TECHNICAL SUPPORT DOCUMENT: ENERGY EFFICIENCY PROGRAM FOR COMMERCIAL AND INDUSTRIAL EQUIPMENT:

CERTAIN CATEGORIES OF COMMERCIAL AIR-CONDITIONING AND HEATING EQUIPMENT

August 2019

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

CHAPTER 1. INTRODUCTION

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

1.1 PURPOSE OF THE DOCUMENT

This technical support document (TSD) is a standalone report that provides the technical analysis and results supporting the information presented in the Notice of Data Availability (NODA) for the certain categories of American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2016 equipment.

1.2 PROCESS FOR AMENDED ENERGY CONSERVATION STANDARDS FOR ASHRAE EQUIPMENT

Title III of the Energy Policy and Conservation Act (EPCA), Pub. L. 94163, as amended, sets forth a variety of provisions concerning energy efficiency. Part C[a] 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 the U.S. Department of Energy (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 26, 2016, ASHRAE officially released the American National Standards Institute (ANSI)/ASHRAE/Illuminating Engineering Society (IES) Standard 90.1-2016 (hereinafter referred to as ASHRAE Standard 90.1-2016), which addressed efficiency levels for certain categories of commercial heating, ventilating, and air-conditioning (HVAC) and water heating equipment covered by EPCA. The new ASHRAE Standard 90.1 revised the efficiency levels of the existing ASHRAE Standard 90.1-2013 for the equipment categories for computer room air conditioners (CRACs) as well as created new efficiency levels for equipment classes not currently subject to Federal standards. The new ASHRAE Standard 90.1-2016 also created new efficiency levels for the equipment category dedicated outdoor air systems (DOASes).

The NODA that this TSD accompanies is the first step pursuant to EPCA's requirements for DOE to consider amended standards for certain categories of commercial equipment covered by ASHRAE Standard 90.1-2016, whenever ASHRAE amends its standard to increase the energy efficiency level for an equipment class within a given equipment category. Specifically, this NODA presents DOE's analysis of the potential energy savings for amended national energy conservation standards for ASHRAE-triggered equipment classes of commercial equipment based on: (1) the amended efficiency levels contained within ASHRAE Standard 90.1-2016, and

---

[a] This Part was subsequently redesignated as Part A1 for editorial reasons after Part C of Title III of EPCA was repealed by Pub. L. 10958.

(2) more-stringent efficiency levels. 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 the process to amend energy conservation standards for ASHRAE equipment and outlines the structure of the document.
Chapter 2	Market Assessment: Characterizes the market for CRACs and DOASes.
Chapter 3	Energy Use Characterization: Discusses the process used for generating energy use estimates for CRACs and DOASes.
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

LIST OF TABLES

LIST OF FIGURES

CHAPTER 2. MARKET ASSESSMENT

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 (IES) Standard 90.1 (hereinafter referred to as ASHRAE Standard 90.1-2016) on October 26, 2016. ASHRAE Standard 90.1-2016 included increased efficiency levels and/or added equipment classes for computer room air conditioners (CRACs) and dedicated outdoor air systems (DOASs) (triggering a review by the U.S. Department of Energy (DOE) of the minimum standards for these certain classes within these equipment categories).

2.1.1 Computer Room Air Conditioners

Computer room air conditioners (CRACs) are part of a subset of commercial package air-conditioning and heating equipment, as defined previously. DOE defines a computer room air conditioner as a "commercial package air-conditioning and heating equipment (packaged or split) that is: Used in computer rooms, data processing rooms, or other information technology cooling applications; rated for sensible coefficient of performance (SCOP) and tested in accordance with 10 CFR 431.96, and is not a covered consumer product under 42 U.S.C. 6291(1)-(2) and 6292. A computer room air conditioner may be provided with, or have as available options, an integrated humidifier, temperature, and/or humidity control of the supplied air, and reheating function." 10 CFR 431.92

The current Federal energy conservation standards for CRACs apply to 30 equipment classes, which can be found in DOE's regulations in 10 CFR 431.97. The Federal energy conservation standards for CRACs are differentiated by condensing system type (air cooled, water cooled, water cooled with fluid economizer, glycol cooled, or glycol cooled with fluid economizer), sensible cooling capacity (less than 65,000 Btu/h, greater than or equal to 65,000 Btu/h and less than 240,000 Btu/h, or greater than or equal to 240,000 Btu/h and less than 760,000 Btu/h), and direction of conditioned air (upflow or downflow). Federal standards established in 10 CFR 431.97 are specified in terms of SCOP, based on rating conditions in ASHRAE 127-2007.

ASHRAE Standard 90.1-2016 disaggregates the upflow CRAC equipment classes into upflow ducted and upflow non-ducted equipment categories; and establishes different sets of efficiency levels for each equipment category based on the rating conditions specified in AHRI 1360-2016. Both upflow ducted and upflow non-ducted equipment categories are currently subject to the same set of energy conservation standards that are applicable to upflow CRAC equipment classes, set forth in 10 CFR 431.97. Additionally, ASHRAE Standard 90.1-2016 includes efficiency levels for 15 horizontal-flow equipment categories which are currently not subject to Federal standards set forth in 10 CFR 431.97.

The efficiency levels for CRACs set forth in ASHRAE 90.1-2016 are specified in terms of net sensible coefficient of performance (NSenCOP), and based on rating conditions in AHRI

1360-2016. DOE presents its "crosswalk analysis" methodology to translate measurements in SCOP into NSenCOP in section II.A.2 of the Notice. DOE's crosswalk analysis determined that ASHRAE Standard 90.1-2016 increased the efficiency levels for 5 equipment classes and added efficiency levels for 15 horizontal-flow equipment classes. DOE's crosswalk analysis determined that the ASHRAE Standard 90.1-2016 was less stringent for all other equipment classes.

2.1.2 Dedicated Outdoor Air Systems (DOAS)

DOAS meet the EPCA definition for "commercial package air conditioning and heating equipment," and are therefore covered equipment (42 U.S.C. 6311(8)(A)). However, DOE has tentatively concluded that DOAS are not subject to existing DOE test procedures or energy conservation standards for categories of commercial package air conditioning and heating equipment. Specifically, DOE does not believe that DOAS are among the commercial "central air conditioners and central air conditioning heat pumps" for which EPCA originally established standards (42 U.S.C. 6313(a)(1)-(2),(7)-(9)), and for which the current test procedure and standards are codified in Table 1 to 10 CFR 431.96 and Tables 1-4 of 10 CFR 431.97 (as air conditioners and heat pumps).

Neither EPCA nor DOE defines commercial "central air conditioners and central air conditioning heat pumps." DOAS operate similarly to central air conditioners and central air conditioning heat pumps, in that they provide space conditioning using a refrigeration cycle consisting of a compressor, condenser, expansion valve, and evaporator. However, DOAS are designed to provide 100 percent outdoor air to the conditioned space, while outdoor air makes up a only a small portion of the total airflow for typical commercial air conditioners, usually less than 50 percent. When operating in humid conditions, the dehumidification load is a much larger percentage of total cooling load for a DOAS than for a typical commercial air conditioner. Additionally, compared to a typical commercial air conditioner, the amount of total cooling (both sensible and latent) is much greater per pound of air for a DOAS at design conditions (*i.e.*, the warmest/most humid expected summer conditions), and a DOAS is designed to accommodate greater variation in entering air temperature and humidity. DOASs are typically installed in addition to a primary cooling system (*e.g.*, CUAC, VRF, chilled water system, water-source heat pumps)—the DOAS conditions the outdoor ventilation air, while the primary system provides cooling to balance building shell and interior loads and solar heat gain.

ASHRAE 90.1-2016 created 14 separate equipment classes for DX-DOAS units that are single-package and remote condenser (hereafter referred to as DOAS), as shown in Table 2.1 of this chapter, and set minimum efficiency levels using the integrated seasonal moisture removal efficiency (ISMRE) metric for all DOAS classes and the integrated seasonal coefficient of performance (ISCOP) metric for air-source heat pump and water-source heat pump DOAS classes. The equipment classes are separated into those without energy recovery and those with energy recovery, and within each subset include one air-cooled class, one air source heat pump class, two water cooled classes (cooling tower condenser water and chilled water), and three water source heat pump classes (ground source closed loop, ground-water source, and water source). The EPCA definition for "commercial package air conditioning and heating equipment" does not include ground-water-source products (42 U.S.C. 6311(8)(A)), and therefore DOE is only considering the remaining 12 DOAS equipment classes.

2.1.3 Federal Energy Conservation Standards and ASHRAE Standard 90.1-2016

On May 16, 2012, DOE published in the Federal Register a final rule for its energy conservation standards for CRACs. 77 FR 28928. The May 2012 final rule established energy conservation standards for many CRAC equipment classes corresponding to the levels in the 2010 revision of ASHRAE Standard 90.1. Id. at 28980 (codified at 10 CFR 431.97). DOE does not have existing energy conservation standards for DOASes.

Table 2.1 displays the existing Federal energy conservation standards and ASHRAE Standard 90.1-2016 levels for equipment classes where ASHRAE Standard 90.1-2016 increased the standard levels in comparison to the federal levels, as well as all other equipment classes within those larger categories. Section II of the Notice assesses each of these equipment classes to determine whether the amendments in ASHRAE Standard 90.1-2016 constitute increased energy efficiency levels, which would necessitate further analysis of the potential energy savings from amended Federal energy conservation standards; the conclusions of this assessment are presented in Table 2.1.

Table 2.1 Federal Energy Conservation Standards and Energy Efficiency Levels in ASHRAE Standard 90.1-2016 for Types of Commercial Equipment[1]

ASHRAE Standard 90.1-2016 Equipment Class[1]	Energy Efficiency Levels in ASHRAE Standard 90.1-2013 (as corrected)[2]	Energy Efficiency Levels in ASHRAE Standard 90.1-2016	Federal Energy Conservation Standards	DOE triggered by ASHRAE Standard 90.1-2016 Amendment?
Commercial Package Air-Conditioning and Heating Equipment – Computer Room Air Conditioners[3]				
CRAC, Air-Cooled, <65,000 Btu/h, Downflow	2.20 SCOP	2.30 NSenCOP	2.20 SCOP	No[4]
CRAC, Air-Cooled, <65,000 Btu/h, Horizontal-flow	N/A	2.45 NSenCOP	N/A	Yes[5]
CRAC, Air-Cooled, <65,000 Btu/h, Upflow Ducted	2.09 SCOP	2.10 NSenCOP	2.09 SCOP	No[4]
CRAC, Air-Cooled, <65,000 Btu/h, Upflow Non-Ducted	2.09 SCOP	2.09 NSenCOP	2.09 SCOP	No[6]

CRAC, Air-Cooled, ≥65,000 and <240,000 Btu/h, Downflow	2.10 SCOP	2.20 NSenCOP	2.10 SCOP	No[4]
CRAC, Air-Cooled, ≥65,000 and <240,000 Btu/h, Horizontal-flow	N/A	2.35 NSenCOP	N/A	Yes[5]
CRAC, Air-Cooled, ≥65,000 and <240,000 Btu/h, Upflow Ducted	1.99 SCOP	2.05 NSenCOP	1.99 SCOP	No[4]
CRAC, Air-Cooled, ≥65,000 and <240,000 Btu/h, Upflow Non-Ducted	1.99 SCOP	1.99 NSenCOP	1.99 SCOP	No[6]
CRAC, Air-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Downflow	1.90 SCOP	2.00 NSenCOP	1.90 SCOP	No[4]
CRAC, Air-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Horizontal-flow	N/A	2.15 NSenCOP	N/A	Yes[5]
CRAC, Air-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Ducted	1.79 SCOP	1.85 NSenCOP	1.79 SCOP	No[4]
CRAC, Air-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Non-ducted	1.79 SCOP	1.79 NSenCOP	1.79 SCOP	No[6]
CRAC, Water-Cooled, <65,000 Btu/h, Downflow	2.60 SCOP	2.50 NSenCOP	2.60 SCOP	No[4]
CRAC, Water-Cooled, <65,000 Btu/h, Horizontal-flow	N/A	2.70 NSenCOP	N/A	Yes[5]

CRAC, Water-Cooled, <65,000 Btu/h, Upflow Ducted	2.49 SCOP	2.30 NSenCOP	2.49 SCOP	No[4]
CRAC, Water-Cooled, <65,000 Btu/h, Upflow Non-ducted	2.49 SCOP	2.25 NSenCOP	2.49 SCOP	No[4]
CRAC, Water-Cooled, ≥65,000 and <240,000 Btu/h, Downflow	2.50 SCOP	2.40 NSenCOP	2.50 SCOP	No[4]
CRAC, Water-Cooled, ≥65,000 and <240,000 Btu/h, Horizontal-flow	N/A	2.60 NSenCOP	N/A	Yes[5]
CRAC, Water-Cooled, ≥65,000 and <240,000 Btu/h, Upflow Ducted	2.39 SCOP	2.20 NSenCOP	2.39 SCOP	No[4]
CRAC, Water-Cooled, ≥65,000 and <240,000 Btu/h, Upflow Non-ducted	2.39 SCOP	2.15 NSenCOP	2.39 SCOP	No[4]
CRAC, Water-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Downflow	2.40 SCOP	2.25 NSenCOP	2.40 SCOP	No[4]
CRAC, Water-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Horizontal-flow	N/A	2.45 NSenCOP	N/A	Yes[5]
CRAC, Water-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Ducted	2.29 SCOP	2.10 NSenCOP	2.29 SCOP	No[4]
CRAC, Water-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Non-ducted	2.29 SCOP	2.05 NSenCOP	2.29 SCOP	No[4]

CRAC, Water-Cooled with fluid economizer, <65,000 Btu/h, Downflow	2.55 SCOP	2.45 NSenCOP	2.55 SCOP	No[4]
CRAC, Water-Cooled with fluid economizer, <65,000 Btu/h, Horizontal-flow	N/A	2.60 NSenCOP	N/A	Yes[5]
CRAC, Water-Cooled with fluid economizer, <65,000 Btu/h, Upflow Ducted	2.44 SCOP	2.25 NSenCOP	2.44 SCOP	No[4]
CRAC, Water-Cooled with fluid economizer, <65,000 Btu/h, Upflow Non-ducted	2.44 SCOP	2.20 NSenCOP	2.44 SCOP	No[4]
CRAC, Water-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Downflow	2.45 SCOP	2.35 NSenCOP	2.45 SCOP	No[4]
CRAC, Water-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Horizontal-flow	N/A	2.55 NSenCOP	N/A	Yes[5]
CRAC, Water-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Upflow Ducted	2.34 SCOP	2.15 NSenCOP	2.34 SCOP	No[4]
CRAC, Water-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Upflow Non-ducted	2.34 SCOP	2.10 NSenCOP	2.34 SCOP	No[4]

