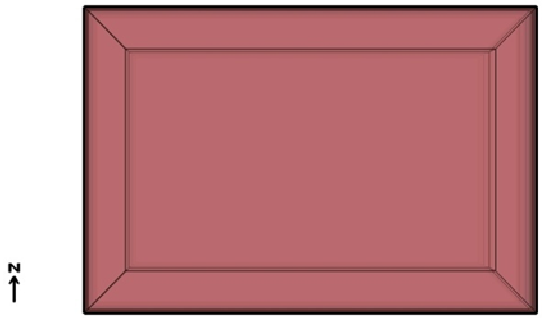
3A.2 MEDIUM OFFICE REFERENCE BUILDING MODEL DESCRIPTION

Table 3A.2.2 provides a high level description of the DOE medium office reference building model.

Table 3A.2.1. Description of DOE Reference Medium Office Building Model

	Item	Description		
Program				
	Vintage	**NEW CONSTRUCTION**		
	Location (Representing 8 Climate Zones)	Zone 1A: Miami (very hot, humid) Zone 2A: Houston (hot, humid) Zone 2B: Phoenix (hot, dry) Zone 3A: Memphis (warm, humid) Zone 3B: El Paso (warm, dry) Zone 3C: San Francisco (warm,marine)	Zone 4A: Baltimore (mild, humid) Zone 4B: Albuquerque (mild, dry) Zone 4C: Salem (mild, marine) Zone 5A: Chicago (cold, humid) Zone 5B: Boise (cold, dry)	Zone 6A: Burlington (cold, humid) Zone 6B: Helena (cold, dry) Zone 7: Duluth (very cold) Zone 8: Fairbanks (subarctic)
	Available fuel types	gas, electricity		
	Building Type (Principal Building Function)	**OFFICE**		
	Building Prototype	**Medium Office**		
Form				
	Total Floor Area (sq feet)	53,600 (163.8 ft x 109.2 ft)		

	Item	Description
	Building shape	
	Aspect Ratio	1.5
	Number of Floors	3
	Window Fraction (Window-to-Wall Ratio)	33%
	Window Locations	even distribution among all four sides
	Shading Geometry	none
	Azimuth	non-directional

	Item	Description	
	Thermal Zoning	Perimeter zone depth: 15 ft. Each floor has four perimeter zones and one core zone.Percentages of floor area: Perimeter 40%, Core 60%	
	Floor to floor height (feet)	13	
	Floor to ceiling height (feet)	9 (4 ft above-ceiling plenum)	
Architecture			
	Exterior walls		
	Construction	Steel-Frame Walls	
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1-1997 Requirements Nonresidential; Walls, Above-Grade, Steel-Framed	
	Roof		
	Construction	Built-up Roof: Roof membrane+Roof insulation+metal decking	
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Roofs, Insulation entirely above deck	
	Window		

	Item	Description
	U-factor (Btu / h * ft^2 * °F)	ASHRAE 90.1 Requirements Nonresidential; Vertical Glazing, 31.1-40%, U_fixed
	SHGC (all)	
	Operable area	0
	Foundation	
	Foundation Type	Slab-on-grade floors (unheated)
	Construction	8" concrete slab poured directly on to the earth
	Thermal properties for ground level floor U-factor (Btu / h * ft2 * °F) and/or R-value (h * ft2 * °F / Btu)	ASHRAE 90.1 Requirements Nonresidential; Slab-on-Grade Floors, unheated
	Infiltration	
	Infiltration	Peak: 0.2016 cfm/sf of above grade exterior wall surface area (when fans turn off) Off Peak: 25% of peak infiltration rate (when fans turn on)
HVAC		
	System Type	
	Heating type	Gas furnace inside the packaged air conditioning unit
	Cooling type	Packaged air conditioning unit
	Distribution and terminal units	VAV terminal box with damper and electric reheating coil Zone control type: minimum supply air at 30% of the zone design peak supply air.
	HVAC Sizing	
	Air Conditioning	autosized to design day
	Heating	autosized to design day
	HVAC Control	
	Thermostat Setpoint	75°F Cooling/70°F Heating
	Thermostat Setback	80°F Cooling/60°F Heating
	Economizers	Various by climate location and cooling capacity Control type: differential dry bulb

