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March 2018

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Summary

This report describes the aggregation and mapping of certain building characteristics data available in the most recent Commercial Building Energy Consumption Survey (CBECS) (DOE EIA 2012) to describe most typical construction practices. Buildings with a date of construction of 1990 or later (referred to as post-1990) were analyzed as a reflection of more recent building construction practices. This report provides summary data for potential use in the support of modifications to the Pacific Northwest National Laboratory's (PNNL's) commercial prototype building models (prototypes) used for building energy code analysis. Mapping of CBECS data to building construction characterized in the building code was conducted to provide actionable insight. This summary outlines findings and most typical design choices for certain building envelope and heating, ventilating, and air-conditioning (HVAC) systems for the prototypes based primarily on the most recent CBECS data. While the conclusions in this summary are reflective of current construction, as captured in the CBECS data, the commercial building prototypes form the basis of other analytical work for PNNL, and any subsequent modifications to the prototypes based on the findings in this report should take into account the historical use of the prototypes as well as other data used in their development.

Building Envelope

Roofs. The DOE Energy Information Administration (EIA) 2012 CBECS (DOE EIA 2012) roof descriptions map clearly to the four American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90.1-2004 (ASHRAE 2004) (and later versions) roof constructions for post-1990 vintage buildings. The most common roof constructions observed in the CBECS data are shown in Table S.1.

Table S.1. Most Common Roof Constructions by Building Type (Post-1990 buildings)

Prototype Building Type	ASHRAE Standard 90.1-2004 Roof Construction
Large Office, Medium Office, Stand-Alone Retail, Primary School, Secondary School, Grocery Store*, Strip Mall, Quick Service Restaurant, Full Service Restaurant, Hospital, and Outpatient Healthcare	Insulation Entirely Above Deck
Small Office and Small Hotel	Split between Attics and Other and Insulation Entirely Above Deck – No recommendation from CBECS
Large Hotel	Attic and Other
Warehouse	Metal Building Roof

* Not in the prototype building set, but analyzed in this report

Walls. The 2012 CBECS wall descriptions do not clearly map to ASHRAE Standard 90.1-2004 (and later versions) wall construction descriptions since the vast majority of commercial wall area falls into a single CBECS description of brick, stone, stucco that can potentially be mapped to all four of the ASHRAE Standard 90.1 wall constructions. Without external information, wall constructions for only four building types (Large Office, Stand-Alone Retail, Grocery, and Warehouse) were conclusive from CBECS data. A number of other building types may be assumed to be framed walls of some type, but the type of framing could be wood or steel. PNNL used a secondary data source, the National Commercial Construction Database to provide additional data to suggest most common wall construction for the other prototype buildings. The most common wall constructions developed are shown in Table S.2.

Table S.2. Most Common Wall Constructions by Building Type (Post-1990 Buildings)

Prototype Building Type	ASHRAE Standard 90.1-2004 Wall Construction
Large Office	Mass Wall
Medium Office	Steel-Framed Wall
Small Office	Wood-Framed Wall
Warehouse	Metal Building Wall
Stand-Alone Retail	Mass Wall
Strip Mall	Mass Wall
Primary School	Mass Wall
Secondary School	Mass Wall
Grocery Store*	Mass Wall
Quick Service Restaurant	Wood-Framed Wall
Full Service Restaurant	Steel-Framed Wall
Hospital	Steel-Framed Wall
Outpatient Health Care	Steel-Framed Wall
Small Hotel	Wood-Framed Wall
Large Hotel	Steel-Framed Wall

* Not in the prototype building set, but analyzed in this report

Windows. The analysis of CBECS data also included the development of window-to-wall ratio (WWR) information for the prototype buildings. A number of detailed tables are available in this report concerning the typical glazing characteristics of prototype buildings (tables are not repeated in this Summary due to size and complexity. Table 2.17, Table 2.18, Table 2.20, and Table 2.21 provide more details). The average WWR within each building type is shown in Table S.3.

Table S.3. Average Window-to-Wall Ratio by Building Type (Post-1990 Buildings)

Prototype Building Type	Average WWR
Large Office	48%
Medium Office	22%
Small Office	14%
Warehouse	4%
Stand-Alone Retail	10%
Strip Mall	24%
Primary School	15%
Secondary School	19%
Grocery Store	4%
Quick Service Restaurant	20%
Full Service Restaurant	16%
Hospital	28%
Outpatient Health Care	19%
Small Hotel	10%
Large Hotel	20%

HVAC Systems

Determining the most common HVAC systems was based on analysis of CBECS 2012 post-1990 buildings, as shown in Table S.4.

Table S.4. Most Common HVAC Equipment in Post-1990 Buildings

		PNNL Determination[a]		
Number	**Type**	**Heating**	**Cooling**	**Air Distribution**
1	Large Office	PCU	Chiller	MZ VAV
2	Medium Office	PCU	PACU	MZ VAV
3	Small Office	PCU	PACU	SZ CAV
4	Warehouse	PCU	PACU	SZ CAV
5	Stand-alone Retail	PCU	PACU	SZ CAV
6	Strip Mall	PCU	PACU	SZ CAV
7	Primary School	Boiler	Chiller	SZ CAV
8	Secondary School	Boiler	Chiller	MZ VAV
9	Grocery Store	PCU	PACU	SZ CAV
10	Quick Service Restaurant	PCU	PACU	SZ CAV
11	Full Service Restaurant	PCU	PACU	SZ CAV
12	Hospital	Boiler	Chiller	FCU, CAV and MZ VAV[b]
13	Outpatient Health Care	PCU	PACU	MZ VAV[c]
14	Small Hotel	ISH	IRAC	SZ CAV
15	Large Hotel	ISH/PCU	IRAC/PACU[d]	SZ CAV

(a) PNNL's determinations of the most common building envelope construction and mechanical system prevalence are based on analysis of CBECS data. PNNL utilizes the research and expertise of the authors to make determinations when either CBECS doesn't capture the data, or its data are conflicting or uncertain.

(b) Hospitals may utilize CV systems in some operating and critical care type areas with variable air flow used for pressurization, but classic VAV multi-zone systems in other areas like offices. CBECS guidance seems limited and other sources should be consulted.

(c) Unclear if single zone or multi-zone is more common globally, but where PCU and PACU are used VAV and likely multi-zone is more common.

(d) Large hotels may be best characterized with two system types serving different areas. Both multi-zone systems (VAV or CAV) may serve public spaces (lobby/conference rooms), whereas single zone IRAC or individual room heat pump systems may be most common for room space. Chiller fan coil systems appear more uncommon in new hotels. VAV appears to be found in the majority of large hotel buildings.

(e) System types

PACU – packaged air-conditioning unit
IRAC – individual room air conditioner
MZ – multi-zone
VAV – variable air volume
ISH – individual space heater
SZ – single zone
CAV – constant air volume
FCU – fan coil unit
PCU – packaged central unit

Acronyms and Abbreviations

AC	air-conditioning
AFO	asphalt, fiberglass, other shingles
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BECP	Building Energy Codes Program
BSS	brick, stone, stucco
CAV	constant air volume
CAC	central air conditioner
CBECS	Commercial Building Energy Consumption Survey
CBP	concrete, block or poured
DOE	U.S. Department of Energy
DX	direct expansion
EER	energy efficiency ratio
EIA	Energy Information Administration
EQGLS	equal glass
FCU	fan coil unit
GLSSPC	glass percentage
HP	heat pump
HVAC	heating, ventilating, and air-conditioning
IESNA	Illuminating Engineering Society of North America
IRAC	individual room air conditioner
ISH	individual space heater
LBNL	Lawrence Berkeley National Laboratory
MOU	memorandum of understanding
MZ	multi-zone
NA	not available
NC3	New Commercial Construction Characteristics
NREL	National Renewable Energy Laboratory
PI	progress indicator
PACU	packaged air-conditioning unit
PBA	Principle Building Activity
PBAplus	Principle Building Activity Plus
PCCP	pre-cast concrete panel
PCU	packaged central units
PNNL	Pacific Northwest National Laboratory
PRS	plastic, rubber, synthetic

PTHP	packaged terminal heat pump
Res CAC	residential-type central air conditioner
SMP	sheet metal panel
SSTS	siding, shingles, tiles, shakes
STS	slate, tile shingles
SZ	single zone
VAV	variable air volume
WLCNS	wall construction
WSSO	wood shingles, shakes, other
WWR	window-to-wall ratio

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1.0 Introduction

To assist the U.S. Department of Energy (DOE), Lawrence Berkeley National Laboratory (LBNL), the National Renewable Energy Laboratory (NREL), and Pacific Northwest National Laboratory (PNNL) developed commercial reference buildings, formerly known as commercial building benchmark models. These reference buildings, described previously in Deru and Griffith (2006), play a critical role in energy modeling software research by providing complete descriptions for whole building energy analysis using EnergyPlus simulation software. The DOE Energy Information Administration's (EIA's) Commercial Building Energy Consumption Survey (CBECS) provided key data for developing these commercial reference buildings.

The reference buildings provide a common starting point in models to support the progress of DOE energy efficiency goals for commercial buildings, which support the aggressive goals of the DOE Building Technologies program for energy efficiency improvements in buildings. More specifically, the models of the reference buildings are used to assess new technologies, optimize designs, analyze advanced controls, and conduct mechanical system and building envelope studies.

In 2006 and 2007, PNNL published analyses (Winiarski et al. 2006 and 2007) of the DOE EIA 2003 CBECS (DOE EIA 2003)[1] disaggregated to DOE's commercial reference building definitions (Deru and Griffith 2006). At that time, the 2003 CBECS was the most current collection of reported commercial building characteristics.

In 2007, as part of its Advanced Codes Initiative, DOE signed a memorandum of understanding (MOU) with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) to develop advanced commercial standards, including an agreed upon goal that ASHRAE Standard 90.1-2010 would result in 30% energy savings relative to Standard 90.1-2004 (ASHRAE 2004).[2] PNNL was funded by DOE's Building Energy Codes Program (BECP) to provide both leadership and technical analysis support for Standard 90.1-2010 to reach the 30% energy savings goal. To closely measure the progress toward the goal, PNNL developed a new metric and process called the "Progress Indicator." A key part of the Progress Indicator was the development of prototype buildings representing approximately 80% of the commercial stock in the United States. These prototype buildings were developed at PNNL and utilized the DOE reference buildings as a starting point, but with added features needed for codes and standards analysis. The prototypes were subjected to thorough peer review by members of the ASHRAE Standard 90.1 Simulation Working Group. As a result of peer review and additional research on building loads and equipment, subsequent modifications to the prototypes were made. In addition, two residential prototype buildings (mid-rise apartment and high-rise apartment) were included as representative of key building types within the scope of ASHRAE 90.1 and the commercial building energy codes. The development of these prototypes is documented in two PNNL reports (Thornton et al. 2011; Goel et al. 2014). In 2011, NREL published updated commercial reference building models (Deru et al. 2011). In 2012, the DOE EIA conducted a new CBECS. The survey microdata (i.e., data for individual building records or samples) used in this report were released in 2016 (DOE EIA 2012).

[1] Each version of the CBECS survey is announced and takes several years to complete the summary and release of all data. Reference in this document are to the date of the survey.

[2] Article describing MOU: https://www.greenbiz.com/microsite/100060/news/2007/08/05/ashraedoe-team-promote-building-energy-efficiency.Article mentioning the MOU: https://energy.gov/sites/prod/files/2013/11/f5/regulatory_programs_mypp.pdf.

The purpose of this PNNL report is to summarize an analysis of the most recent 2012 CBECS data in relation to the prototype buildings. This report's scope is limited to an analysis of 2012 CBECS data related to heating, ventilation, and air-conditioning (HVAC) mechanical systems and building envelopes. It does not include data on multi-family buildings as these are not within the scope of the CBECS survey or CBECS data. This report characterizes data for one building type (Grocery) that is found in the original DOE reference building set, but not in the current PNNL prototype set, in the event that it may support future prototype development. The results of this effort highlight the updated CBECS analysis results and characterization to better represent more recent construction practices as well as support any updates to the prototype buildings to help track progress toward DOE's energy efficiency goals for building codes.

This report is organized into two primary sections: 2012 CBECS building envelope analysis and 2012 CBECS HVAC mechanical systems analysis.

2.0 Analysis of the Building Envelope in 2012 CBECS

This section presents the results of an analysis of the building envelope characteristics reported in the 2012 CBECS, disaggregated to PNNL's prototype building definitions (as listed in Goel et al. 2014). Only buildings constructed on or after 1990 are included in this report to better reflect more recent building construction practices.

Data from the 2012 CBECS is used to the extent feasible. The 2012 CBECS is DOE's most current collection of reported commercial building characteristics. However, there are a number of shortcomings in the available data when it is used for the type of analysis conducted for this report. Key shortcomings related to building envelope characterization are listed below in Table 2.1, along with the approaches used to overcome these shortcomings.

Table 2.1. 2012 CBECS Shortcomings and Approaches Taken to Address Those Shortcomings

2012 CBECS Shortcomings	Approach Taken in This Report
• Wall and roof descriptions describe only the appearance or façade of the building, not the underlying wall or roof structure	• Appearance or façade descriptions are mapped to most probable underlying wall or roof structure; data from New Commercial Construction Characteristics (NC3)* dataset used to provide additional information
• Limited description of building shape without dimension data	• Data from the 1992 CBECS used to characterize building aspect ratio
• Specific number of stories not available for buildings above 14 stories (data are withheld to protect the identity of specific buildings)	• Data from an inventory of U.S. skyscrapers used to estimate relative frequency of number of stories and select most characteristic number of stories in available bin data.
• Specific window area or window area fraction not provided	• Window area from categorical data provided and summarized using mid-points of window area fraction categories.
• Neither floor-to-floor height nor building height is available.	• Estimated floor-to-floor height using new CBECS 2012 floor-to-ceiling height data and presumed height adders by prototype to reflect height above ceilings.

*Richman, E.E., E. Rauch, J. Knappek, J. Phillips, K. Petty, and P. Lopez-Rangel. 2008. *National Commercial Construction Characteristics and Compliance with Building Energy Codes: 1999-2007*. 2008 ACEEE Summer Study on Energy Efficiency in Buildings. ACEEE Publications, Washington D.C

The 2003 CBECS contained neither floor-to-floor height information nor total building height data to determine typical floor-to-floor heights. In the development of the prototype buildings, professional judgment was used to determine floor-to-floor and floor-to-ceiling heights needed for modeling purposes. However, in the 2012 CBECS, DOE EIA included a question on typical floor-to-ceiling heights for buildings and this information was used, in conjunction with an assumed "adder" for a plenum and/or floor thickness, to determine floor-to-floor heights. This calculation is described in Section 2.1.4.

Throughout this report, final determinations for wall and roof types are made in terms of the wall and roof assembly descriptions used in American National Standards Institute (ANSI)/ASHRAE)/Illuminating Engineering Society of North America (IESNA) Standard 90.1-2004.[1] This standard provides the basis for development of PNNL's prototype buildings for code improvement purposes. While older ASHRAE Standards (such as ANSI/ASHRAE/IESNA Standard 90A-1980 and ANSI/ASHRAE/IESNA

[1] These same wall and roof descriptions are used in versions of Standard 90.1 after the 2004 version as well.

Standard 90.1-1989) could have been considered for use in describing post-1990 building construction, neither of these standards has roof or wall assembly descriptions.

The choice of a wall or roof type for a prototype building has energy implications. Versions of ASHRAE Standard 90 (dating back to Standard 90-75) have different U-factor requirements for different types of walls and roofs. For example, ANSI/ASHRAE/IESNA Standard 90.1-2004 has a roof U-factor variation of 0.034 to 0.065 (depending on roof type) and wall U-factor variation of 0.089 to 0.123 (depending on wall type) for non-residential buildings in Climate Zone 5 (typical of Chicago, IL). Values for other climate zones vary, but for this standard and climate zone, the variation is over 90% on roof U-factor and nearly 40% on wall U-factor. This type of variation, a product of the code development process, also carries over into newer versions of ASHRAE Standard 90.1. For instance, for Climate Zone 5 in Standard 90.1-2016 (ASHRAE 2016), roof U-factors for non-residential buildings vary from U-0.021 to U-0.037 (depending on roof type), while wall U-factors for the same non-residential buildings vary from U-0.050 to U-0.090 (depending on wall type). This is a variation of 76% in required roof U-factor and 80% in wall U-factor as a function of wall type.

2.1 Building Envelope Analysis Approach

Data was extracted from the 2012 CBECS dataset and mapped to the commercial prototype buildings using the CBECS Principle Building Activity Plus (PBAplus) information (shown in Appendix A). Additionally, office buildings were divided into the categories of “small,” “medium,” and “large” based on the definitions originally proposed by NREL.[1]

For the purpose of this analysis, each building in the 2012 CBECS data set is treated as a rectangular block with a defined aspect ratio and constant cross sectional area from the bottom floor to top floor. The building footprint is used as a surrogate for roof area and is calculated as the total floor area divided by the number of stories reported for the building. The footprint, shape, and number of stories above grade as well as the floor-to-floor height, are used to estimate the total above grade wall area for each building. The window-to-wall ratio (WWR) is used to estimate the window area and the total above grade opaque wall area of the building. While the 2003 CBECS did not identify building floors as above or below grade, the 2012 CBECS specifically identifies the number of stories that can be considered below grade using the “basement” variable captured in the survey. For the purpose of the envelope analysis, the number of stories above grade was determined as the number of stories reported minus the number of below grade stories identified. Only the total area above grade has been considered in the calculations of total exterior wall area and total window area in each prototype category. This is consistent with the selection of WWR category in the CBECS survey.

To determine the total opaque wall area of the building, the aspect ratio, WWR, floor-to-floor height, and number of above grade floors must be estimated. Below grade walls are not characterized in this analysis since CBECS does not provide data on this building attribute.

[1] Small office is defined as single story, medium office as two to four stories, and large office as greater than four stories.

2.1.1 Development of the Aspect Ratio

The 2003 CBECS asks questions about building shape (square, rectangular, other), but does not directly inquire about aspect ratio[1] of the building footprint. The 1992 CBECS (DOE EIA 1992) was the last version of CBECS to collect aspect ratio data (for square and rectangular buildings), and was used in this analysis. The aspect ratio used for each 2012 CBECS building in this analysis was calculated as: (a) 1.0 for square building shape, (b) average aspect ratio data reported for the Principle Building Activity (PBA) category for rectangle building shapes (based on 1992 CBECS), and (c) 4.0 for all other building shapes (T-shaped, L-shaped, H-shaped, E-shaped, U-shaped, and 'other' shaped). Development of the latter assumption is available in the Appendix B. The 1992 CBECS aspect ratio data for rectangular building shapes are listed in Table 2.2.

Table 2.2. 1992 CBECS Aspect Ratio Data

1992 CBECS PBA	Aspect Ratio	1992 CBECS PBA	Aspect Ratio
Education	2.51	Nursing home	1.30
Food sales	1.86	Office/professional	2.01
Food services (restaurants)	1.88	Other	3.04
Health care (inpatient)	2.09	Public assembly	1.88
Health care (outpatient)	1.73	Public order and safety	1.85
Indoor parking garage	1.81	Religious worship	1.93
Laboratory	2.23	Vacant	2.34
Lodging (hotel/motel/dorm)	2.93	Warehouse (non-refrigerated)	2.56
Mercantile/services	2.07	Warehouse (refrigerated)	2.95

2.1.2 Assignment of WWR with CBECS Categories

The 2003 CBECS asked questions about WWR; the results are presented in five categories (WWR bins) in its Glass Percentage (GLSSPC) (percentage exterior glass) statistic. The midpoint of the range in each category was used as the typical WWR for each prototype building (Table 2.3). The questionnaire asked which bin "best describes the percent of the exterior wall surface of this building that is covered with window glass or glass doors?" It is assumed that the value reported by CBECS is the average for all exposed sides of the building and includes glazed door area. For this exercise, all buildings are assumed free standing. The 2012 CBECS expanded the list of WWR categories to include a category for 1% or less glass and changed the 1% to 10% category to 2% to 10%. This leads to some interesting results relative to the previous 2003 CBECS. A remarkable number of buildings in the 2012 CBECS are listed as having less than 1% glass, which is discussed further in Section 2.3.4.

[1] Aspect ratio is the ratio of the long dimension of the building on the horizontal plane to the short dimension of the building in the same plane.

Table 2.3. Window-to-Wall Ratio Assumptions

Reported Percent Exterior Glass	Assumed WWR
0–1%	0.5%
2–10%	6.0%
10–25%	18%
25–50%	38%
50–75%	63%
Above 75%	88%

2.1.3 Development of Number of Stories for Tall Buildings

The 2012 CBECS provides data on the number of stories for individual buildings. For buildings between 1 and 14 stories, the actual number of stories is reported. However, for buildings greater than 14 stories, the information is provided in ranges to mask the identity of the building. Two fairly broad ranges of building height are provided in CBECS: 15 to 25 stories and greater than 25 stories.

To estimate the number of stories in these buildings, PNNL re-used 2007 data from the previous envelope analysis, which relied on the tall buildings database available at www.skyscraperpage.com.[1] This online database provided limited data available for queries of tall buildings all over the world. The complete database at the time (53,010 structures) was unavailable for download and had to be accessed online. Data are presented for a limited number of buildings at a time. PNNL attempted, but was unable, to get direct access to more recent data or the skyscraperpage.com database. However, updates to the data could be considered for future work.

For the 2007 building envelope analysis, PNNL developed a distribution of buildings by roof height and then used a typical floor-to-floor height developed from the same dataset to generate a distribution by number of stories. For this analysis, PNNL employed data on the tallest 4,548 U.S. buildings in the database, as determined by building roof height, down to a 219-foot (ft) (67.4 meter (m)) height. The building data was binned in 32.8 ft (10 m) height bins, and the number of buildings in each bin tabulated. PNNL then developed a probability curve of building height for tall buildings, shown in Figure 2.1.

