



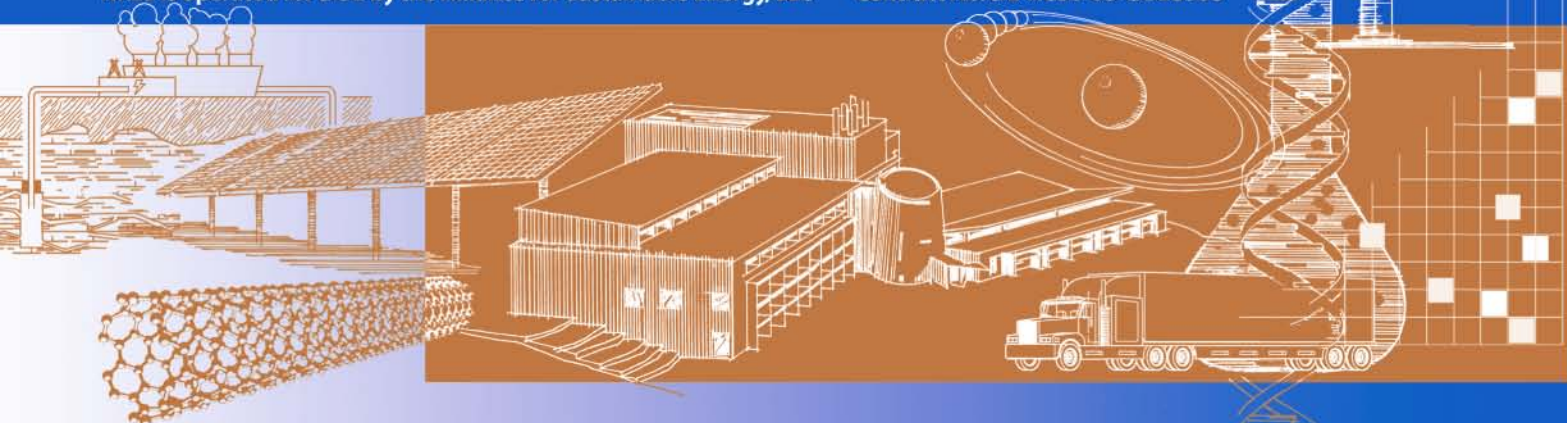
# Evaluation of ANSI/ASHRAE/USGBC/IES Standard 189.1-2009

Nicholas Long, Eric Bonnema, Kristin Field,  
and Paul Torcellini

*Technical Report*  
NREL/TP-550-47906  
July 2010

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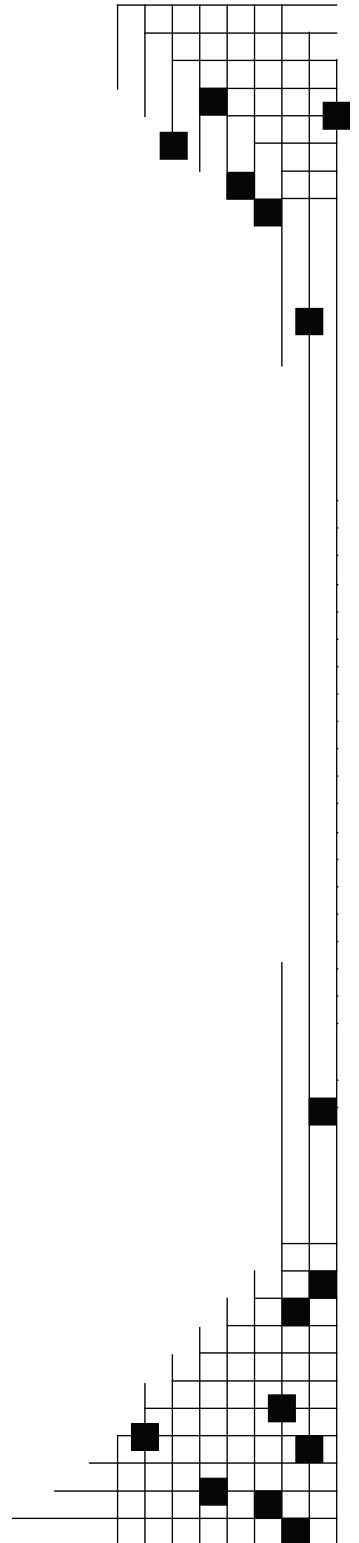


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Nicholas Long, Eric Bonnema, Kristin Field,  
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Prepared under Task No. BEC71121

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## **Nomenclature**

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
DOE	U.S. Department of Energy
EER	energy efficiency ratio
EUI	energy use intensity
HVAC	heating, ventilation, and air conditioning
IESNA	Illuminating Engineering Society of North America
LPD	lighting power density
NREL	National Renewable Energy Laboratory
SEER	seasonal energy efficiency ratio
SHGC	solar heat gain coefficient
USGBC	U.S. Green Building Council
VAV	variable air volume
w.c.	water column

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## **1 Introduction**

The National Renewable Energy Laboratory (NREL) evaluated ANSI/ASHRAE/USGBC/IES Standard 189.1-2009, “The Standard for High-Performance Green Buildings Except Low-Rise Residential Buildings.” NREL performed this evaluation by examining the results of predictions for site energy use from a comprehensive set of EnergyPlus (Crawley et al. 2001) models.

In the interest of expediency, NREL conducted an “order-of-magnitude” analysis to identify the likely overall impact of adopting Standard 189.1-2009 (ASHRAE 2010) over ANSI/ASHRAE/IESNA Standard 90.1-2007 (ASHRAE 2007b). The developers of Standard 189.1-2009 hope to achieve at least 30% energy savings over Standard 90.1-2007 and to understand the variations in impacts between building sectors and climate zones. This analysis is not the official determination of energy savings but rather provided guidance for the project committee as they developed Standard 189.1-2009.

Section 2 provides background on the contents of Standard 189.1-2009 and specifications. Section 3 reviews the methodology used for this study, including energy modeling inputs and assumptions. Section 4 presents the results. Section 5 lists the salient conclusions.

## 2 Background

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), the American National Standards Institute (ANSI), the U.S. Green Building Council (USGBC), and the Illuminating Engineering Society of North America (IESNA), are developing Standard 189.1-2009 Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings (ASHRAE 2010). This standard is written in code-enforceable language, and uses Standard 90.1-2007 (ASHRAE 2007b) as the baseline for determining energy savings. The standard committee hopes to achieve 30% energy savings compared to Standard 90.1-2007 and asked the U.S. Department of Energy's (DOE) NREL to help evaluate its expected energy savings. The energy efficiency chapter contains a set of mandatory provisions and provides two paths to creating a high-performance green building:

1. A prescriptive guideline that provides minimum requirements to meet the Standard.
2. Performance monitoring to ensure compliance.

Besides the energy efficiency chapter, measures in other chapters also have energy impacts (e.g., cool roofs in the sustainable sites chapter). The measures are summarized below; a checkmark (✓) indicates that the measure was included in the analysis. Measures that were not modeled were omitted for various reasons, including simplifications in the thermal model (e.g., neglected doors), lack of modeling capability within the whole-building energy analysis framework (e.g., transformer efficiencies), and limitations in the analysis routines used to generate the models (e.g., waste water heat recovery).

Standard 189.1-2009 includes mandatory provisions (7.3) for all projects in the following technical areas to meet the 30% goal:

- 7.3.1: Mandatory provisions of Standard 90.1 ✓
- 7.3.2: Provision for future on-site renewable energy systems
- 7.3.3: Minimum energy metering.

The energy efficiency chapter includes specific prescriptive recommendations for energy efficiency improvements; these are organized by climate zone in the following technical areas to meet the 30% goal. The prescriptive recommendations follow.

- 7.4.1: General
  - On-site renewable energy requirement of 6.0 kBtu/ft<sup>2</sup> (68 MJ/m<sup>2</sup>) of conditioned space (7.4.3.1b lowers this to 4.0 kBtu/ft<sup>2</sup> [45 MJ/m<sup>2</sup>]) ✓
- 7.4.2: Building Envelope
  - Roofs ✓
  - Walls ✓
  - Floors ✓
  - Slabs ✓
  - Doors
  - Vertical glazing ✓
  - Skylights ✓
  - Overhangs ✓
  - Continuous air barrier ✓

- 7.4.3: HVAC Equipment and Systems
  - Cooling equipment efficiencies✓
  - Economizer thresholds✓
  - Heating equipment efficiencies✓
  - Energy recovery✓
  - Fan power limitations✓
  - Supply fans✓
  - Ventilation controls for high occupancy areas✓
  - Variable-speed kitchen hoods✓
  - Duct sealing
  - Duct insulation
  - Pipe insulation
  - Pipe pressure loss limitations
  - Automatic controls for hotel/motel guest rooms✓
- 7.4.4: Service Water Heating
  - Equipment efficiencies✓
  - Pipe insulation
  - Spa insulation
- 7.4.5: Power
  - Load factor/peak load reduction
- 7.4.6: Lighting
  - Daylighting controls✓
  - Occupancy sensor controls✓
  - Interior electric lighting wattage✓
  - Exterior lighting controls
  - Exterior electric lighting wattages
- 7.4.7: Other Equipment
  - Most equipment and appliances to comply with ENERGY STAR✓
  - High-efficiency ice cube machines, commercial refrigerators and freezers, and commercial clothes washers✓
  - Motor efficiencies✓
  - Condenser waste heat recovery in supermarkets
  - Wastewater heat recovery from commercial dishwashers.

Other chapters include mandatory provisions and prescriptive recommendations that affect energy consumption, either by providing energy savings (e.g., lower hot water consumption) or by increasing energy consumption (e.g., increased outdoor air rates). Examples include:

Chapter 5: Site Sustainability

- 5.3.2.3: Heat island, roof: high-albedo roof (in climate zones 1–3)✓.

Chapter 6: Water Use Efficiency

- 6.3.2.1: Interior water use, plumbing fixtures: lower flow rate for hot water✓

- 6.3.2.2: Interior water use, clothes washers/dishwashers: lower hot water consumption✓
- 6.4.2.2: Interior water use, commercial kitchen equipment: lower hot water consumption✓
- 6.4.2.3: Interior water use, medical laboratories: heat recovery from hot water.

#### Chapter 8: Indoor Environmental Quality

- 8.3.4: Daylighting by skylights in low-rise buildings with large spaces (e.g., retail, grocery, warehouse) in climate zones 1–6: daylight to offset electric lights (will likely also reduce cooling, but increase heating)✓
- 8.4.1: Daylighting by vertical fenestration in offices and classrooms: increased window area over Standard 90.1 will increase heat loss and cooling loads caused by solar gains, but will reduce lighting energy consumption.