	Item	Description
	Ventilation	ASHRAE Ventilation Standard 62.1-1999 0.10 cfm/sf.
	Supply Fan	
	Fan schedules	**See under HVAC Operation Schedules, Below**
	Supply Fan Total Efficiency (%)	60% to 62% depending on the fan motor size
	Supply Fan Pressure Drop	Varies depending on the Equipment Type
Internal Loads & Schedules		
	Lighting	
	Average power density (W/ft^2)	ASHRAE 90.1-2004 Lighting Power Densities Using the Building Area Method
	Schedule	See under **Schedules, Below**
	Daylighting Controls	ASHRAE 90.1 Requirements
	Occupancy Sensors	ASHRAE 90.1 Requirements
	Plug load	
	Average power density (W/ft^2)	0.75
	Schedule	See under **Schedules, Below**
	Occupancy	
	Average people	268 Total (5 persons/1000 sf)
	Schedule	See under **Schedules, Below**
Misc.		
	Elevator	
	Quantity	2
	Motor type	hydraulic
	Peak Motor Power (W/elevator)	16,055

	Item	Description
	Heat Gain to Building	Interior
	Peak Fan/lights Power (W/elevator)	161.9
	Exterior Lighting	
	Peak Power (W)	2,740
	Schedule	See under **Schedules, Below**

Table 3A.2.2. Key Schedules for DOE Reference Medium Office Building Model

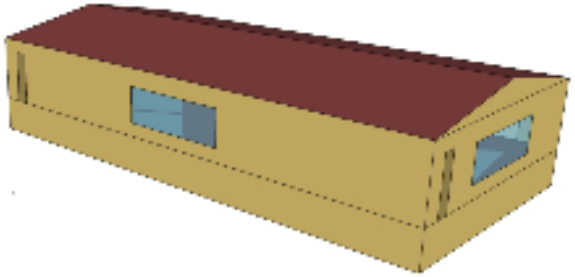
Schedule	Type	Through	Day of Week	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	Noon
Internal Loads Schedules															
BLDG_LIGHT_SCH	Fraction	Through 12/31	WD, SummerDesign	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.9	0.9	0.9	0.9
			Sat, WinterDesign	0.05	0.05	0.05	0.05	0.05	0.05	0.1	0.1	0.3	0.3	0.3	0.3
			Sun, Hol, Other	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
BLDG_EQUIP_SCH	Fraction	Through 12/31	WD, SummerDesign	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.9	0.9	0.9	0.9
			Sat, WinterDesign	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.5	0.5
			Sun, Hol, Other	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
BLDG_OCC_SCH	Fraction	Through 12/31	WD	0	0	0	0	0	0	0.1	0.2	0.95	0.95	0.95	0.95
			SummerDesign	0	0	0	0	0	0	1	1	1	1	1	1
			Sat, WinterDesign	0	0	0	0	0	0	0.1	0.1	0.3	0.3	0.3	0.3
			Sun, Hol, Other	0	0	0	0	0	0	0.05	0.05	0.05	0.05	0.05	0.05
HVAC Schedules															
HVACOperationSchd (Fan Schedule)	on/off	Through 12/31	WD, SummerDesign	0	0	0	0	0	0	1	1	1	1	1	1
			Sat, WinterDesign	0	0	0	0	0	0	1	1	1	1	1	1
			Sun, Hol, Other	0	0	0	0	0	0	0	0	0	0	0	0

Schedule	**Type**	**Through**	**Day of Week**	**1 pm**	**2 pm**	**3 pm**	**4 pm**	**5 pm**	**6 pm**	**7 pm**	**8 pm**	**9 pm**	**10 pm**	**11 pm**	**12 pm**
Internal Loads Schedules															
BLDG_LIGHT_SCH	Fraction	Through 12/31	WD, SummerDesign	0.8	0.9	0.9	0.9	0.9	0.5	0.3	0.3	0.2	0.2	0.1	0.05
			Sat, WinterDesign	0.15	0.15	0.15	0.15	0.15	0.05	0.05	0.05	0.05	0.05	0.05	0.05
			Sun, Hol, Other	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
BLDG_EQUIP_SCH	Fraction	Through 12/31	WD, SummerDesign	0.8	0.9	0.9	0.9	0.9	0.5	0.4	0.4	0.4	0.4	0.4	0.4
			Sat, WinterDesign	0.35	0.35	0.35	0.35	0.35	0.3	0.3	0.3	0.3	0.3	0.3	0.3
			Sun, Hol, Other	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
BLDG_OCC_SCH	Fraction	Through 12/31	WD	0.5	0.95	0.95	0.95	0.95	0.3	0.1	0.1	0.1	0.1	0.05	0.05
			SummerDesign	1	1	1	1	1	1	1	1	1	1	0.05	0.05
			Sat, WinterDesign	0.1	0.1	0.1	0.1	0.1	0.05	0.05	0	0	0	0	0
			Sun, Hol, Other	0.05	0.05	0.05	0.05	0.05	0.05	0	0	0	0	0	0
HVAC Schedules															
HVACOperationSchd (Fan Schedule)	on/off	Through 12/31	WD, SummerDesign	1	1	1	1	1	1	1	1	1	1	0	0
			Sat, WinterDesign	1	1	1	1	1	1	0	0	0	0	0	0
			Sun, Hol, Other	0	0	0	0	0	0	0	0	0	0	0	0