PNNL calculated the average floor-to-floor height for all building records in the data subset as 3.95 m (13 ft). Using this average floor-to-floor height, a second relative probability distribution of the number of buildings with a given number of stories was estimated for all buildings 15 stories and higher, where the sum of the relative probabilities of all buildings 15 stories or greater in height was 1.0. These relative probabilities were then used as weighting factors to develop the average number of floors for buildings in the 15–25 story and greater-than-25 story bins used by CBECS. The results are shown in Table 2.4.

[1] The website www.skyscraperpage.com contains a self-reported database of most, if not all, of the tall buildings in the United States and much of the world, which is maintained by tall building enthusiasts and others interested in architectural issues.

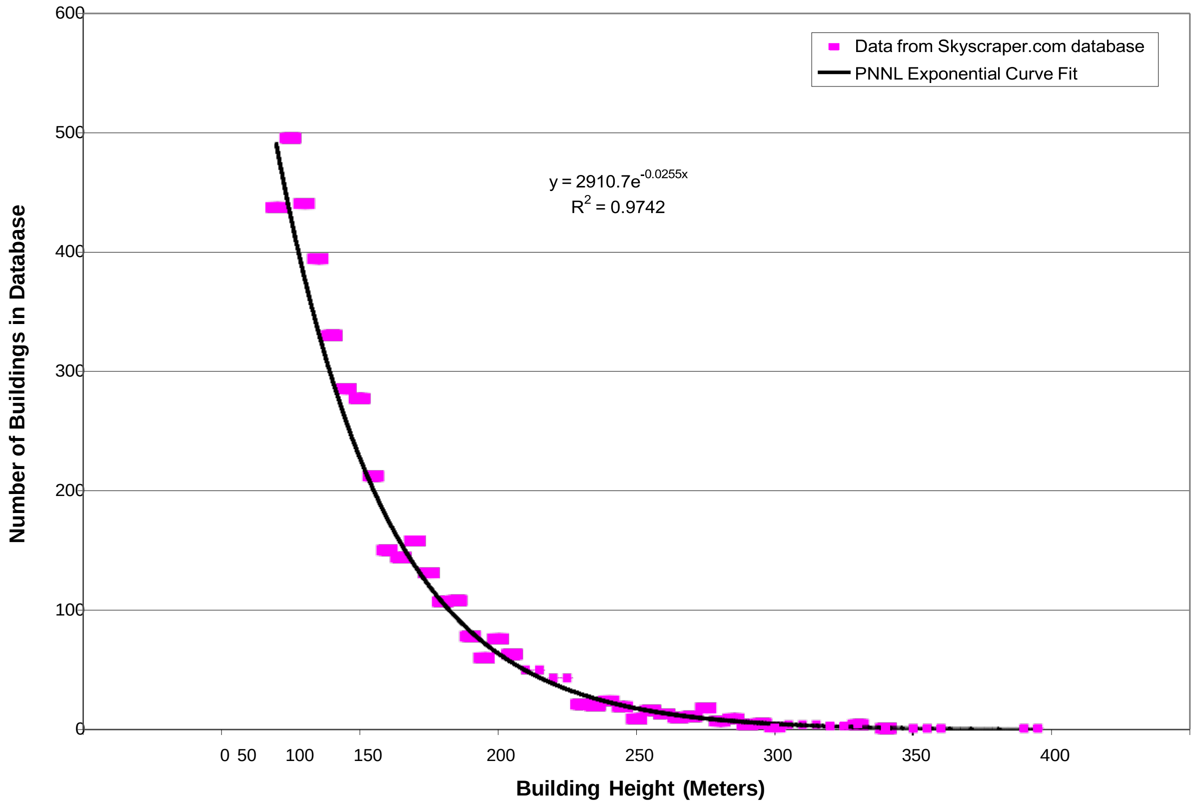

Figure 2.1. Probability Curve of Building Height for Tall Buildings, 2007 Data

Table 2.4. Estimating Number of Floors for CBECS Buildings

CBECS Reported Number of Floors Data	Floors Assumed for Building
1–14	Reported CBECS Data
15–25	19
26 or more	35

2.1.4 Floor-to-Ceiling Height Results by Building Type from the 2012 CBECS

The 2012 CBECS includes a new question that requests the typical floor-to-ceiling height for each building in the sample. The average of the responses for this question by building type is shown in Table 2.5. Table 2.6 provides an estimate of an "adder," developed for this analysis, to convert from floor-to-ceiling height to floor-to-floor height. If a building has a dropped ceiling, as is common in many building types, the space above that dropped ceiling may include an HVAC plenum and space for electrical cabling, ductwork, or floor joists. In addition, the floor itself will have additional thickness. Since the CBECS questions do not address floor-to-floor heights and floor-to-floor heights determine the exterior wall area, PNNL estimated the "adder" to the floor-to-ceiling heights to develop an estimate of the floor-to-floor height.

The average calculated floor-to-ceiling height from CBECS by building prototype is shown in Table 2.5. Results are shown using three methods of calculation: average by building sample count,[1] average by CBECS building weight (reflecting total represented buildings in U.S. population),[2] and average by building floor area.[3]

Table 2.5. Floor-to-Ceiling Heights from 2012 CBECS, Feet

Building Type	Average by Building Samples	Average by Building Population Weight	Average by Building Floor Area
Large Office	11	10	11
Medium Office	11	11	11
Small Office	10	10	11
Warehouse	21	14	21
Stand-alone Retail	17	15	19
Strip Mall	14	13	15
Primary School	10	10	10
Secondary School	11	13	11
Grocery store	17	14	19
Quick Service Restaurant	11	11	11
Full Service Restaurant	12	12	13
Hospital	11	10	11
Outpatient Health Care	10	10	10
Small Hotel	9	8	8
Large Hotel	9	9	10

To calculate the floor-to-floor heights needed to determine exterior wall area, PNNL made a series of engineering estimates about the presence or absence of a building plenum (i.e., space above a dropped ceiling) and the height of that plenum by prototype building. These assumptions are shown in Table 2.6. Not all buildings have a dropped or false ceiling, and ceiling construction is commonly a function of the interior ceiling height as buildings designed with high ceilings (e.g. warehouse, grocery, retail, quick service restaurant, or full service restaurant) often have exposed ductwork, and dropped or pendant light fixtures. Each building record in the 2012 CBECS was evaluated against the maximum floor-to-ceiling height criteria. If the building record's floor-to-ceiling height was less than or equal to the criteria, the specified plenum adder was added reflecting the common use of dropped commercial ceilings in spaces with lower floor-to-ceiling height. The maximum floor-to-ceiling height criterion chosen was 20 feet for all but the stand-alone and strip mall retail buildings, which had a chosen floor-to-ceiling height of 15 feet. Plenum/space adders range from 0 (warehouses and grocery stores) to 2 feet (small offices, quick service restaurants, full service restaurants, and small hotels) to 3 feet (all other building types). Certain buildings are not assigned a "plenum adder," which is reflected in the average floor-to-floor heights by prototype.

[1] Straight average of data by CBECS building record.

[2] Weighted average of data by the number of buildings represented by each CBECS building record.

[3] Weighted average of data by the square footage of the buildings represented by each CBECS building record.

Table 2.6. Maximum Floor-to-Ceiling Height for Plenum/Space and Height of Plenum/Space Adder by Building Type

Building Type	Maximum Floor-to-Ceiling Height for Plenum/Space Adder, ft	Plenum/Space Adder, ft
Large Office	20	3
Medium Office	20	3
Small Office	20	2
Warehouse	20	0
Stand-alone Retail	15	3
Strip Mall	15	3
Primary School	20	3
Secondary School	20	3
Grocery store	20	0
Quick Service Restaurant	20	2
Full Service Restaurant	20	2
Hospital	20	3
Outpatient Health Care	20	3
Small Hotel	20	2
Large Hotel	20	3

The resulting estimated floor-to-floor heights are shown below in Table 2.7 by building prototype. Results are shown in three ways: average by building count (i.e., record or sample), average by CBECS building weight, and average by building floor area.

Table 2.7. Estimated Floor-to-Floor Heights by Building Type Based on 2012 CBECS, Feet

Building Type	Average by Building Samples	Average by Building Population Weight	Average by Total Building Area
Large Office	14	13	14
Medium Office	14	14	14
Small Office	12	12	13
Warehouse	21	14	21
Stand-alone Retail	19	17	21
Strip Mall	16	16	16
Primary School	13	13	13
Secondary School	14	16	14
Grocery store	17	14	19
Quick Service Restaurant	13	13	13
Full Service Restaurant	14	14	15
Hospital	14	13	14
Outpatient Health Care	13	13	13
Small Hotel	11	10	10
Large Hotel	12	12	13

2.1.5 Cross Checking of Floor-to-Floor Height by Building Type

The estimated number of floors shown in Table 2.4 was based on an average floor height of 12.96 ft (3.95 m). This average was calculated from a sample of 4,548 tall buildings that included 2,281 offices, 426 hotels, and 1,492 high-rise residential buildings (not included in CBECS). When all data were binned together in 0.656 ft (0.2-meter) bins, the 13.1 to 13.8 ft bin (4.0- to 4.2-meter) was the most common, followed by the 9.8 to10.5 ft bin (3.0- to 3.2-meter), indicating a bimodal distribution of floor heights. In an attempt to investigate the variation in floor-to-floor height by building type, the average floor-to-floor heights for offices, hotels, and high-rise residential buildings from www.skyscraperpage.com were calculated separately. The average floor-to-floor heights were 13.8 ft for offices, 10.8 ft for high-rise multi-family residential, and 11.8 ft for hotels. If high-rise residential buildings were removed from the sample, the average floor-to-floor height would be 13.5 ft, which is slightly higher than the 13 ft estimate used. Removing high-rise residential buildings from the sample would reduce the assumed number of floors to 18 for buildings of 15–25 stories and 34 for buildings of 26 or more stories. Given other uncertainties in the building floor and height data, these differences were not considered significant.

Given the new floor-to-ceiling height estimates provided in the 2012 CBECS, along with revised assumptions about the presence or absence of plenums, the floor-to-floor heights estimated for this analysis are different than those estimated in the previous analysis for certain building types. Warehouses, stand-alone retail, strip malls, and grocery stores have higher floor-to-floor heights, whereas small hotels have a lower floor-to-floor height. The approach taken in this analysis utilizes the latest CBECS data to better represent these building types. A survey of either building height or direct data on the presence of dropped ceilings or plenum space could further improve these estimates. However, the approach taken should improve the generation of typical wall type and window area characterization. An extension of this analysis would compare the floor-to-floor heights and floor-to-ceiling heights calculated in this analysis with the corresponding values used in the prototype buildings (Thornton et al. 2007) to determine if modification of the prototype building assumptions (or the plenum/space adder or adder height assumptions) is appropriate.

2.2 Building Envelope Roof Results

CBECS provides seven categories of roof construction material along with “other” and “not one major type” categories. For each PNNL prototype, Table 2.8 lists the top five most common roof descriptions, in decreasing order of occurrence by percentage of roof area or fraction of buildings. No consideration was given to the area of roof that contains skylights as these data are not available in CBECS. While the 2012 CBECS asks whether skylights or atriums exist in a building, it provides no data on the relative extent in terms of roof area.

The 2012 CBECS contains a new question that asks whether or not there is an attic present in the building. This data was analyzed and presented in Table 2.8, which includes the fractions of roof area and building weights (i.e., number of buildings) for CBECS building samples marked as having an attic and not having an attic. The sum of all ten related values (by roof area or by fraction of buildings) adds up to approximately 100%. For example, the sum of the percentages shown for large office buildings by fraction of roof area is 101% (due to rounding). Similarly, the sum of percentages for medium offices is only 95%, indicating that there are other roof descriptions reported in the 2012 CBECS below the top five categories shown. The split between roofs with and without attics is useful to differentiate between roof materials typically found above attics versus those found in roofs without attics. Of particular interest is metal surfacing, which may indicate a metal building roof, as defined by ASHRAE Standard 90.1, or which may indicate the presence of a standing seam metal roof over an attic.

Roof area is assumed to correspond to the footprint of the building,[1] meaning that roof area is the parallel projected roof area overlaying the building footprint. PNNL did not attempt to estimate the relative increase in roof area for sloped roofs compared to flat roofs since it was not called for in the development of building prototypes. The 2012 CBECS has a question about roof slope, but this data was not used in this analysis. PNNL also did not attempt to address the impact of roof overhangs since this data was not available in CBECS. Roof slope and overhangs are important inputs for calculating total roof costs and may call for further investigation.

Table 2.8. Roof Descriptions by Prototype Building Category (Post-1990 Buildings)

Prototype No.	Prototype Building	Roof Descriptions By Fraction of Roof Area			Roof Descriptions by Fraction of Buildings		
		Material	**Without Attic**	**With Attic**	**Material**	**Without Attic**	**With Attic**
1	Large Office	PRS	37%	6%	AFO	28%	0%
		Built-Up	32%	10%	PRS	25%	2%
		AFO	8%	0%	Built-Up	19%	5%
		Concrete	5%	0%	Concrete	19%	0%
		STS	1%	0%	STS	1%	0%
2	Medium Office	PRS	40%	4%	AFO	13%	11%
		Built-Up	20%	2%	Metal	17%	7%
		AFO	11%	5%	PRS	19%	4%
		Metal	9%	2%	Built-Up	16%	4%
		Concrete	2%	0%	STS	4%	1%
3	Small Office	Metal	20%	9%	Metal	23%	12%
		PRS	24%	2%	AFO	11%	18%
		AFO	9%	11%	STS	8%	6%
		Built-Up	15%	1%	PRS	12%	1%
		STS	4%	5%	Built-Up	7%	1%
4	Warehouse	Metal	43%	1%	Metal	71%	3%
		PRS	22%	1%	Built-Up	8%	0%
		Built-Up	18%	0%	AFO	6%	1%
		AFO	10%	0%	PRS	5%	2%
		WSSO	2%	0%	WSSO	2%	0%
5	Stand-alone Retail	Metal	39%	2%	Metal	39%	13%
		PRS	27%	0%	PRS	18%	0%
		Built-Up	19%	0%	AFO	10%	4%
		AFO	8%	1%	Built-Up	10%	0%
		Concrete	2%	0%	STS	3%	1%
6	Strip Mall	PRS	46%	0%	PRS	34%	0%
		Built-Up	30%	6%	Built-Up	26%	6%
		AFO	11%	1%	AFO	16%	5%
		Metal	3%	1%	Metal	7%	3%
		Other	1%	0%	Other	2%	0%

[1] The footprint of each building in the 2012 CBECS was estimated as the reported building floor area divided by the number of stories.

Prototype No.	Prototype Building	Roof Descriptions By Fraction of Roof Area			Roof Descriptions by Fraction of Buildings		
		Material	Without Attic	With Attic	Material	Without Attic	With Attic
7	Primary School	Built-Up	30%	4%	Built-Up	33%	3%
		Metal	16%	11%	Metal	19%	7%
		PRS	17%	4%	AFO	12%	11%
		AFO	10%	4%	PRS	10%	1%
		WSSO	0%	2%	STS	2%	1%
8	Secondary School	PRS	24%	5%	Metal	30%	5%
		Metal	25%	3%	AFO	14%	10%
		Built-Up	21%	6%	PRS	16%	3%
		STS	1%	8%	Built-Up	10%	1%
		AFO	4%	1%	STS	5%	5%
9	Grocery Store	Metal	31%	5%	Metal	37%	12%
		PRS	35%	0%	Built-Up	18%	0%
		Built-Up	16%	0%	AFO	16%	0%
		AFO	9%	0%	PRS	15%	0%
		NOMT	3%	0%	NOMT	1%	0%
10	Quick Service Restaurant	PRS	30%	3%	PRS	27%	3%
		Built-Up	28%	2%	Built-Up	26%	2%
		AFO	11%	3%	AFO	12%	5%
		Metal	9%	0%	Metal	11%	0%
		STS	8%	0%	STS	10%	0%
11	Full Service Restaurant	PRS	24%	3%	AFO	19%	10%
		Metal	19%	6%	Metal	19%	7%
		AFO	12%	10%	PRS	19%	2%
		STS	11%	5%	STS	6%	5%
		Built-Up	7%	0%	Built-Up	9%	0%
12	Hospital	PRS	51%	5%	PRS	48%	5%
		Built-Up	21%	3%	Built-Up	16%	2%
		Concrete	6%	1%	Concrete	14%	0%
		AFO	6%	0%	AFO	8%	0%
		Metal	1%	5%	Metal	0%	6%
13	Outpatient Health Care	PRS	43%	4%	AFO	18%	16%
		AFO	16%	7%	PRS	18%	5%
		Built-Up	13%	1%	Built-Up	15%	4%
		Metal	9%	2%	Metal	13%	1%
		STS	3%	0%	STS	5%	2%
14	Small Hotel	Metal	30%	36%	Metal	25%	27%
		Built-Up	16%	0%	AFO	19%	4%
		AFO	3%	4%	PRS	11%	0%
		WSSO	0%	6%	Built-Up	9%	0%
		PRS	4%	0%	STS	0%	2%
15	Large Hotel	AFO	10%	41%	AFO	9%	42%
		PRS	13%	3%	PRS	16%	1%
		Built-Up	14%	2%	Built-Up	12%	1%
		STS	1%	7%	STS	2%	8%
		Metal	4%	2%	Metal	5%	2%

PRS – Plastic, Rubber, Synthetic
STS – Slate, Tile Shingles
Metal – Metal Surfacing
AFO – Asphalt, Fiberglass, Other Shingles
WSSO – Wood Shingles, Shakes, Other
Built-Up – Built-Up roofing

2.2.1 Mapping of CBECS Descriptors to ASHRAE Standard 90.1 Roof Types

ASHRAE Standard 90.1-2004 and all newer versions of Standard 90.1 define three primary roof types based on the location of insulation relative to the roof: Insulation Entirely Above Deck, Metal Building, and Attic and Other. The primary assumption is that Insulation Entirely Above Deck has continuous insulation above the structural roof deck, while Metal Building has insulation compressed between structural members.[1] In the Attic and Other roof type, insulation is laid between roof joists.

Standard 90.1 also has a subclass of the Attic and Other roof type defined as Single-rafter Roofs, in which the same rafter supports the roof above it as well as the ceiling attached beneath it. For Single-rafter Roof assemblies, the requirement in Standard 90.1 is the lesser of two values—the attic requirement or a separate requirement that requires the rafter cavity to be filled with fiberglass insulation. For the purposes of this report, Single-rafter Roofs are classified as Attic and Other and given no further consideration.

CBECS classifies roofing materials in nine categories.

1. Built-up (tar, felts, or fiberglass and a ballast, such as stone)
2. Slate or tile shingles (STS)
3. Wood shingles, shakes, or other (WSSO) wooden materials
4. Asphalt, fiberglass, or other shingles (AFO)
5. Metal surfacing
6. Plastic, rubber, or synthetic (PRS) sheeting (single or multiple ply)
7. Concrete
8. IF VOLUNTEERED: No one major type
9. IF VOLUNTEERED: Other.

Comparison of the three ASHRAE Standard 90.1 roof types with the 2012 CBECS roof descriptions indicates that only one description can be unambiguously mapped to a Standard 90.1 roof type. The CBECS built-up classification (category 1) maps directly to Standard 90.1's Insulation Entirely Above Deck. However, slate, shingles, shakes, and tiles of any material (categories, 2, 3, and 4) map fairly unambiguously to Standard 90.1's Attic and Other category, as these roof materials are typically installed over an attic or single-rafter roof type. The CBECS metal surfacing category (category 5) can be mapped to the 90.1 Metal Building, but it can also indicate that a metal roof has been used in place of shingles over an attic roof structure. The CBECS PRS category (category 6) most likely maps to the Insulation Entirely Above Deck category (mostly commonly where a synthetic membrane is placed over foam). Concrete (category 7) can be mapped to Insulation Entirely Above Deck in the case of a bare concrete roof slab, or to Attic and Other in the case of concrete shingles, tiles, or surfacing over a metal roof deck.

[1] ASHRAE Standard 90.1-2016 defines "metal building roof" as "metal building roof: a roof that a. is constructed with a metal, structural, weathering surface; b. has no ventilated cavity; and c. has the insulation entirely below deck (i.e., does not include composite concrete and metal deck construction nor a roof framing system that is separated from the superstructure by a wood substrate) and whose structure consists of one or more of the following configurations: 1. Metal roofing in direct contact with the steel framing members; 2. Metal roofing separated from the steel framing members by insulation; 3. Insulated metal roofing panels installed as described in sub items (a) or (b)"

Table 2.9 shows the assumed relationship of CBECS roof descriptions to ASHRAE Standard 90.1 roof constructions.

Table 2.9. Relationship of CBECS Roof Descriptions to ASHRAE Standard 90.1 Roof Constructions

CBECS	Insulation Entirely Above Deck	Metal Building	Attic and Other
Asphalt, fiberglass, other shingles (AFO)			X
Built-up	X		
Concrete	X		X
Metal surfacing		X	X
No one major type			
Other			
Plastic, rubber, synthetic (PRS)	X		
Slate, tile shingles (STS)			X
Wood shingles, shakes, other (WSSO)			X

The sum of the built-up and PRS categories shown in Table 2.9 (along with some fraction of the AFO category that may be asphalt only[1] and some fraction of the concrete category) provides an estimate of the number of roofs with Insulation Entirely Above Deck according to ASHRAE. Depending on the building type, metal surfacing may indicate Metal Building roofs or Attic and Other with metal roofing over an attic. All other CBECS roof descriptions are indicative of an attic roof.