### 3 Evaluation Methodology

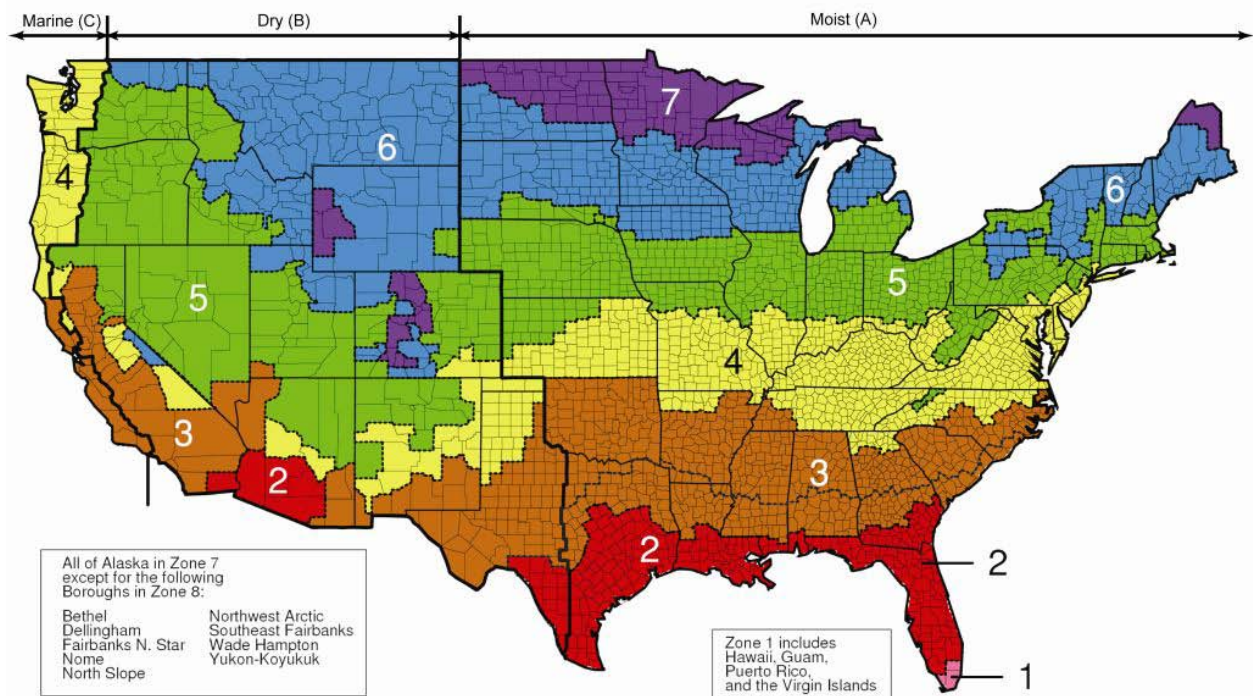
This section clarifies the methods and typical building definitions NREL used for its study of Standard 189.1-2009 (ASHRAE 2010). The methodology involves running EnergyPlus (DOE 2009) simulations on 16 building definitions. The building definitions and locations are borrowed from a separate project within the DOE Office of Energy Efficiency and Renewable Energy and the Building Technologies Program to develop commercial reference building energy models for commercial building analyses (Deru et al. 2010). The 16 building types were modeled in 16 locations for three separate code compliance scenarios; thus, 768 total simulations were run. The three scenarios include an ANSI/ASHRAE/IESNA 90.1-2004 (ASHRAE 2004b) code minimum building, a Standard 90.1-2007 (ASHRAE 2007b) code minimum building, and a Standard 189.1-2009 (ASHRAE 2010) code minimum building. Percent savings are computed on a whole-building basis, including energy used for plug and process loads, and Section 4 presents the results.

#### 3.1 Building Locations

The building models are simulated in 16 locations, representing the same 15 U.S. climate zones referenced in the DOE commercial reference modeling project (Deru et al. 2010). Two locations in climate zone 3B are simulated separately because they represent diverse conditions: Los Angeles, California (referred to as “3B:CA”), versus Las Vegas, Nevada (referred to as “3B:Other”). (See Table 3-1 and Figure 3-1 for more location-dependent information.) DOE chose this set of locations in consultation with various national laboratories, for use in the commercial reference building modeling project.

**Table 3-1 Building Locations**

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



**Figure 3-1 DOE climate zone map**  
 (Credit: Briggs et al. (2002); DOE (2005))

### 3.2 Building Definitions

The building definitions were drawn from a set of buildings developed under separate research being done to create “commercial reference building” EnergyPlus models for typical new construction (Deru et al. 2010). Their overall characteristics were distilled from the 2003 Commercial Buildings Energy Consumption Survey public use data (EIA 2005) and adapted to conform to representative industry practices and Standard 90.1-2004 (ASHRAE 2004b) code requirements. The reference buildings meet the mandatory provisions of Standard 189.1-2009 because they conform to Sections 5.4, 6.4, 7.4, 8.4, 9.4, and 10.4 of Standard 90.1. Table 3-2 summarizes the 16 buildings chosen for this study. Each was modeled with largely uniform characteristics across the 16 locations and was changed only in accordance with the climate-dependent content in the standards.

**Table 3-2 Building Definitions Used in Evaluation**

Building Type	Floor Area (ft <sup>2</sup> )	Floor Area (m <sup>2</sup> )	Number of Floors
Large office	498,588	46,320	12 + basement
Medium office	53,628	4,982	3
Small office	5,500	511	1
Warehouse	52,045	4,835	1
Stand-alone retail	24,962	2,294	1
Strip mall	22,500	2,090	1
Primary school	73,960	6,871	1
Secondary school	210,887	19,592	2
Supermarket	45,000	4,181	1
Quick service restaurant	2,500	232	1
Full service restaurant	5,500	511	1
Hospital	241,351	22,422	5 + basement
Outpatient healthcare	40,946	3,804	3
Small hotel	43,200	4,013	4
Large hotel	122,120	11,345	6
Midrise apartment	33,740	3,135	4

### 3.2.1 Form

In addition to the building form parameters shown in Table 3-2, other parameters, such as window-to-wall ratio and aspect ratio, were fixed and defined by building type from analysis of the national building stock. Deru et al. (2010) provide details on all building form parameters. The data sources are shown in Table 3-3.

**Table 3-3 Sources for Building Model Form Data**

Principal Building Activity	Data Source
Small office	EIA 2005, Jarnagin et al. 2006
Medium office	EIA 2005
Large office	EIA 2005
Primary school	Pless et al. 2007
Secondary school	Pless et al. 2007
Stand-alone retail	EIA 2005
Strip mall	EIA 2005
Supermarket	EIA 2005
Quick service restaurant	Huang et al. 1991
Full service restaurant	Huang et al. 1991
Small hotel	Jiang et al. 2008
Large hotel	Huang et al. 1991
Hospital	Huang et al. 1991
Outpatient healthcare	Bonnema et al. 2009
Warehouse	Liu et al. 2007
Midrise apartment	Gowri et al. 2007

### 3.2.2 Envelope

#### 3.2.2.1 Fabric

A building's fabric includes the construction types and thermal properties of its walls, roofs, floors, and windows. Deru et al. (2010) discuss the choice of all fabric parameters in detail.

Standard 90.1–2004 defines three primary roof types based on the location of insulation relative to the roof, with the following assumptions:

- Insulation Entirely Above Deck: Continuous insulation above the structural roof deck.
- Metal Building: Insulation compressed between structural members.
- Attic and Other: Insulation between roof joists.

Table 3-4 lists the roof constructions used in each building type modeled in this study.

**Table 3-4 Roof Constructions by Building Type**

Building Type	Roof Construction
Small office	Attic and other
Medium office	Insulation entirely above deck
Large office	Insulation entirely above deck
Primary school	Insulation entirely above deck
Secondary school	Insulation entirely above deck
Stand-alone retail	Insulation entirely above deck
Strip mall	Insulation entirely above deck
Supermarket	Insulation entirely above deck
Quick service restaurant	Attic and other
Full service restaurant	Attic and other
Small hotel	Insulation entirely above deck
Large hotel	Insulation entirely above deck
Hospital	Insulation entirely above deck
Outpatient healthcare	Insulation entirely above deck
Warehouse	Metal building roof
Midrise apartment	Insulation entirely above deck

Standard 90.1–2004 defines four exterior wall types based on the functional performance of the wall, with the following assumptions:

- Mass Wall: Continuous insulation.
- Metal Building Wall: Insulation compressed between metal members, possibly augmented by continuous insulation to decrease the overall U-factor.
- Steel Framed Wall: Simple frame wall with different structural members (and therefore different thermal bypass factors).
- Wood Framed and Other Wall: Simple frame wall with different structural members (and therefore different thermal bypass factors).

Table 3-5 shows the exterior wall types used in our building models.



**Table 3-5 Exterior Wall Constructions by Building Type**

<b>Building Type</b>	<b>Exterior Wall Construction</b>
Small office	Mass
Medium office	Steel frame
Large office	Mass
Primary school	Steel frame
Secondary school	Steel frame
Stand-alone retail	Mass
Strip mall	Steel frame
Supermarket	Mass
Quick service restaurant	Wood frame
Full service restaurant	Steel frame
Small hotel	Steel frame
Large hotel	Mass
Hospital	Mass
Outpatient healthcare	Steel frame
Warehouse	Metal building
Midrise apartment	Steel frame

Thermal properties of the fabric parameters were determined based on the standard applied. To model the building fabric (roofs, walls, floors, slabs, doors, vertical glazing, and skylights) recommendations in Standard 189.1-2009, we applied Tables A-1 through A-8 from the Standard to the energy models based on climate zone. In the Standard 189.1-2009 analysis, high albedo roofs were applied in climate zones 1–3.

### **3.2.2.2 Overhangs**

Overhangs were applied as a part of the Standard 189.1-2009 analysis. Overhangs with a projection factor of 0.5 were applied to all west, south, and east windows in climate zones 1–5 to comply with section 7.4.2.5 of Standard 189.1-2009. No overhangs were used on the Standard 90.1 models.

### **3.2.2.3 Air Barrier**

Standard 189.1-2009 requires a continuous air barrier. This was modeled with an infiltration reduction of 25% for buildings with fewer than 7 floors or that are in climate zones 4–8.

## **3.2.3 Internal Loads**

### **3.2.3.1 Lighting Power Density**

We used the space-by-space method from Standard 90.1 to determine maximum lighting power densities (LPDs) for the 90.1 building models. A 10% LPD reduction over Standard 90.1 was applied to all spaces types, except retail, to comply with section 7.4.6.1 of Standard 189.1-2009 for the 189.1-2009 building models.

### **3.2.3.2 Occupancy Sensors**

Neither Standard 90.1-2004 nor 90.1-2007 requires occupancy sensor controls to reduce electric lighting consumption. However, Standard 189.1-2009 does specify such requirements, depending on use type and physical dimensions. This analysis includes these lighting controls in

the Standard 189.1-2009 models when applicable. Occupancy sensors were modeled as a 10% LPD reduction for public spaces, offices, schools, lodging, and unspecified space types and a 5% LPD reduction for warehouses.

### 3.2.3.3 Daylighting

Neither Standard 90.1-2004 nor 90.1-2007 requires daylighting controls to reduce electric lighting consumption. However, Standard 189.1-2009 does specify such requirements, depending on use type and physical dimensions. This analysis includes these lighting controls in the Standard 189.1-2009 models when applicable. Daylighting controls were applied in all zones with windows or skylights, except hotel/motel guest rooms and apartment buildings. There is one continuous dimming daylighting sensor per EnergyPlus zone with a set point of 40 fc (400 lux). Skylights were added in zones if all the following criteria were met:

- In climate zones 1–6
- Square footage greater than 20,000 ft<sup>2</sup> (2,000 m<sup>2</sup>)
- Not an education facility
- Floor-to-floor height greater than 15 ft (3.5 m)
- Three or fewer floors.

If these criteria were met, skylights were added at the following skylight to floor area percentages according to Table 8.3.4.1 in Standard 189.1-2009:

- 3.0% if the LPD was greater than 0.5 W/ft<sup>2</sup> (5 W/m<sup>2</sup>) but less than 0.9 W/ft<sup>2</sup> (10 W/m<sup>2</sup>)
- 3.3% if the LPD was greater than 0.9 W/ft<sup>2</sup> (10 W/m<sup>2</sup>) but less than 1.3 W/ft<sup>2</sup> (14 W/m<sup>2</sup>)
- 3.6% if the LPD was greater than 1.3 W/ft<sup>2</sup> (14 W/m<sup>2</sup>).

### 3.2.3.4 Occupancy Controls

Standard 189.1-2009 requires automatic controls for hotel and motel guest rooms. These controls are modeled by applying a unique schedule for lighting, plug loads, and thermostat set points to mimic unoccupied and occupied times.

### 3.2.3.5 Plug and Process Loads

Determining the plug or process load intensity is difficult because available measured data are scarce. These models used the following assumptions for the reference buildings:

- Experience with a small number of buildings
- Previous work by Huang et al. (1991)
- Levels from ANSI/ASHRAE/IESNA Standard 90.1-1989 (ASHRAE 1989)
- The ASHRAE/AIA/IESNA/USGBC/DOE Advanced Energy Design Guide series.