CRAC, Water-Cooled with fluid economizer, ≥240,000 Btu/h and <760,000 Btu/h, Downflow	2.35 SCOP	2.20 NSenCOP	2.35 SCOP	No[4]
CRAC, Water-Cooled with fluid economizer, ≥240,000 Btu/h and <760,000 Btu/h, Horizontal-flow	N/A	2.40 NSenCOP	N/A	Yes[5]
CRAC, Water-Cooled with fluid economizer, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Ducted	2.24 SCOP	2.05 NSenCOP	2.24 SCOP	No[4]
CRAC, Water-Cooled with fluid economizer, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Non-ducted	2.24 SCOP	2.00 NSenCOP	2.24 SCOP	No[4]
CRAC, Glycol-Cooled, <65,000 Btu/h, Downflow	2.50 SCOP	2.30 NSenCOP	2.50 SCOP	No[4]
CRAC, Glycol-Cooled, <65,000 Btu/h, Horizontal-flow	N/A	2.40 NSenCOP	N/A	Yes[5]
CRAC, Glycol-Cooled, <65,000 Btu/h, Upflow Ducted	2.39 SCOP	2.10 NSenCOP	2.39 SCOP	No[4]
CRAC, Glycol-Cooled, <65,000 Btu/h, Upflow Non-ducted	2.39 SCOP	2.00 NSenCOP	2.39 SCOP	No[4]
CRAC, Glycol-Cooled, ≥65,000 and <240,000 Btu/h, Downflow	2.15 SCOP	2.05 NSenCOP	2.15 SCOP	No[4]

CRAC, Glycol-Cooled, ≥65,000 and <240,000 Btu/h, Horizontal-flow	N/A	2.15 NSenCOP	N/A	Yes[5]
CRAC, Glycol-Cooled, ≥65,000 and <240,000 Btu/h, Upflow Ducted	2.04 SCOP	1.85 NSenCOP	2.04 SCOP	No[4]
CRAC, Glycol-Cooled, ≥65,000 and <240,000 Btu/h, Upflow Non-ducted	2.04 SCOP	1.85 NSenCOP	2.04 SCOP	Yes
CRAC, Glycol-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Downflow	2.10 SCOP	1.95 NSenCOP	2.10 SCOP	No[4]
CRAC, Glycol-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Horizontal-flow	N/A	2.10 NSenCOP	N/A	Yes[5]
CRAC, Glycol-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Ducted	1.99 SCOP	1.80 NSenCOP	1.99 SCOP	No[4]
CRAC, Glycol-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Non-ducted	1.99 SCOP	1.75 NSenCOP	1.99 SCOP	Yes
CRAC, Glycol-Cooled with fluid economizer, <65,000 Btu/h, Downflow	2.45 SCOP	2.25 NSenCOP	2.45 SCOP	No[4]
CRAC, Glycol-Cooled with fluid economizer, <65,000 Btu/h, Horizontal-flow	N/A	2.35 NSenCOP	N/A	Yes[5]

CRAC, Glycol-Cooled with fluid economizer, <65,000 Btu/h, Upflow Ducted	2.34 SCOP	2.10 NSenCOP	2.34 SCOP	No[4]
CRAC, Glycol-Cooled with fluid economizer, <65,000 Btu/h, Upflow Non-ducted	2.34 SCOP	2.00 NSenCOP	2.34 SCOP	Yes
CRAC, Glycol-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Downflow	2.10 SCOP	1.95 NSenCOP	2.10 SCOP	No[4]
CRAC, Glycol-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Horizontal-flow	N/A	2.10 NSenCOP	N/A	Yes[5]
CRAC, Glycol-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Upflow Ducted	1.99 SCOP	1.80 NSenCOP	1.99 SCOP	No[4]
CRAC, Glycol-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Upflow Non-ducted	1.99 SCOP	1.75 NSenCOP	1.99 SCOP	Yes
CRAC, Glycol-Cooled with fluid economizer, ≥240,000 Btu/h and <760,000 Btu/h, Downflow	2.05 SCOP	1.90 NSenCOP	2.05 SCOP	No[4]

CRAC, Glycol-Cooled with fluid economizer, ≥240,000 Btu/h and <760,000 Btu/h, Horizontal-flow	N/A	2.10 NSenCOP	N/A	Yes[5]
CRAC, Glycol-Cooled with fluid economizer, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Ducted	1.94 SCOP	1.80 NSenCOP	1.94 SCOP	No[4]
CRAC, Glycol-Cooled with fluid economizer, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Non-ducted	1.94 SCOP	1.70 NSenCOP	1.94 SCOP	Yes
Electrically-Operated Direct Expansion (DX)-Dedicated Outdoor Air System Units, Single-Package and Remote Condenser				
DOAS, Air-Cooled, without energy recovery	N/A	4.0 ISMRE	N/A	Yes
DOAS, Air-Cooled, with energy recovery	N/A	5.2 ISMRE	N/A	Yes
DOAS, Air-Source heat pumps, without energy recovery	N/A	4.0 ISMRE, 2.7 ISCOP	N/A	Yes [7]
DOAS, Air-Source heat pumps, with energy recovery	N/A	5.2 ISMRE, 3.3 ISCOP	N/A	Yes [7]
DOAS, Water-cooled: cooling tower condenser water, without energy recovery	N/A	4.9 ISMRE	N/A	Yes [7]
DOAS, Water-cooled: cooling tower condenser water, with energy recovery	N/A	5.3 ISMRE	N/A	Yes [7]
DOAS, Water-cooled: chilled water, without energy recovery	N/A	6.0 ISMRE	N/A	Yes [8]

DOAS, Water-cooled: chilled water, with energy recovery	N/A	6.6 ISMRE	N/A	Yes [9]
DOAS, Water-source: ground-source, closed loop, without energy recovery	N/A	4.8 ISMRE, 2.0 ISCOP	N/A	Yes [10]
DOAS, Water-source: ground-source, closed loop, with energy recovery	N/A	5.2 ISMRE, 3.8 ISCOP	N/A	Yes [11]
DOAS, Water-source: ground-water source, without energy recovery	N/A	5.0 ISMRE, 3.2 ISCOP	N/A	Yes
DOAS, Water-source: ground-water source, with energy recovery	N/A	5.8 ISMRE, 4.0 ISCOP	N/A	Yes
DOAS, Water-source: water-source, without energy recovery	N/A	4.0 ISMRE, 3.5 ISCOP	N/A	Yes [7]
DOAS, Water-source: water-source, with energy recovery	N/A	4.8 ISMRE, 4.8 ISCOP	N/A	Yes [7]

[1] Note that equipment classes specified in ASHRAE Standard 90.1-2016 do not necessarily correspond to the equipment classes defined in DOE's regulations.

[2] This table represents values in ASHRAE 90.1-2013 as corrected by various errata sheets issued by ASHRAE.

[3] For CRACs, ASHRAE Standard 90.1-2016 adopted efficiency levels in terms of NSenCOP based on test procedures in AHRI 1360-2016, while DOE's current standards are in terms of SCOP based on the test procedures in ANSI/ASHRAE 127-2007. DOE performed a crosswalk analysis to compare the stringency of the ASHRAE Standard 90.1-2016 efficiency levels with the current Federal standards. See section II.A of the Notice for further discussion on the crosswalk analysis performed for CRACs.

[4] The preliminary CRAC crosswalk analysis indicates that the ASHRAE Standard 90.1-2016 level for this class is less stringent than the current applicable DOE standard.

[5] Horizontal-flow CRACs are identified in ASHRAE Standard 90.1-2016 as a new equipment class, and DOE does not have any data to indicate the market share of horizontal-flow units. In the absence of data regarding market share and efficiency distribution, DOE is unable to estimate potential savings for horizontal-flow equipment classes.

[6] The preliminary CRAC crosswalk analysis indicates that there is no difference in stringency of efficiency levels for this class between ASHRAE 90.1-2016 and the current Federal standard.

[7] DOE did not conduct an energy use analysis on this DOAS equipment class, as it is one of six equipment classes for which the combined market share is estimated to be approximately 5 percent, and as such, standards would result in minimal national energy savings.

[8] DOE evaluated as a single class water-cooled, chilled water DOAS without energy recovery product class and water-cooled, cooling tower condenser water DOAS without energy recovery product class. See section III.A.2 of the Notice for more details.

[9] DOE evaluated as a single class water-cooled, chilled water DOAS with energy recovery product class and water-cooled, cooling tower condenser water DOAS with energy recovery product class. See section II.A.2 of the Notice for more details.
[10] DOE evaluated as a single class water-source: ground-source DOAS without energy recovery product class and water-source: water-source DOAS without energy recovery product class. See section II.A.2 of the Notice for more details.
[11] DOE evaluated as a single class water-source: ground-source DOAS with energy recovery product class and water-source: water-source DOAS with energy recovery product class. See section II.A.2 of the Notice for more details.

DOE has tentatively determined that ASHRAE Standard 90.1-2016 has raised the efficiency level in comparison to the current Federal minimum energy conservation standards for five CRAC equipment classes, maintained equivalent levels for three equipment classes, and reduced stringency for 37 classes. Additionally, ASHRAE Standard 90.1-2016 introduced new efficiency levels for 15 CRAC equipment classes and 12 classes of DOASs that are covered by DOE. DOE assessed the current market and performed a potential energy savings analysis for each equipment class with equipment available on the market, unless DOE found no equipment in the market in that equipment class (in which case there is no potential for energy savings).[a] Therefore, DOE is reviewing 5 classes of CRACs for which ASHRAE 90.1-2016 increased stringency of efficiency levels under the 42 U.S.C. 6313(a)(6)(A)(ii)(II) authority.

The market assessment of the analyzed equipment classes is described in the sections that follow, 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 CRACs and DOASes. The market assessment also summarizes the relevant market performance data for each equipment class where such data are 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 in this rulemaking. The Air-Conditioning, Heating, and Refrigeration Institute (AHRI) is one of the largest trade associations for manufacturers of space-heating, cooling, and water-heating equipment, representing more than 90% of the residential and commercial air-conditioning, space-heating, water-heating, and commercial refrigeration equipment manufactured in the United States.[1] AHRI also develops and publishes test procedures standards for residential and commercial heating, ventilating, and air-conditioning (HVAC) equipment and coordinates with the International Organization for

---

[a] In the case where there is no equipment on the market or insufficient data for analysis, DOE would adopt the ASHRAE level, as required by the statute, without further analysis.

Standardization (ISO) to help harmonize U.S. 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.

Heating, Air-conditioning and Refrigeration Distributors International (HARDI) is a trade association that represents over 450 wholesale heating, ventilating, 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]

The Indoor Environment & Energy Efficiency Association (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 data for CRACs, DOE relied on data from DOE’s Certification and Compliance Database.[4] DOASes are a new equipment category and are not listed in these directories. Therefore, DOE conducted a search of HVAC manufacturer websites to determine the manufacturers of DOAS.

DOE identified 5 manufacturers (comprising 6 brands) of CRACs and 9 manufacturers (comprising 12 brands) of DOASs. The manufacturers for each equipment class are listed in Table 2.2 and Table 2.3.

Table 2.2 Manufacturers of CRAC Systems

Manufacturers	**Brands**
Compu-Aire	Compu-Aire
Data Air, Inc.	Data Air
Liebert	Liebert
	Vertiv
Schneider Electric	Schneider Electric
Stulz Air Technology Systems	Stulz

Table 2.3 Manufacturers of DOASes

Manufacturers	Brands
Johnson Controls	York
LG Electronics, Inc	LG Electronics, Inc
United Technologies	Carrier
Ingersoll Rand	Trane
Desert Aire	Aura Series
	Total Aire
	Vertical Aire
United Cool Air	OmegaAir
Mitsubishi Electric	City Multi
Spinnaker Industries	SPOAU Series
Daikin	Maverick
	RoofPak

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 DOE's Certification Compliance Database for CRACs.[4] DOE also reviewed the CEC appliance database for CRACs; however, that database does not provide enough information to isolate the relevant equipment classes. As a result, DOE relied primarily on DOE's Certification Compliance Database for CRACs to compile databases for each equipment category of models with available efficiency data, separated into the equipment classes by capacity and other relevant characteristics. DOAS is a new equipment category in ASHRAE 90.1-2016 and therefore no models are listed in the AHRI directory, the DOE Certification Compliance Database, or the CEC appliance database. The approach DOE used to derive the efficiency levels is explained in detail in Chapter 3 of the NODA TSD.

2.2.3.1 CRACs

As discussed in section 2.1.1, current Federal standards for CRACs are represented in terms of SCOP as measured by the ASHRAE 127-2007 test procedure. As such, data reported to DOE's Certification and Compliance database and the CEC appliance database are in terms of SCOP. ASHRAE Standard 90.1-2016 presents efficiency levels in terms of Net Sensible Coefficient of Performance (NSenCOP) as measured by the AHRI 1360-2016 test procedure. In order to compare models relative to the ASHRAE Standard 90.1-2016 efficiency levels, DOE performed a crosswalk analysis to translate measurements of SCOP into measurements of NSenCOP. The crosswalk analysis is described in section II.A of the Notice.

In addition to necessitating a crosswalk to compare standards that use different metrics, the differences in the test procedures required DOE to crosswalk the capacity limits that provide the boundaries for the CRAC equipment classes. The capacity values that bound the equipment classes are in terms of net sensible cooling capacity (NSCC). NSCC values determined according to AHRI 1360-2016, the test procedure specified in ASHRAE Standard 90.1-2016, are higher than the NSCC values determined according to ANSI/ASHRAE 127-2007, the required Federal test procedure. To provide for an appropriate comparison and to address potential backsliding, a capacity crosswalk was conducted to adjust the NSCC boundaries that separate equipment classes to account for the difference in measured NSCC values between ASHRAE Standard 90.1-2016 and the current Federal requirements. The capacity crosswalk calculated increases in the capacity boundaries of affected equipment classes (i.e., equipment classes with test procedure changes that increase NSCC) to prevent this equipment class switching issue and avoid potential backsliding that would occur if capacity boundaries were not adjusted (see section II.A.1 of the Notice for details).

In the sections below, the capacity values displayed are in terms of DOE's current test procedure rather than cross-walked values.