Applying the assumptions in the previous paragraph to the data shown in Table 2.8 leads to the following determinations.

- For warehouses, it is assumed that metal surfacing indicates a traditional Metal Building roof. This is the dominant roof type for warehouses, both by area and by building type, with the bulk of the roofs and roof area occurring in buildings without an attic.
- For large offices and medium offices, the combination of built-up and PRS descriptors indicates the use of Insulation Entirely Above Deck. The majority of large office and medium office roofs are without attics. There are appreciable amounts of other descriptors (particularly AFO and metal), but the most typical is Insulation Entirely Above Deck.
- Primary schools, secondary schools, grocery stores, and hospitals are predominantly without attics and typically have a roof type of Insulation Entirely Above Deck, given that 45% to 72% of roof area is characterized as PRS or built-up. It is possible that there are significant amounts of Metal Buildings as well for schools and grocery stores, as metal surfacing accounts for 16% to 31% of roof area.
- For large hotels, the fractions of buildings and building area with and without attics are fairly even. The largest roof category appears to shingled roofs over an attic, represented by AFO and STS, which accounts for 48% of the total roof area and 50% of buildings. This indicates that Attic and Other roof type is the most common for large hotels.

[1] Assumes the use of recycled plastic and rubber shingles is rare in commercial buildings.

- For quick service restaurant, the sum of PRS and built-up is 58% to 53% (by area and by building, respectively) and the majority of buildings and building area are not associated with attics. This indicates the most common roof type for quick service restaurant is Insulation Entirely Above Deck. In the previous 2007 CBECS building envelope report, authors noted that a flat roof with Insulation Entirely Above Deck does not seem appropriate for many quick service restaurants and an assumption was made that many of these buildings may have Mansard-style roofs with an attic. However, the metal or plastic structure that resembles a Mansard-style roof for these buildings is essentially a façade. The authors identified several local quick service restaurants in Richland and Kennewick, Washington and examined the building profiles of these restaurants using the Google Maps[1] street view and satellite view to investigate the roof structure. Based on this research, the authors believe that flat roofs are constructed beneath the metal or plastic "Mansard" façade on quick service restaurants.
- For small offices, metal surfacing is one of the most common descriptors and most likely represents a metal standing seam roof over an attic. However, the majority of the buildings and roof area do not include an attic, even though roof descriptors that might typically be associated with an attic are in the majority. Based on the CBECS data alone, the most typical roof type for small offices may be Insulation Entirely Above Deck or Attic and Other.
- For stand-alone retail, the metal surfacing roof descriptor could refer to either a traditional Metal Building or Attic and Other with metal roofing over an attic. Roofs without attics are predominant and roofs with PRS and built-up characteristics account for 46% of roof area, which is slightly larger than the 39% of roof area that could be Metal Building roofs. Based on this analysis, Insulation Entirely Above Deck is most likely the most typical roof type for stand-alone retail.
- For strip malls, the high percentage of PRS and built-up roofs indicates that these are likely to be Insulation Entirely Above Deck. PRS and built-up roofs combined for 76% of strip mall roof area and prevail in 60% of strip mall buildings.
- For full service restaurant, metal surfacing likely indicates Attic and Other with metal roofing over an attic or a single-rafter roof rather than a Metal Building roof type. The majority of roof area and sampled buildings do not have attics and about 31% of roof area is unambiguously without an attic (PRS and built-up), but a significant fraction of roof area consists of shingles over roofs without attics (AFO and STS, combined for 23%) as well as metal surfacing (19%). Since PRS and built-up account for more roof area than any other type, Insulation Entirely Above Deck is most likely the most typical roof type for full service restaurants.
- For outpatient healthcare, PRS and built-up roofs constitute 59% of roof area, and the majority of buildings and roof area are not associated with attics, indicating that Insulation Entirely Above Deck is the most typical roof type.
- For small hotel, the prevalence of metal surfacing is unlikely to indicate a Metal Building roof type, but rather the Attic and Other roof type with metal surfacing over an attic. There is a relatively even split of roof area between buildings with attics and without attics, while the fraction by number of buildings favors buildings without attics. The most typical roof type for small hotels may be either Attic and Other or Insulation Entirely Above Deck.
- For large hotel, AFO over roofs with attics is the dominant roof type by both building area (41%) and number of buildings (42%). This indicates that Attic and Other is the most typical roof type for large hotels.

[1] http://www.google.com/maps

Based on this mapping, Table 2.10 summarizes PNNL's roof construction determinations for the prototype buildings, based on CBECS data and professional judgment.

Table 2.10. Principle Roof Constructions by Prototype Buildings (Post-1990 Buildings)

Prototype No.	Prototype Building	Roof Construction
1	Large Office	Insulation Entirely Above Deck
2	Medium Office	Insulation Entirely Above Deck
3	Small Office	Split between Attics and Other and Insulation Entirely Above Deck – No determination from CBECS
4	Warehouse	Metal Building
5	Stand-Alone Retail	Insulation Entirely Above Deck
6	Strip Mall	Insulation Entirely Above Deck
7	Primary School	Insulation Entirely Above Deck
8	Secondary School	Insulation Entirely Above Deck
9	Grocery Store	Insulation Entirely Above Deck
10	Quick Service Restaurant	Insulation Entirely Above Deck
11	Full Service Restaurant	Insulation Entirely Above Deck
12	Hospital	Insulation Entirely Above Deck
13	Outpatient Health Care	Insulation Entirely Above Deck
14	Small Hotel	Split between Attics and Other and Insulation Entirely Above Deck – No determination from CBECS
15	Large Hotel	Attics and Other

When CBECS does not offer sufficient guidance to assign a most-prevalent roof construction to a building type, professional judgment or other sources of information must be used. One way to choose between roof construction types is to have a policy of selecting either the most or the least stringent roof type in terms of U-factor. As noted in the Section 2.0, roofs with Insulation Entirely Above Deck construction are always subject to less stringent requirements (i.e., higher U-factor allowances) than roofs with Attics and Other construction in ASHRAE 90.1-2004 and ASHRAE 90.1-2016. This is a function of the ASHRAE specifications development process, which is based on cost-effectiveness assumptions. This process has implied that it is less expensive to pour in cellulose or install more fiberglass insulation in an attic than it is to add continuous foam insulation to a roof deck. As a result, Insulation Entirely Above Deck has the highest U-factors, and the selection of this type of roof for prototype buildings would result in slightly higher energy usage (all other things being equal) than if the Attic and Other roof type were selected.

In the two cases where CBECS data did not present a predominant roof construction type (i.e., small office and small hotel), the Attic and Other roof type was selected as the more stringent roof construction option. The final roof construction determinations are shown in Table 2.11.

Table 2.11. Final Roof Construction Determinations by Prototype Building (Post-1990 Buildings)

Prototype No.	Prototype Building	Roof Construction
1	Large Office	Insulation Entirely Above Deck
2	Medium Office	Insulation Entirely Above Deck
3	Small Office	Attic and Other
4	Warehouse	Metal Building
5	Stand-Alone Retail	Insulation Entirely Above Deck
6	Strip Mall	Insulation Entirely Above Deck
7	Primary School	Insulation Entirely Above Deck
8	Secondary School	Insulation Entirely Above Deck
9	Grocery Store	Insulation Entirely Above Deck
10	Quick Service Restaurant	Insulation Entirely Above Deck
11	Full Service Restaurant	Insulation Entirely Above Deck
12	Hospital	Insulation Entirely Above Deck
13	Outpatient Health Care	Insulation Entirely Above Deck
14	Small Hotel	Attic and Other
15	Large Hotel	Attic and Other

The 2012 CBECS contains information on cool roof coatings, but no attempt was made to incorporate this information in the current analysis.

2.3 Building Envelope Wall Results

CBECS provides the Wall Construction (WLCNS) statistic as a classification of the major wall construction type for each building record. The CBECS WLCNS categories are (a) brick, stone, or stucco (BSS); (b) concrete block or poured concrete (CBP); (c) decorative or construction glass; (d) pre-cast concrete panels (PCCP); (e) sheet metal panels (SMP); (f) siding, shingles, tiles, or shakes (SSTS); and (g) window or vision glass. CBECS also has classifications of (h) no one major type and (i) other. For each prototype building, Table 2.12 lists the top five CBECS wall construction types in decreasing order of occurrence by percentage of calculated total opaque wall area or number of buildings. In determining the percentage of total opaque wall area, the window area for the building has been removed from the frequency statistic (i.e., total wall area). However, some buildings have their primary wall construction characterized as vision or construction glass in CBECS. The wall fraction that is construction glass (commonly spandrel glass) is generally assumed to be non-transparent.[1] The wall material described as vision glass, which on the surface is not an "opaque" wall construction, is included in this CBECS wall characterization. However, since the indicated building window area has been removed as a wall material type for this analysis of wall construction, building samples with a high prevalence of vision glass defined as wall construction will have correspondingly smaller opaque wall areas calculated in this analysis. This may avoid any overstatement of the "vision glass" classification in terms of wall construction. Even with

[1] For CBECS, the EIA defines construction glass as exterior glass covering that cannot be seen through. EIA elaborates that this glass may look like window glass when viewed at street level, but it is commonly opaque and does not let light through. It includes glass blocks, structural glass, or glass curtain walls and is included in the "Other" category of "Predominant Exterior Wall Material" in CBECS.

this taken into account, the large office building prototype has vision glass as a top five wall material by area and number of buildings.

Table 2.12. Wall Descriptions by Prototype Building (Post-1990 Buildings)

Prototype No.	Prototype Building	Wall Descriptions By Fraction of Opaque Wall Area		Wall Descriptions by Fraction of Buildings	
1	Large Office	PCCP	41%	BSS	35%
		BSS	26%	CBP	23%
		Vision Glass	16%	PCCP	22%
		CBP	9%	Vision Glass	15%
		Cons. Glass	4%	No Major Type	3%
2	Medium Office	BSS	45%	BSS	44%
		CBP	18%	CBP	21%
		PCCP	17%	SSTS	15%
		SSTS	9%	SMP	10%
		SMP	8%	PCCP	9%
3	Small Office	BSS	41%	BSS	43%
		SMP	21%	SSTS	24%
		SSTS	18%	SMP	17%
		CBP	11%	CBP	9%
		PCCP	6%	PCCP	4%
4	Warehouse	SMP	41%	SMP	60%
		CBP	22%	CBP	14%
		PCCP	19%	SSTS	10%
		BSS	13%	BSS	10%
		SSTS	5%	PCCP	6%
5	Stand-alone Retail	SMP	29%	BSS	37%
		BSS	29%	SMP	34%
		CBP	28%	CBP	18%
		PCCP	10%	SSTS	8%
		SSTS	4%	PCCP	4%
6	Strip Mall	BSS	53%	BSS	51%
		CBP	30%	CBP	28%
		PCCP	9%	SSTS	8%
		SSTS	5%	PCCP	8%
		SMP	3%	SMP	5%
7	Primary School	BSS	59%	BSS	45%
		CBP	18%	SSTS	27%
		SSTS	13%	CBP	16%
		PCCP	5%	SMP	7%
		SMP	4%	PCCP	3%
8	Secondary School	BSS	59%	BSS	49%
		SMP	18%	SMP	22%
		CBP	12%	SSTS	14%
		SSTS	5%	CBP	10%
		PCCP	3%	PCCP	3%
9	Grocery Store	CBP	43%	BSS	29%
		PCCP	19%	SMP	28%
		BSS	19%	CBP	21%
		SMP	12%	PCCP	12%
		SSTS	4%	SSTS	8%

Prototype No.	Prototype Building	Wall Descriptions By Fraction of Opaque Wall Area		Wall Descriptions by Fraction of Buildings	
10	Quick Service Restaurant	BSS	59%	BSS	58%
		CBP	20%	CBP	21%
		SSTS	17%	SSTS	13%
		SMP	4%	SMP	6%
		Cons. Glass	3%	Cons. Glass	2%
11	Full Service Restaurant	BSS	59%	BSS	47%
		SSTS	20%	SSTS	26%
		CBP	14%	CBP	17%
		SMP	6%	SMP	9%
		PCCP	1%	PCCP	1%
12	Hospital	BSS	55%	BSS	51%
		CBP	19%	CBP	19%
		PCCP	13%	PCCP	14%
		SSTS	5%	SSTS	13%
		No Major Type	2%	Vision Glass	1%
13	Outpatient Health Care	BSS	58%	BSS	62%
		CBP	22%	CBP	24%
		SSTS	13%	SSTS	10%
		PCCP	5%	SMP	3%
		PMP	2%	PCCP	1%
14	Small Hotel	BSS	44%	CBP	47%
		CBP	38%	BSS	31%
		SSTS	18%	SSTS	21%
15	Large Hotel	BSS	64%	BSS	70%
		CBP	15%	CBP	14%
		SSTS	12%	PCCP	9%
		PCCP	9%	SSTS	7%
		Other	0%	Other	0%

BSS – Brick, Stone, Stucco
CBP – Concrete, Block or Poured
SMP – Sheet Metal Panels
PCCP – Pre-Cast Concrete Panel
SSTS – Siding, Shingles, Tiles, Shakes
Cons. Glass – Construction Glass

2.3.1 Mapping of CBECS Descriptors to ASHRAE Standard 90.1 Wall Types

ASHRAE Standard 90.1 defines four wall types based on the material and functional performance of the wall: Mass Wall, Metal Building Wall, Steel-Framed Wall, and Wood Framed and Other Wall. The Mass Wall type is defined by thermal heat capacitance per unit area and most typically has a masonry or concrete underlying structure. The Metal Building Wall type has a structure consisting of metal spanning members supported by large steel structural members. The Steel-Framed Wall and Wood Framed and Other Wall types are simply frame walls with lighter weight structural members, and therefore different thermal bypass factors. The definition of Mass Wall in ASHRAE 90.1 is a wall with a heat capacity exceeding (1) 7 Btu/ft$^2\cdot$°F or (2) 5 Btu/ft$^2\cdot$°F, provided that the wall has a material unit weight not greater than 120 lb/ft^3. The 7 Btu/ft$^2\cdot$°F metric is for any wall weight, while the 5 Btu/ft$^2\cdot$°F is only for walls lighter than 120 lb/ft^3. Thus, regardless of the actual type and placement of insulation, walls exceeding this level of heat capacity are treated as Mass Wall for setting of minimum U-Factor requirements. The definition of Mass Wall is such that a four-inch brick facing on a frame wall construction is too thermally light in weight to create a Mass Wall under the ASHRAE 90.1 definition.

Comparing the four ASHRAE Standard 90.1 wall types with the 2012 CBECS wall descriptions indicates that most of the CBECS surface types can be mapped adequately to the ASHRAE Standard 90.1 wall types. However, the BSS description could conceivably be mapped to any one of the four ASHRAE 90.1 wall constructions. This is problematic since the BSS description is the single most common description in the 2012 CBECS for all prototype buildings examined in this analysis. Relationships between the ASHRAE Standard 90.1 wall types and the 2012 CBECS wall descriptions are shown in Table 2.13.

Table 2.13. Relationship of CBECS Wall Descriptions and Standard 90.1 Wall Constructions

		ASHRAE Standard 90.1 Wall Construction		
CBECS Wall Descriptions	**Mass Wall**	**Metal Building Wall**	**Steel-Framed Wall**	**Wood Framed and Other Wall**
Brick, Stone, Stucco (BSS)	X	X	X	X
Concrete, Block or Poured (CBP)	X			
Pre-Cast Concrete Panels (PCCP)	X			
Sheet metal panels (SMP)		X		
Siding, Shingles, Tiles, Shakes (SSTS)			X	X
Decorative or Construction Glass			X	
Window or Vision Glass			X	
No Major Type	Unknown	Unknown	Unknown	Unknown
Other	Unknown	Unknown	Unknown	Unknown

The only unambiguous wall descriptions are CBP and PCCP, which are expected to fall under Standard 90.1's Mass Wall construction and SMP, which can be assumed to indicate Metal Building Walls. Buildings that report the use of (1) decorative or construction glass or (2) window or vision glass are believed to be very high WWR buildings (see Section 2.3.4). Many of these buildings are likely to have some type of curtain-wall construction. Curtain-wall construction falls under the 90.1 construction category of Steel-Framed Wall.

The single most common opaque wall category in CBECS is BSS, which is also the most ambiguous category insofar as mapping to the Standard 90.1 construction categories. Brick, stone, and stucco are all commonly used to enhance the aesthetics of a building façade covering either a Mass Wall, Steel-Framed Wall, or Wood Framed and Other Wall. Even though brick and stone can both be the primary supporting construction material used in a building, this is uncommon in newer buildings, which are represented by the prototype buildings. The underlying Standard 90.1 construction is important for establishing the baseline ASHRAE 90.1-2004 U-factor requirements, as well as determining the incremental cost for improvements to the baseline prototype building efficiency. However, any attempt to assign wall constructions to prototype buildings from the CBECS data will undoubtedly require professional judgment. PNNL expects the relative fraction of brick or stone over metal building construction to be small, and the primary question is whether these BSS façades are over Mass Wall, Steel-Framed Wall, or Wood Frame and Other Wall.

Based on the results shown in Table 2.12, the following determinations were made.

- For large office buildings (tall office building under the current classification), the high fraction of concrete-related construction (PCCP and CBP) (50% by opaque wall area) along with some fraction of mass underlying the BSS indicates that Mass Wall construction is predominant.

- For medium office and small office buildings, BSS is clearly predominant (41% to 45% of wall area) and Mass Wall construction of CBP or PCCP represents a significant fraction of opaque wall area (35%) for medium offices and a smaller fraction (17%) for small offices. SSTS also represents a significant fraction (18%) for small offices. If over 22% of the BSS category for medium office buildings were over Mass Wall, then medium offices may reflect more Mass Wall construction and small offices are likely split between Mass Wall, Steel-Framed Wall, or Wood Framed and Other Wall with an edge to one of the frame wall types. However, given its limitations, CBECS does not offer a way to differentiate Steel-Framed Wall and Wood Frame and Other Wall unless there are significant amounts of glass that may indicate curtain-wall construction.
- For warehouses, SMPs, indicative of Metal Building construction, represent the most common post-1990 construction at 41%. However, the combination of Mass Wall (PCCP and CBP) also adds up to 41% by wall area. The additional wall area in terms of BSS (some fraction of which may reflect be mass wall, and some may indicate frame wall), and SSTS (likely frame wall) make it likely that overall warehouse wall area is a split between Mass Wall at approximately 41%, Steel-Framed Wall at 41%, and Wood Frame and Other Wall at 17%. By building weight, SMP clearly predominates, indicating that warehouse buildings are best mapped to Metal Building construction as most typical.
- For stand-alone retail buildings, Mass Wall construction is the most frequently cited by wall area at 38%, with significant amounts of BSS (29%) and SMP (29%). As noted earlier, BSS surfaces can overlay frame construction (i.e., Steel-Framed Wall or Wood Frame and Other Wall) or a traditional Mass Wall. Steel-Framed Wall underlying siding is also common for small retail. Thus, this category seems divided into thirds by surface characteristic with Mass Wall having the edge. This may be partially due to the wide range of building sizes in this category. Even if all the BSS were added to the SSTS, the total would be 33%, or less than the Mass Wall categories in total. This suggests that by area, Mass Wall likely predominates.
- For strip malls, BSS represents 53% and CBP and PCCP combine to represent 39% by opaque wall area. Given the high fraction of Mass Wall (CBP or PCCP) and the low fraction of SSTS, it's likely that strip malls will fall into the Mass Wall category. If as little as 18% of the BSS were surfacing over a masonry wall, Mass Wall would be the predominant wall type.
- For primary and secondary school buildings, Mass Wall construction (in this case CBP and PCCP) represents 23% of wall area for primary school buildings and 17% for secondary school buildings. Approximately 59% of wall area for primary school buildings and 59% for secondary school buildings is in BSS construction, and roughly 13% for primary school buildings and 3% for secondary school buildings are in siding or shingles. A relatively small fraction of primary school (4%) is in metal panels, but a larger fraction of secondary school is in metal panels (18%). Given that it is unknown what underlies the BSS, no single determination is forthcoming from CBECS. These buildings could be either Mass Wall, Steel-Framed Wall, or Wood Frame and Other Wall.
- For grocery stores, the obvious Mass Wall constructions (CBP, PCCP) taken together represent 62% of wall area, much more than BSS at 18% and metal panels at 12%. Grocery stores are likely to be Mass Wall construction.
- For quick service and full service restaurants, the very high fraction of BSS (55% and 59%, respectively) and the moderate amount of known Mass Wall (21% and 15%, respectively) suggests that CBECS can provide little guidance as to underlying wall construction. Any decision on underlying wall structure will depend on how to classify the BSS underlying construction. No underlying single recommendation is forthcoming from CBECS. These buildings could be either Mass Wall, Steel-Framed Wall, or Wood Frame and Other Wall.
- For small hotels, BSS makes up 44% of the wall area, while concrete (CBP) makes up 38% and siding (SSTS) makes up 18%. This suggests that if approximately 28% of the BSS were clad over a

masonry wall, then mass wall construction would be predominant in small hotels. However, CBECS provides little guidance as to whether Mass Wall, Steel-Framed Wall, or Wood Frame and Other Wall construction is the underlying construction.

- BSS makes up over 55% of the wall area for each of the remaining prototype building categories (hospital, outpatient health care, and large hotels). Known Mass Wall constructions (CBP and PCCP) range from 24% (outpatient healthcare and large hotel) to 35% (hospital) of wall area. This suggests that Mass Wall construction may be predominant in hospitals. For outpatient healthcare and large hotels, Mass Wall construction may also be predominant, but it is difficult to determine from the CBECS data.