The plug and process loads and schedules were determined at the zone level, based on the activities in each zone (Deru et al. 2010). Table 3-6 lists the main references for the plug and process loads by building type. Kitchen loads for all building models with kitchens are shown in Table 3-7.

Standard 189.1-2009 specifies ENERGY STAR equipment for office computers, photocopiers, ice machines, dishwashers, clothes washers, commercial kitchen fryers, etc. This analysis accounts for this often significant measure in the 189.1-2009 models. However, it does not account for the energy savings associated with each piece of equipment in each model. For expediency, we assumed a reduction of 10% to represent efficient miscellaneous equipment.

All lighting, occupancy, and plug and process load inputs are combined in EnergyPlus with schedule values. Deru et al. (2010) discuss data sources for the schedule values used in these models.

**Table 3-6 Plug and Process Load References**

Building Type	Data Source
Small office	Huang et al. 1991
Medium office	Huang et al. 1991
Large office	Huang et al. 1991
Primary school	Pless et al. 2007
Secondary school	Pless et al. 2007
Stand-alone retail	Engineering judgment
Strip mall	Engineering judgment
Supermarket	Engineering judgment
Small hotel	Jiang et al. 2008
Large hotel	Huang et al. 1991
Hospital	Bonnema et al. 2009, GGHC 2007
Outpatient healthcare	Bonnema et al. 2009, GGHC 2007
Warehouse	Liu et al. 2007
Midrise apartment	Hendron 2007

**Table 3-7 Commercial Kitchen Loads**

Building	Gas Load (kW)	Electricity Load (kW)
Primary school	160	40
Secondary school	242	60
Supermarket deli	6	5
Supermarket bakery	11	3
Quick service restaurant	150	50
Full service restaurant	167	75
Large hotel	167	75
Hospital	283	75

Elevators were included in all buildings with multiple floors. They were modeled in EnergyPlus as a zone load but labeled as “elevators,” so they are reported separately in the EnergyPlus output. The number of elevators and the peak elevator motor power in the reference building models is shown in Table 3-8. These numbers were used in conjunction with the operating schedules to estimate the total electricity consumption of the elevators. For buildings with fewer than six stories (counting the basement), we assumed the elevators use hydraulic motors with no over counter weighting. In this case, the heat gain was added to a first floor zone. For buildings six stories and higher, we assumed the elevators use traction motors with 40% over counter weighting. In this case, the heat gain was considered an exterior load, as the elevator motors would likely be located in a dedicated mechanical room exhausted to the outdoors. The schedules were taken from Standard 90.1-1989 (ASHRAE 1989). Also, a motor efficiency of

91% is assumed, given the size of the motors and the guidance in Table 10.8 of Standard 90.1-2004 (ASHRAE 2004b).

**Table 3-8 Number of Elevators Installed and Motor Power**

<b>Building Type</b>	<b>Number of Elevators</b>	<b>Peak Motor Power (W/each)</b>
Medium office	2	14,610
Large office	12	18,537
Secondary school	2	14,610
Small hotel	2	14,610
Large hotel	6	18,537
Hospital	8	18,537
Outpatient healthcare	3	14,610
Midrise apartment	1	14,610

The peak service water heating (SWH) demand for each reference building model space type is shown in Table 3-9. These numbers were used in conjunction with the operating schedules to estimate the total hot water consumption. Natural gas water heaters were used in all cases, and storage tanks were kept at 140°F (60°C). The application of the standards determines the efficiencies of the storage tank heaters. Deru et al. (2010) discuss the data sources for the SWH model inputs.

SWH equipment efficiencies were determined from an EnergyPlus sizing simulation to establish system size and Table C-12 in Standard 189.1-2009. Mains water temperature variation by location is taken into account during the EnergyPlus sizing simulation. Also, water flow rates were reduced by an assumed 10% in all zones and by 20% in food sales and healthcare zones to model low-flow fixtures.

**Table 3-9 Nominal Peak Service Water Heating Demand**

Space Type	Peak Nominal Use Rate	
	gal/h	L/h
Guest room (small hotel)	1.75	6.6
Guest room (large hotel)	1.25	4.7
Laundry (small hotel)	67.5	255.5
Laundry (large hotel)	156.6	592.8
Restrooms (primary school)	56.5	214.0
Restrooms (secondary school)	104.4	395.0
Gym (secondary school)	189.5	717.2
Small office	3.0	11.4
Medium office (per floor)	9.9	37.5
Large office (per floor)	21.3	80.6
Apartment	3.5	13.2
Outpatient health care	40.0	155.0
Hospital ER waiting room	1.0	3.8
Hospital operating/surgical	2.0	7.6
Hospital lab	2.0	7.6
Hospital patient room	1.0	3.8
Kitchen (primary school)	100.0	379.0
Kitchen (secondary school)	133.0	503.0
Kitchen (full service restaurant)	133.0	503.0
Kitchen (quick service restaurant)	40.0	155.0
Kitchen (large hotel)	133.0	503.0
Kitchen (hospital)	150.0	568.0
Supermarket bakery	5.0	19.0
Supermarket deli	5.0	19.0

### 3.2.4 HVAC Mechanical Equipment

#### 3.2.4.1 System Types and Sizes

Appendix G of Standard 90.1-2004 (ASHRAE 2004b) specifies HVAC equipment to use for baseline buildings, depending on a building's floor area, number of floors, and whether its primary use is residential or nonresidential. The resulting system types used in this study are shown in Table 3-10. In some cases, these system types differ from those used in the reference building models, as Deru et al. (2010) did not employ Appendix G criteria to choose system types.

**Table 3-10 HVAC Equipment Types**

Building Type	System Number	System Type	Heating Type	Cooling Type	Fan Control
Small office	3. PSZ-AC	Packaged rooftop air conditioner	Fossil fuel furnace	Direct expansion	Constant volume
Medium office	3. PSZ-AC	Packaged rooftop air conditioner	Fossil fuel furnace	Direct expansion	Constant volume
Large office	7. VAV with reheat	Packaged rooftop variable air volume with reheat	Hot water fossil fuel boiler	Chilled water	Variable volume
Primary school	3. PSZ-AC	Packaged rooftop air conditioner	Fossil fuel furnace	Direct expansion	Constant volume
Secondary school	7. VAV with reheat	Packaged rooftop variable air volume with reheat	Hot water fossil fuel boiler	Chilled water	Variable volume
Stand-alone retail	3. PSZ-AC	Packaged rooftop air conditioner	Fossil fuel furnace	Direct expansion	Constant volume
Strip mall	3. PSZ-AC	Packaged rooftop air conditioner	Fossil fuel furnace	Direct expansion	Constant volume
Supermarket	3. PSZ-AC	Packaged rooftop air conditioner	Fossil fuel furnace	Direct expansion	Constant volume
Quick service restaurant	3. PSZ-AC	Packaged rooftop air conditioner	Fossil fuel furnace	Direct expansion	Constant volume
Full service restaurant	3. PSZ-AC	Packaged rooftop air conditioner	Fossil fuel furnace	Direct expansion	Constant volume
Small hotel	1. PTAC	Packaged terminal air conditioner	Hot water fossil fuel boiler	Direct expansion	Constant volume
Large hotel	1. PTAC	Packaged terminal air conditioner	Hot water fossil fuel boiler	Direct expansion	Constant volume
Hospital	7. VAV with reheat	Packaged rooftop variable air volume with reheat	Hot water fossil fuel boiler	Chilled water	Variable volume
Outpatient healthcare	3. PSZ-AC	Packaged rooftop air conditioner	Fossil fuel furnace	Direct expansion	Constant volume
Warehouse	3. PSZ-AC	Packaged rooftop air conditioner	Fossil fuel furnace	Direct expansion	Constant volume
Midrise apartment	1. PTAC	Packaged terminal air conditioner	Hot water fossil fuel boiler	Direct expansion	Constant volume

Equipment sizing for all models was determined from design day runs by EnergyPlus for each location with a sizing factor of 1.2. Nominal coefficient of performance, energy efficiency ratio (EER), seasonal energy efficiency ratio (SEER), and boiler and furnace efficiencies were taken from the appropriate energy standard based on equipment type and size.

#### **3.2.4.2 HVAC Equipment Efficiency**

Cooling equipment efficiencies for the Standard 189.1-2009 analysis were determined from an EnergyPlus sizing simulation to establish system size and Tables C-1 through C-5 (depending on system type). Heating equipment efficiencies were determined from an EnergyPlus sizing simulation to establish system size and Table C-6 and Table C-7 (depending on system type). In the 90.1 analysis, Tables 6.8.1 were used to determine the HVAC equipment efficiencies. Details on HVAC equipment efficiency calculations are presented in Appendix B.

#### **3.2.4.3 Economizers**

Economizer operation was determined from the cooling system size and climate zone following Standard 90.1-2004 requirements. In the Standard 189.1-2009 analysis, economizers were not applied in climate zones 1A, 1B, and 2A. In all other climates zones, economizers were applied by first performing an EnergyPlus sizing run to determine the air system size. If the system was larger than 33,000 Btu/h (9.7 kW), a differential enthalpy controlled economizer was modeled.

#### **3.2.4.4 Demand Control Ventilation**

Whether a system employs demand control ventilation (DCV) depends on the provisions of the applied standard. The Standard 90.1 criteria determine the presence or absence of DCV on any given system in the Standard 90.1 models. Standard 189.1-2009 outlines some carbon dioxide monitoring criteria, but these are difficult to quantify from those in Standard 90.1 in terms of the energy models. As a simplification, DCV was installed in EnergyPlus zones with occupancy higher than 25 people per 1000 ft<sup>2</sup> (25 people per 100 m<sup>2</sup>).

#### **3.2.4.5 Energy Recovery**

Implementing energy recovery on a system also follows the guidelines of the applied standard. Standard 189.1-2009 guidelines differ substantially from those in Standards 90.1-2004 and 90.1-2007. The latter specify energy recovery for systems with airflow greater than 5,000 ft<sup>3</sup>/min (2,360 L/s) and a minimum outside air ratio of 70%. Standard 189.1-2009 specifies energy recovery depending on air flow, climate zone, and outside air ratios. Including the climate zones enables Standard 189.1-2009 to capture more systems for which energy recovery produces a saving instead of a penalty. Energy recovery requirements were determined from an EnergyPlus sizing simulation to determine system size and Table 7.4.3.8 in Standard 189.1-2009.

#### **3.2.4.6 Fans**

EnergyPlus requires the fan pressure rise, total efficiency, motor efficiency, and fraction of the motor in the air stream. For all cases, we assumed that the fraction of the motor in the air stream is 1.0. The other inputs are summarized in Table 3-11 for each fan type. Table 3-11 also lists the nominal motor efficiencies. The actual motor efficiency is determined for each case automatically by applying the standard after a sizing run is completed. Fan system flow rates are determined by EnergyPlus during system sizing.

**Table 3-11 Fan System Inputs**

System Type	Pressure Rise		Fan Mechanical Efficiency	Motor Efficiency	Total Fan Efficiency
	in. w.c.	Pa			
Exhaust fans	0.5	125	(a)	(a)	0.338
Packaged rooftop air conditioner	2.0	500	0.26	(b)	(c)
Packaged terminal air conditioner	1.2	300	0.16	(b)	(c)
Packaged rooftop variable air volume with reheat	2.4	600	0.25	(b)	(c)

- (a) Exhaust fans were modeled as exterior loads, so only the total efficiency is important.
- (b) Motor efficiency was calculated for each simulation from the total system flow rate, pressure rise, and fan mechanical efficiency to meet Standard 90.1-2004 requirements.
- (c) Total fan efficiency is the product of fan mechanical efficiency and nominal motor efficiency. For example, a nominal motor efficiency of 80% and a fan mechanical efficiency of 60% produce a total fan efficiency of 48%.