Glycol-Cooled, ≥65,000 and <240,000 Btu/h, Upflow. The Federal energy conservation standard for this equipment is 2.04 SCOP (10 CFR 431.97). The ASHRAE Standard 90.1-2016 changes the efficiency level to 1.85 NSenCOP for upflow non-ducted equipment. From the crosswalk analysis, the Federal standard translates to 1.77 NSenCOP for upflow non-ducted equipment. Due to lack of available data, DOE assumed the SCOP distribution for upflow equipment (see Figure 2.2.1) was representative of upflow non-ducted equipment classes. DOE analyzed the efficiency distribution by crosswalking the SCOP distribution into NSenCOP distributions for upflow non-ducted. Making the assumption that all upflow models are upflow non-ducted, the average value of the distribution is 1.89 NSenCOP and 21 models (35.6% of total models) have NSenCOP lower than the ASHRAE Standard 90.1-2016 level.

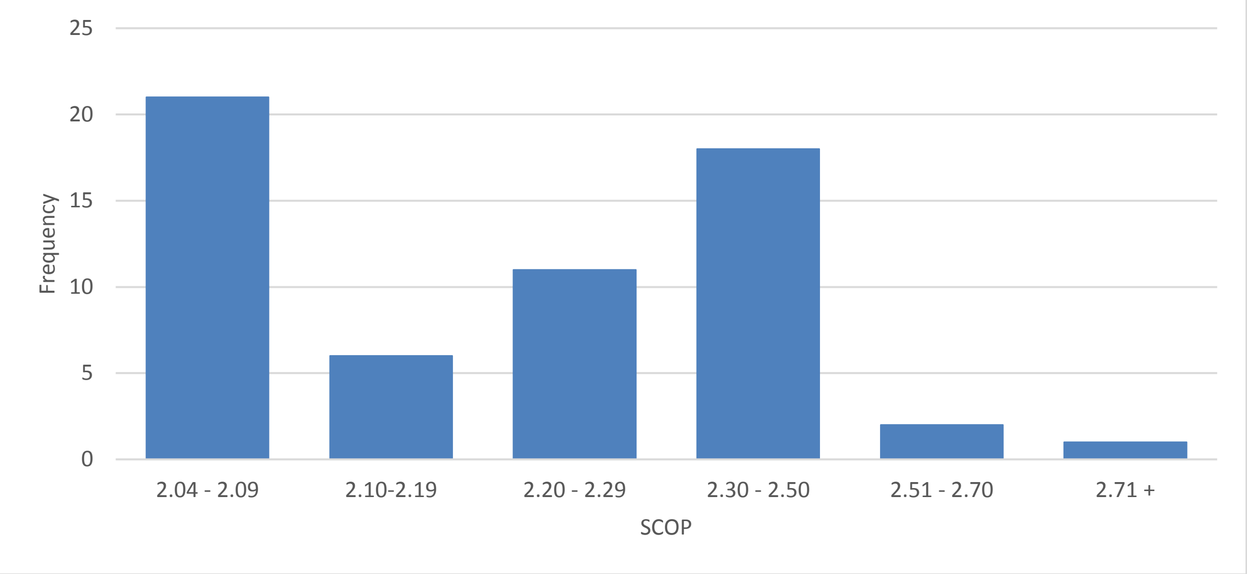

Figure 2.2.1 SCOP histogram of CRACS, Glycol-Cooled, ≥65,000 and <240,000 Btu/h, Upflow

Glycol-Cooled, ≥240,000 and <760,000 Btu/h, Upflow. The Federal energy conservation standard for this equipment is 1.99 SCOP (10 CFR 431.97). The ASHRAE Standard 90.1-2016 changes the efficiency level to 1.75 NSenCOP for upflow non-ducted equipment. From the crosswalk analysis, the Federal standard translates to 1.73 NSenCOP for upflow non-ducted equipment. Due to lack of available data, DOE assumed the SCOP distribution for upflow equipment (see Figure 2.2.2) was representative of upflow non-ducted equipment classes. DOE analyzed the efficiency distribution by crosswalking the SCOP distribution into NSenCOP distributions for upflow non-ducted. Making the assumption that all upflow models are upflow non-ducted, the average value of the distribution is 1.90 NSenCOP and no models have NSenCOP lower than the ASHRAE Standard 90.1-2016 level.

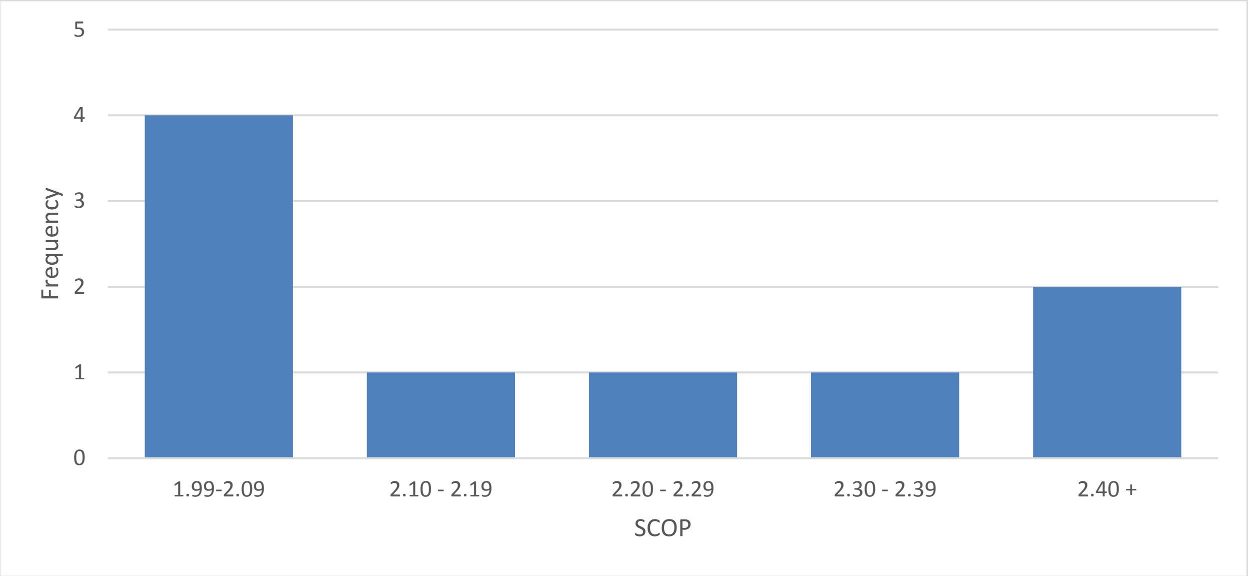

Figure 2.2.2 SCOP histogram of CRACS, Glycol-Cooled, ≥240,000 and <760,000 Btu/h, Upflow

Glycol-Cooled with fluid economizer, <65,000 Btu/h, Upflow. The Federal energy conservation standard for this equipment is 2.34 SCOP (10 CFR 431.97). The ASHRAE Standard 90.1-2016 changes the efficiency level to 2.0 NSenCOP for upflow non-ducted equipment. From the crosswalk analysis, the Federal standard translates to 1.99 NSenCOP for upflow non-ducted equipment. Due to lack of available data, DOE assumed the SCOP distribution for upflow equipment (see Figure 2.2.3) was representative of upflow non-ducted equipment classes. DOE analyzed the efficiency distribution by crosswalking the SCOP distribution into NSenCOP distributions for upflow non-ducted. Making the assumption that all upflow models are upflow non-ducted, the average value of the distribution is 2.17 NSenCOP and no models have NSenCOP lower than the ASHRAE Standard 90.1-2016 level.

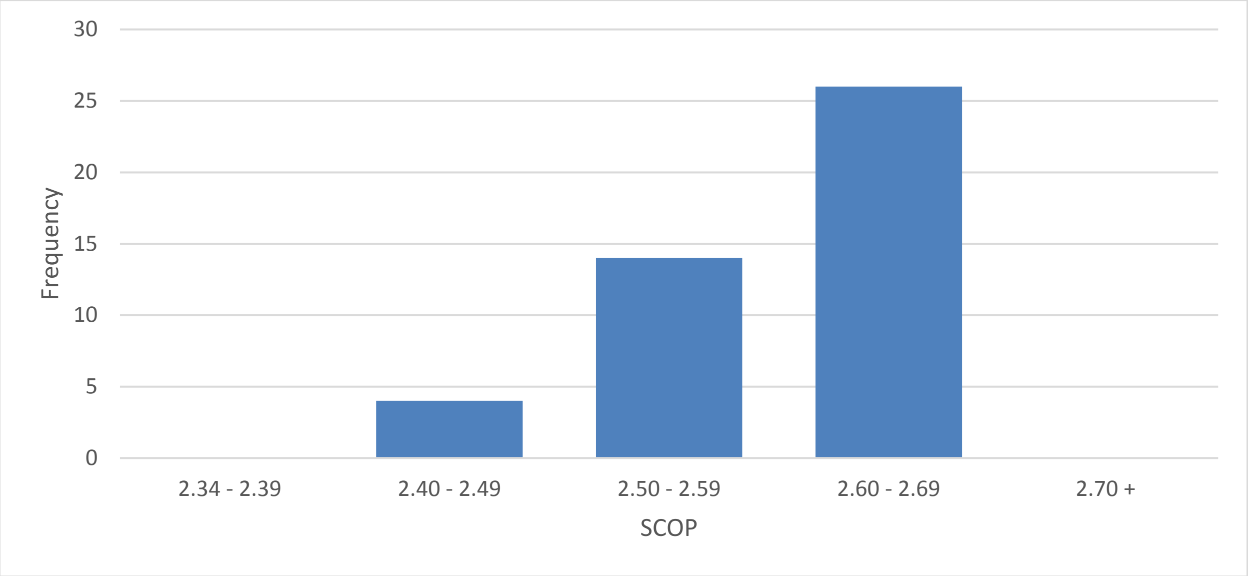

Figure 2.2.3 **SCOP histogram of CRACS, Glycol-Cooled with fluid economizer, <65,000 Btu/h, Upflow**

Glycol-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Upflow. The Federal energy conservation standard for this equipment is 1.99 SCOP (10 CFR 431.97). The ASHRAE Standard 90.1-2016 changes the efficiency level to 1.75 NSenCOP for upflow non-ducted equipment. From the crosswalk analysis, the Federal standard translates to 1.73 NSenCOP for upflow non-ducted equipment. Due to lack of available data, DOE assumed the SCOP distribution for upflow equipment (see Figure 2.2.4) was representative of upflow non-ducted equipment classes. DOE analyzed the efficiency distribution by crosswalking the SCOP distribution into NSenCOP distributions for upflow non-ducted. Making the assumption that all upflow models are upflow non-ducted, the average value of the distribution is 1.84 NSenCOP and 12 models (12.6% of total models) have NSenCOP lower than the ASHRAE Standard 90.1-2016 level.

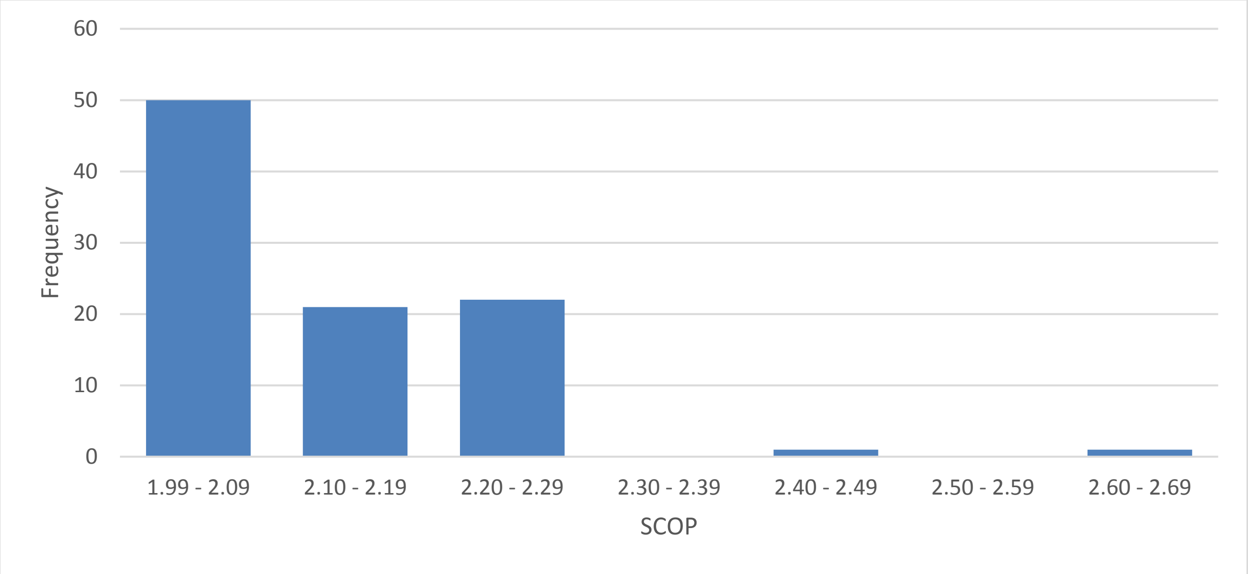

Figure 2.2.4 SCOP histogram of CRACs, Glycol-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Upflow

Glycol-Cooled with fluid economizer, ≥240,000 and <760,000 Btu/h, Upflow. The Federal energy conservation standard for this equipment is 1.94 SCOP (10 CFR 431.97). The ASHRAE Standard 90.1-2016 changes the efficiency level to 1.70 NSenCOP for upflow non-ducted equipment. From the crosswalk analysis, the Federal standard translates to 1.69 NSenCOP for upflow non-ducted equipment. Due to lack of available data, DOE assumed the SCOP distribution for upflow equipment (see Figure 2.2.5) was representative of upflow non-ducted equipment classes. DOE analyzed the efficiency distribution by crosswalking the SCOP distribution into NSenCOP distributions for upflow non-ducted. Making the assumption that all upflow models are upflow non-ducted, the average value of the distribution is 1.78 NSenCOP and no models have NSenCOP lower than the ASHRAE Standard 90.1-2016 level.