3A.3 MODULAR CLASSROOM BUILDING MODEL DESCRIPTION

Table 3A.3.1. Description of Modular Classroom Building Model

	Item	Descriptions		
Program				
	Vintage	**RECENT CONSTRUCTION**		
	Location (Representing 8 Climate Zones)	Zone 1A: Miami (very hot, humid) Zone 2A: Houston (hot, humid) Zone 2B: Phoenix (hot, dry) Zone 3A: Memphis (warm, humid) Zone 3B: El Paso (warm, dry) Zone 3C: San Francisco (warm,marine)	Zone 4A: Baltimore (mild, humid) Zone 4B: Albuquerque (mild, dry) Zone 4C: Salem (mild, marine) Zone 5A: Chicago (cold, humid) Zone 5B: Boise (cold, dry)	Zone 6A: Burlington (cold, humid) Zone 6B: Helena (cold, dry) Zone 7: Duluth (very cold) Zone 8: Fairbanks (subarctic)
	Available fuel types	electricity		
	Building Type (Principal Building Function)	**Education**		
	Building Prototype	**Modular Classroom**		
Form				
	Total Floor Area (sq feet)	1568 (56 ft x 28 ft)		

	Item	Descriptions
	Building shape	
	Aspect Ratio	2
	Number of Floors	1
	Window Fraction (Window-to-Wall Ratio)	9.4%
	Window Locations	equal window area among all four sides
	Shading Geometry	none
	Azimuth	Long Axis E-W
	Thermal Zoning	Single Zone
	Floor to ceiling height (feet)	7.5 (Low Slope Attic)
Architecture		
	Exterior walls	
	Construction	Wood-Frame Walls
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1-2004 Requirements Nonresidential; Walls, Above-Grade, Wood-Framed
	Roof	

	Item	Descriptions
	Construction	Low Attic: Insulation Layer on Ceiling, Attic Space, Wood Decking, Asphalt Shingles
	U-factor (Btu / h * ft^2 * °F) and/or R-value (h * ft^2 * °F / Btu)	ASHRAE 90.1-1994 Requirements Nonresidential; Roofs, Attic
	Window	
	U-factor (Btu / h * ft^2 * °F)	ASHRAE 90.1-1994 Requirements Nonresidential; Vertical Glazing, 0-10%, U_fixed w/Blinds
	SHGC (all)	
	Operable area	0
	Foundation	
	Foundation Type	Crawlspace
	Infiltration	
	Infiltration	Infiltration based on Airflow Net Model. 7 ACH at 50 PA . Adapted from Residential Manufactured Housing Model
HVAC		
	System Type	
	Heating type	Forced Air Electric Resistance or Single Package Vertical Heat Pump
	Cooling type	Single Package Vertical Air Conditioner or Heat Pump Unit
	Distribution and terminal units	Single Zone
	HVAC Sizing	
	Air Conditioning	autosized to design day (0.4% Conditions)
	Heating	autosized to design day (99.6% Conditions)
	HVAC Control	
	Thermostat Setpoint	75°F Cooling/70°F Heating
	Thermostat Setback	80°F Cooling/60°F Heating
	Economizers	None

	Item	Descriptions
	Ventilation	ASHRAE Ventilation Standard 62.1 20 CFM/Occupant
	Supply Fan	
	Fan schedules	**See under HVAC Schedules, Below**
	Supply Fan Total Efficiency (%)	31% for SPVU Baseline (9.0 EER)
	Supply Fan Pressure Drop (in H_20)	1.3
Internal Loads & Schedules		
	Lighting	
	Average power density (W/ft^2)	1.4 Based on DOE Primary School Reference Building Model and ASHRAE 90.1-Requirements
	Schedule	See under **Schedules, Below**
	Daylighting Controls	None
	Occupancy Sensors	None
	Plug load	
	Average power density (W/ft^2)	1.4 Based on DOE Primary School Reference Building Model and ASHRAE 90.1-Requirements
	Schedule	See under **Schedules, Below**
	Occupancy	
	Average people	40 Total (25 persons/1000 sf)
	Schedule	See under **Schedules, Below**