Exhaust fans typically have lower total efficiencies than do space-conditioning fans. We assume a pressure rise of 0.5 in. w.c. (125 Pa) and a total fan efficiency of 0.338 for typical exhaust fans. Because the heat from exhaust fans is released to the outdoors, only their total efficiencies are important. In Standard 189.1-2009, commercial kitchen exhaust fans are required to have variable-speed controls that reduce their speed to 50% while they are in standby mode. Because few reliable data are available to inform the schedule of these exhaust fan turn-downs, and in the interest of expediency, we used a simplified approach to capture this effect. As with miscellaneous ENERGY STAR equipment, kitchen exhaust fans are reduced by 10% at all times in the Standard 189.1-2009 models.

For the packaged rooftop air conditioner, we modeled pressure rise of 2.0 in. w.c. (500 Pa) and a mechanical fan efficiency of 0.26. For the packaged terminal air conditioner, we modeled a pressure rise of 1.2 in. w.c. (300 Pa) and a mechanical fan efficiency of 0.16. For the packaged rooftop variable air volume with reheat, we modeled a pressure rise of 2.4 in. w.c. (600 Pa) and a mechanical fan efficiency of 0.25. These are the results of performing the calculations in Appendix B.

### **3.2.5 On-Site Power Generation**

According to Standard 189.1-2009, there are two possible prescriptive paths for compliance with the equipment efficiencies portion (7.4.3.1). The “higher efficiency” path (7.4.3.1b) is modeled in this study, instead of the “EPAAct baseline” path (7.4.3.1a). Notably, the “higher efficiency” choice reduces the amount of annual renewable energy production required from 6.0 kBtu/ft<sup>2</sup> (68 MJ/m<sup>2</sup>) of conditioned space to 4.0 kBtu/ft<sup>2</sup> (45 MJ/m<sup>2</sup>).

We followed 7.4.3.1b, so our on-site renewable energy requirement is 4.0 kBtu/ft<sup>2</sup> (45 MJ/m<sup>2</sup>). Modeling this requirement required three steps:

- (1) Applied 1 m<sup>2</sup> of PV to the building surface.
- (2) Ran an EnergyPlus annual simulation to determine how much energy 1 m<sup>2</sup> of PV generates for the particular building in the particular climate zone.
- (3) Used the square footage of the building and the generation capacity of 1 m<sup>2</sup> of PV to expand the size of the PV array to meet the 4.0 kBtu/ft<sup>2</sup> (45 MJ/m<sup>2</sup>) requirement.



### **3.2.6 Weighting Factors**

Table 3-12 lists the weighting factors used in the analysis. Each building in each location has a weighting factor that represents how many such buildings are built each year. The weighting factors were developed separately as part of the reference building research and are based on McGraw-Hill Construction Projects Starts Database (McGraw Hill 2009).

McGraw-Hill (2009) draws from permit data for new commercial building starts in the United States and represents more than 90% of new commercial buildings. Data are collected in real time, and the collection process is independently monitored to ensure most U.S. commercial construction is covered. The strengths of this database are the number of samples, the frequency of data collection, the detailed data on project locations down to the local community level, and the fact that high-rise residential buildings are included (contrary to the Commercial Buildings Energy Consumption Survey). A weakness is the lack of characteristic data.

Jarnagin and Bandyopadhyay (2010) analyzed the McGraw-Hill database from 2003 to 2007 to develop weighting factors for the new construction reference building models. Total building areas for each model type and climate zone were determined over the five-year period. These numbers were divided by five to find the annual average, and then divided by the areas of the reference building models to find the weighting factors in Table 3-12.

**Table 3-12 Weighting Factor Matrix**

Building Type	Climate Zone															
	1A	2A	2B	3A	3B:CA	3B:Other	3C	4A	4B	4C	5A	5B	6A	6B	7	8
Small office	202	2,560	696	2,316	197	946	187	2,251	114	295	2,213	774	580	73	78	11
Medium office	32	200	72	189	73	103	34	294	9	48	261	84	74	9	8	2
Large office	3	9	2	12	5	3	3	30	0	4	12	3	4	0	0	0
Primary school	11	167	29	169	22	58	9	160	5	17	165	40	30	7	4	1
Secondary school	10	96	14	119	19	32	7	126	4	15	143	27	26	5	5	1
Stand-alone retail	119	1,177	269	1,265	174	489	101	1,349	63	227	1,818	420	503	48	58	7
Strip mall	81	583	149	600	99	269	61	593	13	63	601	118	90	9	4	1
Supermarket	3	49	14	58	10	26	5	94	2	11	113	16	25	3	3	1
Quick service restaurant	41	485	107	539	78	257	37	471	28	76	680	136	134	16	19	1
Full service restaurant	22	254	59	268	29	85	14	306	14	25	344	75	75	10	9	0
Small hotel	3	88	9	82	7	28	7	96	6	12	112	27	33	9	6	1
Large hotel	12	67	14	69	20	66	11	104	4	13	100	22	25	6	4	0
Hospital	2	26	5	26	7	7	2	34	1	6	45	12	12	1	2	0
Outpatient healthcare	12	183	43	188	31	58	20	264	8	58	342	70	111	11	13	1
Warehouse	89	659	148	754	136	443	39	622	17	111	910	175	118	12	11	1
Midrise apartment	101	429	37	324	272	66	102	664	9	145	440	125	123	22	13	0

## 4 Results

The evaluation results characterize the percent energy savings between Standards 90.1-2004, 90.1-2007, and 189.1-2009. Section 4.1 presents results by building type, and Section 4.2 presents results by climate zone. In both sections, multiple simulation results are averaged together using the weighting factors presented in Table 3-12. A list of all simulation results, in terms of percent savings and energy use intensity (EUI), appears in Table 4-1.

Overall, the weighted average savings of buildings complying with Standard 189.1-2009 over 90.1-2007 sum to 29.7%. Approximately two-thirds of these savings result from energy efficiency measures, and approximately one-third from renewable energy requirements.

### 4.1 Effect of Building Type

This section presents the level of percent savings achieved by following the recommendations in Standard 189.1-2009 over those achieved by following Standard 90.1-2007. Similarly, the savings associated with Standard 90.1-2007 are compared with those associated with the 2004 version of the Standard. Table 4-1 shows the percent savings results aggregated by building type.

**Table 4-1 Weighted Average Savings and EUI by Building Type**

Building Type	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007	90.1-2004 EUI (kBtu/ft <sup>2</sup> )	90.1-2007 EUI (kBtu/ft <sup>2</sup> )	189.1-2009 EUI (kBtu/ft <sup>2</sup> )
Small office	5.30%	30.90%	62.27	58.95	40.64
Medium office	3.55%	31.03%	45.61	43.99	30.33
Large office	3.53%	31.91%	36.74	35.41	24.09
Primary school	4.80%	32.85%	62.39	59.42	39.59
Secondary school	3.93%	32.37%	45.69	43.89	29.67
Stand-alone retail	4.68%	26.20%	72.00	68.65	49.92
Strip mall	3.56%	21.54%	68.32	65.86	51.49
Supermarket	1.78%	22.59%	185.10	181.78	140.16
Quick service restaurant	0.78%	27.57%	426.54	423.25	306.16
Full service restaurant	0.47%	33.03%	592.34	589.55	392.74
Small hotel	1.60%	34.30%	57.18	56.26	36.95
Large hotel	0.67%	25.48%	111.59	110.85	82.69
Hospital	2.00%	24.43%	86.10	84.36	63.56
Outpatient healthcare	4.84%	14.81%	136.99	130.38	111.10
Warehouse	1.43%	42.30%	21.04	20.74	11.92
Midrise apartment	3.21%	31.82%	46.92	45.37	30.68
All	3.76%	29.72%	108.87	106.11	75.26

The results in Table 4-1 show that the percent savings seen by complying with Standard 189.1-2009 depend significantly on the primary activity of a building.

The warehouse building type shows the greatest savings of all the 16 types studied. Recalling the method that renewable energy requirements are specified in Standard 189.1-2009 makes this result fairly simple to explain. We used the “EPAct baseline” prescriptive path to determine

equipment efficiencies (Section 7.4.3.1 of Standard 189.1-2009); the amount of renewable energy required was calculated as 4.0 kBtu/ft<sup>2</sup> (45 MJ/m<sup>2</sup>) of conditioned floor area. The warehouse building type shows the lowest EUIs—the weighted average of Standard 90.1-2007 compliant buildings totals 20.7 kBtu/ft<sup>2</sup> (234 MJ/m<sup>2</sup>)—of the set of building types simulated. Therefore, the renewable energy requirement alone lowers the average warehouse EUI by 19%. The renewable EUI reduction is constant for all building types, so its impact on the total percent savings increases for buildings starting with low EUIs, and vice versa.

All three office building models (small, medium, and large), both school models (primary and secondary), and the midrise apartment building model experience the same effect because of the renewable energy requirement. All these building types begin with EUIs lower than 60.0 kBtu/ft<sup>2</sup> (681 MJ/m<sup>2</sup>) for Standard 90.1-2007 models, so the 4.0 kBtu/ft<sup>2</sup> (45 MJ/m<sup>2</sup>) of energy offset by renewables has a significant impact on the Standard 189.1-2009 results.

The small hotel also shows significant savings with Standard 189.1-2009, compared to Standard 90.1-2007. The same effect of the renewable energy requirement can be seen for the small hotel as for the warehouse, but it does not entirely explain the larger savings in the small hotel. The small hotel model consists almost exclusively of guest rooms, and Standard 189.1-2009 requires that lighting, plug loads, and HVAC equipment respond to occupancy sensor signals. When rooms are vacant, lights, plug loads, and ventilation turn off, and temperature set points are set up or back to save HVAC energy.

The large hotel Standard 189.1-2009 model also complies with the guest room rules, but its savings are less dramatic. The explanation for this difference involves the effect of the renewable energy requirement; the weighted average of the large hotel model is roughly double that of the small hotel model.

Both healthcare models—hospital and outpatient facility—show relatively low savings between Standard 90.1-2007 and Standard 189.1-2009. Because these facilities have high process load requirements, and because medical plug loads do not have the same identifiable means for saving energy as food service and office equipment (ENERGY STAR), these facilities have more difficulty reducing energy by simply lowering lighting wattage and increasing HVAC efficiencies.

## **4.2 Effect of Climate**

Similar to Section 4.1, this section presents the level of percent savings of Standard 189.1-2009 over Standard 90.1-2007, as well as Standard 90.1-2007 over Standard 90.1-2004. Table 4-2 shows the percent savings results aggregated by climate zone.

**Table 4-2 Weighted Average Savings by Climate Zone**

<b>Climate Zone (Representative City)</b>	<b>90.1-2007 Versus 90.1-2004</b>	<b>189.1-2009 Versus 90.1-2007</b>
1A (Miami, Florida)	2.2%	25.8%
2A (Houston, Texas)	5.8%	25.5%
2B (Phoenix, Arizona)	7.8%	27.2%
3A (Atlanta, Georgia)	3.0%	28.0%
3B:CA (Los Angeles, California)	2.0%	25.8%
3B:Other (Las Vegas, Nevada)	2.9%	28.6%
3C (San Francisco, California)	2.1%	27.0%
4A (Baltimore, Maryland)	3.7%	31.6%
4B (Albuquerque, New Mexico)	3.5%	27.8%
4C (Seattle, Washington)	3.5%	28.6%
5A (Chicago, Illinois)	3.2%	33.7%
5B (Boulder, Colorado)	3.2%	28.9%
6A (Minneapolis, Minnesota)	3.1%	35.6%
6B (Helena, Montana)	3.0%	31.3%
7 (Duluth, Minnesota)	3.0%	40.0%
8 (Fairbanks, Alaska)	1.5%	43.1%
All	3.8%	29.7%

For comparisons between standards, the percent savings by climate do not stray far from the weighted average in most climate zones. In the comparison of Standards 189.1-2009 and 90.1-2007, only three climate zones deviate more than 5% from the weighted average of 29.7% savings. Climate zones 6A, 7, and 8 show more than 5% savings than the weighted average. For these three, the savings increase with the heating degree days associated with that climate zone.