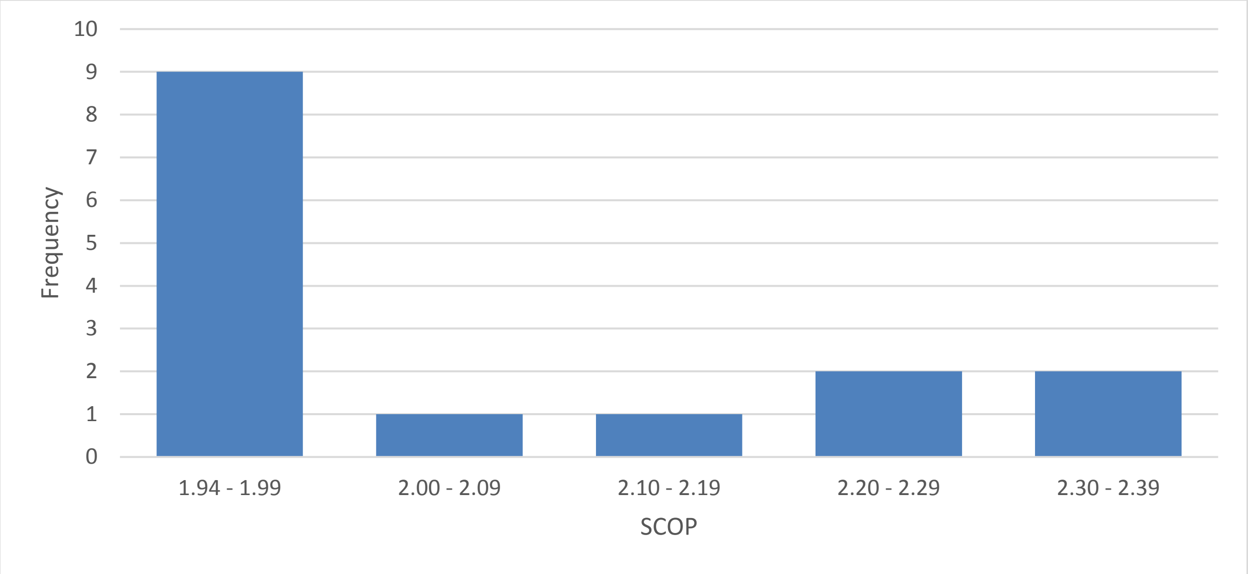

Figure 2.2.5 **SCOP histogram of CRACs, Glycol-Cooled with fluid economizer, ≥240,000 and <760,000 Btu/h, Upflow**

Horizontal Flow Equipment Classes. ASHRAE Standard 90.1-2016 introduced 15 new horizontal flow equipment classes which do not currently have a Federal energy conservation standard. DOE was unable to obtain market data for these classes that would allow for estimates of energy savings potential.

REFERENCES

1. Air-Conditioning, Heating, and Refrigeration Institute (AHRI). AHRI Directory of Certified Product Performance. 2017. http://www.ahridirectory.org/ahridirectory/pages/home.aspx.

2. Heating, Air-conditioning & Refrigeration Distributors International (HARDI). About HARDI. 2017. http://hardinet.org/about-hardi/.

3. The Indoor Environment & Energy Efficiency Association. About ACCA. 2017. http://www.acca.org/about-acca.

4. United States Department of Energy (DOE). Compliance Certification Management System (CCMS) Database. 2019. http://www.regulations.doe.gov/certification-data/CCMS-81578122497.html.

CHAPTER 3. ENERGY USE CHARACTERIZATION

TABLE OF CONTENTS

LIST OF TABLES

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 customers would realize from the establishment of standards at the levels set forth in American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2016 for specific classes of equipment analyzed as well as for more energy efficient standards.

This chapter describes the energy use analysis for computer room air conditioners (CRACs) and dedicated outdoor air systems (DOASes). These equipment categories 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 equipment classes within each of the two equipment categories examined. This chapter also describes the development of UEC estimates for more efficient equipment, up to the max-tech levels defined later in this TSD.

For each of these equipment categories, the Federal standard is expressed in terms of an efficiency metric or metrics: net sensible coefficient of performance (NSenCOP) for cooling efficiency; integrated seasonal coefficient of performance (ISCOP) for heating efficiency, and integrated seasonal moisture removal efficiency (ISMRE) for dehumidification 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 CATEGORY

3.2.1 Computer Room Air Conditioners (CRACs)

DOE conducted an energy analysis for 15 downflow CRAC equipment classes as part of the 2012 ASHRAE FR.[1] DOE is using these results as the basis for the energy savings potential analysis presented in this NODA. In the 2012 ASHRAE FR, DOE adopted a modified outside temperature bin analysis. For each air-cooled equipment class, DOE calculated fan energy and condensing unit power consumption at each 5° F outdoor air dry bulb temperature bin. The condensing unit power in this context included the compressor(s) and condenser fan(s) and/or pump(s) included as part of the equipment rating. For water-cooled and glycol-cooled equipment, the 2012 ASHRAE FR analysis first estimated the condensing water supply temperature from either an evaporative cooling tower or a dry cooler, for water-cooled and for glycol-cooled CRAC equipment, respectively, based on binned weather data. Using these results, DOE then estimated the condensing unit power consumption and adds to this the estimated supply fan power. The sum of the CRAC condensing unit power and the CRAC supply fan power is the estimated average CRAC total power consumption for each temperature bin. Annual estimates of energy use are developed by multiplying the power consumption at each temperature bin by the number of hours in that bin for each climate analyzed. DOE then took a population-weighted average over results for 239 different climate locations to derive nationally representative CRAC annual energy use values.[2]

For this NODA, DOE identified the baseline, intermediate, and maximum technologically feasible (max-tech) efficiency levels for each analyzed equipment class. The Federal standard is used as a baseline when estimating energy savings associated with adopting the ASHRAE Standard 90.1-2016 level. Savings from higher efficiency levels are measured relative to the ASHRAE Standard 90.1-2016 level. In the tables below, EL0 refers to the ASHRAE 90.1-2016 level.

For the intermediate and max-tech efficiency levels, DOE created an equipment database comprising CRAC models rated in terms of SCOP, certified in DOE's Compliance Certification Database[3], and the California Energy Commission (CEC) appliance database.[4] Using this database, DOE created efficiency distribution plots for each equipment class and identified intermediate efficiency levels that correspond to efficiencies with a higher frequency of models available on the market. The max-tech efficiency levels correspond to units with the maximum efficiency observed in each equipment class. SCOP levels are translated into NSenCOP levels for the analyzed equipment classes in order to perform the energy savings determination analysis using the crosswalk equations described in section II.A.2 of the Notice. Table 3.1 presents the NSenCOP levels for each efficiency level for the analyzed CRACs equipment classes. Note that the table displays results in terms of current net sensible cooling capacity ranges (measured per the current DOE test procedure), rather than crosswalked NSCC ranges (see section II.A.2 of the Notice for further discussion of the capacity crosswalk and equipment class switching issue for CRACs).

Table 3.1 NSenCOP Efficiency Levels for CRACs

Equipment Type	Cooling Medium	Net Sensible Cooling Capacity	Current Federal Standard	EL 0[*]	EL 1	EL 2	EL 3	EL 4	Max-Tech
			(NSenCOP)						
Upflow, non-ducted	Glycol-Cooled without a Fluid Economizer	≥65,000 Btu/h and <240,000 Btu/h	1.77	1.85	1.87[**]	1.89	1.99	2.14[**]	2.29
		≥240,000 Btu/h and <760,000 Btu/h	1.73	1.75	1.78[**]	1.81	1.94	2.01	2.04
	Glycol-Cooled with a Fluid Economizer	<65,000 Btu/h	1.99	2.00	2.04[**]	2.07	2.14	2.20	2.24
		≥65,000 Btu/h and <240,000 Btu/h	1.73	1.75	1.77	1.88	1.94	2.08[**]	2.22
		≥240,000 Btu/h and <760,000 Btu/h	1.69	1.70	1.72	1.77	1.87	1.90	1.97

[*] EL 0 represents the ASHRAE Standard 90.1-2016 level.

[**] EL was interpolated between adjacent levels.

To derive UECs for the equipment classes analyzed in this NODA, DOE started with the annual UECs corresponding to the current DOE standard for the downflow equipment classes analyzed in the 2012 ASHRAE FR. DOE assumed that this UEC corresponds to the NSenCOP derived through the crosswalk analysis. For higher efficiency levels, DOE determined the UEC by dividing the baseline NSenCOP level by the NSenCOP for each higher EL and multiplied the resulting percentage by the baseline UEC.

In the 2012 ASHRAE FR, DOE assumed energy savings estimates derived for downflow products classes would be representative of upflow product classes which differed by a fixed 0.11 SCOP. However, in this NODA the standard levels set by ASHRAE for the upflow non-ducted equipment classes do not differ from the downflow equipment class by a fixed amount. To account for the difference in NSenCOP levels, DOE adjusted the UEC based on the fractional increase/decrease in NSenCOP between upflow and downflow units based on the corresponding proportional decrease/increase in the baseline UEC within a given equipment class grouping of cooling medium and capacity. Table 3.2 presents the scalars DOE used to derive the UECs for the considered CRACs equipment classes.

Table 3.2 Proportional relationship of ASHRAE level Downflow NSenCOP to Upflow NSenCOP

Cooling Medium	Cooling Capacity	Adjustment Scaler
Glycol-Cooled, Upflow non ducted	≥65,000 Btu/h and <240,000 Btu/h	117%
	≥240,000 Btu/h and <760,000 Btu/h	117%
Glycol-Cooled with a Fluid Economizer, Upflow non ducted	<65,000 Btu/h	116%
	≥65,000 Btu/h and <240,000 Btu/h	117%
	≥240,000 Btu/h and <760,000 Btu/h	118%

Table 3.3 and Table 3.4 present the national annual UECs developed for each analyzed equipment class.

Table 3.3 National UEC Estimates (kWh/year) for Glycol-Cooled, Upflow, Non-Ducted CRACs

	≥ 65,000 Btu/h and < 240,000 Btu/h*	**≥ 240,000 Btu/h and < 760,000 Btu/h***
Baseline – Federal Standard	119,105	266,479
Efficiency Level 0*	113,955	263,434
Efficiency Level 1	112,736	258,994
Efficiency Level 2	111,543	254,701
Efficiency Level 3	105,938	237,633
Efficiency Level 4	98,512	229,358
Efficiency Level 5– “Max-Tech”	92,060	225,985

*Efficiency Level 0 corresponds to ASHRAE 90.1-2016 level.

Table 3.4 National UEC Estimates (kWh/year) for Glycol-Cooled with a Fluid Economizer, Upflow, Non-Ducted CRACs

	<65,000 Btu/h*	**≥ 65,000 Btu/h and < 240,000 Btu/h***	**≥ 240,000 Btu/h and < 760,000 Btu/h***
Baseline – Federal Standard	22,992	95,830	214,348
Efficiency Level 0*	22,877	94,735	213,087
Efficiency Level 1	22,428	93,510	210,609
Efficiency Level 2	22,103	88,135	204,741
Efficiency Level 3	21,380	85,467	194,103
Efficiency Level 4	20,797	79,690	191,082
Efficiency Level 5– “Max-Tech”	20,426	74,678	183,986

*Efficiency Level 0 corresponds to ASHRAE 90.1-2016 level.

3.2.2 Dedicated Outdoor Air Systems (DOASes)

DOE conducted an energy use analysis for two classes of DOASes: (1) DOAS, air-cooled, without energy recovery and (2) DOAS, air-cooled, with energy recovery.

In order to develop energy use estimates in this NODA, DOE first identified efficiency levels to analyze. DOE was unable to find any information about DOAS efficiency in the AHRI directory, nor was it able to find ISMRE or ISCOP in much of the manufacturer data. Therefore, DOE developed a baseline efficiency level that is equivalent to the performance standards published in the ASHRAE Standard 90.1-2016. DOE also analyzed two efficiency levels above the ASHRAE level for both classes of DOASes. Table 3.5 shows the Efficiency Levels used in the energy use analysis.

Table 3.5 Efficiency Levels Air-Cooled DX-DOAS

Equipment Class		Efficiency Levels (ISMRE)		
		Baseline	**EL 1**	**EL 2**
Air-Cooled	w/o Energy Recovery	4.0	5.0	6.0
	w/ Energy Recovery	5.2	6.2	7.2

DOE used CBECS 2012[5] to develop a building sample to estimate the baseline UEC for the two DOAS equipment classes. CBECS 2012 has two variables that identify if a building's heating or cooling ventilation is provided by a DOAS. CBECS 2012 also provides variables to indicate the square footage per building, the representative national sample weight for each building, the ventilation energy use, the cooling energy use, and the main cooling equipment in a building. As CBECS 2012 uses separate variables for heating and cooling ventilation, DOE only included buildings that used a DOAS for both heating and cooling ventilation in its sample. The two DOAS equipment classes being analyzed are both air cooled. Therefore, DOE built its sample using buildings whose main cooling was provided by air-cooled equipment (residential style AC, package air conditioners, and room air conditioners). The makeup of the building sample is presented in Table 3.6.

Table 3.6 Makeup of the DOAS Sample from CBECS 2012

Building Type	Number of Buildings	Average Square Footage
Education	3,760	67,788
Enclosed mall	96	1,303,327
Food sales	4,998	7,223
Food service	5,758	4,642
Healthcare	6,131	27,222
Lodging	981	90,738
Non-refrigerated warehouse	1,214	167,197
Nursing	422	74,575
Office	8,613	25,835
Public assembly	5,735	24,665
Religious	4,122	14,756
Retail (other than mall)	9,278	82,316
Service	3,467	9,371
Strip shopping	4,499	35,934

The manufacturer literature shows that DOAS equipment is sized in tons of cooling capacity; therefore, DOE began its analysis by estimating the tons of cooling required for each building in the DOAS sample. DOE used square footage per ton of cooling estimates, presented in Table 3.7 from PDH Online[6] to calculate the tons of cooling required for each building in the sample.

Table 3.7 Square Footage per Ton of Cooling by Building Type

Building Type	Sq. Ft. per ton of cooling
Education	250
Enclosed mall	300
Food sales	350
Food service	200
Healthcare	280
Lodging	400
Non-refrigerated warehouse	400
Nursing	280
Office	340
Public assembly	N/A*
Religious	N/A*
Retail (other than mall)	300
Service	340
Strip shopping	225

* sized based on occupancy, 20 people per ton of cooling

A DOAS is used for latent cooling and ventilation, and CBECS 2012 provides the annual cooling energy and ventilation energy used in each building. DOE divided the total ventilation energy use and the total cooling energy use by the tons of cooling required for each building to come up with an annual kWh/ton energy use metric per building. The average tons of cooling along with the average kWh/ton for each building type are displayed in Table 3.8.