Based on this discussion, the determinations shown in Table 2.14 were made for the prototype buildings.

Table 2.14. Wall Constructions for Prototype Buildings (Post-1990 Buildings, CBECS data)

Prototype No.	Prototype Building	Wall Construction*
1	Large Office	Mass Wall
2	Medium Office	Mass Wall or Frame Wall
3	Small Office	Mass Wall or Frame Wall
4	Warehouse	Metal Building Wall
5	Stand-Alone Retail	Mass Wall
6	Strip Mall	Mass Wall or Frame Wall
7	Primary School	Mass Wall or Frame Wall
8	Secondary School	Mass Wall or Frame Wall
9	Grocery Store	Mass Wall
10	Quick Service Restaurant	Mass Wall or Frame Wall
11	Full Service Restaurant	Mass Wall or Frame Wall
12	Hospital	Mass Wall or Frame Wall
13	Outpatient Health Care	Mass Wall or Frame Wall
14	Small Hotel	Mass Wall or Frame Wall
15	Large Hotel	Mass Wall or Frame Wall

Frame Wall refers to either of the ASHRAE Standard 90.1 wall construction categories Steel Framed Wall or Wood Frame and Other Wall.

2.3.2 Wall Construction Data from NC3

Many of the building types in the CBECS data have a surface material of BSS which could map to any of the ASHRAE wall construction types. This is very problematic for using analysis of CBECS data to inform updates to the prototype building specifications. In an attempt to provide a better estimate for wall construction for new buildings, data from the New Commercial Construction Characteristics (NC3) dataset was extracted. (Richman 2008) The NC3 data set includes fields for more than 130 possible building characteristics extracted from building construction plans and specifications for a set of 340 commercial buildings from across the U.S., as acquired from the F.W. DODGE Division of McGraw Hill.

Table 2.15 presents the results of that extraction. While the sample size of NC3 is fairly low for most prototype buildings types, the results provide some useful data.[1] The NC3 data were based on building

[1] The NC3 database contains a field where building samples were pre-assigned to the ASHRAE 90.1 prototypes and this assignment was used in this work. In particular, small hotel and large hotel are defined in that way which may

construction plans in the bid process from 2001 through 2007, which suggests that these data are applicable to the post-1990 buildings considered in this report. The NC3 data represent a detailed data source that can supplement the CBECS data and provide information on the underlying wall structure rather than just exterior wall surfacing.

Table 2.15 provides data from NC3 to identify the most common wall construction type out of the four ASHRAE wall construction classifications by building count, floor area, wall area, and opaque wall area. For this analysis, the major wall construction data fields were used to represent the building construction whereas secondary/minor wall construction data fields were not further examined.[1]

NC3 has four wall construction categories: masonry block, metal frame, solid concrete, and wood frame. For this effort, masonry wall construction includes both concrete block and solid concrete walls, as both would generally be considered Mass Wall in Standard 90.1. In addition, the NC3 database does not differentiate between Steel-Framed Walls and Metal Building walls, both are captured as metal frame. For the purpose of this analysis, where metal frame wall construction is indicated in NC3, it is presumed that it refers primarily to Steel-Framed Wall construction with the exception of the warehouse building prototype, which is assumed to reflect Metal Building construction.

Some of the NC3 data samples have been identified as having inconsistent dimensional data in the database (e.g. floor area not consistent with wall area and structure information) and not all buildings had their major wall construction type identified. For the results shown in Table 2.15, the “Sample Count” column reflects all buildings where the major wall construction type was identified in the data set and where the building was mapped to one of the prototypes. This was used to identify the most common 90.1 wall construction type for the “Building Count” column in the table. The “Sample Count Dim(ensional) Data” column reflects all buildings where: (1) the major wall type was identified, (2), the mapped building prototype was previously identified in the dataset, and (3) no flag regarding dimensional data was indicated. The calculated fraction of total wall area and of opaque wall area are based on the fraction of samples where the wall construction type was identified and the dimensional data was not identified as inconsistent.

In Table 2.15, each column under the “Most Common Construction Type” provides the most common wall construction type from the NC3 sample along with the corresponding fraction represented by the most common construction. For example, for medium office buildings, 82% of the building opaque wall area was found in buildings with Steel-Framed Wall building construction as the primary wall construction used in the building.

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not reflect the same building assignment used elsewhere in the report based on CBECS motel/hotel principal building activity (PBA).

[1] Secondary exterior walls in the NC3 database can differ from primary walls by underlying wall construction or by simply wall surfacing (e.g. brick face and siding on the same underlying frame construction). Based on data captured in NC3, approximately 11 % (29/262) of the prototype samples indicated that there was a secondary wall construction different than the primary wall construction. Of those 11% of buildings, the simple average of the fraction of secondary construction indicated was 20% of the wall area. This net secondary construction was small and deemed not likely to impact the most-common wall construction represented.

Table 2.15. NC3 Wall Type Most Common 90.1 Wall Construction Type Results

Prototype No.	Prototype Building	Sample Count	Sample Count – Dim Data	Most Common 90.1 Wall Construction Type by: Building Count Const.	Building Count Fract.	Floor Area Const.	Floor Area Fract.	Wall Area Const.	Wall Area Fract.	Opaque Wall Area Const.	Opaque Wall Area Fract.
1	Large Office	5	2	Steel-Framed	80%	Steel-Framed	100%	Steel-Framed	100%	Steel-Framed	100%
2	Medium Office	27	22	Steel-Framed	67%	Steel-Framed	75%	Steel-Framed	82%	Steel-Framed	82%
3	Small Office	15	11	Steel-Framed	53%	Steel-Framed	82%	Wood-Framed	74%	Wood-Framed	76%
4	Warehouse	19	18	Metal Building	53%	Metal Building	58%	Metal Building	65%	Metal Building	67%
5	Stand-Alone Retail	32	32	Mass	56%	Steel-Framed	72%	Mass	62%	Mass	60%
6	Strip Mall	18	16	Mass	56%	Steel-Framed	58%	Mass	53%	Mass	52%
7	Primary School	26	22	Mass	62%	Mass	70%	Mass	60%	Mass	59%
8	Secondary School	23	21	Mass	52%	Mass	68%	Mass	54%	Mass	49%
9	Grocery Store	16	15	Mass	63%	Mass	83%	Mass	69%	Mass	68%
10	Quick Service Restaurant	12	11	Wood-Framed	83%	Wood-Framed	80%	Wood-Framed	97%	Wood-Framed	97%
11	Full Service Restaurant	19	19	Steel-Framed	47%	Wood-Framed	48%	Steel-Framed	77%	Steel-Framed	77%
12	Hospital	10	9	Steel-Framed	100%	Steel-Framed	100%	Steel-Framed	100%	Steel-Framed	100%
13	Outpatient Health Care	14	11	Wood-Framed	57%	Wood-Framed	44%	Steel-Framed	51%	Steel-Framed	51%
14	Small Hotel	18	17	Wood-Framed	72%	Wood-Framed	72%	Wood-Framed	53%	Wood-Framed	52%
15	Large Hotel	8	8	Steel-Framed	80%	Steel-Framed	90%	Steel-Framed	93%	Steel-Framed	91%
	Total	262	234								

Depending on the metric used, the most common wall construction type found in NC3 varies. For instance, for small offices, the most common construction type by building count was Steel-Framed Wall. However, the most common by wall area, particularly opaque wall area, was Wood-Framed by a substantial margin. In general, for purposes of this analysis, total opaque wall area is considered the most insightful metric for determining the most common wall construction type and so forms the basis of much of the analytical selection. However, the small office and outpatient healthcare prototypes have smaller sample sizes when only buildings with adequate dimensional data are considered, introducing some uncertainty into the selection of most common wall construction category.

When comparing the NC3 results with the CBECS data (based only on surface wall features) and using opaque wall area as the key feature identifying the most common wall construction type, the following observations were made for the prototypes:

- There is disagreement between NC3 and CBECS with regards to large office. The NC3 analysis suggests Steel-Framed Wall whereas the CBECS analysis indicated Mass Wall. The CBECS determination was not modified based on the NC3 analysis due to the small sample size of the NC3 data for large offices.

- Medium office is predominantly Steel-Framed Wall.
- Small office appears to be predominantly Wood-Framed Wall in terms of opaque wall area or total wall area. However, the building count statistic suggests a higher fraction of Steel-Framed construction.
- Strip mall appears to have Mass Wall as the predominant construction by opaque wall construction (52%), but frame building walls are also common. Steel-Framed Walls represented 29% of the opaque wall area and Wood-Framed Walls represented an additional 19%. Based on these observations, mass walls are considered the most common of the three wall type categories for strip malls.
- Primary schools indicated Mass Wall as the most common construction type across all NC3 metrics.
- Secondary schools indicated Mass Wall as slightly more common than Steel-Framed Walls in terms of opaque wall area, at 49%. Steel-Framed was 47% of opaque wall area. The difference is very slight, resulting in an inconclusive determination. For the remaining, Wood-Framed Walls represent another 4.5% of the opaque wall area (approximately 9.5% of the total frame wall construction), indicating that frame walls are slightly more common than Mass Walls overall. Mass Wall is most likely the most typical wall construction of the three Standard 90.1 categories.
- Quick service restaurant buildings use Wood-Framed Wall construction based on the NC3 sample data.
- Full service restaurants use Steel-Framed Wall construction generally.
- Hospital used Steel-Framed Wall construction.
- Outpatient health care used Steel-Framed Wall construction in terms of opaque wall area, but the building count statistic suggests Wood-Framed wall usage may also be common. By opaque wall area, Steel-Framed Wall made up 51%, Wood-Framed Wall made up 39% and Mass Wall made up 11%.
- The building samples identified as small hotel most commonly used Wood-Framed Wall construction at 52% of the opaque area. Steel-Framed Wall was indicated as 44% of the opaque area whereas Mass Wall represented approximately 4% of the opaque wall area.
- The NC3 sample size for large hotel was small with eight NC3 observations, but all had useful dimensional data. The most common construction type was decidedly Steel-Framed Wall construction.

In Table 2.16, NC3 results were used to provide wall types for prototype buildings for which CBECS determinations were unclear. However, given the small sample sizes for many of the NC3 buildings, these determinations are not definitive. No attempt was made to replace wall constructions derived from CBECS, as shown in Table 2.14, with those from NC3. Constructions informed using NC3 data are shown with asterisks (“*”). Constructions that appear to be most tentative either due to very small sample size or close splits between mass and frame construction (secondary schools, strip malls) are also marked accordingly. Table 2.16 offers wall construction determinations based on a combination of the NC3 results in Table 2.15 and the CBECS results in Table 2.14.

Table 2.16. Wall Construction Determinations by Building Type (Post-1990 Buildings, based on 2012 CBECS data and 2008 NC3 data)

Prototype No.	Prototype Building	Wall Construction
1	Large Office	Mass Wall
2	Medium Office	Steel-Framed Wall*
3	Small Office	Wood-Framed Wall*,***
4	Warehouse	Metal Building Wall
5	Stand-Alone Retail	Mass Wall
6	Strip Mall	Mass Wall*,**
7	Primary School	Mass Wall*
8	Secondary School	Mass Wall*,**
9	Grocery Store	Mass Wall
10	Quick Service Restaurant	Wood-Framed Wall*
11	Full Service Restaurant	Steel-Framed Wall*
12	Hospital	Steel-Framed Wall*
13	Outpatient Health Care	Steel-Framed Wall*,***
14	Small Hotel	Wood-Framed Wall*
15	Large Hotel	Steel-Framed Wall*

* Informed by NC3 data

** Choice of Mass Wall or Steel-Framed Wall tentatively assigned based on limited or indeterminate NC3 data

*** Choice of Steel-Framed Wall or Wood-Framed Wall tentatively assigned based on NC3.

2.3.3 Consideration of Gross Wall Area

In considering opaque wall area, CBECS records were included for wall types that were identified as construction or vision glass as part of the analysis. If the wall construction data in the 2012 CBECS is examined, the only prototype building type where the wall construction material was categorized as glass with significant frequency was large office at 18% (3% of gross wall area in large office buildings with the Wall Construction [WCNS] statistics as decorative or construction glass and 15% of gross wall area in large office buildings listed as window or vision glass).

The results in Table 2.17 indicate that glass accounts for a trivial amount of the main wall construction material in prototype buildings other than large office buildings. The question asked in the 2012 CBECS was regarding the primary wall construction, not about the windows. The typical respondent to the CBECS survey likely does not consider windows, operable or not, with or without frames, to be wall construction.

As categories of primary wall construction, a determination of vision or construction glass depends on whether a high WWR building wall construction is considered glass, masonry, metal, or other underlying opaque structure, which may be highly subjective to the survey respondent. Upon further examination, of the individual CBECS 2012 observations that fall in the 76–100% exterior glass category (86 observations across all years falling into the prototype categories), only 21 list “window or vision” glass as the wall construction and six list “decorative or construction glass” as the wall construction. The majority of these very high WWR buildings have wall construction classified as another (opaque) construction material. Similarly, of the 204 observations falling into the prototype categories and reporting 51–75% WWR, only three list construction glass as the wall construction material and 30 list vision glass as the wall construction material. The vast majority of these observations are found in the Large Office category.

When analyzing the CBECS building records mapped to prototypes, 28 records showed 76–100% exterior glass with seven indicating vision glass as the wall construction material and two reporting construction glass as the wall construction material. Furthermore, 77 records had 51–75% exterior glass with 14 indicating vision glass as the wall construction material and one reporting construction glass as the wall construction material. In addition, 200 records showed 26–50% exterior glass with eight indicating vision glass as the wall construction material and two reporting construction glass as the wall construction material. Based on these observations, it appears that there is a correlation between reporting vision glass as the construction material and reporting high WWR, but even at the highest 76–100% exterior glass category, roughly 68% of records do not report that wall construction material is glass. Removing vision glass as one of the wall material categories in Table 2.12 has essentially no significant impacts on the characterization of the envelope for prototypes, other than large office, by either wall area or building weights. For large office, removing vision class alters the fractions of wall area and building weight from those shown in Table 2.12, but it does not alter the relative order.

Table 2.17. Fraction of Total Wall Area in Prototype Building Category in Buildings Reporting 'Glass' for Main Wall Construction Material (Post-1990 Buildings)

Prototyp e No.	Prototype Building	Decorative or Construction Glass	Window or Vision Glass	Total Glass
1	Large Office	2.3%	16.4%	18.7%
2	Medium Office	0.2%	1.6%	1.7%
3	Small Office	0.0%	0.3%	0.3%
4	Warehouse	0.0%	0.0%	0.0%
5	Stand-alone Retail	0.0%	0.0%	0.0%
6	Strip Mall	0.0%	0.0%	0.0%
7	Primary School	0.0%	0.0%	0.0%
8	Secondary School	0.0%	1.2%	1.2%
9	Grocery Store	0.0%	0.0%	0.0%
10	Quick Service Restaurant	2.6%	0.0%	2.6%
11	Full Service Restaurant	0.0%	0.0%	0.0%
12	Hospital	0.1%	0.4%	0.45%
13	Outpatient Health Care	0.0%	0.7%	0.7%
14	Small Hotel	0.0%	0.0%	0.0%
15	Large Hotel	0.0%	0.0%	0.0%

2.3.4 Window-to-Wall Area

To estimate glass area from the CBECS data, analysis was conducted on data for reported percent exterior glass. As noted previously, CBECS uses six different WWR categories for classifying the percent exterior glass for those buildings reporting this statistic.[1] Table 2.18 shows the fraction of total wall area (opaque and glass area) for each WWR category by prototype building using the percent exterior glass assumptions from Table 2.3 (the midpoint of each WWR range) and ignoring buildings for which the WWR area statistic was not reported. Table 2.18 also provides the average window area to total wall area

[1] 2003 CBECS used five categories of WWR and grouped the 0–1% and the 2–10% categories into one 0-10% category.

ratio calculated for each prototype building. The bins that contain the highest amount of total wall area by WWR bin are shown in **bold** font. Table 2.19 shows the fraction of all window area for the prototype buildings as determined by WWR bin and expected WWR within the bin (highest fraction shown in **bold** font). The average WWR is calculated as the sum of window area in all WWR bins divided by the sum of total wall area for all buildings reporting a WWR bin and provides the average WWR as shown in Table 2.18.

Table 2.20 shows the fraction of buildings represented by the CBECS data set in each WWR bin, based on samples reporting this data and CBECS building weights. The bin that contains the most observations (i.e., most typical) for each prototype building category is shown in **bold** font. There are a significant number of buildings with 1% or less glass in all building types except large office and hospital. Warehouses, grocery stores, and stand-alone retail have large numbers of buildings with little or no glass, as expected. However, the WWR analysis results did not align with conventional wisdom for a number of other buildings that had less than 1% to 10% of glass in their building. This may have been due to the design of CBECS, which asked survey respondents to pick the bin that most closely matched the surveyed building, with the 1% or less and 2 to 10% pictures appearing similar in the survey. While EIA's intent to identify very low WWR buildings in CBECS is laudable, it is difficult for survey respondents to look at a building façade and determine without detailed measurement the difference between a 0.5–1.0% WWR and 2% WWR building, which may have been a shortcoming when reporting the data for the 2012 CBECS.

Table 2.18. Window-to-Wall Area Fraction for Post-1990 Buildings (Fraction of total wall area in each Window-to-Wall Area Bin)

Prototype No.	Prototype Building[a]	1 percent or less	2 to 10 percent	11 to 25 percent	26 to 50 percent	51 to 75 percent	76 to 100 percent	Avg. WWR
1	Large Office	0%	0%	28%	21%	**41%**	10%	48%
2	Medium Office	5%	21%	**52%**	15%	4%	3%	22%
3	Small Office	14%	35%	**38%**	13%	0%	0%	14%
4	Warehouse	**64%**	27%	6%	3%	0%	0%	4%
5	Stand-alone Retail	**45%**	23%	24%	5%	0%	3%	10%
6	Strip Mall	5%	23%	**36%**	26%	10%	0%	24%
7	Primary School	9%	**42%**	37%	9%	4%	1%	15%
8	Secondary School	17%	24%	**30%**	25%	4%	0%	19%
9	Grocery Store	**54%**	36%	9%	0%	0%	0%	4%
10	Quick Service Restaurant	23%	21%	**27%**	20%	9%	0%	20%
11	Full Service Restaurant	29%	16%	**30%**	24%	1%	0%	16%
12	Hospital	0%	8%	**47%**	40%	4%	2%	28%
13	Outpatient Health Care	6%	32%	**41%**	17%	3%	1%	19%
14	Small Hotel	14%	**49%**	37%	0%	0%	0%	10%
15	Large Hotel	0%	24%	**63%**	4%	7%	1%	20%

(a) Window area fractions developed consider only those buildings in which window area fraction was reported. For the Post-1990 buildings mapped to prototypes, the fraction not reporting is relatively small (< 9% of total gross wall area in buildings not reporting, < 13% of buildings for most building prototype). For large office, however, the fraction not reporting, although only 12% of large office samples or records, added up to 25% of total gross wall area and 46% of buildings represented. For hospitals, the fraction not reporting added up to 17% of total gross wall area and 15% of buildings represented.

Table 2.19. Window-to-Wall Area Fraction for Post-1990 Buildings (Fraction of total window area in each Window-to-Wall Area Bin)

Prototyp e No.	Building Type[(a)]	1 percen	2 to 10 percen	11 to 25 percent	26 to 50 percent	51 to 75 percent	76 to 100 percent	Avg. WWR
1	Large Office	0%	0%	10%	17%	**54%**	19%	48%
2	Medium Office	0%	6%	**43%**	26%	11%	13%	22%
3	Small Office	1%	15%	**49%**	35%	0%	0%	14%
4	Warehouse	8%	**38%**	26%	28%	0%	0%	4%
5	Stand-alone Retail	2%	13%	**41%**	19%	2%	22%	10%
6	Strip Mall	0%	6%	27%	**41%**	26%	1%	24%
7	Primary School	0%	16%	**43%**	21%	15%	5%	15%
8	Secondary School	0%	8%	28%	**51%**	13%	0%	19%
9	Grocery Store	7%	53%	40%	0%	0%	0%	4%
10	Quick Service Restaurant	1%	6%	25%	**39%**	29%	0%	20%
11	Full Service Restaurant	1%	6%	32%	**56%**	5%	0%	16%
12	Hospital	0%	2%	30%	**54%**	9%	5%	28%
13	Outpatient Health	0%	10%	**40%**	34%	10%	5%	19%
14	Small Hotel	1%	31%	**69%**	0%	0%	0%	10%
15	Large Hotel	0%	7%	**57%**	8%	24%	4%	20%

(a) Window area fractions developed consider only those buildings where window area fraction was reported. For the Post-1990 buildings mapped to prototypes, the fraction not reporting is relatively small (< 13% of total gross wall area in buildings not reporting, < 13% of buildings for most building prototype). For large office, however, the fraction not reporting, although only 12% of large office samples or records, added up to 25% of total gross wall area and 46% of buildings represented. For hospitals, the fraction not reporting added up to 17% of total gross wall area and 15% of buildings represented.