We may be tempted to conclude that increased heating efficiencies or DCV controls have caused this trend; however, an examination of the weighting factors in Table 3-12 by climate zone reveals that such a conclusion is not easily justified. Although climate zone 6A contains a significant share of the weighting, climate zones 7 and 8 do not. Drawing a conclusion about the effects of applying Standard 189.1-2009 in northern Minnesota (climate zone 7), for example, may not be prudent, as only 0.6% of all buildings represented by these data are in the same climate.

On the other hand, an examination of the percent savings by building type and climate (not multiplied by any weighting factors) shown in the tables of the Appendix, reveals a trend toward significantly greater savings in climate zones 7 and 8. All building types except hotels and warehouses follow this trend. Occupancy control-based savings dominate the savings in the hotel models, and renewable energy savings comprise most of the warehouse savings; therefore, heating or outdoor air savings would seem relatively small by comparison, and the hotel and warehouse models would show less variation in savings by climate zone than the other building types.

These results indicate that buildings (except for hotels and warehouses) that comply with Standard 189.1-2009 in very cold climates are likely to show significantly higher savings than their counterparts in warmer climates.

### 4.3 Comparison to DOE Commercial Reference Buildings

We used the commercial reference buildings as a starting point. In the interest of model validation, we compared the Standard 90.1-2004 models to those released as new construction, Standard 90.1-2004, commercial reference buildings. Table 4-3 shows the results.

**Table 4-3 Comparison to Reference Buildings**

Building Type	Reference Building EUI (kBtu/ft <sup>2</sup> )	90.1-2004 EUI (kBtu/ft <sup>2</sup> )	Percent Difference*
Small hotel	75	57	-24%
Large hotel	121	112	-8%
Small office	45	62	38%
Medium office	43	46	6%
Large office	39	37	-6%
Hospital	144	86	-40%
Midrise apartment	41	47	14%
Outpatient care	273	137	-50%
Primary school	58	62	8%
Secondary school	66	46	-31%
Quick service restaurant	596	427	-28%
Full service restaurant	476	592	24%
Supermarket	178	185	4%
Stand-alone retail	69	72	4%
Strip mall	71	68	-4%
Warehouse	21	21	0%

\* With respect to the reference building EUI

Most of the variations between models result from the use of Standard 90.1-2004 Appendix G systems in this analysis, as opposed to those the ASHRAE 90.1 Mechanical Subcommittee agreed on for the commercial reference buildings. Table 4-3 shows some relatively insignificant differences for the large hotel, medium and large offices, primary school, supermarket, stand-alone retail, strip mall, and warehouse. The EUI values from these models do not vary significantly from those of the commercial reference buildings. However, some building types show significant differences because of the changes in system types.

The hospital and outpatient care buildings show the largest EUI deviations from the commercial reference buildings. Their reference building versions include particularly important system features that are not captured by the application of Standard 90.1-2004 Appendix G system types. The most important system features that appear in the commercial reference buildings and not in the Standard 90.1-2004 Appendix G system types of this analysis are humidification controls and minimum supply air flows dictated by AIA Standard 2001 (AIA 2001). Humidification controls in the healthcare reference buildings increase cooling energy and reheat heating energy, and the increased supply air flows in the healthcare reference buildings significantly increase fan energy.

## 5 Conclusions

The energy impacts analysis of Standard 189.1-2009 is not overly complicated or detailed; rather, it is an order-of-magnitude analysis. Several conclusions, which would likely persist in a more detailed analysis, can thus be drawn from its results. The most important conclusions are:

- Standard 189.1-2009 goes much further in terms of energy savings over Standard 90.1-2007 than Standard 90.1-2007 does over its 2004 counterpart. This analysis shows that the weighted average savings seen in the former comparison are roughly 8 times those seen in the latter.
- Results vary significantly by building type.
- Except for hotels and warehouses, buildings in very cold climate zones (6A, 7, 8) show significantly higher savings than those in climate zones 1–5.
- About two-thirds of the savings of Standard 189.1-2009 over Standard 90.1-2007 come from energy efficiency measures, and about one-third from the renewable energy requirement in Standard 189.1-2009.
- Low-EUI sectors, such as offices and warehouses, show large energy savings because the 4.0 kBtu/ft<sup>2</sup> (45 MJ/m<sup>2</sup>) renewable energy savings constitute a larger percentage of the total building EUI than for high-EUI sectors.
- Lodging buildings dominated by guest room space, as in the small hotel model, show significant additional savings. These savings come from the Standard 189.1-2009 requirements to setback lighting, plug loads, and HVAC when rooms are unoccupied.
- Healthcare buildings see smaller savings because medical plug loads constitute such a large portion of their energy consumption, yet standard methods for reducing their intensity (ENERGY STAR) have not been written.
- Generally, as Standard 189.1-2009 pushes the boundaries of efficiency for lighting and HVAC equipment, as well as some plug loads, the “other” process loads become more critical to a building’s potential for energy savings. Future research needs to address these loads.

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## Appendix A. Simulation Results

Appendix A presents numerous tables showing simulation results. Table A-1 shows average percent savings by building type, Table A-2 through Table A-17 show average percent savings by climate zone for each of the 16 building types, and Table A-18 through Table A-21 show percent savings comparisons for each standard by building type. Table A-22 through Table A-33 show energy intensity values for each of the standards by building type, in both SI and IP units.

### A.1 Percent Savings

**Table A-1 Average Percent Savings by Building Type**

<b>Building Type</b>	<b>90.1-2007 versus 90.1-2004</b>	<b>189.1-2009 versus 90.1-2007</b>
Small hotel	1.60%	34.30%
Large hotel	0.67%	25.48%
Small office	5.30%	30.90%
Medium office	3.55%	31.03%
Large office	3.53%	31.91%
Hospital	2.00%	24.43%
Midrise apartment	3.21%	31.82%
Outpatient care	4.84%	14.81%
Primary school	4.80%	32.85%
Secondary school	3.93%	32.37%
Quick service restaurant	0.78%	27.57%
Full service restaurant	0.47%	33.03%
Supermarket	1.78%	22.59%
Stand-alone retail	4.68%	26.20%
Strip mall	3.56%	21.54%
Warehouse	1.43%	42.30%
All	3.76%	29.72%

**Table A-2 Percent Savings by Climate Zone: Quick Service Restaurant**

Climate Zone	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007
1A	0.82%	23.28%
2A	0.79%	25.11%
2B	0.74%	27.14%
3A	0.90%	27.00%
3B:CA	0.92%	25.59%
3B:Other	1.09%	25.55%
3C	0.83%	24.41%
4A	0.78%	29.06%
4B	1.11%	24.07%
4C	0.91%	22.57%
5A	0.55%	30.74%
5B	0.87%	22.73%
6A	0.54%	32.39%
6B	0.52%	29.11%
7	0.30%	33.91%
8	0.19%	36.27%
All	0.78%	27.57%

**Table A-3 Percent Savings by Climate Zone: Hospital**

Climate Zone	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007
1A	0.05%	22.72%
2A	3.15%	21.95%
2B	5.08%	19.42%
3A	1.00%	22.54%
3B:CA	0.43%	18.50%
3B:Other	1.05%	19.46%
3C	0.88%	18.27%
4A	2.00%	25.90%
4B	1.60%	18.93%
4C	2.30%	17.60%
5A	2.12%	28.29%
5B	1.83%	18.07%
6A	2.02%	33.40%
6B	2.03%	28.85%
7	2.20%	37.11%
8	1.39%	44.10%
All	2.00%	24.43%

**Table A-4 Percent Savings by Climate Zone: Large Hotel**

Climate Zone	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007
1A	1.02%	29.46%
2A	0.94%	27.71%
2B	1.13%	28.12%
3A	0.67%	25.82%
3B:CA	0.66%	25.66%
3B:Other	0.67%	27.13%
3C	0.36%	24.42%
4A	0.59%	24.85%
4B	0.70%	24.76%
4C	0.41%	23.85%
5A	0.58%	24.02%
5B	0.58%	23.86%
6A	0.68%	23.23%
6B	0.54%	22.70%
7	0.65%	22.07%
8	0.94%	21.38%
All	0.67%	25.48%

**Table A-5 Percent Savings by Climate Zone: Large Office**

Climate Zone	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007
1A	0.01%	32.26%
2A	8.45%	27.68%
2B	9.70%	30.48%
3A	1.69%	28.64%
3B:CA	0.28%	29.85%
3B:Other	1.78%	28.70%
3C	1.14%	29.98%
4A	3.78%	33.90%
4B	2.89%	31.83%
4C	4.29%	33.20%
5A	3.48%	32.52%
5B	2.96%	35.86%
6A	3.05%	36.16%
6B	2.98%	36.12%
7	2.98%	38.61%
8	2.09%	45.35%
All	3.53%	31.91%

**Table A-6 Percent Savings by Climate Zone: Medium Office**

<b>Climate Zone</b>	<b>90.1-2007 Versus 90.1-2004</b>	<b>189.1-2009 Versus 90.1-2007</b>
1A	2.16%	28.53%
2A	2.39%	28.68%
2B	2.53%	31.07%
3A	3.39%	31.80%
3B:CA	2.51%	29.47%
3B:Other	3.70%	30.08%
3C	2.80%	30.23%
4A	4.87%	32.28%
4B	4.55%	29.74%
4C	4.64%	30.77%
5A	3.64%	31.77%
5B	3.31%	30.32%
6A	3.91%	32.60%
6B	3.81%	31.90%
7	2.06%	34.75%
8	0.42%	39.98%
All	3.55%	31.03%

**Table A-7 Percent Savings by Climate Zone: Midrise Apartment**

<b>Climate Zone</b>	<b>90.1-2007 Versus 90.1-2004</b>	<b>189.1-2009 Versus 90.1-2007</b>
1A	1.32%	31.92%
2A	4.10%	30.26%
2B	4.46%	28.74%
3A	3.75%	29.72%
3B:CA	0.70%	22.10%
3B:Other	2.89%	28.47%
3C	1.35%	22.95%
4A	3.29%	34.19%
4B	2.85%	28.80%
4C	3.04%	28.05%
5A	3.76%	37.27%
5B	3.23%	32.52%
6A	4.03%	43.41%
6B	3.78%	38.16%
7	10.39%	45.42%
8	10.04%	52.74%
All	3.21%	31.82%

**Table A-8 Percent Savings by Climate Zone: Outpatient Care**

Climate Zone	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007
1A	3.63%	18.37%
2A	4.31%	17.53%
2B	4.55%	19.01%
3A	5.32%	18.04%
3B:CA	5.17%	18.49%
3B:Other	6.10%	15.85%
3C	4.35%	16.30%
4A	5.75%	16.23%
4B	6.11%	13.72%
4C	5.56%	11.81%
5A	4.23%	11.96%
5B	4.60%	11.13%
6A	4.16%	10.39%
6B	4.35%	7.54%
7	2.77%	20.64%
8	1.14%	22.17%
All	4.84%	14.81%

**Table A-9 Percent Savings by Climate Zone: Full Service Restaurant**

Climate Zone	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007
1A	0.74%	25.86%
2A	0.55%	28.32%
2B	0.76%	27.24%
3A	0.39%	31.03%
3B:CA	0.54%	25.89%
3B:Other	0.58%	29.00%
3C	0.23%	30.27%
4A	0.24%	34.95%
4B	0.28%	31.88%
4C	0.14%	34.44%
5A	0.53%	37.32%
5B	0.54%	34.42%
6A	0.75%	39.05%
6B	0.78%	37.49%
7	0.76%	48.48%
8	0.37%	55.83%
All	0.47%	33.03%

**Table A-10 Percent Savings by Climate Zone: Stand-Alone Retail**

<b>Climate Zone</b>	<b>90.1-2007 Versus 90.1-2004</b>	<b>189.1-2009 Versus 90.1-2007</b>
1A	2.03%	15.47%
2A	9.34%	14.80%
2B	12.11%	19.35%
3A	3.02%	21.88%
3B:CA	2.78%	16.94%
3B:Other	3.16%	19.96%
3C	2.43%	22.58%
4A	3.93%	30.18%
4B	3.74%	20.58%
4C	4.09%	24.19%
5A	3.88%	35.20%
5B	3.45%	22.19%
6A	3.76%	39.34%
6B	3.86%	25.13%
7	3.67%	45.00%
8	0.67%	48.74%
All	4.68%	26.20%