Table 3.8 Average Tons of Cooling and Average Annual kWh per Ton by Building Type

Building Type	Average Tons of Cooling	kWh / ton	
		Cool	Vent
Education	215	564	536
Enclosed mall	4,016	1,131	1,308
Food sales	19	608	1,015
Food service	18	839	1,064
Healthcare	93	1,960	3,415
Lodging	218	1,397	534
Non-refrigerated warehouse	40	688	3,267
Nursing	238	986	1,025
Office	63	855	1,456
Public assembly	93	1,095	450
Religious	106	186	250
Retail (other than mall)	254	828	1,280
Service	18	1,008	505
Strip shopping	135	583	973

DOE then incorporated the building weights to calculate a national weighted average kWh/ton value for cooling and ventilation energy use, which is presented in Table 3.9.

Table 3.9 National Average kWh per Ton values in DOAS sample

Cooling kWh per ton	Ventilation kWh per ton
854	1,184

*These include four buildings that are vacant and have no cooling energy use.

Next, DOE had to estimate the latent percentage of the cooling kWh per ton. DOE used data from engineering toolbox, which stated that latent cooling consists of 20 to 40 percent of typical commercial building cooling loads[7]. For this analysis, DOE assumed that 30 percent of the cooling load would be latent. To determine the kWh/ton for a DOAS, DOE added 30 percent of the cooling kWh/ton to the ventilation kWh/ton. This accounts for latent cooling and ventilation provided by the DOAS. DOE then multiplied the national weighted average kWh/ton by 20 tons (the size of the representative capacity unit) to determine the baseline energy use. CBECS 2012 does not provide information about the existence of an energy recovery wheel; however, manufacturer feedback has indicated that approximately 60 percent of the DOASes sold do not have energy recovery wheels. Therefore, the kWh/ton value from CBECS 2012 was used to determine the baseline unit energy consumption (UEC) for DOASes without heat recovery (Table 3.10).

Table 3.10 Baseline kWh per Ton and UEC for DOASes without energy recovery

Baseline kWh per Ton	0.3 * 854 + 1,184 = 1,140
Baseline UEC (kWh)	1,140 * 20 = 28,796

To estimate the baseline UEC for DOASes with heat recovery, DOE divided the baseline ISMRE level of units without heat recovery by the ISMRE of baseline units with heat recovery. The ISMRE for DOASes with heat recovery is 5.2, compared to an ISMRE of 4.0 for DOASes without heat recovery. Table 3.11 displays the scaling approach.

Table 3.11 Baseline UEC for DOASes with energy recovery

Baseline UEC (kWh)	28,796 * (4 / 5.2) = 22,151

DOE calculated energy use for efficiency levels beyond the ASHRAE baseline by dividing the baseline ISMRE by the ISMRE of each higher efficiency level, for each equipment class. The resulting percentage was then multiplied by the baseline UEC. The resulting UEC's can be found in Table 3.12 and Table 3.13 below.

Table 3.12 UECs for DOASes without heat recovery

Efficiency Level	ISMRE	Without Heat Recovery
EL 0 -ASHRAE	4.0	28,796
EL 1	5.0	23,037
EL 2 – "Max Tech"	6.0	19,198

Table 3.13 UECs for DOASes with heat recovery

Efficiency Level	ISMRE	With Heat Recovery
EL 0 -ASHRAE	5.2	22,151
EL 1	6.2	18,578
EL 2 – "Max Tech"	7.2	15,998

REFERENCES

1. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Energy Conservation Standards for Commercial Heating, Air Conditioning, and Water-Heating Equipment, Technical Support Document. 2012. https://www.regulations.gov/document?D=EERE-2011-BT-STD-0029-0021.

2. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Energy Conservation Standards for Commercial Heating, Air Conditioning, and Water-Heating Equipment, Technical Support Document. 2012. https://www.regulations.gov/document?D=EERE-2011-BT-STD-0029-0021.

3. United States Department of Energy (DOE). Compliance Certification Management System (CCMS) Database. 2019. http://www.regulations.doe.gov/certification-data/CCMS-81578122497.html.

4. California Energy Commission (CEC). California Energy Commission Appliance Database. 2015. https://cacertappliances.energy.ca.gov/Pages/ApplianceSearch.aspx.

5. U.S. Department of Energy–Energy Information Administration. *2012 CBECS Survey Data*. (Last accessed July 26, 2016.) http://www.eia.gov/consumption/commercial/data/2012/index.cfm?view=microdata.

6. Bhatia, A., HVAC Refresher – Facilities Standard for the Building Services (Part 2), PDH Online (Available at: https://pdhonline.com/courses/m216/m216content.pdf) (Last accessed 3/28/2019).

7. Sensible Heat Ratio. The Engineering Toolbox. (Available at: *https://www.engineeringtoolbox.com/shr-sensible-heat-ratio-d_700.html*) (Last accessed 4/3/2019).

CHAPTER 4. NATIONAL ENERGY SAVINGS ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER 4. NATIONAL ENERGY SAVINGS ANALYSIS

4.1 INTRODUCTION

This chapter describes the national energy savings (NES) analysis for computer room air conditioners (CRACs) and dedicated outdoor air systems (DOASes). Each subsection of this chapter discusses each of these equipment categories in separate sections.

The NES for all equipment considers the ASHRAE 90.1-2016 standard level as well as several higher efficiency standard levels. The effective date of a standard depends upon the equipment category, equipment capacity, and standard selected. Section 4.3.5 contains the compliance dates for all equipment classes analyzed in the NES.

DOE analyzed the National Energy Savings (NES) of amended energy conservation standards for (refer to Section 4.4 for the specific equipment classes):

- 5 equipment classes of CRACs; and
- 2 equipment classes of DOAS.

DOE examined various standard levels for each class of equipment, including the ASHRAE Standard 90.1-2016 efficiency level, the max tech level (the highest efficiency level of equipment currently on the market), and several levels between. For CRACs, DOE performed the analysis relative to two baselines – the current Federal standard and the ASHRAE 90.1-2016 level. For DOASes, DOE performed the analysis relative to the ASHRAE 90.1-2016 level.

4.2 NATIONAL ENERGY SAVINGS CALCULATION

The NES is the difference between the national energy consumption in the no-new-standards case (*i.e.*, the case without amended energy conservation standards) and the standards case (*i.e.*, the case with amended energy conservation standards). DOE developed spreadsheet models to calculate the NES from equipment standards for the equipment classes of interest to this analysis.

For each equipment class and standards case, DOE calculated the total energy savings using a stock accounting method. DOE projected shipments into the future based on available information for each equipment class. The number of new shipments in any given year is assumed to remain in the commercial building stock for a total of the assumed lifetime of the equipment, at which point that entire year’s shipments disappear 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 (lifetime minus 1) years.

The annual base total energy use in any given year is the sum product of the shipments for that year and the previous (lifetime minus 1) years and the market weighted average base unit energy consumption (UEC[a]) in each relevant year (multiplied by primary and upstream conversion factors).

$$\begin{aligned} &\mathit{Annual\ Base\ Total\ Energy\ Use}_{year=n} \\ &\quad = \sum_{year=n-lifetime-1}^{n} \mathit{Shipments}_{year} \times \mathit{Base\ UEC}_{year} \end{aligned}$$

Eq. 4.1

The annual standards case total energy use in any given year is the sum product of the shipments for that year and the previous (lifetime minus 1) years and the market weighted average standards case UEC[b] in each relevant year (multiplied by primary and upstream conversion factors).

$$\begin{aligned} &\mathit{Annual\ Standards\ Case\ Total\ Energy\ Use}_{year=n} \\ &\quad = \sum_{year=n-lifetime-1}^{n} \mathit{Shipments}_{year} \times \mathit{Standards\ UEC}_{year} \end{aligned}$$

Eq. 4.2

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 no-new-standards case total energy use and the standards case total energy use.

$$\begin{aligned} &\mathit{Annual\ Energy\ Savings}_{year=n} \\ &\quad = \mathit{Annual\ Base\ Total\ Energy\ Use}_{year=n} \\ &\quad - \mathit{Annual\ Standards\ Case\ Total\ Energy\ Use}_{year=n} \end{aligned}$$

Eq. 4.3

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 equipment, 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 (No-New-Standards Case). It includes equipment both meeting and exceeding the current federal minimum efficiency. It is *not* the UEC for a product at a specified NSenCOP, ISMRE, or ISCOP.

[b] The market weighted average standards UEC is based on the distribution of efficiencies under a given amended federal standards scenario. It may include equipment 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 equipment exceeds the amended federal standards level). It is *not* the UEC for a product at a specified NSenCOP, ISMRE, or ISCOP.

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

Eq. 4.4

For the ASHRAE standard, the cumulative energy savings are presented as above. For higher efficiency levels, DOE uses the ASHRAE UEC instead of the Base UEC to calculate the annual total energy use that the annual standards case total energy use is compared to. This is because the ASHRAE standard is the presumed default.

4.3 INPUTS TO THE NATIONAL ENERGY SAVINGS CALCULATION

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

4.3.1 Shipments

4.3.1.1 CRACs

In the 2012 ASHRAE Final Rule, as a result of lack of CRAC shipment data for the United States, DOE estimated CRAC shipments by scaling historical data for the Australian CRAC market based on the relative number of businesses between the two countries and extrapolating shipments for future years[1]. Historical data of the Australian CRAC market may not be representative of the US market. In addition, recent trends toward consolidation of smaller data centers into large, hyper-scale data centers, which usually rely on air handling units (AHU) with chilled water coils served by chillers[c] rather than CRACs, indicate that an extrapolation of historical trends may not be appropriate. For this analysis, DOE instead estimates CRAC shipments by analyzing trends in the cooling demand required from CRAC-cooled data centers. DOE’s approach first estimates total annual shipments for the entire CRAC market and then uses market share data to estimate shipments for ASHRAE Standard 90.1-2016 triggered equipment classes.

DOE first estimated the installed base of CRACs using information on data centers in the 2012 Commercial Business Energy Consumption Survey (CBECS)[2]. CBECS identifies buildings that contain data centers, the number of servers in the data center, and associated square footage. Although CBECS does not specifically inquire about the presence of CRACs, DOE assumed any building identified as having a data center that did not have a central chiller or district chilled water system would be serviced by a CRAC. DOE assumed that a building with a central chiller or district chilled water system would use a computer room air handler (CRAH) and not a CRAC for its data center cooling, and thus was not included in the analysis.

CBECS includes buildings that do not identify the presence of a data center, but do contain a significant number of servers, which would require some form of dedicated cooling. DOE assumed buildings with 10 or more servers that did not identify as having a datacenter and did not have a central chiller or district chilled water system would be serviced by CRAC units.

---

[c] DOE does not have standards for non-DX chilled water units.

CBECS 2012 provides the actual amount of servers per building up to 500, at which point the server number variable is coded "500 or more." CBECS 2003 provides the actual amount of servers in a building with no limit. The largest data center in CEBCS 2003 has 8,000 servers. In order to more accurately estimate the energy use in CBECS 2012, all data centers with greater than 500 servers from CBECS 2003 along with their weights were compared to CBECS 2012 data centers with greater than 500 servers. The actual server numbers from CBECS 2003 were assigned proportionally to the CBECS 2012 buildings with greater than 500 servers.

In order to estimate the CRAC cooling capacity required for each data center in CBECS 2012, DOE first had to estimate the amount of heat generated from servers, network, and storage equipment within data centers. Based on estimates from the LBNL data center report[3], DOE estimated average power consumption of volume servers, network equipment, and storage equipment at 330 Watts, 13 Watts, and 75 Watts, respectively. Servers that were not in a data center were assumed to only have network equipment, while servers in a data center had both network and storage equipment, and thus a higher power draw. Volume servers represent 97 percent of the market in the U.S. To account for the small use of mid-range and high-end servers, which use more energy, DOE assigned mid-range servers to four data centers and high-end servers to one large data center. Mid-range servers have an estimated power consumption of 1,000 Watts (1,256 Watts including network and storage equipment) while high-end servers have an estimate power consumption of 1,800 Watts (2,278 Watts including network and storage equipment). DOE assumed 100 percent of the power draw was converted into heat exhaust that would need to be removed by a CRAC. DOE calculated the cooling load for each data center by multiplying the total server power draw by the number of servers in each building with a data center or more than 10 servers in CBECS 2012. The total cooling load was then multiplied by an oversize factor of 1.3. Oversizing of the cooling load gives the data center operator the flexibility to add more servers (and thus more heat) without having to increase the size of the cooling system.[d]

One ton of cooling can remove 3.5 kW of heat from a space[4]. DOE calculated the total heat generated by multiplying number of servers in each building by the average power consumption of a server in Watts. This provided DOE with the total heat per data center or server room. The total amount of heat was multiplied by 1.3 to account for oversizing of the CRAC system, and then divided by 3.5 kW, to determine the tons of cooling necessary. All data centers without central chillers were assumed to have CRACs and the cooling capacity of the CRAC units were based on the three representative capacities analyzed in the 2012 ASHRAE FR. For CRACs with a cooling capacity of less than 65,000 Btu/h, a 3 ton unit was assigned as the representative capacity, cooling capacities from 65,000 Btu/h to 240,000 Btu/h were assigned a representative capacity of 11 tons, and air conditioners greater than or equal to 240,000 Btu/h and less than 760,000 Btu/h were assigned a 24 ton unit. For data centers with more than 24 tons in capacity, a second unit was assigned based on the amount of extra capacity needed, using the same formula as above.

---

[d] Rasmussen, N., *Calculating Total Cooling Requirements for Data Centers – White paper 25. Schneider Electric* (Available at: *http://www.apc.com/salestools/NRAN-5TE6HE/NRAN-5TE6HE_R3_EN.pdf*).

The final part of the stock methodology is estimating the redundancy requirements of the data center which reduces the per-unit energy use and increases the total estimated shipment of CRACs. Redundancy varies significantly across data centers ranging from having one extra unit (N+1 redundancy) to having complete redundancy (2N redundancy).[5] DOE assigned redundancy depending on the data center square footage provided in CBECS 2012. Categories 1-4 (data centers under 10,000 square feet) were given N+1 redundancy, category 5 (greater than 10,000+ sq ft) was assigned 2N redundancy. Servers that were not in a data center do not have cooling redundancy.