Table 2.20. Fraction of Buildings in Each Window-to-Wall Ratio Bin (Post-1990 Buildings)

Prototype No.	Prototype Building	1 percent or less	2 to 10 percent	11 to 25 percent	26 to 50 percent	51 to 75 percent	76 to 100 Percent	Avg. WWR
1	Large Office	0%	0%	33%	24%	**35%**	8%	40%
2	Medium Office	9%	25%	**53%**	9%	1%	2%	14%
3	Small Office	17%	**40%**	33%	11%	0%	0%	13%
4	Warehouse	**79%**	15%	5%	1%	0%	0%	4%
5	Stand-alone Retail	32%	**34%**	24%	7%	0%	3%	13%
6	Strip Mall	5%	27%	**33%**	27%	8%	0%	22%
7	Primary School	20%	**43%**	25%	7%	3%	0%	14%
8	Secondary School	**36%**	32%	15%	15%	3%	0%	14%
9	Grocery Store	**42%**	40%	19%	0%	0%	0%	8%
10	Quick Service Restaurant	23%	23%	**27%**	20%	8%	0%	18%
11	Full Service Restaurant	**32%**	16%	28%	22%	2%	0%	14%
12	Hospital	0%	10%	62%	24%	2%	1%	17%

Prototype No.	Prototype Building	1 percent or less	2 to 10 percent	11 to 25 percent	26 to 50 percent	51 to 75 percent	76 to 100 Percent	Avg. WWR
13	Outpatient Health Care	12%	**43%**	31%	12%	1%	0%	15%
14	Small Hotel	21%	**55%**	24%	0%	0%	0%	11%
15	Large Hotel	0%	31%	**64%**	2%	3%	0%	12%

(a) Fraction of buildings statistic considers only those buildings where WWR was reported. For all buildings but office and hospital, the fraction not reporting was relatively small (< 13% of buildings by buildings represented). For Large Office, however, the fraction not reporting added up to 46% buildings represented. For Hospital, it added up to 15% of buildings represented.

2.3.5 Distribution of Glazing

CBECS 2012 also reports whether or not the glass in a building is distributed equally on all sides with the Equal Glass (EQGLS) statistic. The CBECS 2012 data for post-1990 buildings is shown in Table 2.21 based on buildings represented in the population. Building samples heavily weighted (60% or greater) toward equal or unequal dispersion are identified in the last two columns.[1] No approach was implemented for records in which the weighting was more or less equivalent, though it may make sense to presume equal distribution.

Quick service and full service restaurants are a potential anomaly, as the authors' expertise indicates that few, if any, have equal glazing on all sides. Rather, the glass is likely equally distributed in the dining area, but kitchen areas are seldom glazed.

Table 2.21. Distribution of Glazing for Post-1990 Buildings

Prototype Number	Prototype Building Type	Fraction of Buildings with Equal Glazing Distribution	Fraction of Buildings with Unequal Glazing Distribution	More Equally Distributed	Less Equally Distributed
1	Large Office	81%	19%	X	
2	Medium Office	50%	50%		
3	Small Office	44%	56%		
4	Warehouse	70%	30%	X	
5	Stand-alone Retail	25%	75%		X
6	Strip Mall	16%	84%		X
7	Primary School	72%	28%	X	
8	Secondary School	64%	36%	X	
9	Grocery Store	16%	84%		X
10	Quick Service Restaurant	32%	68%		X
11	Full Service Restaurant	34%	66%		X
12	Hospital	62%	38%	X	
13	Outpatient Health Care	49%	51%		
14	Small Hotel	51%	49%		
15	Large Hotel	77%	23%	X	

[1] Three building types were heavily weighted one way or the other, but not quite at 60%. These include motel at 59% equally distributed and small office and fast food at 58% unequal distribution. These are marked as though they were heavily weighted because the 60% cutoff is fairly arbitrary.

3.0 Analysis of HVAC Mechanical Systems in 2012 CBECS

This section presents the results of an analysis of the HVAC mechanical system characteristics reported in the 2012 CBECS, disaggregated to the PNNL prototype building definitions.

3.1 Background for HVAC Mechanical System 2012 CBECS Analysis

Before describing the 2012 CBECS HVAC results, it is important to understand some background information about the 2012 CBECS building data.

3.1.1 HVAC Information Available in 2012 CBECS

Useful information regarding heating and cooling equipment is available in the CBECS data, primarily in the main cooling equipment and main heating equipment fields. For each building in the CBECS survey, the record identifies the main heating and the main cooling equipment. The categories for these are as follows.

- Main Heating Equipment
  - boilers inside the building
  - district steam or hot water
  - furnaces that heat air directly
  - heat pumps for heating
  - individual space heaters (ISH)
  - packaged central units (PCUs), roof mounted
  - some other heating equipment.
- Main Cooling Equipment
  - central chillers inside the building
  - district chilled water
  - heat pumps for cooling
  - individual room air conditioners (IRAC)
  - packaged air-conditioning units (PACU)
  - residential-type central air conditioners (Res CAC)
  - swamp coolers or evaporative coolers
  - some other cooling equipment.

CBECS also presents data on the percentage of each building heated and cooled based on survey response, as well as the percentage heated or cooled (assumed to refer to percent floor space) by specific equipment categories. The latter data collected are in a similar form to the main cooling and main heating categories.

- Percent Heated by:
  - Furnace

- Boiler
- PCU
- ISH
- Heat pumps
- District steam/hot water
- Other heating equipment.

- Percent Cooled by:
  - PACU
  - Central AC
  - IRAC
  - Heat pumps
  - District chilled water
  - Central chillers
  - Swamp coolers
  - Other cooling equipment.

For records in which main heating or cooling equipment is identified, further detail on the type of equipment or system is provided, usually in the form of a yes/no indicator whether a specific equipment type or component is found in the building. For instance, where heat pumps are used, the survey asks additional questions regarding the presence or absence of specific types of heat pumps (e.g., water source, ground source, air source, packaged, split system, individual room) used for heating and cooling in the building, which is presented in the building record data. Similar detailed data about the presence or absence of particular equipment types are found for most other main heating or cooling equipment categories. For boiler and chiller heating and cooling systems, the terminal distribution equipment (e.g., radiator, induction unit) is provided. CBECS also presents data on whether the building uses a variable air volume (VAV) system, underfloor air distribution, dedicated outside air systems, and the main and secondary heating or cooling fuel types.

3.1.2 CBECS Limitations in Survey Terminology

Unfortunately, not all of the CBECS questions and responses for equipment categories are mutually exclusive, which can lead to difficulties clarifying the HVAC equipment used in a building. This was a larger problem with previous versions of CBECS.

CBECS defines a “packaged unit” as a type of heating and/or cooling equipment assembled at a factory and installed as a self-contained unit. Packaged units are in contrast to engineer-specified equipment built from individual components and specifically designed for use in a given building. Some types of electric packaged units are also called direct expansion (DX) units. While this definition exists in the CBECS 2012 glossary, the responses captured in the survey are for PCUs. PCUs are defined as simply “boxes that provide heating” to many occupants. Identifying what that heating component of the box is, be it a furnace, a boiler hydronic coil, electric heat, or a heat pump, is beyond the interest or knowledge of survey respondents, and so a PCU heating section could also mean any of these three categories. The most common PCU is expected by the authors to be a gas furnace installed as part of packaged rooftop cooling unit. However, other components could also be installed for heating.

CBECS defines a "furnace" as a type of space-heating equipment with an enclosed chamber where fuel is burned or electrical resistance is used to heat air directly, without using steam or hot water. Air ducts then distribute the heated air throughout the building. However, a furnace survey response could refer to a gas or electric furnace in a packaged rooftop unit, a stand-alone gas or electric furnace, or a gas or electric furnace with a direct expansion coil—as with a residential split system furnace/air handler.

"Heat pump" is another term that was more problematic in previous versions of CBECS. In the 2012 CBECS, the definitions and follow-on questions help identify the various classes of heat pumps. In the case of certain equipment types, heat pumps will overlap with other buildings heating or cooling equipment (e.g., water source heat pump systems commonly require boilers and in some cases chillers). Heat pumps can also potentially be package heating units or individual room heating units as in the case of packaged terminal heat pumps.

Unlike previous CBECS versions, the 2012 CBECS questionnaire goes through a more elaborate questionnaire and logic process to identify and categorize both heating and cooling equipment. The 2012 CBECS questionnaire first asks whether heating equipment falls into one or more of the seven specific categories (defined in Section 3.1.1) for the building. Then, an additional 20 follow-up questions elicits responses that provide greater detail on the type of equipment found in the building, and in some cases, re-categorizes and re-maps certain responses to specifically lead the respondent to understand which types and subcategories of equipment and systems are embodied in the CBECS seven main heating equipment types, including heating distribution systems and terminal equipment. The CBECS questionnaire then asks for the fraction of the building served by each of the seven major heating equipment types to identify the main heating equipment of the building. When equal fractions of the building are reported as served by different equipment categories (i.e., a tie), the respondent is asked to identify what they believe to be the main heating equipment.

Similarly, for cooling equipment, the 2012 CBECS questionnaire asks about the presence of eight different cooling equipment types, and then follows up with 11 additional questions regarding details of the cooling equipment and distribution system, including whether the distribution system is also used for heating. It then asks for the fraction of the building served by each of the eight major cooling equipment types to better identify the main cooling equipment for the building. When an equal fraction of the building is reportedly served by different cooling equipment categories, the respondent is asked to identify the main cooling equipment

Based on the responses to the questions discussed above, CBECS describes the main heating and main cooling equipment using the equipment categories described in Section 3.1.1. In general, much of the overlap that may have existed between equipment types is removed by follow-up questions and explicit mapping to defined CBECS equipment types (e.g., ISH) as appropriate. However, in the case of PCU, CBECS 2012 opted to define PCU clearly as rooftop equipment, but allowed for various packaged heating components (e.g., gas furnaces, electric furnaces, and heat pumps) to fit into the definition for PCU without separately indicating the prevalence of these equipment types in a particular building.

3.1.3 CBECS Limitations on Percent of Floor Space Heated and Cooled

While CBECS provides estimates of the fraction of floor space heated or cooled by the different equipment categories, analysis of the data indicates that it is quite common for the sum of the estimates to exceed 100 percent.[1] For simple buildings, it may be relatively easy to define one heating or cooling

[1] Approximately 11 percent of building records that report space heating have a sum of heating equipment by floor space that exceeds 100 percent.

equipment type for each portion of floor space, preventing this issue. However, for buildings with either multiple systems serving multiple spaces, poorly defined or unknown HVAC zoning, or uncertainty between terminal equipment and central plant equipment, assigning a fraction of floor area to a particular system may be very difficult. The main heating or cooling equipment is not specifically assessed in terms of thermal load served or fuel use by CBECS. Instead, CBECS defines what it considers the main heating or main cooling equipment through questions regarding the fraction of floor space served.

3.2 HVAC 2012 CBECS Analysis

To examine HVAC system selection, data was extracted for all 2012 CBECS buildings with 1990 or later construction, referred to in this report as “Post-1990” construction. The analysis of this data is summarized by main heating, main cooling, and fan system, and mapped to the prototype buildings.

3.2.1 Main Heating and Main Cooling Results

Table 3.1 provides the results of national-scale data aggregation for post-1990 CBECS building samples on main heating and main cooling equipment, indicating the most common main heating and main cooling HVAC equipment types by building prototype[1] in terms of the number of represented buildings and the total represented floor area. For some building types, a significant fraction of the aggregate building floor area is reported as unheated or uncooled, and this fraction was defined as having no heating or cooling equipment, as shown in Table 3.1. Data for post-1990 buildings aggregated at the Census region level have also been developed and are presented in Appendix C along with the total number of samples by region and building type. In the identification of equipment type, no attempt was made to declare whether certain equipment is associated with a specific fuel type (e.g. electric furnace versus gas furnace). While most cooling equipment are electrically powered, a number of different heating fuels are utilized in commercial buildings. In a separate effort to examine the predominance of electric versus fossil fuel used for heating commercial buildings, PNNL examined heating fuel in the prototype building sample by climate zone and geographic location. Methodology and results for this analysis are discussed in Appendix D for the readers to draw insight, but no conclusions are provided in the body of this report.

Table 3.1 exhibits two unique points of interest (in bold text): (1) the high percentage of unheated and uncooled warehouses[2] and (2) the significant fraction of district heating and cooling in secondary schools.

[1] This analysis defines large, medium, and small offices based on the number of stories in the building with small referring to one story, medium referring to two to four stories, and large referring to greater than four stories. Other methods of categorizing office building size would presumably influence the relative equipment usage statistics for these office prototypes.

[2] A review of the 2012 CBECS data indicates that a significant fraction of buildings and associated building floor space are reported as “unheated,” identified in the building record by zero space heated in the building, or a specific survey response that no energy was used for heating. For these buildings, no energy is assigned for either primary or secondary heating. On review, often these buildings are either warehouses or listed as vacant. The CBECS questionnaire asks what fraction of floor space is heated to greater than 50 °F and if the response is recorded as zero percent the CBECS questionnaire proceeds to ask if any of the building space is heated to less than 50 °F. In the post-1990 sample, four buildings samples, only two of which were mapped to a prototype, were indicated as being heated to less than 50 °F. Heating equipment for these buildings is included in that shown in Table 3.1.

Table 3.1. HVAC Equipment in Post-1990 Buildings in 2012 CBECS

Prototype Number	Prototype Building	By Number of Buildings		By Floor Area	
		Heating	Cooling	Heating	Cooling
1	Large Office	PCU 67% Boilers 17% HP 10%	PACU 61% Chillers 27% HP 10%	PCU 48% Boilers 24% District 15%	Chillers 52% PACU 30% District 10%
2	Medium Office	PCU 50% Furnace 22% Boilers 9%	PACU 42% Res CAC 31% HP 18%	PCU 54% Boilers 18% Furnace 11%	PACU 56% HP 18% Res CAC 13%
3	Small Office	PCU 56% Furnace 22% HP 16%	Res CAC 43% PACU 33% HP 18%	PCU 67% Furnace 16% HP 12%	PACU 46% Res CAC 32% HP 16%
4	Warehouse	**None 55%** PCU 26% ISH 9%	**None 57%** PACU 16% Res CAC 16%	PCU 51% **None 24%** ISH 9%	PACU 49% **None 23%** Res CAC 13%
5	Stand-alone Retail	PCU 63% HP 15% Furnace 11%	PACU 49% Res CAC 25% HP 17%	PCU 81% HP 6% None 6%	PACU 73% Res CAC 10% HP 7%
6	Strip Mall	PCU 76% Furnace 11% HP 6%	PACU 63% Res CAC 18% Heat Pumps 16%	PCU 85% Furnace 4% Other 4%	PACU 80% Res CAC 9% Heat Pumps 9%
7	Primary School	PCU 59% HP 14% Boilers 14% Furnace 7% None 3%	PACU 48% HP 15% Res CAC 14% Chillers 11% District 8%	Boilers 45% PCU 37% HP 13% ISH 2% Furnace 2%	Chillers 39% PACU 31% HP 15% Res CAC 6% District 4%
8	Secondary School	PCU 55% Boilers 15% District 11% HP 10% ISH 4%	PACU, 34% Res CAC, 22% Chillers, 15% District, 14% HP, 9%	Boilers 41% **District 26%** PCU 20% HP 10% Furnace 1%	Chillers, 39% **District, 30%** PACU, 16% HP, 10% Res CAC, 4%
9	Grocery Store	PCU 66% None 20% ISH 7%	PACU 53% Res CAC 21% IRAC 10%	PCU 87% Boilers 6% Furnace 4%	PACU 78% Res CAC 16% None 5%
10	Quick Service Restaurant	PCU 72% None 11% HP 7%	PACU 65% Res CAC 12% None 9%	PCU 78% None 9% HP 7%	PACU 67% Res CAC 15% None 8%
11	Full Service Restaurant	PCU 62% HP 11% Furnace 10%	PACU 40% Res CAC 33% HP 14%	PCU 69% HP 7% Furnace 7%	PACU 42% Res CAC 24% HP 13%
12	Hospital	Boilers 67% PCU 14% District 14%	Chillers 76% PACU 17% District 7%	Boilers 76% District 17% PCU 6%	Chillers 79% District 12% PACU 9%
13	Out Patient Health Care	PCU 67% Furnace 13% Boilers 10%	Res CAC 44% PACU 32% HP 13%	PCU 57% Boilers 29% Furnace 6%	PACU 45% Chillers 31% Res CAC 17%
14	Small Hotel	ISH 40% Boilers 24% PCU 17%	IRAC 73% Res CAC 17% None 6%	Boilers 40% ISH 36% PCU 17%	IRAC 74% Res CAC 17% HP 5%
15	Large Hotel	ISH 39% HP 34% PCU 21%	IRAC 45% PACU 30% HP 20%	ISH 27% PCU 26% HP 21%	IRAC 37% PACU 22% Chillers 16%

As discussed previously, it is challenging to draw a practical or clear distinction between PCUs and furnaces as well as between PCUs and heat pumps when both equipment types are found in a building when reviewing data on the heat source and air/thermal distribution system.

For post-1990 buildings reporting PCU as the main heating type, Table 3.2 provides the indicated responses respective to the PCU heating components. The main questions asked in the survey were:

- whether the PCU used are factory-assembled, custom built, or both
- whether packaged heating components includes furnaces
- whether packaged heating components includes heat pumps
- whether packaged heat components includes heating coils
- whether packaged heating components including induction units
- whether packaged heating components include duct reheat.

Survey questions regarding induction units and packaged heating components (including duct reheat) can be considered *heating system* equipment more so than PCU equipment, though both are relevant to how heating may be provided in conjunction with the PCU equipment. Powered induction units are not defined in CBECS 2012. However, this commonly refers to HVAC zone terminal equipment that incorporates a separate heating or cooling coil (i.e., the heating coil can be electric or hydronic) and which can introduce or temper the cold supply air with warm air from the space served. Duct reheat indicates that either a coil or duct furnace (electric or gas) can reheat air after leaving the packaged equipment. Where called out in the questionnaire and "show cards"[1] for a duct reheat heating system type, CBECS specifically states that duct reheat is common with VAV systems. Where called out in CBECS relative to cooling equipment categorization, duct reheat is discussed as being used in buildings to heat areas that are "too cold". PNNL believes the intent of the questionnaire is to imply that VAV terminal reheat is a class of CBECS duct reheat.

Table 3.2 illustrates the use of heating components or powered induction and duct reheat systems for buildings that report PCU as the main heating equipment. Induction and duct reheat systems are relatively rare for packaged equipment except in large offices. Duct reheat with PCU is found at a low to moderate level in prototypes reporting PCU as main heating equipment with exception to small hotel, large hotel, quick service restaurant, and grocery store where duct reheat was reported in less than 5% of building records with PCU as main heating equipment. In addition, outside of the large office, large hotel, and hospital prototypes, furnaces represent the dominant heating component of PCU equipment. For hospitals and small hotels, the sample sizes for PCU as main heat are small and may result in non-meaningful data. For large hotels, both heat pumps and other heating coils incorporated in the PCU are more common than furnaces. In strip malls, heat pumps and heating coils were relatively common.

[1] EIA defines show cards as questionnaire aids that contain response lists, examples, and illustrations that accompanied some of the survey questions.

Table 3.2. Components and Equipment used with PCU as Main Heating Equipment (Post-1990 Building Weights)

Proto-type No.	Prototype Building	Sample Count	All PCU Factory-Assembled	Furnace Heating Section	Heat Pump Heating Section	Heating Coil	Powered Induction Unit	Duct Reheat
1	Large Office	46	90%	28%	9%	13%	45%	53%
2	Medium Office	76	95%	70%	24%	16%	5%	14%
3	Small Office	92	95%	65%	27%	9%	4%	12%
4	Warehouse	162	98%	56%	21%	14%	3%	16%
5	Stand-alone Retail	109	97%	89%	12%	10%	6%	8%
6	Strip Mall	102	78%	79%	47%	32%	4%	19%
7	Primary School	79	88%	49%	19%	24%	3%	14%
8	Secondary School	35	88%	71%	12%	11%	0%	17%
9	Grocery Store	17	68%	73%	1%	36%	0%	0%
10	Quick Service Restaurant	33	100%	50%	34%	12%	7%	5%
11	Full Service Restaurant	46	89%	66%	20%	13%	1%	8%
12	Hospital	9	36%	6%	64%	30%	0%	8%
13	Out Patient Health Care	39	89%	54%	27%	5%	4%	21%
14	Small Hotel	2	100%	63%	37%	0%	0%	0%
15	Large Hotel	23	94%	18%	46%	56%	0%	4%

CBECS Heating Coils are not clearly defined as hydronic coils. CBECS uses the term coil to describe electric heating coils in certain parts of the survey questionnaire. A cross tabulation with buildings using boilers would potentially help clarify this. Induction units are not defined in the CBECS questionnaire.

A similar breakout of components for package cooling equipment (PACU) is available, but less detailed, and the actual data on incorporation of different cooling components in the PACU is sparse. For instance, when heat pumps components are identified as part of the packaged heating (PCU) equipment, they are not explicitly identified as part of the PACU equipment, and typically the response field is left blank for the heat pump component of the PACU.

If a chiller is installed in the building, a variable indicator is provided that reports whether any of the PACU incorporate hydronic cooling coil. However, for post-1990 buildings that report packaged cooling equipment as the main cooling, only five out of the 710 building records mapped to prototype categories had hydronic chilled water coils in the building's PACU equipment. Due to the small number of observations with chilled water coils and the limit to heat pump identification, further analysis of packaged cooling components in PACU, as captured in CBECS, was determined to be of limited use.

3.2.2 Fan System Results

PNNL also performed an extraction of heating and cooling equipment with the cooling equipment choices further disaggregated by whether or not the building had a *central air handling* CAV or VAV system.[1] Unfortunately, CBECS does not state which cooling systems this response applies to within a building or what fraction of the building the CAV or VAV system services. In addition, there is no information in CBECS to help directly indicate the fraction of floor space covered by individual air distribution systems that are multi-zone or single zone. PNNL assumed that, in most systems, a VAV response of "yes" implies a multi-zone central air handler system somewhere in the building (although there may be exceptions, as when VAV is used for building pressurization control in hospitals or laboratories).