**Table A-11 Percent Savings by Climate Zone: Primary School**

<b>Climate Zone</b>	<b>90.1-2007 Versus 90.1-2004</b>	<b>189.1-2009 Versus 90.1-2007</b>
1A	1.18%	30.57%
2A	4.93%	31.06%
2B	5.14%	29.34%
3A	5.43%	32.68%
3B:CA	4.08%	27.51%
3B:Other	5.87%	24.72%
3C	3.60%	23.33%
4A	5.71%	36.86%
4B	6.01%	20.19%
4C	3.89%	15.89%
5A	3.49%	39.63%
5B	4.22%	16.83%
6A	4.23%	42.33%
6B	4.07%	35.09%
7	3.02%	46.33%
8	0.05%	47.96%
All	4.80%	32.85%

**Table A-12 Percent Savings by Climate Zone: Secondary School**

Climate Zone	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007
1A	0.01%	30.98%
2A	1.23%	31.01%
2B	1.80%	32.30%
3A	3.39%	31.07%
3B:CA	-1.00%	27.62%
3B:Other	2.97%	31.91%
3C	2.87%	29.72%
4A	6.35%	32.45%
4B	5.03%	32.69%
4C	4.39%	31.02%
5A	4.84%	33.94%
5B	4.39%	33.46%
6A	5.92%	36.99%
6B	5.78%	35.54%
7	4.54%	39.38%
8	0.80%	42.81%
All	3.93%	32.37%

**Table A-13 Percent Savings by Climate Zone: Supermarket**

Climate Zone	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007
1A	0.67%	19.43%
2A	2.88%	19.65%
2B	2.84%	16.91%
3A	1.20%	21.38%
3B:CA	0.33%	14.95%
3B:Other	1.09%	16.31%
3C	0.16%	15.98%
4A	1.74%	23.84%
4B	1.42%	17.12%
4C	1.02%	17.87%
5A	1.93%	25.96%
5B	1.66%	18.37%
6A	2.07%	28.97%
6B	1.89%	21.12%
7	2.03%	35.18%
8	0.31%	42.06%
All	1.78%	22.59%



**Table A-14 Percent Savings by Climate Zone: Small Hotel**

Climate Zone	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007
1A	1.53%	37.23%
2A	1.58%	36.07%
2B	2.41%	36.50%
3A	1.21%	34.55%
3B:CA	0.60%	34.72%
3B:Other	1.35%	35.89%
3C	0.04%	33.91%
4A	1.46%	33.80%
4B	1.17%	33.74%
4C	0.68%	32.91%
5A	1.86%	33.31%
5B	1.48%	33.11%
6A	2.48%	33.71%
6B	1.95%	32.76%
7	4.27%	33.52%
8	5.52%	35.55%
All	1.60%	34.30%

**Table A-15 Percent Savings by Climate Zone: Small Office**

Climate Zone	90.1-2007 Versus 90.1-2004	189.1-2009 Versus 90.1-2007
1A	3.33%	29.86%
2A	8.78%	28.21%
2B	11.82%	28.84%
3A	3.50%	29.52%
3B:CA	2.89%	27.58%
3B:Other	3.81%	29.90%
3C	2.01%	30.11%
4A	4.79%	31.90%
4B	4.12%	30.59%
4C	4.30%	31.45%
5A	4.37%	33.78%
5B	3.82%	31.74%
6A	3.17%	35.87%
6B	3.21%	34.68%
7	2.78%	40.31%
8	2.44%	42.04%
All	5.30%	30.90%

**Table A-16 Percent Savings by Climate Zone: Strip Mall**

<b>Climate Zone</b>	<b>90.1-2007 Versus 90.1-2004</b>	<b>189.1-2009 Versus 90.1-2007</b>
1A	1.95%	18.01%
2A	1.58%	20.13%
2B	3.00%	20.36%
3A	3.99%	20.24%
3B:CA	3.42%	16.36%
3B:Other	4.43%	20.28%
3C	4.09%	22.86%
4A	4.81%	22.93%
4B	5.88%	21.21%
4C	5.62%	24.74%
5A	3.30%	23.62%
5B	4.57%	22.30%
6A	3.64%	25.31%
6B	4.12%	25.57%
7	2.46%	38.12%
8	-0.04%	55.72%
All	3.56%	21.54%

**Table A-17 Percent Savings by Climate Zone: Warehouse**

<b>Climate Zone</b>	<b>90.1-2007 Versus 90.1-2004</b>	<b>189.1-2009 Versus 90.1-2007</b>
1A	2.20%	30.05%
2A	2.11%	33.03%
2B	0.69%	40.62%
3A	1.87%	39.15%
3B:CA	1.64%	48.38%
3B:Other	0.58%	44.54%
3C	0.80%	46.00%
4A	1.45%	46.37%
4B	1.67%	49.80%
4C	0.95%	46.92%
5A	1.18%	45.76%
5B	1.26%	46.74%
6A	0.91%	47.98%
6B	0.93%	47.19%
7	0.45%	45.96%
8	0.20%	43.33%
All	1.43%	42.30%

**Table A-18 Percent Savings for 189.1-2009 Versus 90.1-2007: Climate Zones 1–3**

Building Type	Climate Zone							
	1A	2A	2B	3A	3B:CA	3B:Other	3C	All
Small hotel	37.2%	36.1%	36.5%	34.6%	34.7%	35.9%	33.9%	34.3%
Large hotel	29.5%	27.7%	28.1%	25.8%	25.7%	27.1%	24.4%	25.5%
Small office	29.9%	28.2%	28.8%	29.5%	27.6%	29.9%	30.1%	30.9%
Medium office	28.5%	28.7%	31.1%	31.8%	29.5%	30.1%	30.2%	31.0%
Large office	32.3%	27.7%	30.5%	28.6%	29.9%	28.7%	30.0%	31.9%
Hospital	22.7%	22.0%	19.4%	22.5%	18.5%	19.5%	18.3%	24.4%
Midrise apartment	31.9%	30.3%	28.7%	29.7%	22.1%	28.5%	23.0%	31.8%
Outpatient care	18.4%	17.5%	19.0%	18.0%	18.5%	15.9%	16.3%	14.8%
Primary school	30.6%	31.1%	29.3%	32.7%	27.5%	24.7%	23.3%	32.9%
Secondary school	31.0%	31.0%	32.3%	31.1%	27.6%	31.9%	29.7%	32.4%
Quick service restaurant	23.3%	25.1%	27.1%	27.0%	25.6%	25.6%	24.4%	27.6%
Full service restaurant	25.9%	28.3%	27.2%	31.0%	25.9%	29.0%	30.3%	33.0%
Supermarket	19.4%	19.7%	16.9%	21.4%	15.0%	16.3%	16.0%	22.6%
Stand-alone retail	15.5%	14.8%	19.4%	21.9%	16.9%	20.0%	22.6%	26.2%
Strip mall	18.0%	20.1%	20.4%	20.2%	16.4%	20.3%	22.9%	21.5%
Warehouse	30.1%	33.0%	40.6%	39.2%	48.4%	44.5%	46.0%	42.3%
All	25.8%	25.5%	27.2%	28.0%	25.8%	28.6%	27.0%	29.7%

**Table A-19 Percent Savings for 189.1-2009 Versus 90.1-2007: Climate Zones 4–8**

Building Type	Climate Zone									
	4A	4B	4C	5A	5B	6A	6B	7	8	All
Small hotel	33.8%	33.7%	32.9%	33.3%	33.1%	33.7%	32.8%	33.5%	35.6%	34.3%
Large hotel	24.9%	24.8%	23.9%	24.0%	23.9%	23.2%	22.7%	22.1%	21.4%	25.5%
Small office	31.9%	30.6%	31.5%	33.8%	31.7%	35.9%	34.7%	40.3%	42.0%	30.9%
Medium office	32.3%	29.7%	30.8%	31.8%	30.3%	32.6%	31.9%	34.8%	40.0%	31.0%
Large office	33.9%	31.8%	33.2%	32.5%	35.9%	36.2%	36.1%	38.6%	45.4%	31.9%
Hospital	25.9%	18.9%	17.6%	28.3%	18.1%	33.4%	28.9%	37.1%	44.1%	24.4%
Midrise apartment	34.2%	28.8%	28.1%	37.3%	32.5%	43.4%	38.2%	45.4%	52.7%	31.8%
Outpatient care	16.2%	13.7%	11.8%	12.0%	11.1%	10.4%	7.5%	20.6%	22.2%	14.8%
Primary school	36.9%	20.2%	15.9%	39.6%	16.8%	42.3%	35.1%	46.3%	48.0%	32.9%
Secondary school	32.5%	32.7%	31.0%	33.9%	33.5%	37.0%	35.5%	39.4%	42.8%	32.4%
Quick service restaurant	29.1%	24.1%	22.6%	30.7%	22.7%	32.4%	29.1%	33.9%	36.3%	27.6%
Full service restaurant	35.0%	31.9%	34.4%	37.3%	34.4%	39.1%	37.5%	48.5%	55.8%	33.0%
Supermarket	23.8%	17.1%	17.9%	26.0%	18.4%	29.0%	21.1%	35.2%	42.1%	22.6%
Stand-alone retail	30.2%	20.6%	24.2%	35.2%	22.2%	39.3%	25.1%	45.0%	48.7%	26.2%
Strip mall	22.9%	21.2%	24.7%	23.6%	22.3%	25.3%	25.6%	38.1%	55.7%	21.5%
Warehouse	46.4%	49.8%	46.9%	45.8%	46.7%	48.0%	47.2%	46.0%	43.3%	42.3%
All	31.6%	27.8%	28.6%	33.7%	28.9%	35.6%	31.3%	40.0%	43.1%	29.7%

**Table A-20 Percent Savings for 90.1-2007 Versus 90.1-2004: Climate Zones 1–3**

Building Type	Climate Zone							
	1A	2A	2B	3A	3B:CA	3B:Other	3C	All
Small hotel	1.5%	1.6%	2.4%	1.2%	0.6%	1.4%	0.0%	1.6%
Large hotel	1.0%	0.9%	1.1%	0.7%	0.7%	0.7%	0.4%	0.7%
Small office	3.3%	8.8%	11.8%	3.5%	2.9%	3.8%	2.0%	5.3%
Medium office	2.2%	2.4%	2.5%	3.4%	2.5%	3.7%	2.8%	3.6%
Large office	0.0%	8.5%	9.7%	1.7%	0.3%	1.8%	1.1%	3.5%
Hospital	0.1%	3.2%	5.1%	1.0%	0.4%	1.1%	0.9%	2.0%
Midrise apartment	1.3%	4.1%	4.5%	3.8%	0.7%	2.9%	1.4%	3.2%
Outpatient care	3.6%	4.3%	4.6%	5.3%	5.2%	6.1%	4.4%	4.8%
Primary school	1.2%	4.9%	5.1%	5.4%	4.1%	5.9%	3.6%	4.8%
Secondary school	0.0%	1.2%	1.8%	3.4%	-1.0%	3.0%	2.9%	3.9%
Quick service restaurant	0.8%	0.8%	0.7%	0.9%	0.9%	1.1%	0.8%	0.8%
Full service restaurant	0.7%	0.6%	0.8%	0.4%	0.5%	0.6%	0.2%	0.5%
Supermarket	0.7%	2.9%	2.8%	1.2%	0.3%	1.1%	0.2%	1.8%
Stand-alone retail	2.0%	9.3%	12.1%	3.0%	2.8%	3.2%	2.4%	4.7%
Strip mall	2.0%	1.6%	3.0%	4.0%	3.4%	4.4%	4.1%	3.6%
Warehouse	2.2%	2.1%	0.7%	1.9%	1.6%	0.6%	0.8%	1.4%
All	2.2%	5.8%	7.8%	3.0%	2.0%	2.9%	2.1%	3.8%