Table 4.1 Estimated Stock of CRACs in 2012

CRAC Capacity	Buildings with >10 servers	Data Centers	CRACs in building without data centers	CRACs in buildings with data centers	Total CRACs
3 ton	69,414	58,422	10,992	116,844	127,836
11 ton	6,345	5,346	998	10,693	11,691
24 ton	2,382	2,345	37	10,025	10,062

The 2012 stock of CRACs was the starting point for the shipments analysis. Over time, the stock of servers in server rooms and small data centers is expected to decline as businesses transition their data to third party managed hyper-scale data centers.[6] While the stock declines, server density is expected to increase and as computing power improves, the power draw of each server would increase. The result is that a drop in servers will not necessarily lead to an equivalent drop in CRACs as high density spaces will present cooling challenges.[7,8] However, increased density only benefits a data center using air-cooling to a certain point, around 11 kW per rack, after which the cost savings from increased density level off.[9] DOE considered the above trends in its estimate of the future market for CRACs. First, DOE took the same sample of buildings used to develop the 2012 stock and altered the number of servers and the heat generated by each server. DOE assumed a 10% reduction in the number of servers in small data centers in 2050 and a doubling of the power per server (to 836 Watts) in 2050. DOE then recalculated the server heat generated in each data center and assigned a CRAC capacity using the same methodology described above. Table 4.2 displays DOE's estimates of the stock in 2050.

Table 4.2 Estimated Stock of CRACs in 2050

CRAC Capacity	All Buildings with >10 servers	Data Centers	CRACS
3 ton	53,547	44,845	98,392
11 ton	20,778	17,576	38,355
24 ton	3,815	3,692	16,723

Once the stock in 2050 was calculated, DOE used a linear approach to estimate the stock for the years 2013-2049. The stock in a given year was equal to the prior year’s stock plus the change in stock over the analysis period (Stock in 2050 – Stock in 2012) divided by the number of years between 2050 and 2012 (38 years). For 3-ton units, there is a decline in stock over that period, so the annual stock of 3-ton units is reduced each year. For 11 and 24 ton units, there is an increase in stock in 2050, and therefore the stock increases each year. New shipments were equal to the year over year difference in stock.

To estimate replacement shipments, DOE also began with the estimated 2012 stock. Due to data center consolidation, historical stock and shipments would not be representative of future replacements. Therefore, DOE assumed that the CRAC stock in 2012 developed over one CRAC lifetime of 15 years.[e] 1997 was the first year in the analysis, when the stock of CRACs was zero. Between 1997 and 2012, DOE assumed that an equal number of CRACs were shipped in each intermediate year,[f] so that by 2012, the number of shipments over the 15 year period equaled the stock calculated from CBECS 2012 (see Table 4.1). Beginning in 2013, replacement shipments were included in the calculation. DOE assumed that all CRACs are replaced after 15 years, so replacement shipments are equal to the shipments from 15 years prior.

As the power and density of servers increases, the cooling load will increase, even with the reduction of the population of servers in smaller data centers. While overall shipments are not expected to change significantly between 2012 and 2050, there will be a shift to CRACs with a larger cooling capacity. Table 4.3 shows the reference case shipments used to estimate potential energy savings.

---

[e] 15 years was the lifetime used in the ASHRAE 2012 FR

[f] Future shipments are expected to remain fairly constant, based on manufacturer feedback. Therefore, DOE assumed historical shipments were shipped in equal increments so that replacements would be constant.

Table 4.3 Estimated CRACs Shipments by Capacity

Year	< 65,000 Btu/h	≥65,000 Btu/h and ≤240,000 Btu/h	≥240,000 Btu/h and ≤760,000 Btu/h
2019	7,748	1,481	846
2020	7,748	1,481	846
2021	7,748	1,481	846
2022	7,748	1,481	846
2023	7,748	1,481	846
2024	7,748	1,481	846
2025	7,748	1,481	846
2026	7,748	1,481	846
2027	7,748	1,481	846
2028	6,973	2,183	1,021
2029	6,973	2,183	1,021
2030	6,973	2,183	1,021
2031	6,973	2,183	1,021
2032	6,973	2,183	1,021
2033	6,973	2,183	1,021
2034	6,973	2,183	1,021
2035	6,973	2,183	1,021
2036	6,973	2,183	1,021
2037	6,973	2,183	1,021
2038	6,973	2,183	1,021
2039	6,973	2,183	1,021
2040	6,973	2,183	1,021
2041	6,973	2,183	1,021
2042	6,973	2,183	1,021
2043	6,198	2,884	1,197
2044	6,198	2,884	1,197
2045	6,198	2,884	1,197
2046	6,198	2,884	1,197
2047	6,198	2,884	1,197
2048	6,198	2,884	1,197
2049	6,198	2,884	1,197

DOE's analysis of CBECS server stock provides estimates of shipments by cooling capacity. To further disaggregate shipments by equipment class, DOE used model counts of units in the Certification Compliance database.[10] The Certification Compliance database does not disaggregate upflow into ducted and non-ducted products. Therefore, DOE assumed upflow market share would be evenly split between the upflow ducted and upflow non-ducted equipment classes. DOE's database also does not include horizontal flow classes, as those do not currently have Federal standards. Table 4.4 shows CRAC market share by equipment class grouping. Note that the table displays results in terms of current net sensible cooling capacity ranges (measured per the current DOE test procedure), rather than crosswalked NSCC ranges (see section II.A of the Notice for further discussion of the capacity crosswalk and equipment class switching issue for CRACs).

Table 4.4 Estimated Market Share for CRAC Equipment Classes by Equipment Category

Condenser System	Orientation	< 65,000 Btu/h*	≥ 65,000 Btu/h and < 240,000 Btu/h*	≥240,000 Btu/h and <760,000 Btu/h*
Air-cooled	Downflow	3.2%	8.1%	6.8%
	Upflow	4.8%	11.0%	6.2%
Water-cooled	Downflow	1.2%	4.0%	1.2%
	Upflow	2.2%	4.6%	1.6%
Water-cooled with fluid economizer	Downflow	1.8%	5.5%	1.2%
	Upflow	1.7%	6.1%	2.1%
Glycol-cooled	Downflow	1.1%	2.7%	0.5%
	Upflow	2.1%	3.3%	0.5%
Glycol-cooled with fluid economizer	Downflow	2.5%	4.5%	0.6%
	Upflow	2.5%	5.3%	0.8%

* Capacity measured per the current Federal test procedure.

DOE's Compliance Certification Database does not distinguish between upflow ducted and upflow non-ducted CRACs. DOE assumed upflow market share would be evenly split between the upflow ducted and upflow non-ducted equipment classes. DOE's database also does not include horizontal flow classes, as those models do not yet have standards.

Table 4.5 presents CRAC shipments in 2018 and 2050 for equipment classes analyzed for potential energy savings. Note that the capacity ranges for the analyzed upflow, non-ducted equipment are not impacted by the change from SCOP to NSenCOP (see section II.A.1 of the Notice for details.)

Table 4.5 Estimated Shipments for Analyzed Equipment Classes

Equipment Class	Shipments in 2018	Shipments in 2050
Glycol-cooled, ≥65,000 and <240,000 Btu/h, Upflow Non-ducted	44	87
Glycol-cooled, ≥240,000 and <760,000 Btu/h, Upflow Non-ducted	10	14
Glycol-cooled with economizer, <65,000 Btu/h, Upflow Non-ducted	412	329
Glycol-cooled with economizer, ≥65,000 and <240,000 Btu/h, Upflow Non-ducted	72	139
Glycol-cooled with economizer, ≥240,000 and <760,000 Btu/h, Upflow Non-ducted	17	23

4.3.1.2 DOASes

DOE developed its DOAS shipments estimates based on manufacturer feedback that shipments in 2016 were around 36,000 units and that DOAS growth is expected to be similar to that of VRF equipment through 2022. A report by Cadeo Group provided data for VRF shipments from 2011-2016 as well as future growth estimates (approximately 10% growth per year).[11] In order to develop DOAS shipments, DOE scaled the 2011-2016 shipments based on the ratio of DOAS shipments to VRF shipments in 2016. Table 4.6 shows the estimated shipments of DOASes from 2011-2016.

Table 4.6 Estimates of DOAS Shipments from 2011 to 2016

Year	2011	2012	2013	2014	2015	2016
National Shipments	18,642	20,973	24,209	28,222	31,329	36,249

For years prior to 2011, DOE used an exponential growth rate with an assumed initial year of shipments of 1999,[12] as outdoor air requirements in commercial building increased that year. Finally, to project shipments past 2016, DOE used a 10 percent growth rate through to 2022 and beyond 2022, DOE used the same growth rate as other CUAC equipment based the growth rate on the value from the January 2016 CUAC-CUHP CWAF DFR.[13] Table 4.7 displays the annual shipments projections used in the analysis.

Table 4.7 Total DOAS Shipments from 2020 to 2049

Year	Shipments	Year	Shipments
2020	53,072	2035	72,632
2021	58,379	2036	73,527
2022	64,217	2037	73,939
2023	64,773	2038	74,422
2024	65,297	2039	74,775
2025	65,912	2040	75,078
2026	66,452	2041	75,729
2027	66,961	2042	76,417
2028	67,464	2043	77,120
2029	68,047	2044	77,752
2030	68,658	2045	78,496
2031	69,352	2046	79,242
2032	70,242	2047	79,993
2033	71,028	2048	80,775
2034	71,793	2049	81,565

The total shipments were distributed to each DOAS equipment class and capacity in the following amounts, based on manufacturer feedback of the market in 2016.

Table 4.8 Distribution of DOAS Equipment by Equipment Class and Capacity

	Air-Cooled
With energy recovery	41%
Without energy recovery	59%

4.3.2 No-New Standard and Standard Case Market Share and Market-Weighted UEC

The UECs associated with the no-new-standards case and standards case scenarios – or market weighted average UECs – are dependent on the market shares of equipment at each efficiency level and the UECs for equipment at each efficiency level (see chapter 3 of this NODA TSD for details and results). In the NES, the market shares are based on model distributions as a proxy for shipment distributions.

DOE reviewed available market data and product directories to determine the distribution of efficiency levels for commercially available models within each equipment class analyzed in the NODA. For CRACs, DOE used products listed in DOE's Certification and Compliance database.[10] For DOASes, because no industry-wide model or market share data are available, DOE used a uniform distribution, assigning 1/3rd of the market to each efficiency level in each equipment class. DOE assumed that this no-new-standards case market share remained the same throughout the analysis period.

For the standards case for all equipment in this NODA, DOE assumed shipments at lower efficiencies were most likely to roll up into higher efficiency levels in response to more stringent energy conservation standards. For each efficiency level analyzed within a given equipment class, DOE used a "roll-up" scenario to establish the market shares by efficiency level for the year that standards would become effective (*e.g.*, 2019, 2020, or 2023). DOE estimated that the efficiencies of equipment in the no-new-standards case that did not meet the standard level under consideration would roll up to meet the standard level. DOE assumed that all equipment efficiencies in the no-new-standards 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 UECs for each efficiency level 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:

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

Eq. 4.5

Table 4.9 through Table 4.15 show the distribution of efficiencies within the no-new-standards 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 no-new-standards case to standards case on the relevant compliance date.

Table 4.9 Distribution of Efficiencies in the No-new-standards Case and Standards Cases for Glycol-cooled, Upflow, Non-ducted CRACs, ≥65,000 and <240,000 Btu/h

	NSenCOP							**Market Weighted Average UEC (kWh/yr)**
	1.77	1.85	1.87	1.89	1.99	2.14	2.29	
No-New-Standards Case	36%	7%	3%	19%	31%	3%	2%	111,957
Efficiency Level 0	0%	42%	3%	19%	31%	3%	2%	110,123
Efficiency Level 1	0%	0%	46%	19%	31%	3%	2%	109,607
Efficiency Level 2	0%	0%	0%	64%	31%	3%	2%	109,061
Efficiency Level 3	0%	0%	0%	0%	95%	3%	2%	105,451
Efficiency Level 4	0%	0%	0%	0%	0%	98%	2%	98,403
Efficiency Level 5 - “Max Tech”	0%	0%	0%	0%	0%	0%	100%	92,060

Table 4.10 Distribution of Efficiencies in the No-new-standards Case and Standards Cases for Glycol-cooled, Upflow, Non-ducted CRACs, ≥240,000 and <760,000 Btu/h

	NSenCOP							Market Weighted Average UEC (kWh/yr)
	1.77	1.85	1.78	1.81	1.94	2.01	2.04	
No-New-Standards Case	22%	22%	0%	11%	11%	11%	22%	248,165
Efficiency Level 0	0%	44%	0%	11%	11%	11%	22%	247,488
Efficiency Level 1	0%	0%	44%	11%	11%	11%	22%	245,515
Efficiency Level 2	0%	0%	0%	56%	11%	11%	22%	243,607
Efficiency Level 3	0%	0%	0%	0%	67%	11%	22%	234,125
Efficiency Level 4	0%	0%	0%	0%	0%	78%	22%	228,608
Efficiency Level 5 - “Max Tech”	0%	0%	0%	0%	0%	0%	100%	225,985

Table 4.11 Distribution of Efficiencies in the No-new-standards Case and Standards Cases for Glycol-cooled with a Fluid Economizer, Upflow, Non-ducted CRACs, <65,000 Btu/h

	NSenCOP							Market Weighted Average UEC (kWh/yr)
	1.99	2	2.04	2.07	2.14	2.2	2.24	
No-New-Standards Case	0%	0%	5%	5%	32%	45%	14%	21,066
Efficiency Level 0	0%	0%	5%	5%	32%	45%	14%	21,066
Efficiency Level 1	0%	0%	5%	5%	32%	45%	14%	21,066
Efficiency Level 2	0%	0%	0%	9%	32%	45%	14%	21,051
Efficiency Level 3	0%	0%	0%	0%	41%	45%	14%	20,985
Efficiency Level 4	0%	0%	0%	0%	0%	86%	14%	20,747
Efficiency Level 5 - “Max Tech”	0%	0%	0%	0%	0%	0%	100%	20,426

Table 4.12 **Distribution of Efficiencies in the No-new-standards Case and Standards Cases for Glycol-cooled with a Fluid Economizer, Upflow, Non-ducted CRACs, ≥65,000 and <240,000 Btu/h**

	NSenCOP							**Market Weighted Average UEC (kWh/yr)**
	1.73	1.75	1.77	1.88	1.94	2.08	2.22	
No-New-Standards Case	13%	11%	29%	22%	23%	1%	1%	90,538
Efficiency Level 0	0%	23%	29%	22%	23%	1%	1%	90,399
Efficiency Level 1	0%	0%	53%	22%	23%	1%	1%	90,116
Efficiency Level 2	0%	0%	0%	75%	23%	1%	1%	87,287
Efficiency Level 3	0%	0%	0%	0%	98%	1%	1%	85,293
Efficiency Level 4	0%	0%	0%	0%	0%	99%	1%	79,637
Efficiency Level 5 - “Max Tech”	0%	0%	0%	0%	0%	0%	100%	74,678