The decision as to whether or not a CAV or VAV system is the "most typical" equipment used in a particular prototype building is complicated by the extent to which buildings with VAV systems also possess other systems that could be the "most typical" in that building. Determining which system is the "most typical" for a prototype building is contingent upon the responses to both the CBECS main cooling and main heating categories, and whether those equipment are considered independent systems of one another. To make this determination, PNNL first examined what fraction of the total building floor space is reported as using VAV systems.

Table 3.3 shows the relative fraction of floor space in buildings reporting use of CAV or VAV controls (either as part of the heating air distribution system or cooling air distribution system) by building type. Note that because multiple systems may exist in a building, the actual fraction of floor space served by CAV or VAV systems may be less than the floor space fractions shown in Table 3.3. In addition, it is recognized that when a given equipment type is specified as the "most representative" for a building type, the relative fraction of floor space using CAV or VAV could be different from the Table 3.3 results.

For certain prototypes, the CAV and VAV fractions in Table 3.3 do not add to 100%. In these instances, the information was either not reported for the records or the records indicated that no central air handling CAV or VAV system exists. A significant number of warehouse, stand-alone retail, primary school, and small hotel records either showed no response for central air handling system, suggesting that the building was not served by central air handlers, or showed that neither CAV or VAV were used. For prototypes in which the fractions shown for CAV and VAV system add up to over 100% (e.g., hospitals), it is presumed that both CAV and VAV system types exist in the same buildings.

Table 3.3. Total Floor Space in Buildings Reporting Use of CAV and VAV Systems

Number	Prototype Building	Fraction of Floor space in Buildings Using CAV systems*	Fraction of Floor space in Buildings Using VAV systems*	Fraction of Floor space in Buildings Not Reporting CAV or VAV**
1	Large Office	19%	86%	6%
2	Medium Office	46%	55%	7%
3	Small Office	64%	34%	6%
4	Warehouse	47%	27%	30%

[1] A detailed review of CBECS 2012 data indicates that *central* CAV or VAV system is commonly indicated for most system types for which heated/cooled air may be distributed to multiple rooms/spaces in the building (e.g. central hydronic air handlers, packaged systems and water loop heat pumps). However, these records typically do not indicate the use of ISH, IRAC, fan coil systems, or radiators. In certain instances, these records have no data to indicate specific sub-categories of heat pumps (e.g. individual room heat pumps) either.

5	Stand-alone Retail	53%	12%	23%
6	Strip Mall	94%	33%	2%
7	Primary School	45%	46%	14%
8	Secondary School	25%	77%	8%
9	Grocery Store	87%	14%	2%
10	Quick Service Restaurant	66%	29%	7%
11	Full Service Restaurant	64%	29%	7%
12	Hospital	57%	92%	3%
13	Outpatient Health Care	36%	66%	7%
14	Small Hotel	57%	8%	35%
15	Large Hotel	46%	58%	13%

* Fractions shown may exceed actual fraction of floor space served by central air handling CAV or VAV
** Comprised of buildings not reporting CAV and VAV usage information (i.e., blank fields) and buildings *definitely* reporting no use of central air handling CAV or VAV systems for cooling or heating

PCU and PACU equipment are dominant in many prototype buildings, as indicated in Table 3.2. Since separate PCU and/or PACU systems are in service for a given building, it is possible for both CAV and VAV to apply to an individual building as these responses are not mutually exclusive in the survey. Thus, in some cases, the CAV and VAV fractions of floor space for buildings reporting their usage add up to more than 100% in Table 3.4. Additionally, it is also possible that these responses may refer to equipment other than the PCU or PACU.

Approximately 89% of the post-1990 buildings reporting PCU as the main heating equipment are denoted as having 100% of the floor space heated by PCU equipment. Table 3.4 provides the survey sample size and building population fraction for CAV and VAV usage for heating ventilation in buildings where PCU is listed as main heating, as well as the sample size and CAV and VAV population fractions for the subset where PCUs provide 100% of the building heating. In some building types, it was common to report both CAV and VAV usage in the same building where PCU was the main heating equipment type. Strip malls were the most distinct example of this, but stand-alone retail buildings, hospitals, and large hotels also showed this relationship.

In general, there is relatively little difference between reported CAV and VAV usage by building type where packaged equipment is used. VAV is found between 20% and 40% of buildings for most prototypes that use PCU as main heating. Exceptions are for large offices, where VAV is by far the most common fan system option with PCU, and large hotels, where it is found in a slight majority of buildings. Hospital responses are less clear, with VAV being more common when 100% of space heat is provided through PCU, although the low sample counts indicate that this may not be reflective of the general population of Post-1990 hospital buildings using PCU. VAV equipment was not found in the small hotel prototype; however the sample count is very low. VAV equipment in grocery buildings with PCU was also only found in a low fraction of buildings.

PNNL also examined reported use of VAV ventilation systems for cooling where PACU was listed as the main cooling equipment as well as when it was reported as providing 100% of cooling. Table 3.5 provides the sample size and reported use of CAV and VAV equipment for cooling air distribution corresponding to the represented building prototypes. For most prototypes, the fraction of buildings which identified the use of VAV in packaged cooling was somewhat higher than those indicating VAV for packaged heating.

Table 3.4. Constant Volume and Variable Air Volume Equipment Building Fractions used with PCU (Post-1990 Buildings)

Proto-	Prototype	Main Heat = PCU	100% of Space Heat is through PCU

type No.	Building	Sample Count	CAV	VAV	Both CAV &VAV	Sample Count	CAV	VAV	Both CAV &VAV
1	Large Office	46	4%	96%	0%	40	4%	96%	0%
2	Medium Office	76	69%	28%	1%	67	68%	28%	0%
3	Small Office	92	67%	33%	1%	83	66%	33%	0%
4	Warehouse	162	73%	24%	0%	146	72%	24%	0%
5	Stand-alone Retail	109	62%	35%	7%	97	64%	37%	7%
6	Strip Mall	102	93%	37%	31%	87	93%	30%	23%
7	Primary School	79	65%	26%	4%	76	66%	25%	4%
8	Secondary School	35	63%	33%	4%	33	63%	33%	3%
9	Grocery Store	17	92%	10%	2%	12	94%	6%	0%
10	Quick Service Restaurant	33	74%	29%	3%	31	73%	30%	3%
11	Full Service Restaurant	46	73%	26%	0%	45	74%	24%	0%
12	Hospital	9	73%	36%	9%	6	25%	100%	25%
13	Out Patient Health Care	39	65%	35%	4%	38	64%	33%	1%
14	Small Hotel	2	100%	0%	0%	2	100%	0%	0%
15	Large Hotel	23	55%	56%	11%	13	47%	63%	11%

Table 3.5. Constant Volume and Variable Air Volume Equipment Building Fractions used with PACU (Post-1990 Buildings)

		Main Cooling = PACU				100% of Space Cooling is through PACU			
Proto-type No.	Prototype Building	Sample Count	CAV	VAV	Both CAV &VAV	Sample Count	CAV	VAV	Both CAV &VAV
1	Large Office	30	2%	98%	0%	23	2%	98%	0%
2	Medium Office	74	55%	46%	2%	65	56%	45%	1%
3	Small Office	56	62%	41%	2%	51	61%	40%	1%
4	Warehouse	139	63%	32%	1%	128	59%	36%	1%
5	Stand-alone Retail	92	61%	35%	6%	90	60%	36%	6%
6	Strip Mall	96	91%	45%	37%	88	90%	45%	36%
7	Primary School	67	65%	26%	4%	63	65%	25%	4%
8	Secondary School	27	57%	34%	5%	25	58%	33%	6%
9	Grocery Store	14	81%	22%	2%	12	78%	22%	0%
10	Quick	28	72%	31%	3%	26	70%	33%	3%

Proto-type No.	Prototype Building	Main Cooling = PACU				100% of Space Cooling is through PACU			
		Sample Count	CAV	VAV	Both CAV &VAV	Sample Count	CAV	VAV	Both CAV &VAV
	Service Restaurant								
11	Full Service Restaurant	30	76%	21%	0%	29	76%	22%	0%
12	Hospital	9	16%	98%	13%	5	14%	96%	11%
13	Out Patient Health Care	31	45%	56%	3%	29	44%	56%	1%
14	Small Hotel	0	NA	NA	NA	0	NA	NA	NA
15	Large Hotel	17	2%	98%	4%	9	74%	33%	6%

Finally, in examining packaged systems, it was recognized that larger buildings were more likely to have VAV equipment installed with PCU and PACU equipment. To this end, Table 3.6 provides the weighted area fraction for prototypes reporting 100% of the cooling as serviced with PACU units. These weighted fractions represent the floor space in buildings which report the use of CAV equipment, VAV equipment, or both CAV and VAV in the same building. The fractions do not represent the area served by CAV and VAV since that level of detail is not available from CBECS at the individual building level. For most building prototypes, the heating and cooling CAV and VAV building area fractions shown in Table 3.6 are very close. In the case of Medium and Large Office prototypes, a somewhat greater fraction reports the use of VAV for cooling than for heating.

In comparing the fractions of building area using VAV in Table 3.6 to the fractions of buildings using VAV shown in Table 3.5, a smaller fraction of the large office report use of VAV with PACU when weighted by area but a significantly larger fraction of the medium office report use VAV when weighted by area. In the case of the large office prototype, examination of the CBECS microdata suggests that this is due to some very large buildings not reporting use of VAV equipment even where PACU provides 100 percent of the space cooling. When weighted by building area for buildings 100% cooled by PACU equipment, VAV is the predominant system for the large office, medium office, secondary school, and hospital prototype buildings. For strip malls and warehouses served by PACU, nearly 50% of total building area is reported to use of VAV equipment, but a greater fraction is reported as using CAV equipment. In particular, because the CAV and VAV fractions can add to more than 100%, it is expected that for strip malls, CAV is more common by building area than VAV equipment.

Finally, in examining specific building records in which the floor space fraction was indicated as 100% PACU systems, a non-trivial number of observations indicated that no CAV or VAV was used for heating or cooling, notably for stand-alone retail, primary school, and secondary school prototypes. Building records with 100% PACU represented 5% or less of the floor area by prototype. However, for stand-alone retail, over 25% of the floor area has neither CAV nor VAV systems, but uses 100% PACU equipment. This inconsistency is most likely due to a mistake in administering the survey.

Table 3.6. Constant Volume and Variable Air Volume Equipment Building Floor Space Fractions used with 100% PACU (Post-1990 Buildings)

Prototype No.	Prototype Building	Sample Count	Heating Ventilation Fan			Cooling Ventilation Fan		
			CAV	VAV	Both CAV &VAV	CAV	VAV	Both CAV &VAV
1	Large Office	23	10%	79%	0%	10%	87%	0%

Prototype No.	Prototype Building	Sample Count	Heating Ventilation Fan CAV	Heating Ventilation Fan VAV	Heating Ventilation Fan Both CAV &VAV	Cooling Ventilation Fan CAV	Cooling Ventilation Fan VAV	Cooling Ventilation Fan Both CAV &VAV
2	Medium Office	65	30%	67%	5%	30%	73%	5%
3	Small Office	51	65%	39%	3%	65%	39%	3%
4	Warehouse	128	53%	45%	8%	57%	46%	8%
5	Stand-alone Retail	90	42%	40%	9%	42%	40%	9%
6	Strip Mall	88	91%	49%	43%	89%	49%	40%
7	Primary School	63	58%	41%	12%	60%	41%	12%
8	Secondary School	25	51%	57%	20%	51%	61%	20%
9	Grocery Store	12	84%	15%	0%	84%	16%	0%
10	Quick Service Restaurant	26	72%	28%	3%	72%	31%	3%
11	Full Service Restaurant	29	67%	29%	0%	67%	29%	0%
12	Hospital	5	43%	95%	38%	43%	95%	38%
13	Out Patient Health Care	29	33%	65%	3%	34%	66%	3%
14	Small Hotel	0	NA	NA	NA	NA	NA	NA
15	Large Hotel	9	83%	30%	14%	83%	30%	14%

No small hotel sample reported being 100% cooled by PACU. Most small hotels incorporate individual room cooling and heating equipment, with a possible use of central cooling for a lobby, hallway, or other space only (in some cases this is small and served by ISH/IRAC units as well).

The authors' experience supports the results of the CBECS analysis for equipment and fan system data indicating that hospitals and large hotels commonly rely on multiple mechanical system types and utilize both CAV and VAV systems in the same buildings. The vast majority of hospital buildings in CBECS report the use of VAV systems. However, hospitals are sophisticated buildings and multiple distribution system types are both common in recent construction and likely in future construction. While VAVs are reported in buildings comprising 92% of the hospital floor space, CAV systems are reported in hospital buildings comprising 57% of the floor space, suggesting considerable overlap. Only 5% of hospital floor space is found in buildings that only report the use of CAV systems. This suggests the majority of buildings use both CAV and VAV systems in the same building. Approximately 41% of post-1990 hospital floor space is in buildings which report only VAV cooling systems. Further review of the CBECS data shows that when considering cooling systems, approximately 43% of hospital floor area is in buildings reporting use of fan coils and 14% of floor area is in hospitals reporting water loop heat pumps, both typically/historically constant-volume air systems. As noted in Table 3.4 and Table 3.5, constant volume packaged systems are also found in conjunction with VAV packaged systems. The choice of which system type serves which hospital space will be influenced by outdoor air ventilation, air exchange, contaminant/filtration, and pressurization concerns for individual hospital space types and is beyond the scope of this analysis. However, further analysis of hospital HVAC system using CBECS and other resources could provide additional insight into the prevalence of systems and system components.

The use of multiple systems in large hotels is a characteristic shared with hospitals. An examination of the cooling system for large hotels in post-1990 buildings indicated that:

- Of 69 samples, 25 reported IRAC as main cooling, and when this was evident, in most cases a PACU, or in a few cases residential central air conditioners (Res CAC), represented the remaining cooling in the building.
- 11 records reported heat pumps as main cooling. Of these, eight indicated individual room heat pumps, one indicated mini-split heat pumps, one indicated packaged heat pump, and one indicated variable refrigerant volume heat pumps.

- 16 records identified main cooling as either chillers (13) or district chilled water (3). In these instances, the percentage cooled by chilled water was greater or equal to 70%, and in 13 of the records fan coils are indicated.

Based on the detailed analysis for large hotels along with the data shown in Table 3.1, large hotels are typically served by one or more PCU/PACU unit with IRAC, or a PCU/PACU using individual room heat pumps (most likely packaged terminal heat pump (PTHP) units). The use of chilled water and presumably fan coils is relatively uncommon in recent hotel construction, representing only 16% of the floor area.

In addition, when considering the use of district cooling or district heating, PNNL believes the most important consideration is whether these systems are hydronic systems for the purposes of understanding HVAC system design as well as overall building energy consumption. If the primary heating or cooling equipment source (boiler or chiller) is assumed to be in the building such that the energy consumption of that equipment can be captured when modeling, then these district systems are probably best categorized by lumping district cooling with chillers and district heating with boilers. Given that the fraction of district heating and cooling is generally moderate, it does not seem to change the determinations for main cooling or heating system.

3.2.3 HVAC Summary Analysis for CBECS Post-1990 Buildings

Based on Table 3.1, PNNL considers the heating and cooling equipment that has the highest fraction of floor area as "most typical" for each prototype building. This approach attempts to capture the floor space served by the various equipment types. For many building types, the most typical classes of equipment are expressed in terms of fraction of buildings served and are consistent with the most common classes of equipment by floor space served. In this case, the choice of selection method is not important. In the post-1990 buildings, there are some notable exceptions: cooling equipment in large and small office buildings; heating in small hotels; and heating and cooling in primary schools, secondary schools, and hospitals. In addition, when warehouses are heated and cooled, the same equipment (i.e., PCU and PACU equipment) appears to be used for both heating and cooling when characterized by either buildings represented or building floor space. Whether considering buildings or floor space, the fraction of unheated space reported by CBECS is similar to that of uncooled space, indicating that no heating or cooling equipment is servicing those areas of the buildings.

Based on the analysis of main heating, main cooling, and fan systems, the following determinations were concluded for the prototype buildings.

- In large office buildings, PCU represents the most common heating equipment by floor space, whereas chillers represent the most common cooling equipment by floor space, and the fraction of buildings served by PACU is significantly less than that of PCU. Since relatively few PACU are reported using chilled water hydronic coils as components, it is unclear what type of air distribution system is present and whether the high fraction of PCU found in large office buildings should translate into an equivalent fraction of PACU air handlers or describe separate packaged air handlers with cooling coils. However, in either case, it appears that the main air handlers are most commonly VAV systems.
- For medium office buildings, PCU and PACU represent the most common heating and cooling units respectively. By floor area, VAV units predominate. By the buildings population, however, CAV units predominate.
- For small office buildings, PCU and PACU represent the most common heating and cooling units respectively, and CAV units predominate.

- For warehouses, PCU and PACU represent the most common heating and cooling units respectively, and CAV units predominate. The majority of warehouse floor space is both heated and cooled according to CBECS.
- For stand-alone retail buildings, PCU and PACU represent the most common heating and cooling units respectively. When examining this equipment in terms of air systems, the aggregate floor space in buildings reporting CAV and VAV reported is roughly similar. The relatively high fraction of residential equipment (Res CAC and HP) suggests that in the overall population, the most common air systems are likely CAV.[1]
- For strip malls, PCU and PACU represent the most common heating and cooling units, respectively, with CAV represented as occurring in almost 90% of buildings and VAV in less than 50% of buildings. However, nearly 50% of building floor space is reported as using VAV. Given the large fraction of buildings reporting the use of both, the majority of space is likely served by CAV systems.
- In primary schools, the most common heating system by number of buildings is the PCU. However, the most common heating system by floor space is the boiler. The same pattern holds true for secondary schools. Secondary schools report a high fraction of district heating and cooling at 26% and 30% of floor space, respectively. This suggests a very high fraction of hydronic systems with dedicated air handlers for secondary schools. By floor space, boiler and chiller systems are also the most common systems for primary schools, but district heating and cooling is low. For air systems, VAV appear to be the most common air system used in the secondary schools when weighted by floor space. When considering all systems, it is roughly an even split of CAV and VAV central air in primary schools. However, when PCU/PACU are examined, CAV equipment are predominant in primary schools, so it appears that CAV equipment generally may be more common in this prototype.
- PCU and PACU are the most common systems for grocery stores, which characteristically report the use of CAV systems for air distribution.
- PCU and PACU are the most common systems for quick service and full service restaurants, which use CAV systems for air distribution.
- For hospitals, the most common systems appear to be boilers and chillers. The low fraction of PCU/PACU suggests that site-built air handlers were installed for these systems or other HVAC equipment (e.g., fan coils). Multiple systems types likely co-exist in hospital buildings, so multi-zone VAV, and SZ CAV were both assigned.
- For outpatient health care buildings, PCU and PACU are the most common systems, and based on Table 3.3, a majority of floor space uses CAV systems only (55%). Examination of the data in Table 3.1 indicates that the fraction of PACU is less than the PCU fraction by floor area and number of buildings. Further examination of Table 3.4 and Table 3.5 indicates that the majority of the buildings that report main heating as PCU report only CAV. However, systems that report PACU as main cooling report VAV as the majority of air systems. By represented floor area, it suggests that when both PCU and PACU equipment types are selected as representative of the HVAC system, the most common air system is VAV.
- In small hotels, boilers and IRAC are the most common heating and cooling systems by main heating type in terms of floor space served. While boilers are shown as 40% of the floor space, ISH is a close second at 36%. By number of small hotel buildings, ISH is the main heating, and significantly more

[1] Note that the use of single-zone VAV systems, such as are found with higher efficiency Res CAC and HP equipment today, and required by Standard 90.1since 2010 for certain packaged equipment are difficult to ascertain through analysis of the 2012 CBECS. The use of this style of equipment as opposed to multi-zone VAV is an area for additional exploration.

common than boiler (40% of buildings versus 26%). However, due to the very small sample size of 13 small hotel building records, it is difficult to draw strong conclusions from this data. Examining the raw CBECS data, there are three building records reporting the use of boilers for heating, six reporting ISH, two reporting PCU, one reporting individual room heat pump, and one reporting a furnace.

The CBECS definition of IRAC units includes packaged terminal air conditioners, which in the authors' experience is the most common type of specific IRAC unit in small hotels. The CBECS definition of ISH includes packaged terminal air conditioners as well, though not individual room heat pumps (e.g., packaged terminal heat pumps). The building records reporting boilers indicate that 100% of the cooling is serviced by IRAC units. In general, for either heating or cooling systems, the selected main heating type covers 90% or greater of the building. Due to the high prevalence of IRAC units, the limited sample size, and considering the authors' professional judgement, PNNL suggests that the most representative heating and cooling systems be considered ISH and IRAC respectively.

- In large hotels, ISH and IRAC are the most common main heating and main cooling in terms of both the number of buildings serviced and floor area represented. By represented floor area, the main heating equipment reported as ISH is 27% and the main heating equipment reported as PCU is 26%. HP is the third largest reported heating equipment at 21%, which predominantly coexists with reported individual room heat pumps. However, in the case of large hotels, nearly half of the PCUs reported by number of buildings included heat pump components (and nearly half also reported heating coils). The fraction of building floor space reporting main cooling as IRAC is 37%, which is considerably higher than the next two most frequently cited equipment types. Since the individual room space is generally both heated and cooled, and equipped with individual room thermostats, there is a discrepancy between the fraction of ISH and IRAC. It is possible that further disaggregation of the CBECS data on systems and equipment in large hotels could potentially provide more insight. PNNL considers ISH and IRAC as the main HVAC systems for hotel rooms, and PCU and PACU may better represent the common areas in large hotels.