**Table A-21 Percent Savings for 90.1-2007 Versus 90.1-2004: Climate Zones 4–8**

Building Type	Climate Zone									
	4A	4B	4C	5A	5B	6A	6B	7	8	All
Small hotel	1.5%	1.2%	0.7%	1.9%	1.5%	2.5%	2.0%	4.3%	5.5%	1.6%
Large hotel	0.6%	0.7%	0.4%	0.6%	0.6%	0.7%	0.5%	0.7%	0.9%	0.7%
Small office	4.8%	4.1%	4.3%	4.4%	3.8%	3.2%	3.2%	2.8%	2.4%	5.3%
Medium office	4.9%	4.6%	4.6%	3.6%	3.3%	3.9%	3.8%	2.1%	0.4%	3.6%
Large office	3.8%	2.9%	4.3%	3.5%	3.0%	3.1%	3.0%	3.0%	2.1%	3.5%
Hospital	2.0%	1.6%	2.3%	2.1%	1.8%	2.0%	2.0%	2.2%	1.4%	2.0%
Midrise apartment	3.3%	2.9%	3.0%	3.8%	3.2%	4.0%	3.8%	10.4%	10.0%	3.2%
Outpatient care	5.8%	6.1%	5.6%	4.2%	4.6%	4.2%	4.4%	2.8%	1.1%	4.8%
Primary school	5.7%	6.0%	3.9%	3.5%	4.2%	4.2%	4.1%	3.0%	0.1%	4.8%
Secondary school	6.4%	5.0%	4.4%	4.8%	4.4%	5.9%	5.8%	4.5%	0.8%	3.9%
Quick service restaurant	0.8%	1.1%	0.9%	0.6%	0.9%	0.5%	0.5%	0.3%	0.2%	0.8%
Full service restaurant	0.2%	0.3%	0.1%	0.5%	0.5%	0.8%	0.8%	0.8%	0.4%	0.5%
Supermarket	1.7%	1.4%	1.0%	1.9%	1.7%	2.1%	1.9%	2.0%	0.3%	1.8%
Stand-alone retail	3.9%	3.7%	4.1%	3.9%	3.5%	3.8%	3.9%	3.7%	0.7%	4.7%
Strip mall	4.8%	5.9%	5.6%	3.3%	4.6%	3.6%	4.1%	2.5%	0.0%	3.6%
Warehouse	1.5%	1.7%	1.0%	1.2%	1.3%	0.9%	0.9%	0.5%	0.2%	1.4%
All	3.7%	3.5%	3.5%	3.2%	3.2%	3.1%	3.0%	3.0%	1.5%	3.8%

## A.2 Energy Intensity

**Table A-22 Energy Intensity (MJ/m<sup>2</sup>) for 90.1-2004: Climate Zones 1–3**

Building Type	Climate Zone							
	1A	2A	2B	3A	3B:CA	3B:Other	3C	All
Small hotel	699	671	655	641	618	633	599	649
Large hotel	1,186	1,220	1,162	1,245	1,210	1,187	1,242	1,267
Small office	718	707	740	660	577	659	536	707
Medium office	564	535	529	518	444	511	415	518
Large office	411	440	416	407	342	398	334	417
Hospital	982	992	963	936	899	890	850	977
Midrise apartment	565	538	506	509	424	481	413	533
Outpatient care	1,591	1,569	1,556	1,545	1,371	1,518	1,319	1,555
Primary school	652	656	646	662	537	630	584	708
Secondary school	582	537	538	505	437	508	453	519
Quick service restaurant	4,911	4,845	4,653	4,799	4,335	4,540	4,298	4,842
Full service restaurant	6,046	6,182	5,907	6,346	5,596	6,018	5,905	6,724
Supermarket	1,841	1,949	1,838	1,974	1,767	1,837	1,916	2,101
Stand-alone retail	771	772	747	727	527	664	571	817
Strip mall	684	691	648	720	519	651	589	776
Warehouse	239	227	233	217	163	225	153	239
All	1,050	1,172	1,140	1,195	886	1,116	878	1,236

**Table A-23 Energy Intensity (MJ/m<sup>2</sup>) for 90.1-2004: Climate Zones 4–8**

Building Type	Climate Zone									
	4A	4B	4C	5A	5B	6A	6B	7	8	All
Small hotel	639	628	604	648	634	684	652	698	815	639
Large hotel	1,286	1,274	1,279	1,328	1,322	1,379	1,370	1,440	1,546	1,286
Small office	709	663	621	762	686	847	764	912	1,259	709
Medium office	523	501	445	527	495	575	521	577	736	523
Large office	435	389	374	429	398	456	422	463	576	435
Hospital	986	887	895	1,012	920	1,091	985	1,132	1,419	986
Midrise apartment	546	487	460	590	526	707	599	772	1,100	546
Outpatient care	1,574	1,529	1,386	1,567	1,530	1,664	1,572	1,693	2,008	1,574
Primary school	741	657	668	800	710	926	822	999	1,364	741
Secondary school	521	479	443	528	480	580	520	584	749	521
Quick service restaurant	4,898	4,641	4,480	5,032	4,727	5,267	4,891	5,370	6,131	4,898
Full service restaurant	6,904	6,394	6,520	7,408	6,808	8,002	7,447	8,554	10,414	6,904
Supermarket	2,128	1,955	2,064	2,261	2,078	2,435	2,284	2,610	3,191	2,128
Stand-alone retail	833	716	740	929	790	1,057	944	1,168	1,622	833
Strip mall	847	733	765	944	812	1,092	983	1,216	1,705	847
Warehouse	244	228	188	275	251	331	297	341	540	244
All	1,254	1,324	1,030	1,424	1,177	1,505	1,367	1,639	1,660	1,254

**Table A-24 Energy Intensity (MJ/m<sup>2</sup>) for 90.1-2007: Climate Zones 1–3**

Building Type	Climate Zone							
	1A	2A	2B	3A	3B:CA	3B:Other	3C	All
Small hotel	688	660	639	634	615	624	599	639
Large hotel	1,173	1,208	1,149	1,237	1,202	1,179	1,237	1,258
Small office	694	645	653	637	560	634	525	669
Medium office	552	522	515	501	433	492	403	499
Large office	411	403	375	400	341	391	330	402
Hospital	982	961	914	927	895	880	843	958
Midrise apartment	557	516	484	490	421	467	408	515
Outpatient care	1,533	1,501	1,485	1,463	1,300	1,426	1,261	1,480
Primary school	644	624	613	626	515	593	563	675
Secondary school	582	531	528	488	441	493	440	498
Quick service restaurant	4,871	4,806	4,619	4,756	4,295	4,490	4,263	4,805
Full service restaurant	6,002	6,148	5,862	6,321	5,566	5,984	5,891	6,693
Supermarket	1,829	1,893	1,786	1,950	1,761	1,817	1,913	2,064
Stand-alone retail	756	700	656	705	512	643	557	779
Strip mall	671	680	629	691	501	622	564	748
Warehouse	234	223	231	213	161	223	152	235
All	1,033	1,127	1,079	1,171	872	1,092	864	1,205

**Table A-25 Energy Intensity (MJ/m<sup>2</sup>) for 90.1-2007: Climate Zones 4–8**

Building Type	Climate Zone									
	4A	4B	4C	5A	5B	6A	6B	7	8	All
Small hotel	630	621	600	636	625	667	640	669	770	639
Large hotel	1,279	1,265	1,273	1,320	1,314	1,370	1,363	1,431	1,531	1,258
Small office	675	635	595	728	660	820	740	887	1,229	669
Medium office	498	479	424	508	479	552	501	565	733	499
Large office	419	378	358	414	386	442	409	449	564	402
Hospital	966	873	874	990	903	1,069	965	1,107	1,399	958
Midrise apartment	528	473	446	568	509	679	576	692	990	515
Outpatient care	1,483	1,435	1,309	1,501	1,460	1,595	1,504	1,647	1,985	1,480
Primary school	698	618	642	772	680	887	788	969	1,363	675
Secondary school	488	455	424	502	459	545	489	558	743	498
Quick service restaurant	4,860	4,589	4,439	5,004	4,686	5,238	4,866	5,354	6,119	4,805
Full service restaurant	6,887	6,377	6,511	7,369	6,771	7,942	7,389	8,489	10,375	6,693
Supermarket	2,091	1,927	2,043	2,217	2,044	2,384	2,241	2,557	3,181	2,064
Stand-alone retail	801	689	710	893	763	1,017	908	1,125	1,611	779
Strip mall	806	690	722	913	775	1,053	943	1,186	1,706	748
Warehouse	240	224	186	272	248	328	294	339	539	235
All	1,223	1,295	1,004	1,394	1,150	1,472	1,338	1,606	1,640	1,205

**Table A-26 Energy Intensity (MJ/m<sup>2</sup>) for 189.1-2009: Climate Zones 1–3**

Building Type	Climate Zone							
	1A	2A	2B	3A	3B:CA	3B:Other	3C	All
Small hotel	432	422	406	415	401	400	396	419
Large hotel	828	873	826	917	894	859	935	939
Small office	487	463	465	449	406	444	367	461
Medium office	395	373	355	341	305	344	281	344
Large office	279	291	261	285	239	279	231	273
Hospital	759	750	736	718	729	709	689	722
Midrise apartment	379	360	345	345	328	334	314	348
Outpatient care	1,252	1,238	1,203	1,199	1,059	1,200	1,056	1,261
Primary school	447	430	433	421	374	447	432	449
Secondary school	402	366	358	336	319	335	309	337
Quick service restaurant	3,737	3,599	3,366	3,472	3,196	3,343	3,222	3,476
Full service restaurant	4,450	4,407	4,265	4,360	4,125	4,248	4,108	4,458
Supermarket	1,474	1,521	1,484	1,533	1,498	1,520	1,607	1,591
Stand-alone retail	639	597	529	551	425	514	431	567
Strip mall	550	543	501	551	419	496	435	584
Warehouse	164	149	137	129	83	124	82	135
All	777	842	793	849	659	803	641	854

**Table A-27 Energy Intensity (MJ/m<sup>2</sup>) for 189.1-2009: Climate Zones 4–8**

Building Type	Climate Zone									
	4A	4B	4C	5A	5B	6A	6B	7	8	All
Small hotel	417	411	402	424	418	442	430	445	496	419
Large hotel	961	952	970	1,003	1,001	1,052	1,054	1,115	1,204	939
Small office	460	441	408	482	450	526	483	529	712	461
Medium office	337	336	294	347	334	372	341	369	440	344
Large office	277	258	239	279	248	282	261	276	308	273
Hospital	716	708	720	710	740	712	687	696	782	722
Midrise apartment	347	337	321	356	343	384	356	378	468	348
Outpatient care	1,242	1,238	1,154	1,321	1,297	1,429	1,390	1,307	1,545	1,261
Primary school	441	493	540	466	565	511	512	520	709	449
Secondary school	330	306	292	332	305	344	316	338	425	337
Quick service restaurant	3,448	3,485	3,437	3,466	3,621	3,542	3,449	3,538	3,900	3,476
Full service restaurant	4,480	4,344	4,269	4,619	4,440	4,841	4,619	4,374	4,583	4,458
Supermarket	1,593	1,597	1,678	1,641	1,668	1,694	1,768	1,657	1,843	1,591
Stand-alone retail	559	547	538	579	594	617	680	619	826	567
Strip mall	621	543	543	697	602	786	702	734	755	584
Warehouse	129	113	99	147	132	171	155	183	305	135
All	848	949	742	941	837	965	928	970	931	854