Table 4.13 **Distribution of Efficiencies in the No-new-standards Case and Standards Cases for Glycol-cooled with a Fluid Economizer, Upflow, Non-ducted CRACs, ≥240,000 and <760,000 Btu/h**

	NSenCOP							**Market Weighted Average UEC (kWh/yr)**
	1.69	1.70	1.72	1.77	1.87	1.90	1.97	
No-New-Standards Case	0%	27%	33%	7%	7%	13%	13%	203,625
Efficiency Level 0	0%	27%	33%	7%	7%	13%	13%	203,625
Efficiency Level 1	0%	0%	60%	7%	7%	13%	13%	202,964
Efficiency Level 2	0%	0%	0%	67%	7%	13%	13%	199,443
Efficiency Level 3	0%	0%	0%	0%	73%	13%	13%	192,351
Efficiency Level 4	0%	0%	0%	0%	0%	87%	13%	190,136
Efficiency Level 5 - “Max Tech”	0%	0%	0%	0%	0%	0%	100%	183,986

Table 4.14 Distribution of Efficiencies in the No-new-Standards Case and Standards Cases for Air-Cooled DOAS with Energy Recovery

	ISMRE			Market Weighted Average UEC
	5.2	6.2	7.2	(kWh/yr)
No-New-Standards Case	33.33%	33.33%	33.33%	18,906
Efficiency Level 0	0%	66.66%	33.33%	17,715
Max-Tech	0%	0%	100%	15,988

Table 4.15 Distribution of Efficiencies in the No-new-standards Case and Standards Case for Air-cooled DOAS without Energy Recovery

	ISMRE			Market Weighted Average UEC
	4.0	5.0	6.0	(kWh/yr)
No-New-Standards Case	33.33%	33.33%	33.33%	23,677
Efficiency Level 0	0%	66.66%	33.33%	21,757
Max-Tech	0%	0%	100%	19,198

4.3.3 Equipment Lifetime

DOE defines "equipment lifetime" as the age when a unit is retired from service. DOE estimated CRAC equipment lifetime ranged between 10 and 25 years, with an average lifespan of 15 years,[1] based on estimates cited in available CRAC literature used in the ASHRAE 2012 Final Rule. DOE does not have any data on the lifetime of DOAS; however, given the similarities between DOAS and commercial package air conditioners, DOE used the median lifetime for 15 ton air conditioners of 22.6 years from the January 2016 CUAC-CUHP CWAF DFR for all DOAS rating conditions.[10]

4.3.4 Conversion of Site Energy Savings

DOE converted the annual site energy savings into the annual amount of energy saved at the source of electric generation (*i.e.*, primary energy) using annual multiplicative factors calculated from the *AEO2019* projections.[14] For electricity, the conversion factors vary over time because of projected changes in generation sources (*i.e.*, the types of power plants projected to provide electricity to the country).

The full-fuel-cycle (FFC) measure includes point-of-use (site) energy, the energy losses associated with generation, transmission, and distribution of electricity, and the energy consumed in extracting, processing, and transporting or distributing primary fuels. To complete the full-fuel-cycle by encompassing the energy consumed in extracting, processing, and transporting or distributing primary fuels, which we refer to as "upstream" activities, DOE developed FFC multipliers using the data and projections generated by the National Energy Modeling System (NEMS) used for *AEO2019*. The *AEO* provides extensive information about the energy system, including projections of future oil, natural gas and coal supply, energy use for oil and gas field and refinery operations, and fuel consumption and emissions related to electric power production. This information can be used to define a set of parameters representing the energy intensity of energy production.

Table 4.16 shows the energy multipliers used to calculate the upstream component of the FFC for selected years. The method used to calculate the multipliers is described in Appendix 4-A.

Table 4.16 Upstream Energy Multipliers (Based on AEO 2019)

	2020	**2025**	**2030**	**2040**	**2050**
Electricity	0.049	0.048	0.048	0.047	0.044

4.3.5 Compliance Dates and Analysis Period

If DOE were to prescribe energy conservation standards at the efficiency levels contained in ASHRAE Standard 90.1-2016, EPCA states that any such standard shall become effective on or after a date that is two or three years (depending on the equipment type or size) after the effective date of the applicable minimum energy efficiency requirement in the amended ASHRAE standard. (42 U.S.C. 6313(a)(6)(D)) If DOE were to prescribe standards more stringent than the efficiency levels contained in ASHRAE Standard 90.1-2016, EPCA dictates that any such standard will become effective for equipment manufactured on or after a date which is four years after the date of publication of a final rule in the *Federal Register*. (42 U.S.C. 6313(a)(6)(D))

For purposes of calculating the NES for the equipment in this evaluation, DOE used a 30-year analysis period starting with the assumed year of compliance listed in Table 4.17 for each equipment class. This is the standard analysis period of 30 years that DOE typically uses in its

NES analysis. For equipment classes with a compliance date in the last six months of the year, DOE starts its analysis period in the first full year after compliance. For example, if CRACs greater than 65,000 Btu/h and less than 240,000 Btu/h were to have a compliance date of October 26, 2019, the analysis period for calculating NES would begin in 2020 and extend to 2049.

While the analysis periods remain the same for assessing the energy savings of efficiency levels higher than the ASHRAE levels, those energy savings would not begin accumulating until 2023 (the assumed compliance date if DOE were to determine that standard levels more stringent than the ASHRAE levels are justified).

.

Table 4.17 Approximate Compliance Date of an Amended Energy Conservation Standard for Each Equipment Class

Equipment Class	Approximate Compliance Date for Adopting the Efficiency Levels in ASHRAE Standard 90.1-2016	Approximate Compliance Date for Adopting More-Stringent Efficiency Levels than Those in ASHRAE Standard 90.1-2016
Computer Room Air Conditioners		
CRAC, Glycol-Cooled, ≥65,000 and <240,000 Btu/h, Upflow Non-ducted	10/26/2019	4/26/2023
CRAC, Glycol-Cooled, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Non-ducted	10/26/2019	4/26/2023
CRAC, Glycol-Cooled with fluid economizer, <65,000 Btu/h, Upflow Non-ducted	10/26/2018	4/26/2023
CRAC, Glycol-Cooled with fluid economizer, ≥65,000 and <240,000 Btu/h, Upflow Non-ducted	10/26/2019	4/26/2023
CRAC, Glycol-Cooled with fluid economizer, ≥240,000 Btu/h and <760,000 Btu/h, Upflow Non-Ducted	10/26/2019	4/26/2023
Dedicated Outdoor Air Systems		
All Equipment Classes	10/26/2019	4/26/2023

4.4 NATIONAL ENERGY SAVINGS RESULTS

Table 4.18 through Table 4.20 summarize the NES due to potential energy conservation standards for the equipment classes examined in this NODA. Recall that levels higher than ASHRAE are shown as net energy savings relative to the ASHRAE 90.1-2016 level.

Table 4.18 Potential Energy Savings for CRACs, glycol-cooled, upflow, non-ducted

	≥ 65,000 Btu/h and < 240,000 Btu/h*		≥ 240,000 Btu/h and <760,000 Btu/h*	
Site Energy Savings Estimate (quads)				
	NSenCOP	**quads**	**NSenCOP**	**quads**
Level 0	1.85	0.000	1.75	0.000
Level 1	1.87	0.000	1.78	0.000
Level 2	1.89	0.000	1.81	0.000
Level 3	1.99	0.000	1.94	0.000
Level 4	2.14	0.001	2.01	0.000
Level 5 – “Max Tech”	2.29	0.002	2.04	0.000
Primary Energy Savings Estimate (quads)				
	NSenCOP	**quads**	**NSenCOP**	**quads**
Level 0	1.85	0.000	1.75	0.000
Level 1	1.87	0.000	1.78	0.000
Level 2	1.89	0.000	1.81	0.000
Level 3	1.99	0.001	1.94	0.001
Level 4	2.14	0.003	2.01	0.001
Level 5 – “Max Tech”	2.29	0.004	2.04	0.001
FFC Energy Savings Estimate (quads)				
Level 0	1.85	0.000	1.75	0.000
Level 1	1.87	0.000	1.78	0.000
Level 2	1.89	0.000	1.81	0.000
Level 3	1.99	0.001	1.94	0.001
Level 4	2.14	0.003	2.01	0.001
Level 5 – “Max Tech”	2.29	0.005	2.04	0.001

* The potential energy savings for Level 0 (the ASHRAE 90.1-2016 level) were calculated relative to the Federal standard. The potential energy savings for efficiency Levels 1-5 were calculated relative to Level 0.

Table 4.19 Potential Energy Savings for CRACS, glycol-cooled with a fluid economizer, upflow, non-ducted

	< 65,000 Btu/h*		≥ 65,000 Btu/h and < 240,000 Btu/h*		≥ 240,000 Btu/h and < 760,000 Btu/h*	
Site Energy Savings Estimate (quads)						
	NSenCOP	**quads**	**NSenCOP**	**quads**	**NSenCOP**	**quads**
Level 0	2.00	0.000	1.75	0.000	1.70	0.000
Level 1	2.04	0.000	1.77	0.000	1.72	0.000
Level 2	2.07	0.000	1.88	0.000	1.77	0.000
Level 3	2.14	0.000	1.94	0.001	1.87	0.000
Level 4	2.20	0.000	2.08	0.002	1.90	0.000
Level 5 – “Max Tech”	2.24	0.000	2.22	0.002	1.97	0.001
Primary Energy Savings Estimate (quads)						
	NSenCOP	**quads**	**NSenCOP**	**quads**	**NSenCOP**	**quads**
Level 0	2.00	0.000	1.75	0.000	1.70	0.000
Level 1	2.04	0.000	1.77	0.000	1.72	0.000
Level 2	2.07	0.000	1.88	0.001	1.77	0.000
Level 3	2.14	0.000	1.94	0.002	1.87	0.001
Level 4	2.20	0.000	2.08	0.004	1.90	0.001
Level 5 – “Max Tech”	2.24	0.001	2.22	0.006	1.97	0.001
FFC Energy Savings Estimate (quads)						
Level 0	2.00	0.000	1.75	0.000	1.70	0.000
Level 1	2.04	0.000	1.77	0.000	1.72	0.000
Level 2	2.07	0.000	1.88	0.001	1.77	0.000
Level 3	2.14	0.000	1.94	0.002	1.87	0.001
Level 4	2.20	0.000	2.08	0.004	1.90	0.001
Level 5 – “Max Tech”	2.24	0.001	2.22	0.006	1.97	0.001

* The potential energy savings for Level 0 (the ASHRAE 90.1-2016 level) were calculated relative to the Federal standard. The potential energy savings for efficiency Levels 1-5 were calculated relative to Level 0.

Table 4.20 Potential Energy Savings for Air Cooled DOASes, with and without Energy Recovery

	Without Energy Recovery		**With Energy Recovery**	
Efficiency Level	**ISMRE**	**quads**	**ISMRE**	**quads**
	Site Energy Savings Estimate			
Level 0 – ASHRAE	4.0	**-**	5.2	**-**
Level 1	5.0	0.155	6.2	0.067
Level 2 = “Max Tech”	6.0	0.362	7.2	0.164
	Primary Energy Savings Estimate			
Efficiency Level	**ISMRE**	**quads**	**ISMRE**	**quads**
Level 0 – ASHRAE	4.0	-	5.2	-
Level 1	5.0	0.408	6.2	0.176
Level 2 = “Max Tech”	6.0	0.951	7.2	0.431
	FFC Energy Savings Estimate			
Level 0 – ASHRAE	4.0	-	5.2	-
Level 1	5.0	0.426	6.2	0.184
Level 2 = “Max Tech”	6.0	0.994	7.2	0.450

REFERENCES

1. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Energy Conservation Standards for Commercial Heating, Air Conditioning, and Water-Heating Equipment, Technical Support Document. 2012. https://www.regulations.gov/document?D=EERE-2011-BT-STD-0029-0021.

2. U.S. Department of Energy–Energy Information Administration. *2012 CBECS Survey Data*. (Last accessed July 26, 2016.) http://www.eia.gov/consumption/commercial/data/2012/index.cfm?view=microdata.

3. Shehabi, A. et al. *United States Data Center Energy Usage Report.* 2016. Lawrence Berkeley National Laboratory. Report No. LBNL-1005775. https://eta.lbl.gov/publications/united-states-data-center-energy.

4. Rasmussen, N. *Calculating Total Cooling Requirements for Data Centers*. Schneider Electric. Report No. 25. http://www.apc.com/salestools/NRAN-5TE6HE/NRAN-5TE6HE_R3_EN.pdf.

5. Shehabi, A. et al. *United States Data Center Energy Usage Report.* 2016. Lawrence Berkeley National Laboratory. Report No. LBNL-1005775. https://eta.lbl.gov/publications/united-states-data-center-energy.

6. *Server Primer: Understanding the Current State of the Industry*. 2012. Golisano Institute for Sustainability. http://www.epeat.net/wp-content/uploads/2012/11/ServerPrimer2012.pdf.

7. Minas, L. *The Problem of Power Consumption in Servers*. 2009. https://software.intel.com/en-us/articles/the-problem-of-power-consumption-in-servers.

8. *Server Primer: Understanding the Current State of the Industry*. 2012. Golisano Institute for Sustainability. http://www.epeat.net/wp-content/uploads/2012/11/ServerPrimer2012.pdf.

9. Verge, J. The Myth of the Data Center’s High Density Future. *Data Center Knowledge*. 2014. http://www.datacenterknowledge.com/archives/2014/10/20/myth-data-centers-high-density-future/.

10. United States Department of Energy (DOE). Compliance Certification Management System (CCMS) Database. 2019. http://www.regulations.doe.gov/certification-data/CCMS-81578122497.html.

11. Cadeo Group. *Variable Refrigerant Flow: A Preliminary Market Assessment*. 2016.

12. Mumma, S. Designing Dedicated Outdoor Air Systems. *ASHRAE Journal*. 2001. http://doas-radiant.psu.edu/Journal1.pdf.

13. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Energy Conservation Standards for Small, Large, and Very Large Commercial Package Air Conditioning and Heating Equipment, Technical Support Document. 2016. https://www.regulations.gov/docketBrowser?rpp=50&so=DESC&sb=postedDate&po=0&dct=SR%2BO&D=EERE-2013-BT-STD-0007.

14. U.S. Energy Information Administration. *Annual Energy Outlook 2019 with Projections to 2050*. 2019. Washington, D.C. Report No. DOE/EIA-0383(2016). (Last accessed August 12, 2019.) https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf.