The final determinations for HVAC equipment and air distribution systems are shown in Table 3.7.

Table 3.7. HVAC Equipment and Air Distribution Determinations in Post-1990 Buildings

		PNNL Determination		
Number	**Type**	**Heating**	**Cooling**	**Air Distribution**
1	Large Office	PCU	Chiller	MZ VAV
2	Medium Office	PCU	PACU	MZ VAV
3	Small Office	PCU	PACU	SZ CAV
4	Warehouse	PCU	PACU	SZ CAV
5	Stand-alone Retail	PCU	PACU	SZ CAV
6	Strip Mall	PCU	PACU	SZ CAV
7	Primary School	Boiler	Chiller	SZ CAV
8	Secondary School	Boiler	Chiller	MZ VAV
9	Grocery Store	PCU	PACU	SZ CAV
10	Quick Service Restaurant	PCU	PACU	SZ CAV
11	Full Service Restaurant	PCU	PACU	SZ CAV
12	Hospital	Boiler	Chiller	FCU, CAV and MZ VAV[(a)]
13	Outpatient Health Care	PCU	PACU	MZ VAV[(b)]
14	Small Hotel	ISH	IRAC	SZ CAV
15	Large Hotel	ISH/PCU	IRAC/PACU[(c)]	SZ CAV

(a) Hospitals may utilize CV systems in some operating and critical care type areas with variable air flow used for pressurization, but classic VAV multi-zone systems in other areas like offices. CBECS guidance seems limited here and other sources should be consulted.

(b) Unclear if single zone or multi-zone is more common globally, but where PCU and PACU are both used, VAV and likely multi-zone is more common.

(c) Large hotels may be best characterized with two system types serving different areas. Both multi-zone systems (VAV or CAV) may serve public spaces (lobby/conference rooms), whereas single zone IRAC or individual room heat pump systems may be most common for room space. Chiller fan coil systems appear more uncommon in new hotels. VAV appears to be found in the majority of large hotel buildings.

(d) System types

PACU – packaged air-conditioning unit	ISH – individual space heater
IRAC – individual room air conditioner	SZ – single zone
MZ – multi-zone	CAV – constant air volume
VAV – variable air volume	FCU – fan coil unit
	PCU – packaged central unit

4.0 References

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Appendix A

Mapping of Prototype Buildings to CBECS Data

Appendix A

Mapping of Prototype Buildings to CBECS Data

Table A.1. Mapping of Prototype Buildings to CBECS Principle Building Activities

Number	Prototype Building	CBECS PBA-Plus	Number of Records	Number of Buildings	Building Area (ft^2)
1	Large Office*	02: Administrative/professional office 03: Bank/other financial 04: Government office 06: Mixed-use office 07: Other office	93	6,600	1,313,622,644
2	Medium Office*	02: Administrative/professional office 03: Bank/other financial 04: Government office 06: Mixed-use office 07: Other office	151	83,487	1,947,922,938
3	Small Office*	02: Administrative/professional office 03: Bank/other financial 04: Government office 06: Mixed-use office 07: Other office	158	188,133	1,269,776,933
4	Warehouse	09: Distribution/shipping center 10: Non-refrigerated warehouse 11: Self-storage	323	351,427	5,814,405,769
5	Stand-alone Retail	41: Vehicle dealership/showroom 42: Retail store 43: Other retail	146	135,839	2,815,589,528

Number	Prototype Building	CBECS PBA-Plus	Number of Records	Number of Buildings	Building Area (ft^2)
6	Strip Mall	50: Strip shopping mall	118	60,499	2,158,529,850
7	Primary School	28: Elementary/middle school 30: Preschool/daycare	179	111,800	2,596,335,444
8	Secondary School	27: College/university 29: High school 31: Other classroom education	105	43,018	2,190,201,447
9	Grocery Store	14: Grocery store/food market	23	17,507	394,328,503
10	Quick Service Restaurant	32: Fast food	43	44,724	128,751,757
11	Full Service Restaurant	33: Restaurant/cafeteria 34: Other food service 53: Bar/pub/lounge	75	86,103	473,899,698
12	Hospital	35: Hospital/inpatient health	133	3,389	883,664,230
13	Outpatient Healthcare	18: Medical office (diagnostic) 19: Clinic/other outpatient health	78	46,911	849,994,921
14	Small Hotel	39: Motel or inn	13	12,061	114,777,748
15	Large Hotel	38: Hotel	69	15,498	1,250,642,308
Total			1,707	1,206,996	24,202,443,719

[*]This analysis defines large, medium, and small offices based on the number of stories in the building with small office referring to one story, medium office referring to two to four stories, and large office referring to greater than four stories.

Appendix B

Development of Aspect Ratio Data for Odd Shaped Buildings

Appendix B

Development of Aspect Ratio Data for Odd Shaped Buildings

Aspect ratios are important in determining the relative amount of perimeter area to core area for a given building. This impacts a buildings responsiveness to the outdoor environment including the potential for daylighting. Aspect ratio coupled with orientation and self -shading would also be relevant in determining insolation. Unfortunately aspect ratio information has not been collected in the CBECS since 1992, so general information on actual aspect ratios has been limited. What information was collected in these early CBECS distributions was solely for rectangular buildings. Several of the CBECS versions have also captured data on building shape. Table B.1 shows how the CBECS 2003 categorizes building shape, as well as the fraction of buildings in the data set in each shape category.

Table B.1. Shape Categories in 2003 CBECS

CBECS 2003 Shape Categories	Fraction of Building
No response	16%
+ or cross shaped	2%
E shaped	1%
H shaped	2%
L shaped	5%
T shaped	2%
U shaped	2%
Narrow rectangle	6%
Other shape	4%
Rectangle/square with courtyard	3%
Square	9%
Wide rectangle	47%
Total	100%

CBECS 2003 categorized 62% of the buildings as either rectangular or square (ignoring those rectangular or square buildings with courtyards), and showed 16% of the buildings as not reporting a shape. The remaining 22% of buildings have more elaborate shapes. While data for estimating aspect ratios are unavailable in CBECS, it is clear that these more elaborate shapes represent a substantial fraction of buildings. Some thinking as to reasonable building design can help in assessing likely equivalent aspect ratios for these elaborately shaped buildings. Equivalent aspect ratio here refers to rectangular buildings with perimeter length to core area ratios equivalent to the original building; they are developed to estimate the wall and window fraction in the general population, but are also useful in developing revised aspect ratios for the prototype buildings.

An L-shaped building with two equal length legs is shown below with each leg having an outside length of 2 units and width of 1 unit in Figure B.1 with roughly drawn images and dimensions. The ratio of the perimeter, P, for this building to the Area, A, of the building is 8:3.

A rectangular building with an aspect ratio of 3 has the same ratio of P:A. It is not hard to envision bending one of the L legs around the corner of the building to form the rectangle with this aspect ratio. Sliding one of the legs toward the middle of the other leg forms a T-shaped building of similar dimensions. Such a building would also have an equivalent aspect ratio of 3.

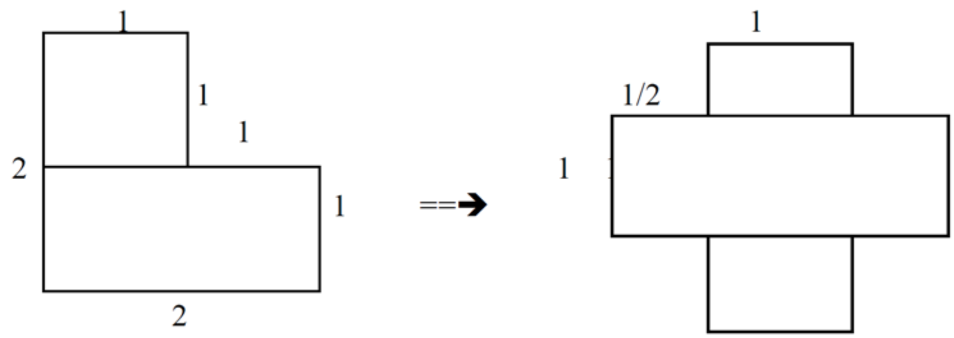

Figure B.1. L-Shaped and T-Shaped Buildings

A U-shaped building might look like the picture in Figure B.2 (with the unit dimensions shown). Assume a total linear dimension of 12 for the perimeter and an area of 5. This could be thought of as a building with an aspect ratio of 5. (Rotate the arms of the U to the sides to stretch the shape into a line, and you get a 5 unit by 1 unit rectangle.

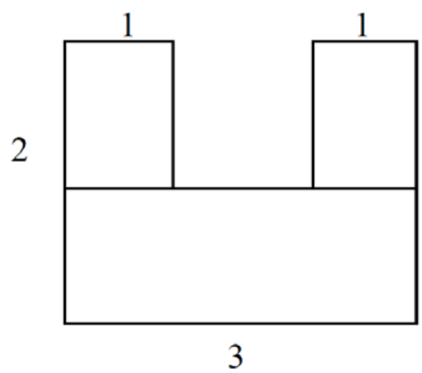

Figure B.2. U-Shaped Building

An H-shaped building could look like the structure below in Figure B.3, with a perimeter to area ratio similar to the U-shaped building above (12:5) and equivalent to that of a rectangle with an aspect ratio of 5.

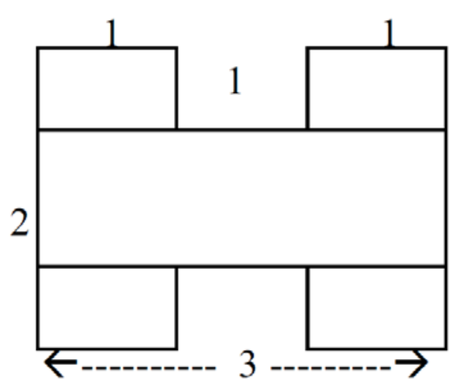

Figure B.3. H-Shaped Building

Other building shapes in CBECS include buildings shaped like a cross, buildings shaped like an E, as well as other, less identified building shapes. Dimensions for the lengths of individual elements for all of the shapes discussed are not documented in CBECS, so actual equivalent aspect ratios could not be calculated. However the dimensions used above appear to reflect reasonable building design based on experience. The simplifying assumption made for this analysis was that all non-rectangular shapes would be given an aspect ratio of 4. This allows inclusion of non-rectangular buildings in this analysis and provides a more reasonable assessment of perimeter loads in the general building population. In the future, the NC3 data set may be able to provide greater insight for developing equivalent aspect ratios.

Appendix C

Regional Heating and Cooling Equipment Distributions

Appendix C

Regional Heating and Cooling Equipment Distributions

Table C.1. Census Region 1, Post-1990 Buildings in 2012 CBECS

		By Number of Buildings		By Floor Area	
Number	**Type**	**Heating**	**Cooling**	**Heating**	**Cooling**
1	Large Office	Boiler 52% PCU 31% Furnace 10%	Chiller 68% PACU 32% None 0%	PCU 41% Boiler 34% District 20%	PACU 50% Chiller 50% None 0%
2	Medium Office	PCU 45% Furnace 24% None 13%	PACU 35% Res CAC 26% None 13%	PCU 58% Boiler 26% Furnace 8%	PACU 70% HP 14% Res CAC 7%
3	Small Office	PCU 56% HP 16% Furnace 13%	HP 29% IRAC 27% Res CAC 23%	PCU 50% HP 25% Boiler 16%	PACU 40% HP 35% IRAC 15%
4	Warehouse	None 44% PCU 38% HP 5%	None 66% Res CAC 13% PACU 13%	PCU 58% Furnace 15% None 14%	PACU 59% None 21% Chiller 7%
5	Stand-alone Retail	PCU 68% Furnace 17% Other 9%	PACU 71% None 15% Res CAC 8%	PCU 86% Furnace 11% Boiler 1%	PACU 93% Res CAC 4% None 2%
6	Strip Mall	PCU 100% None 0% None 0%	Chiller 48% PACU 45% Res CAC 7%	PCU 100% None 0% None 0%	PACU 78% Res CAC 14% Chiller 7%
7	Primary School	Furnace 32% ISH 30% Boiler 29% PCU 9% None 0%	PACU 52% IRAC 40% None 5% Chiller 3% District 0%	Boiler 89% ISH 5% PCU 5% Furnace 2% None 0%	PACU 51% IRAC 27% Chiller 11% None 10% District 0%
8	Secondary School	PCU 48% Boiler 23% HP 16% District 13% None 0%	PACU, 50 District, 18 Chiller, 16 Heat Pumps, 16 None, 0	Boiler 69% HP 14% District 11% PCU 6% None 0%	Chiller, 52 District, 22 Heat Pumps, 14 PACU, 11 None, 0
9	Grocery Store	PCU 76% ISH 20% Boiler 4%	PACU 96% Res CAC 4% None 0%	PCU 87% Boiler 10% ISH 2%	PACU 90% Res CAC 10% None 0%
10	Quick Service Restaurant	None 37% PCU 37% HP 25%	None 47% PACU 28% HP 25%	None 44% PCU 41% HP 15%	None 63% PACU 22% HP 15%
11	Full Service Restaurant	PCU 78% Boiler 17% District 5%	Res CAC 54% PACU 31% HP 10%	PCU 59% District 37% Boiler 5%	District 37% Res CAC 31% PACU 17%
12	Hospital	Boiler 92% District 8% None 0%	Chiller 92% District 8% None 0%	Boiler 89% District 11% None 0%	Chiller 89% District 11% None 0%
13	Out Patient Health Care	PCU 74% Boiler 26% District 0%	PACU 84% Chiller 16% District 0%	Boiler 54% PCU 45% District 1%	PACU 52% Chiller 47% District 1%

Number	Type	By Number of Buildings		By Floor Area	
		Heating	Cooling	Heating	Cooling
14	Small Hotel	NA	NA	NA	NA
15	Large Hotel	HP 42% ISH 42% Boiler 10%	IRAC 47% HP 43% Chiller 9%	Boiler 37% ISH 26% PCU 22%	IRAC 48% Chiller 34% HP 15%

Table C.2. Census Region 1, Pre-1990 Buildings in 2012 CBECS

Number	Type	By Number of Buildings		By Floor Area	
		Heating	Cooling	Heating	Cooling
1	Large Office	Boiler 34% District 31% PCU 23%	PACU 53% Chiller 40% District 2%	District 46% Boiler 33% ISH 9%	Chiller 48% PACU 37% District 6%
2	Medium Office	Boiler 36% PCU 34% Furnace 11%	PACU 29% Res CAC 28% IRAC 27%	PCU 38% Boiler 29% District 21%	PACU 49% District 15% Chiller 14%
3	Small Office	PCU 68% ISH 17% HP 12%	PACU 42% IRAC 19% Res CAC 17%	PCU 74% Boiler 10% ISH 8%	PACU 71% Res CAC 15% HP 7%
4	Warehouse	PCU 33% None 28% ISH 27%	None 52% PACU 26% IRAC 11%	PCU 43% ISH 35% Boiler 9%	PACU 59% None 26% Res CAC 8%
5	Stand-alone Retail	PCU 45% Boiler 31% ISH 14%	PACU 32% IRAC 31% None 19%	PCU 40% Boiler 32% ISH 10%	PACU 46% IRAC 25% None 16%
6	Strip Mall	PCU 72% Furnace 21% ISH 7%	PACU 64% Res CAC 32% IRAC 3%	PCU 71% Furnace 17% ISH 8%	PACU 77% Res CAC 21% IRAC 2%
7	Primary School	Boiler 89% PCU 5% Furnace 3% ISH 3% None 0%	PACU 28% None 24% Res CAC 21% IRAC 21% Chiller 6%	Boiler 92% ISH 4% PCU 3% Furnace 1% None 0%	PACU 32% Res CAC 26% IRAC 21% Chiller 13% None 7%
8	Secondary School	Boiler 46% Furnace 30% HP 15% PCU 5% District 4%	IRAC, 28 None, 26 PACU, 19 Heat Pumps, 15 Chiller, 7	Boiler 71% District 12% PCU 7% Furnace 6% HP 4%	PACU, 44 Chiller, 19 IRAC, 17 District, 10 None, 4
9	Grocery Store	PCU 62% ISH 38% None 0%	Res CAC 62% None 38% Chiller 0%	PCU 60% ISH 40% None 0%	Res CAC 60% None 40% Chiller 0%
10	Quick Service Restaurant	PCU 55% ISH 29% Boiler 16%	PACU 55% IRAC 18% Res CAC 16%	PCU 51% ISH 29% Boiler 19%	PACU 51% None 24% Res CAC 19%
11	Full Service Restaurant	PCU 47% ISH 16% HP 11%	Res CAC 38% PACU 31% IRAC 18%	PCU 43% ISH 18% Boiler 14%	PACU 35% IRAC 26% Res CAC 26%

Number	Type	By Number of Buildings Heating	By Number of Buildings Cooling	By Floor Area Heating	By Floor Area Cooling
12	Hospital	Boiler 75% District 18% PCU 5%	Chiller 79% District 13% PACU 7%	Boiler 59% District 26% PCU 14%	Chiller 61% District 20% PACU 17%
13	Out Patient Health Care	PCU 77% Boiler 20% District 3%	PACU 53% Res CAC 20% HP 11%	Boiler 48% PCU 34% District 18%	PACU 51% Chiller 39% Res CAC 5%
14	Small Hotel	ISH 63% HP 35% Boiler 2%	None 40% HP 35% IRAC 24%	ISH 88% HP 9% Boiler 3%	IRAC 80% None 11% HP 9%
15	Large Hotel	ISH 41% PCU 40% District 14%	IRAC 64% Chiller 20% PACU 12%	PCU 39% District 32% ISH 20%	IRAC 47% Chiller 41% PACU 9%

Table C.3. Census Region 2, Post-1990 Buildings in 2012 CBECS

Number	Type	By Number of Buildings Heating	By Number of Buildings Cooling	By Floor Area Heating	By Floor Area Cooling
1	Large Office	HP 40% PCU 22% Boiler 21%	Chiller 49% HP 35% District 11%	Boiler 33% HP 24% PCU 24%	Chiller 71% HP 14% District 10%
2	Medium Office	PCU 58% Furnace 18% Boiler 12%	PACU 53% Res CAC 42% Chiller 5%	PCU 61% Furnace 15% Boiler 12%	PACU 60% Res CAC 21% Chiller 11%
3	Small Office	PCU 61% Furnace 30% HP 9%	Res CAC 67% PACU 24% HP 9%	PCU 71% Furnace 25% HP 4%	Res CAC 48% PACU 47% HP 4%
4	Warehouse	None 65% ISH 19% PCU 9%	None 73% Res CAC 13% PACU 9%	PCU 44% None 26% ISH 20%	PACU 51% None 37% Res CAC 6%
5	Stand-alone Retail	PCU 79% Furnace 12% ISH 9%	PACU 56% Res CAC 37% HP 7%	PCU 92% ISH 5% Furnace 2%	PACU 88% Res CAC 11% HP 0%
6	Strip Mall	PCU 92% ISH 6% Boiler 2%	PACU 59% Res CAC 34% IRAC 6%	PCU 83% Boiler 11% ISH 6%	PACU 80% Res CAC 14% IRAC 6%
7	Primary School	Boiler 62% PCU 35% HP 3% None 0% None 0%	Chiller 37% PACU 30% Res CAC 14% IRAC 13% HP 5%	Boiler 79% PCU 17% HP 4% None 0% None 0%	Chiller 58% PACU 19% IRAC 8% Res CAC 8% HP 6%
8	Secondary School	PCU 67% Boiler 21% District 6% Furnace 5% ISH 0%	PACU, 53 Res CAC, 25 Chiller, 17 District, 5 None, 0	Boiler 64% PCU 18% District 15% Furnace 2% ISH 1%	Chiller, 57 PACU, 22 District, 14 Res CAC, 7 None, 0
9	Grocery Store	PCU 100% None 0% None 0%	Res CAC 94% PACU 6% None 0%	PCU 100% None 0% None 0%	Res CAC 72% PACU 28% None 0%

Number	Type	By Number of Buildings Heating	By Number of Buildings Cooling	By Floor Area Heating	By Floor Area Cooling
10	Quick Service Restaurant	PCU 100% None 0% None 0%	PACU 83% Res CAC 17% None 0%	PCU 100% None 0% None 0%	PACU 82% Res CAC 18% None 0%
11	Full Service Restaurant	PCU 46% Furnace 22% ISH 11%	Res CAC 45% PACU 31% None 14%	PCU 52% Furnace 20% Boiler 14%	Res CAC 40% PACU 37% Chiller 10%
12	Hospital	Boiler 93% District 6% PCU 1%	Chiller 86% PACU 11% District 2%	Boiler 85% District 10% PCU 6%	Chiller 74% PACU 20% District 6%
13	Out Patient Health Care	PCU 44% Furnace 28% HP 18%	Res CAC 53% PACU 22% HP 18%	Boiler 43% PCU 39% Furnace 11%	Chiller 40% PACU 34% Res CAC 20%
14	Small Hotel	Furnace 49% PCU 34% Boiler 16%	IRAC 66% Res CAC 34% None 0%	Boiler 72% PCU 21% Furnace 7%	IRAC 79% Res CAC 21% None 0%
15	Large Hotel	ISH 72% HP 18% PCU 6%	IRAC 57% PACU 22% HP 18%	ISH 59% Boiler 24% PCU 8%	IRAC 49% Chiller 24% PACU 22%