**Table A-28 Energy Intensity (kBtu/ft<sup>2</sup>) for 90.1-2004: Climate Zones 1–3**

Building Type	Climate Zone							
	1A	2A	2B	3A	3B:CA	3B:Other	3C	All
Small hotel	62	59	58	56	54	56	53	57
Large hotel	104	107	102	110	107	105	109	112
Small office	63	62	65	58	51	58	47	62
Medium office	50	47	47	46	39	45	37	46
Large office	36	39	37	36	30	35	29	37
Hospital	87	87	85	82	79	78	75	86
Midrise apartment	50	47	45	45	37	42	36	47
Outpatient care	140	138	137	136	121	134	116	137
Primary school	57	58	57	58	47	56	51	62
Secondary school	51	47	47	44	38	45	40	46
Quick service restaurant	433	427	410	423	382	400	379	427
Full service restaurant	533	545	520	559	493	530	520	592
Supermarket	162	172	162	174	156	162	169	185
Stand-alone retail	68	68	66	64	46	58	50	72
Strip mall	60	61	57	63	46	57	52	68
Warehouse	21	20	21	19	14	20	13	21
All	93	103	100	105	78	98	77	109

**Table A-29 Energy Intensity (kBtu/ft<sup>2</sup>) for 90.1-2004: Climate Zones 4–8**

Building Type	Climate Zone									
	4A	4B	4C	5A	5B	6A	6B	7	8	All
Small hotel	56	55	53	57	56	60	57	62	72	57
Large hotel	113	112	113	117	116	122	121	127	136	112
Small office	62	58	55	67	60	75	67	80	111	62
Medium office	46	44	39	46	44	51	46	51	65	46
Large office	38	34	33	38	35	40	37	41	51	37
Hospital	87	78	79	89	81	96	87	100	125	86
Midrise apartment	48	43	40	52	46	62	53	68	97	47
Outpatient care	139	135	122	138	135	147	138	149	177	137
Primary school	65	58	59	70	63	82	72	88	120	62
Secondary school	46	42	39	46	42	51	46	51	66	46
Quick service restaurant	431	409	395	443	416	464	431	473	540	427
Full service restaurant	608	563	574	653	600	705	656	754	917	592
Supermarket	187	172	182	199	183	214	201	230	281	185
Stand-alone retail	73	63	65	82	70	93	83	103	143	72
Strip mall	75	65	67	83	72	96	87	107	150	68
Warehouse	21	20	17	24	22	29	26	30	48	21
All	110	117	91	125	104	133	120	144	146	109

**Table A-30 Energy Intensity (kBtu/ft<sup>2</sup>) for 90.1-2007: Climate Zones 1–3**

Building Type	Climate Zone							
	1A	2A	2B	3A	3B:CA	3B:Other	3C	All
Small hotel	61	58	56	56	54	55	53	56
Large hotel	103	106	101	109	106	104	109	111
Small office	61	57	58	56	49	56	46	59
Medium office	49	46	45	44	38	43	36	44
Large office	36	36	33	35	30	34	29	35
Hospital	86	85	80	82	79	78	74	84
Midrise apartment	49	45	43	43	37	41	36	45
Outpatient care	135	132	131	129	114	126	111	130
Primary school	57	55	54	55	45	52	50	59
Secondary school	51	47	47	43	39	43	39	44
Quick service restaurant	429	423	407	419	378	396	376	423
Full service restaurant	529	542	516	557	490	527	519	590
Supermarket	161	167	157	172	155	160	169	182
Stand-alone retail	67	62	58	62	45	57	49	69
Strip mall	59	60	55	61	44	55	50	66
Warehouse	21	20	20	19	14	20	13	21
All	91	99	95	103	77	96	76	106

**Table A-31 Energy Intensity (kBtu/ft<sup>2</sup>) for 90.1-2007: Climate Zones 4–8**

Building Type	Climate Zone									
	4A	4B	4C	5A	5B	6A	6B	7	8	All
Small hotel	55	55	53	56	55	59	56	59	68	56
Large hotel	113	111	112	116	116	121	120	126	135	111
Small office	59	56	52	64	58	72	65	78	108	59
Medium office	44	42	37	45	42	49	44	50	65	44
Large office	37	33	32	36	34	39	36	40	50	35
Hospital	85	77	77	87	80	94	85	98	123	84
Midrise apartment	47	42	39	50	45	60	51	61	87	45
Outpatient care	131	126	115	132	129	141	132	145	175	130
Primary school	62	54	57	68	60	78	69	85	120	59
Secondary school	43	40	37	44	40	48	43	49	65	44
Quick service restaurant	428	404	391	441	413	461	429	472	539	423
Full service restaurant	607	562	574	649	596	700	651	748	914	590
Supermarket	184	170	180	195	180	210	197	225	280	182
Stand-alone retail	71	61	63	79	67	90	80	99	142	69
Strip mall	71	61	64	80	68	93	83	104	150	66
Warehouse	21	20	16	24	22	29	26	30	47	21
All	108	114	88	123	101	130	118	141	144	106

**Table A-32 Energy Intensity (kBtu/ft<sup>2</sup>) for 189.1-2009: Climate Zones 1–3**

Building Type	Climate Zone							
	1A	2A	2B	3A	3B:CA	3B:Other	3C	All
Small hotel	38	37	36	37	35	35	35	37
Large hotel	73	77	73	81	79	76	82	83
Small office	43	41	41	40	36	39	32	41
Medium office	35	33	31	30	27	30	25	30
Large office	25	26	23	25	21	25	20	24
Hospital	67	66	65	63	64	62	61	64
Midrise apartment	33	32	30	30	29	29	28	31
Outpatient care	110	109	106	106	93	106	93	111
Primary school	39	38	38	37	33	39	38	40
Secondary school	35	32	32	30	28	30	27	30
Quick service restaurant	329	317	296	306	282	294	284	306
Full service restaurant	392	388	376	384	363	374	362	393
Supermarket	130	134	131	135	132	134	142	140
Stand-alone retail	56	53	47	49	37	45	38	50
Strip mall	48	48	44	49	37	44	38	51
Warehouse	14	13	12	11	7	11	7	12
All	68	74	70	75	58	71	56	75

**Table A-33 Energy Intensity (kBtu/ft<sup>2</sup>) for 189.1-2009: Climate Zones 4–8**

Building Type	Climate Zone									
	4A	4B	4C	5A	5B	6A	6B	7	8	All
Small hotel	37	36	35	37	37	39	38	39	44	37
Large hotel	85	84	85	88	88	93	93	98	106	83
Small office	40	39	36	42	40	46	43	47	63	41
Medium office	30	30	26	31	29	33	30	32	39	30
Large office	24	23	21	25	22	25	23	24	27	24
Hospital	63	62	63	63	65	63	61	61	69	64
Midrise apartment	31	30	28	31	30	34	31	33	41	31
Outpatient care	109	109	102	116	114	126	122	115	136	111
Primary school	39	43	48	41	50	45	45	46	62	40
Secondary school	29	27	26	29	27	30	28	30	37	30
Quick service restaurant	304	307	303	305	319	312	304	312	344	306
Full service restaurant	395	383	376	407	391	426	407	385	404	393
Supermarket	140	141	148	145	147	149	156	146	162	140
Stand-alone retail	49	48	47	51	52	54	60	54	73	50
Strip mall	55	48	48	61	53	69	62	65	67	51
Warehouse	11	10	9	13	12	15	14	16	27	12
All	75	84	65	83	74	85	82	85	82	75

## Appendix B. HVAC Equipment Efficiency Calculation

### B.1 Total Fan Efficiency

To target Standard 90.1, the total fan efficiencies are a function of the maximum allowable nameplate motor horsepower and the fan static pressure. The maximum nameplate motor power is a function of the type of fan and the supply air volume (e.g., 1.5 hp/1,000 cfm). Reducing the power delivered by the fan divided by the power delivered to the motor, the equation is reduced to **(B-1)**. The total fan efficiency is defined differently than the ASHRAE Systems and Equipment Handbook (Page 18.9). The ASHRAE handbook defines the mechanical fan efficiency and the total fan efficiency as the power output of fan divided by the power input to the fan, where the equation below is the power output of the fan divided by power input to the motor (which is the total fan efficiency as defined by EnergyPlus). Also, this function is only valid if the supply flow rate is the same for the supply fan, filter, and heat recovery.

$$\eta_t = \frac{P_{tf}}{\varepsilon \cdot TR \cdot PC_f \cdot PC_{hr}} \quad (\text{B-1})$$

where

- $\eta_t$  = total fan efficiency
- $P_{tf}$  = fan total pressure: fan pressure at outlet minus fan pressure at inlet, Pa
- $\varepsilon$  = allowable nameplate motor power per supply air volume, W per (m<sup>3</sup>/s)
- TR = temperature ratio
- $PC_f$  = pressure credit for filter, Pa
- $PC_{hr}$  = pressure credit for heat recovery, Pa

The term for pressure credit for the filter is used only if the filter pressure drop is greater than 1 in. w.c. (249 Pa) and is calculated in **(B-2)**. The 0.585 is assuming a fan efficiency of 65% and a motor efficiency of 90% per ASHRAE 90.1-2004 User's Manual (pg 6-63).

$$PC_f = \frac{(P_f - 249.0)}{0.585} \quad (\text{B-2})$$

where

- $PC_f$  = pressure credit for filter, Pa
- $P_f$  = pressure drop of filter, Pa

If heat recovery is installed, the pressure credit is calculated as shown in **(B-3)**.

$$PC_{hr} = \frac{P_{hr}}{0.585} \quad (\text{B-3})$$

where

- $PC_{hr}$  = pressure credit for heat recovery, Pa
- $P_{hr}$  = pressure drop of heat recovery, Pa

The TR is set to 1.0 unless the difference between the supply temperature and the temperature set point is greater than 20°F (11.1°C). If the difference is greater than this value, use (B-4) to find the temperature ratio.

$$TR = \frac{(T_{t-stat} - T_s)}{11.1} \quad (B-4)$$

where

- TR = temperature ratio
- $T_{t-stat}$  = design room temperature set point, °C
- $T_s$  = cooling design zone supply air temperature, °C

To further comply with the standards, it is important to know the correct motor efficiency, which is a function of the nameplate horsepower of the motor and the supply air volume flow rate. To calculate the nameplate horsepower, apply (B-5).

$$W_e = \frac{Q \cdot P_{tf}}{\eta_t} \quad (B-5)$$

where

- $W_e$  = power input to motor, W
- Q = supply air volume flow rate, m<sup>3</sup>/s
- $P_{tf}$  = fan total pressure (fan pressure at outlet minus fan pressure at inlet), Pa
- $\eta_t$  = total fan efficiency

The fan break horsepower is the power delivered directly to the fan, which is equal to the nameplate horsepower minus the frictional losses in the motor (bearings and winding losses) and losses in the drive system in the case of a belt-driven fan. The fan break horsepower is always smaller than the nameplate horsepower.

## B.2 Applying to HVAC System Efficiency

When HVAC system efficiencies are reported in SEER or EER, the values need to be converted to a COP; however, these values contain the supply fan, compressor, and condenser power in the efficiency. To model the system in EnergyPlus, remove the supply fan power from the COP to get the accurate COP for the compressor/condenser. The following steps show how to do this.

Determine EER from SEER:

$$EER = 0.697 \cdot SEER + 2.0394$$

Convert to total kilowatts electricity per ton of cooling

$$\text{Total}_{kW_e/\text{ton}_c} = \frac{12}{EER}$$

Approximate the component of the overall unit EER that is attributable to the supply fan by determining the unit tonnage and unit supply air flow efficiency.

$$\text{ton}_c = \frac{\text{CoolCap} \cdot 3412}{12000}$$

where

$\text{ton}_c$  = ton of refrigeration (cooling)

CoolCap = cooling capacity, W

and

$$SF_{kW_c/\text{ton}_c} = \frac{W_{sf}}{\text{ton}_c \cdot 1000}$$

where

$SF_{kW_c/\text{ton}_c}$  = Supply fan efficiency

$W_{sf}$  = power of supply fan (input to motor)

$\text{ton}_c$  = ton of refrigeration (cooling)

Remove the supply fan from the total efficiency to calculate the compressor/condenser efficiency, then convert to COP.

$$\text{CompCond}_{kW_e/\text{ton}_c} = \text{Total}_{kW_e/\text{ton}_c} - SF_{kW_e/\text{ton}_c}$$

$$\text{COP} = \frac{12}{3.412 \cdot \text{CompCond}_{kW_e/\text{ton}_c}}$$

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