Table 3A.3.2. Key Schedules for Modular Classroom Building Model

Schedule	Type	Through	Day of Week	1 am	2 am	3 am	4 am	5 am	6 am	7 am	8 am	9 am	10 am	11 am	Noon
Internal Loads Schedules															
BLDG_LIGHT_SCH	Fraction	1/1 - 6/30 and 9/1-12/31	WD, SummerDesign	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.9	0.9	0.9	0.9	0.9
(Study Periods)			Sat, Sun, Hol, WinterDesign, Other	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
BLDG_LIGHT_SCH	Fraction	6/30 - 9/1	WD, SummerDesign	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.5	0.5	0.5	0.5
(Summer Holiday)			Sat, Sun, Hol, WinterDesign, Other	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
BLDG_EQUIP_SCH	Fraction	1/1 - 6/30 and 9/1-12/31	WD, SummerDesign	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.95	0.95	0.95	0.95
(Study Periods)			Sat, Sun, Hol, WinterDesign, Other	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
BLDG_EQUIP_SCH	Fraction	6/30 - 9/1	WD, SummerDesign	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.5	0.5	0.5	0.5
(Summer Holiday)			Sat, Sun, Hol, WinterDesign, Other	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
BLDG_OCC_SCH	Fraction	1/1 - 6/15 and 9/15-12/31	WD, SummerDesign	0	0	0	0	0	0	0	0	0.95	0.95	0.95	0.95
(Study Periods)			Sat, Sun, Hol, WinterDesign, Other	0	0	0	0	0	0	0	0	0	0	0	0
BLDG_OCC_SCH	Fraction	6/15 - 9/15	WD, SummerDesign	0	0	0	0	0	0	0	0	0.15	0.15	0.15	0.15
(Summer Holiday)			Sat, Sun, Hol, WinterDesign, Other	0	0	0	0	0	0	0	0	0	0	0	0
HVAC Schedules															
HVACOperationSchd	on/off	Through 12/31	WD, SummerDesign, WinterDesign	0	0	0	0	0	0	0	1	1	1	1	1
			Sat, Sun, Hol, Other	0	0	0	0	0	0	0	0	0	0	0	0

Schedule	Type	Through	Day of Week	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 pm
Internal Loads Schedules															
BLDG_LIGHT_SCH	Fraction	1/1 - 6/30 and 9/1-12/31	WD, SummerDesign	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.18	0.18	0.18
(Study Periods)			Sat, Sun, Hol, WinterDesign, Other	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
BLDG_LIGHT_SCH	Fraction	6/30 - 9/1	WD, SummerDesign	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.18	0.18	0.18	0.18
(Summer Holiday)			Sat, Sun, Hol, WinterDesign, Other	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
BLDG_EQUIP_SCH	Fraction	1/1 - 6/30 and 9/1-12/31	WD, SummerDesign	0.95	0.95	0.95	0.95	0.95	0.35	0.35	0.35	0.35	0.35	0.35	0.35
(Study Periods)			Sat, Sun, Hol, WinterDesign, Other	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
BLDG_EQUIP_SCH	Fraction	6/30 - 9/1	WD, SummerDesign	0.5	0.5	0.5	0.5	0.5	0.25	0.25	0.25	0.25	0.25	0.25	0.25
(Summer Holiday)			Sat, Sun, Hol, WinterDesign,	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25

Schedule	Type	Through	Day of Week	1 pm	2 pm	3 pm	4 pm	5 pm	6 pm	7 pm	8 pm	9 pm	10 pm	11 pm	12 pm
			Other												
BLDG_OCC_SCH	Fraction	1/1 - 6/15 and 9/15-12/31	WD, SummerDesign	0.95	0.95	0.95	0.95	0.15	0.15	0.15	0.15	0.15	0	0	0
(Study Periods)			Sat, Sun, Hol, WinterDesign, Other	0	0	0	0	0	0	0	0	0	0	0	0
BLDG_OCC_SCH	Fraction	6/15 - 9/15	WD, SummerDesign	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0	0	0
(Summer Holiday)			Sat, Sun, Hol, WinterDesign, Other	0	0	0	0	0	0	0	0	0	0	0	0
HVAC Schedules															
HVACOperationSchd	on/off	Through 12/31	WD, SummerDesign, WinterDesign	1	1	1	1	1	1	1	1	1	0	0	0
			Sat, Sun, Hol, Other	0	0	0	0	0	0	0	0	0	0	0	0