APPENDIX 4A. FULL-FUEL-CYCLE ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX 4A. FULL-FUEL-CYCLE ANALYSIS

4A.1 INTRODUCTION

This appendix summarizes the methods the U.S. Department of Energy (DOE) used to calculate the estimated full-fuel-cycle (FFC) energy savings from potential energy conservation standards. The FFC measure includes point-of-use (site) energy; the energy losses associated with generation, transmission, and distribution of electricity; and the energy consumed in extracting, processing, and transporting or distributing primary fuels. DOE's method of analysis previously encompassed only site energy and the energy lost through generation, transmission, and distribution of electricity. In 2011 DOE announced its intention, based on recommendations from the National Academy of Sciences, to use FFC measures of energy use and emissions when analyzing proposed energy conservation standards.[1] This appendix summarizes the methods DOE used to incorporate impacts of the full fuel cycle into the analysis.

In the national energy savings calculation, DOE estimates the site, primary and full-fuel-cycle (FFC) energy consumption for each standard level, for each year in the analysis period. DOE defines these quantities as follows:

- Site energy consumption is the physical quantity of fossil fuels or electricity consumed at the site where the end-use service is provided.[a] The site energy consumption is used to calculate the energy cost input to the NPV calculation.
- Primary energy consumption is defined by converting the site fuel use from physical units, for example cubic feet for natural gas, or kWh for electricity, to common energy units (million Btu or mmBtu). For electricity the conversion factor is a marginal heat rate that incorporates losses in generation, transmission and distribution, and depends on the sector, end use and year.
- The full-fuel-cycle (FFC) energy use is equal to the primary energy use plus the energy consumed "upstream" of the site in the extraction, processing and distribution of fuels. The FFC energy use was calculated by applying a fuel-specific FFC energy multiplier to the primary energy use.

For electricity from the grid, site energy is measured in terawatt-hours (TWh). The primary energy of a unit of grid electricity is equal to the heat content of the fuels used to generate that electricity, including transmission and distribution losses.[b] DOE typically measures the primary energy associated with the power sector in quads (quadrillion Btu). Both primary fuels and electricity are used in upstream activities. The treatment of electricity in full-fuel-cycle analysis must distinguish between electricity generated by fossil fuels and electricity generated from renewable sources (wind, solar, and hydro). For the former, the upstream fuel cycle relates

---

[a] For fossil fuels, this is the site of combustion of the fuel.

[b] For electricity sources like nuclear energy and renewable energy, the primary energy is calculated using the convention described below.

to the fuel consumed at the power plant. There is no upstream component for the latter, because no fuel *per se* is used.

4A.2 HEAT RATES

DOE uses heat rates to convert site electricity savings in TWh to primary energy savings in quads. The heat rates are developed as a function of the sector, end-use and year of the analysis period. For this analysis DOE uses output of the DOE/Energy Information Administration (EIA)'s National Energy Modeling System (NEMS).[2] EIA uses the NEMS model to produce the *Annual Energy Outlook* (*AEO*). DOE's approach uses the most recently available edition, in this case *AEO2019*.[3] The *AEO* publication includes a reference case and a series of side cases incorporating different economic and policy scenarios. DOE calculates marginal heat rates as the ratio of the change in fuel consumption to the change in generation for each fossil fuel type, where the change is defined as the difference between the reference case and the side case. DOE calculates a marginal heat rate for each of the principal fuel types: coal, natural gas and oil. DOE uses the EIA convention of assigning a heat rate of 10.5 Btu/Wh to nuclear power and 9.5 Btu/Wh to electricity from renewable sources. The fuel specific marginal heat rates are shown in Figure 4A.2.1.

DOE multiplied the fuel share weights for sector and end-use, described in appendix 15A of this TSD, by the fuel specific marginal heat rates, and summed over all fuel types, to define a heat rate for each sector/end-use. This step incorporates the transmission and distribution losses. In equation form:

$$h(u,y) = (1 + TDLoss)*\sum_{r,f} g(r,f,y)\, H(f,y)$$

Where:

$TDLoss$ = the fraction of total generation that is lost in transmission and distribution, equal to 0.07037
u = an index representing the sector/end-use (e.g. commercial cooling)
y = the analysis year
f = the fuel type
$H(f,y)$ = the fuel-specific heat rate plotted in Figure 4A.2.1
$g(r,f,y)$ = the fraction of generation provided by fuel type f for end-use u in year y
$h(u,y)$ = the end-use specific marginal heat rate

The sector/end-use specific heat rates are shown in Table 4A.2.1. These heat rates convert site electricity to primary energy in quads; i.e., the units used in the table are quads per TWh.

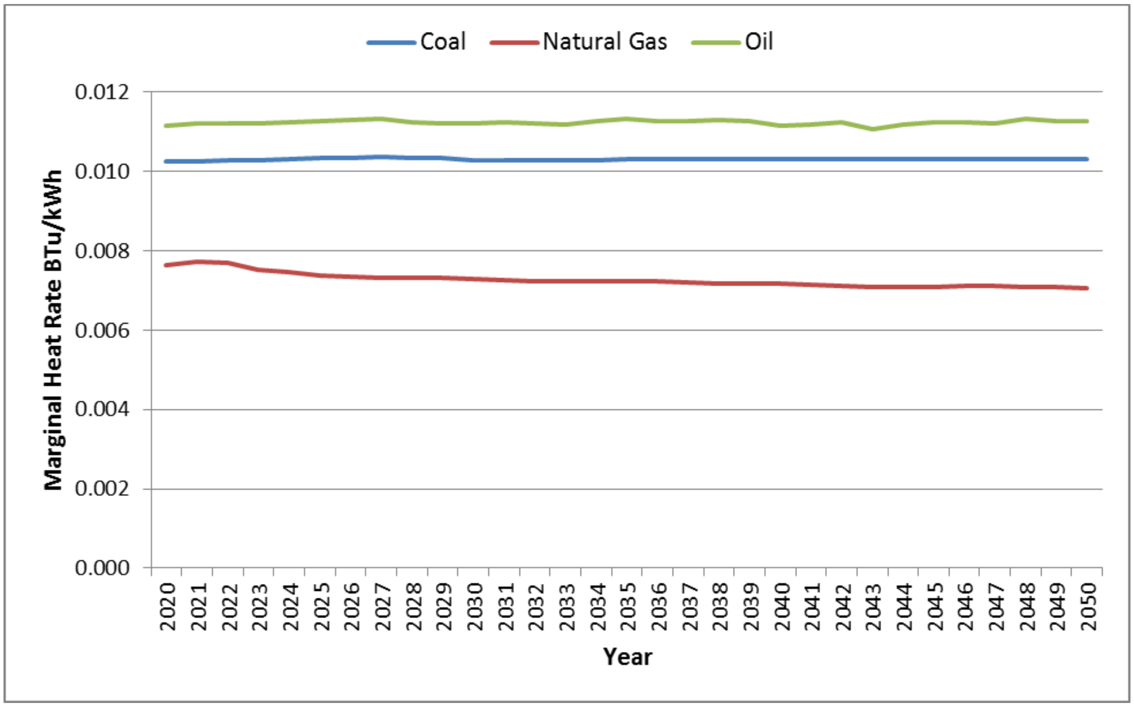

Figure 4A.2.1 Fuel Specific Marginal Heat Rates

Table 4A.2.1 Electric Power Heat Rates (quads/TWh) by Sector and End-Use

	2025	2030	2040	2050
Commercial Sector				
cooking	9.20E-03	9.08E-03	8.95E-03	8.91E-03
lighting	9.24E-03	9.12E-03	8.99E-03	8.94E-03
office equipment (non-pc)	9.13E-03	9.01E-03	8.89E-03	8.84E-03
office equipment (pc)	9.13E-03	9.01E-03	8.89E-03	8.84E-03
other uses	9.16E-03	9.04E-03	8.92E-03	8.87E-03
refrigeration	9.33E-03	9.23E-03	9.09E-03	9.04E-03
space cooling	9.19E-03	9.07E-03	8.93E-03	8.87E-03
space heating	9.44E-03	9.35E-03	9.19E-03	9.15E-03
ventilation	9.34E-03	9.24E-03	9.09E-03	9.04E-03
water heating	9.20E-03	9.08E-03	8.95E-03	8.91E-03
Industrial Sector				
all uses	9.16E-03	9.04E-03	8.92E-03	8.87E-03
Residential Sector				
clothes dryers	9.35E-03	9.25E-03	9.11E-03	9.06E-03
cooking	9.33E-03	9.23E-03	9.08E-03	9.03E-03
freezers	9.38E-03	9.29E-03	9.14E-03	9.08E-03
lighting	9.40E-03	9.30E-03	9.15E-03	9.11E-03
other uses	9.35E-03	9.25E-03	9.11E-03	9.06E-03
refrigeration	9.38E-03	9.28E-03	9.13E-03	9.08E-03
space cooling	9.23E-03	9.11E-03	8.96E-03	8.90E-03
space heating	9.42E-03	9.33E-03	9.18E-03	9.13E-03
water heating	9.36E-03	9.26E-03	9.12E-03	9.07E-03

4A.3 FFC METHODOLOGY

The methods used to calculate FFC energy use are summarized here. The mathematical approach to determining FCC is discussed in Coughlin (2012).[5] Details related to the modeling of the fuel production chain are presented in Coughlin (2013).[6]

When all energy quantities are normalized to the same units, FFC energy use can be represented as the product of the primary energy use and an FFC multiplier. Mathematically the FFC multiplier is a function of a set of parameters that represent the energy intensity and material losses at each stage of energy production. Those parameters depend only on physical data, so the calculations require no assumptions about prices or other economic factors. Although the parameter values may differ by geographic region, this analysis utilizes national averages.

The fuel cycle parameters are defined as follows.

- a_x is the quantity of fuel x burned per unit of electricity produced for grid electricity. The calculation of a_x includes a factor to account for losses incurred through the transmission and distribution systems.
- b_y is the amount of grid electricity used in producing fuel y, in MWh per physical unit of fuel y.
- c_{xy} is the amount of fuel x consumed in producing one unit of fuel y.
- q_x is the heat content of fuel x (MBtu/physical unit).

All the parameters are calculated as functions of an annual time step; hence, when evaluating the effects of potential new standards, a time series of annual values is used to estimate the FFC energy and emissions savings in each year of the analysis period and cumulatively.

The FFC multiplier is denoted μ (mu). A separate multiplier is calculated for each fuel used on site. Also calculated is a multiplier for electricity that reflects the fuel mix used in its generation. The multipliers are dimensionless numbers applied to primary energy savings to obtain the FFC energy savings. The upstream component of the energy savings is proportional to (μ-1). The fuel type is denoted by a subscript on the multiplier μ.

The method for performing the full-fuel-cycle analysis utilizes data and projections published in the *AEO 2019*.[3] Table 4A.3.1 summarizes the data used as inputs to the calculation of various parameters. The column titled "AEO Table" gives the name of the table that provided the reference data.

Table 4A.3.1 Dependence of FFC Parameters on *AEO* Inputs

Parameter(s)	Fuel(s)	*AEO* Table	Variables
q_x	All	Conversion factors	MMBtu per physical unit
a_x	All	Electricity supply, disposition, prices, and emissions Energy consumption by sector and source	Generation by fuel type Electric energy consumption by the power sector
b_c, c_{nc}, c_{pc}	Coal	Coal production by region and type	Coal production by type and sulfur content
b_p, c_{np}, c_{pp}	Petroleum	Refining industry energy consumption Liquid fuels supply and disposition International liquids supply and disposition Oil and gas supply	Refining-only energy use Crude supply by source Crude oil imports Domestic crude oil production
c_{nn}	Natural gas	Oil and gas supply Natural gas supply, disposition, and prices	U.S. dry gas production Pipeline, lease, and plant fuel
z_x	All	Electricity supply, disposition, prices, and emissions	Power sector emissions

The *AEO 2019* does not provide all the information needed to estimate total energy use in the fuel production chain. Coughlin (2013) describes the additional data sources needed to complete the analysis. The time dependence in the FFC multipliers, however, arises exclusively from variables taken from the *AEO*.

4A.4 ENERGY MULTIPLIERS FOR THE FULL FUEL CYCLE

FFC energy multipliers for selected years are presented in Table 4A.4.1. The 2050 value was held constant for the analysis period beyond 2050, which is the last year in the *AEO 2019* projection. The multiplier for electricity reflects the shares of various primary fuels in total electricity generation throughout the forecast period.

Table 4A.4.1 Energy Multipliers for the Full Fuel Cycle (Based on *AEO 2019*)

	2021	2025	2030	2040	2050
Electricity	1.049	1.048	1.048	1.047	1.044
Natural gas	1.111	1.110	1.112	1.112	1.106
Petroleum fuels	1.179	1.177	1.177	1.180	1.186

REFERENCES

1. U.S. Department of Energy–Office of Energy Efficiency and Renewable Energy. *Federal Register*. August 18, 2011. vol. 76, no. 160: pp. 51281–51289. (Last accessed July 8, 2015.) http://www.gpo.gov/fdsys/pkg/FR-2011-08-18/pdf/FR-2011-08-18.pdf.

2. U.S. Department of Energy-Energy Information Administration. *The National Energy Modeling System: An Overview 2009*. 2009. Report No. DOE/EIA-0581. (Last accessed June 15, 2015.) http://www.eia.gov/oiaf/aeo/overview/.

3. U.S. Energy Information Administration. *Annual Energy Outlook 2019 with Projections to 2050*. 2019. Washington, D.C. Report No. DOE/EIA-0383(2019). (Last accessed March 22, 2019.) https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf.

4. Coughlin, K. *Utility Sector Impacts of Reduced Electricity Demand*. 2014. Lawrence Berkeley National Laboratory: Berkeley, CA. Report No. LBNL-6864E. (Last accessed June 10, 2015.) http://www.osti.gov/scitech/servlets/purl/1165372.

5. Coughlin, K. A Mathematical Analysis of Full Fuel Cycle Energy Use. *Energy*. 2012. 37(1): pp. 698–708. (Last accessed June 15, 2015.) http://www.sciencedirect.com/science/article/pii/S0360544211006803.

6. Coughlin, K. *Projections of Full-Fuel-Cycle Energy and Emissions Metrics*. 2013. Lawrence Berkeley National Laboratory: Berkeley, CA. Report No. LBNL-6025E. (Last accessed June 10, 2015.) http://ees.lbl.gov/sites/all/files/lbnl6025e_ffc.pdf.