Table C.4. Census Region 2, Pre-1990 Buildings in 2012 CBECS

Number	Type	By Number of Buildings Heating	By Number of Buildings Cooling	By Floor Area Heating	By Floor Area Cooling
1	Large Office	Boiler 71% PCU 25% ISH 2%	Chiller 70% PACU 29% Evap Cooler 1%	Boiler 63% ISH 14% PCU 14%	Chiller 79% PACU 17% Evap Cooler 2%
2	Medium Office	Furnace 39% PCU 35% Boiler 18%	Res CAC 48% PACU 31% IRAC 10%	PCU 43% Boiler 30% Furnace 17%	PACU 47% Res CAC 22% Chiller 21%
3	Small Office	PCU 52% Furnace 23% ISH 17%	Res CAC 51% PACU 31% HP 9%	PCU 49% Boiler 26% Furnace 18%	PACU 40% Res CAC 31% Chiller 21%
4	Warehouse	None 45% PCU 30% ISH 13%	None 62% Res CAC 17% PACU 11%	PCU 35% ISH 21% None 17%	PACU 38% None 27% Res CAC 23%
5	Stand-alone Retail	PCU 63% ISH 14% Furnace 10%	Res CAC 42% PACU 24% None 16%	PCU 63% Furnace 19% ISH 11%	PACU 48% Res CAC 37% IRAC 7%
6	Strip Mall	PCU 57% Furnace 33% ISH 10%	PACU 66% Res CAC 30% IRAC 4%	PCU 84% Furnace 15% ISH 1%	PACU 83% Res CAC 11% IRAC 7%
7	Primary School	Boiler 49% PCU 37% Furnace 10% Other 3% HP 1%	PACU 36% Res CAC 24% Chiller 14% IRAC 14% None 7%	Boiler 59% PCU 31% Furnace 4% Other 3% HP 3%	PACU 40% Chiller 25% IRAC 17% Res CAC 6% None 6%

Number	Type	By Number of Buildings		By Floor Area	
		Heating	Cooling	Heating	Cooling
8	Secondary School	PCU 49% Boiler 22% ISH 13% District 9% HP 5%	None, 35 PACU, 24 Chiller, 13 IRAC, 10 Res CAC, 9	Boiler 57% PCU 19% District 15% ISH 5% HP 4%	Chiller, 47 PACU, 29 District, 11 None, 6 Heat Pumps, 4
9	Grocery Store	PCU 62% Boiler 38% None 0%	Res CAC 76% PACU 14% IRAC 10%	PCU 55% Boiler 45% None 0%	IRAC 38% Res CAC 37% PACU 25%
10	Quick Service Restaurant	PCU 89% Furnace 11% None 0%	PACU 100% None 0% None 0%	PCU 97% Furnace 3% None 0%	PACU 100% None 0% None 0%
11	Full Service Restaurant	PCU 65% Furnace 21% Boiler 8%	PACU 52% Res CAC 39% IRAC 9%	PCU 68% Furnace 19% Boiler 8%	PACU 61% Res CAC 34% IRAC 5%
12	Hospital	Boiler 49% PCU 21% ISH 18%	Chiller 56% PACU 18% IRAC 18%	Boiler 56% District 31% PCU 12%	Chiller 62% District 22% PACU 15%
13	Out Patient Health Care	PCU 58% Furnace 34% ISH 5%	Res CAC 53% PACU 42% None 5%	PCU 59% Furnace 19% Boiler 17%	PACU 56% Res CAC 34% Chiller 8%
14	Small Hotel	Boiler 73% HP 14% HP 14%	IRAC 73% HP 27% None 0%	Boiler 55% ISH 41% HP 4%	IRAC 80% HP 20% None 0%
15	Large Hotel	HP 35% Boiler 31% PCU 27%	IRAC 37% PACU 31% Chiller 27%	Boiler 51% PCU 20% HP 15%	Chiller 53% PACU 25% HP 13%

Table C.5. Census Region 3, Post-1990 Buildings in 2012 CBECS

Number	Type	By Number of Buildings		By Floor Area	
		Heating	Cooling	Heating	Cooling
1	Large Office	PCU 85% HP 9% Boiler 4%	PACU 76% Chiller 15% HP 8%	PCU 62% District 15% HP 13%	Chiller 45% PACU 32% District 14%
2	Medium Office	PCU 52% Furnace 20% HP 17%	HP 39% PACU 37% Res CAC 18%	PCU 52% HP 20% Furnace 16%	HP 39% PACU 38% Res CAC 11%
3	Small Office	PCU 57% Furnace 19% HP 17%	Res CAC 44% PACU 36% HP 18%	PCU 69% Furnace 13% HP 13%	PACU 51% Res CAC 34% HP 12%
4	Warehouse	None 57% PCU 24% HP 8%	None 60% PACU 15% Res CAC 14%	PCU 51% None 23% ISH 8%	PACU 50% None 19% Res CAC 17%
5	Stand-alone Retail	PCU 51% HP 29% Furnace 8%	PACU 36% Res CAC 28% HP 26%	PCU 62% HP 15% None 12%	PACU 56% Res CAC 17% HP 17%
6	Strip Mall	PCU 63% HP 13% Furnace 13%	PACU 65% HP 24% Res CAC 11%	PCU 77% Other 9% Furnace 7%	PACU 81% HP 14% Res CAC 5%

Number	Type	By Number of Buildings Heating	Cooling	By Floor Area Heating	Cooling
7	Primary School	PCU 63% HP 10% Furnace 9% Boiler 8% None 7%	PACU 36% Res CAC 20% District 17% HP 15% Chiller 12%	PCU 41% Boiler 31% HP 19% ISH 3% Furnace 3%	Chiller 39% PACU 25% HP 22% District 7% Res CAC 7%
8	Secondary School	PCU 49% HP 15% District 11% ISH 9% Boiler 9%	Res CAC, 31 District, 18 Chiller, 13 PACU, 13 IRAC, 12	District 34% PCU 24% Boiler 23% HP 16% Furnace 2%	District, 42 Chiller, 24 Heat Pumps, 14 PACU, 13 Res CAC, 5
9	Grocery Store	PCU 45% None 34% Furnace 20%	PACU 41% IRAC 34% Res CAC 25%	PCU 53% Furnace 34% None 13%	PACU 52% Res CAC 35% IRAC 13%
10	Quick Service Restaurant	PCU 71% None 10% Furnace 9%	PACU 65% Res CAC 16% IRAC 10%	PCU 77% HP 8% None 7%	PACU 66% Res CAC 20% IRAC 9%
11	Full Service Restaurant	PCU 59% HP 17% Furnace 10%	PACU 45% Res CAC 24% HP 21%	PCU 76% HP 12% Furnace 5%	PACU 56% HP 19% Res CAC 17%
12	Hospital	Boiler 57% PCU 23% None 12%	Chiller 79% PACU 13% District 7%	Boiler 71% District 17% PCU 9%	Chiller 82% District 13% PACU 4%
13	Out Patient Health Care	PCU 75% HP 12% Furnace 11%	Res CAC 44% PACU 30% HP 20%	PCU 75% Furnace 9% Boiler 6%	PACU 46% Res CAC 25% Chiller 21%
14	Small Hotel	ISH 57% Boiler 43% None 0%	IRAC 100% None 0% None 0%	ISH 60% Boiler 40% None 0%	IRAC 100% None 0% None 0%
15	Large Hotel	HP 46% PCU 28% ISH 21%	PACU 38% IRAC 38% HP 19%	PCU 39% HP 34% ISH 17%	IRAC 35% PACU 32% HP 19%

Table C.6. Census Region 3, Pre-1990 Buildings in 2012 CBECS

Number	Type	By Number of Buildings Heating	Cooling	By Floor Area Heating	Cooling
1	Large Office	Boiler 43% PCU 39% District 13%	Chiller 69% PACU 19% HP 7%	PCU 37% Boiler 33% District 23%	Chiller 65% District 16% PACU 13%
2	Medium Office	PCU 47% HP 18% Furnace 18%	Res CAC 41% PACU 27% HP 17%	PCU 34% Boiler 26% HP 13%	Chiller 26% PACU 26% Res CAC 21%
3	Small Office	PCU 50% HP 26% Furnace 11%	PACU 40% Res CAC 32% HP 23%	PCU 52% HP 28% Furnace 9%	PACU 47% HP 25% Res CAC 22%
4	Warehouse	None 48% PCU 24% Furnace 10%	None 41% Res CAC 23% PACU 19%	PCU 38% None 33% ISH 12%	PACU 40% Res CAC 24% None 21%

		By Number of Buildings		By Floor Area	
Number	**Type**	**Heating**	**Cooling**	**Heating**	**Cooling**
5	Stand-alone Retail	PCU 48% HP 18% Furnace 14%	PACU 39% Res CAC 31% HP 22%	PCU 52% HP 18% Furnace 15%	PACU 60% HP 19% Res CAC 15%
6	Strip Mall	PCU 77% Furnace 7% HP 6%	PACU 56% Res CAC 27% HP 15%	PCU 89% Furnace 4% None 4%	PACU 67% Res CAC 20% HP 8%
7	Primary School	PCU 43% HP 23% ISH 16% Boiler 14% None 2%	Res CAC 37% PACU 27% HP 19% Chiller 9% IRAC 6%	PCU 41% Boiler 26% HP 26% ISH 4% Furnace 2%	PACU 39% HP 25% Chiller 22% Res CAC 9% IRAC 5%
8	Secondary School	PCU 59% Boiler 12% HP 11% District 8% None 5%	PACU, 34 Heat Pumps, 20 District, 19 Chiller, 13 Res CAC, 9	PCU 38% Boiler 32% District 16% HP 8% Furnace 3%	Chiller, 32 PACU, 32 District, 20 Heat Pumps, 9 IRAC, 5
9	Grocery Store	PCU 66% None 20% Furnace 12%	PACU 61% Res CAC 39% None 0%	PCU 71% None 12% Furnace 10%	PACU 89% Res CAC 11% None 0%
10	Quick Service Restaurant	PCU 85% Furnace 10% HP 5%	PACU 82% Res CAC 13% HP 5%	PCU 86% Furnace 10% HP 4%	PACU 84% Res CAC 12% HP 4%
11	Full Service Restaurant	PCU 55% Furnace 20% HP 11%	PACU 41% Res CAC 35% HP 12%	PCU 62% Furnace 20% HP 8%	PACU 49% Res CAC 28% HP 10%
12	Hospital	Boiler 35% HP 32% PCU 12%	PACU 47% Chiller 41% IRAC 8%	Boiler 61% District 26% HP 6%	Chiller 69% District 17% PACU 13%
13	Out Patient Health Care	PCU 54% HP 24% None 11%	PACU 44% Res CAC 32% HP 23%	PCU 60% HP 25% None 6%	PACU 57% HP 19% Res CAC 18%
14	Small Hotel	PCU 30% HP 26% None 19%	IRAC 51% Res CAC 18% HP 17%	PCU 43% HP 23% ISH 18%	IRAC 59% HP 22% PACU 14%
15	Large Hotel	ISH 66% Boiler 17% HP 12%	IRAC 68% Chiller 14% Heat Pumps 13%	Boiler 47% ISH 37% PCU 10%	Chiller 56% IRAC 32% PACU 6%

Table C.7. Census Region 4, Post-1990 Buildings in 2012 CBECS

		By Number of Buildings		By Floor Area	
Number	**Type**	**Heating**	**Cooling**	**Heating**	**Cooling**
1	Large Office	Boiler 59% PCU 24% District 6%	Chiller 48% PACU 36% HP 11%	Boiler 50% PCU 35% District 9%	Chiller 62% PACU 27% District 6%
2	Medium Office	PCU 42% Furnace 28% Boiler 13%	PACU 42% Res CAC 37% HP 13%	PCU 47% Boiler 29% Furnace 6%	PACU 57% HP 13% Res CAC 11%
3	Small Office	PCU 51% Furnace 23% HP 18%	PACU 39% Res CAC 30% HP 22%	PCU 66% Furnace 20% HP 10%	PACU 37% Res CAC 28% HP 23%
4	Warehouse	None 43% PCU 41% ISH 6%	None 37% PACU 25% Res CAC 22%	PCU 54% None 28% HP 12%	PACU 41% None 23% HP 17%
5	Stand-alone Retail	PCU 76% Furnace 15% HP 5%	PACU 64% Res CAC 17% HP 12%	PCU 95% None 3% Furnace 1%	PACU 77% Evap Cooler 17% Res CAC 4%
6	Strip Mall	PCU 82% Furnace 17% HP 1%	PACU 64% Res CAC 21% HP 15%	PCU 91% Furnace 5% HP 4%	PACU 80% Res CAC 12% HP 7%
7	Primary School	PCU 67% HP 25% Boiler 4% Furnace 4% None 0%	PACU 66% HP 21% Res CAC 8% Chiller 3% None 2%	PCU 70% Boiler 17% HP 12% Furnace 1% None 0%	PACU 65% Chiller 13% HP 12% None 9% Res CAC 1%
8	Secondary School	PCU 55% Boiler 18% District 16% HP 8% None 3%	PACU, 54 Chiller, 18 Heat Pumps, 15 District, 13 None, 0	Boiler 42% District 30% PCU 21% None 5% HP 3%	Chiller, 46 District, 22 PACU, 20 Heat Pumps, 12 None, 0
9	Grocery Store	PCU 61% None 38% Boiler 1%	Evap Cooler 38% PACU 37% None 24%	PCU 95% Boiler 3% None 2%	PACU 80% None 15% Res CAC 3%
10	Quick Service Restaurant	PCU 85% ISH 15% None 0%	PACU 85% Evap Cooler 15% None 0%	PCU 93% ISH 7% None 0%	PACU 93% Evap Cooler 7% None 0%
11	Full Service Restaurant	PCU 83% None 12% HP 5%	PACU 47% Res CAC 24% IRAC 18%	PCU 83% None 14% HP 3%	PACU 38% IRAC 35% Res CAC 18%
12	Hospital	Boiler 59% District 28% PCU 12%	Chiller 61% PACU 30% District 9%	Boiler 72% District 22% PCU 4%	Chiller 76% District 14% PACU 10%
13	Out Patient Health Care	PCU 69% Boiler 21% Furnace 7%	Res CAC 53% PACU 25% Chiller 21%	PCU 58% Boiler 25% District 12%	PACU 47% Res CAC 25% Chiller 19%
14	Small Hotel	ISH 58% PCU 25% HP 17%	IRAC 34% None 25% None 25%	ISH 43% PCU 40% HP 18%	Res CAC 40% IRAC 28% HP 18%
15	Large Hotel	ISH 43% PCU 30% HP 22%	IRAC 49% PACU 34% HP 12%	District 31% ISH 26% PCU 22%	District 31% IRAC 28% PACU 18%

Table C.8. Census Region 4, Pre-1990 Buildings in 2012 CBECS

		By Number of Buildings		By Floor Area	
Number	**Type**	**Heating**	**Cooling**	**Heating**	**Cooling**
1	Large Office	PCU 39% Boiler 35% HP 19%	PACU 47% Chiller 23% HP 23%	Boiler 52% District 16% PCU 13%	Chiller 69% PACU 13% District 8%
2	Medium Office	PCU 62% HP 16% Furnace 8%	PACU 44% Res CAC 21% HP 20%	PCU 55% Boiler 20% HP 12%	PACU 42% Chiller 23% HP 21%
3	Small Office	PCU 63% ISH 15% HP 6%	PACU 49% Res CAC 18% HP 15%	PCU 72% Boiler 8% ISH 7%	PACU 57% HP 24% Res CAC 14%
4	Warehouse	None 39% PCU 36% ISH 17%	None 40% PACU 26% Res CAC 20%	PCU 53% None 28% ISH 13%	PACU 47% Res CAC 20% None 20%
5	Stand-alone Retail	PCU 42% ISH 22% None 20%	Res CAC 27% PACU 25% None 22%	PCU 49% None 25% ISH 10%	PACU 45% Res CAC 21% None 13%
6	Strip Mall	PCU 94% ISH 3% Boiler 3%	PACU 83% IRAC 8% Evap Cooler 3%	PCU 95% Boiler 3% ISH 2%	PACU 91% Res CAC 3% Chiller 3%
7	Primary School	PCU 59% Boiler 17% HP 15% ISH 4% Furnace 3%	PACU 43% HP 15% IRAC 14% None 11% Res CAC 9%	Boiler 42% PCU 42% Other 6% ISH 4% HP 3%	PACU 42% Chiller 25% None 12% Evap Cooler 6% HP 5%
8	Secondary School	PCU 42% None 17% Furnace 14% Boiler 11% District 9%	PACU, 36 None, 20 Res CAC, 13 Heat Pumps, 10 Evap Cooler, 9	PCU 36% Boiler 35% District 14% None 9% Furnace 3%	PACU, 35 Chiller, 18 None, 14 District, 9 Heat Pumps, 9
9	Grocery Store	PCU 73% None 20% Furnace 7%	None 41% PACU 25% Evap Cooler 18%	PCU 87% Furnace 10% None 4%	PACU 63% Chiller 19% None 9%
10	Quick Service Restaurant	PCU 61% Boiler 24% None 15%	PACU 76% Res CAC 12% HP 6%	PCU 68% Boiler 24% None 8%	PACU 73% Res CAC 14% None 8%
11	Full Service Restaurant	PCU 66% Furnace 13% ISH 12%	PACU 36% Res CAC 22% None 16%	PCU 71% Furnace 13% ISH 6%	PACU 38% Res CAC 26% None 25%
12	Hospital	Boiler 51% PCU 40% District 6%	Chiller 50% District 26% PACU 23%	Boiler 75% District 12% PCU 11%	Chiller 75% District 16% PACU 8%
13	Out Patient Health Care	PCU 62% HP 16% Boiler 14%	PACU 53% Res CAC 22% HP 12%	PCU 46% Boiler 27% HP 18%	PACU 43% Chiller 19% Res CAC 13%
14	Small Hotel	ISH 47% HP 25% Furnace 13%	IRAC 38% HP 23% Res CAC 13%	ISH 41% Furnace 34% HP 17%	IRAC 48% Res CAC 34% HP 8%
15	Large Hotel	Boiler 44% HP 31% None 13%	Chiller 35% District 19% IRAC 16%	Boiler 45% None 30% HP 12%	Chiller 64% PACU 13% District 12%

Table C.9. Region 1: Sample Size by Building Type and Time Period

Number	Type	Pre-1990 Sample	Post 1990 Sample
1	Large Office	70	14
2	Medium Office	84	21
3	Small Office	21	12
4	Warehouse	67	31
5	Stand-alone Retail	38	23
6	Strip Mall	28	13
7	Primary School	58	11
8	Secondary School	38	12
9	Grocery store	2	8
10	Quick Service Restaurant	5	4
11	Full Service Restaurant	33	8
12	Hospital	85	10
13	Outpatient Health Care	22	7
14	Small Hotel	6	0
15	Large Hotel	14	8

Table C.10. Region 2: Sample Size by Building Type and Time Period

Number	Type	Pre-1990 Sample	Post 1990 Sample
1	Large Office	43	12
2	Medium Office	98	35
3	Small Office	47	24
4	Warehouse	91	54
5	Stand-alone Retail	63	30
6	Strip Mall	34	16
7	Primary School	58	40
8	Secondary School	56	29
9	Grocery store	5	3
10	Quick Service Restaurant	9	5
11	Full Service Restaurant	43	20
12	Hospital	54	25
13	Outpatient Health Care	35	19
14	Small Hotel	4	4
15	Large Hotel	14	13

Table C.11. Region 3: Sample Size by Building Type and Time Period

Number	Type	Pre-1990 Sample	Post 1990 Sample
1	Large Office	93	47
2	Medium Office	117	50
3	Small Office	123	81
4	Warehouse	141	144
5	Stand-alone Retail	74	55
6	Strip Mall	79	53
7	Primary School	82	79
8	Secondary School	71	43
9	Grocery store	8	6
10	Quick Service Restaurant	20	27
11	Full Service Restaurant	71	31
12	Hospital	94	61
13	Outpatient Health Care	28	30
14	Small Hotel	23	4
15	Large Hotel	41	30

Table C.12. Region 4: Sample Size by Building Type and Time Period

Number	Type	Pre-1990 Sample	Post 1990 Sample
1	Large Office	50	20
2	Medium Office	94	45
3	Small Office	72	41
4	Warehouse	116	94
5	Stand-alone Retail	48	38
6	Strip Mall	37	36
7	Primary School	70	49
8	Secondary School	38	21
9	Grocery store	10	6
10	Quick Service Restaurant	17	7
11	Full Service Restaurant	45	16
12	Hospital	43	37
13	Outpatient Health Care	34	22
14	Small Hotel	15	5
15	Large Hotel	21	18

Appendix D

Analysis of Heating Fuel by Climate Region

Appendix D

Analysis of Heating Fuel by Climate Region

To provide insight into the relative predominance of electric heat (including heat pumps) versus fossil fuel heating by climate zone, several tables are presented in this appendix based on the available data in CBECS 2012. Since the prototype buildings are developed based on Standard 90.1 defined climate zones, this analysis relied on the available climate regions and geographic data (i.e. Census division) data in CBECS 2012 to best map results to the Standard 90.1 zones.

D.1 Climate Zones

CBECS "Pubclim" variable aggregates the Building America climate zones (Baechler, 2010), derived from analysis conducted in support of ASHRAE Standard 90.1, into four larger, aggregate, climate zones. Table D.1 shows the CBECS 2012 Pubclim variable and the Building America and IECC (and ASHRAE) climate zones defined as of 2010. Figure D.1 illustrates the CBECS 2012 climate aggregations. Climate zone data may not precisely map to the latest ASHRAE Standard 90.1 due to remapping of any locations after 2010. However, any differences in mapping are believed to be well within the error of the CBECS climate sampling.

Table D.1. CBECS Pubclim Variable and Included Climate Zones

CBECS 2012 Pubclim Value	Building America Climate Zone	IECC/ASHRAE Climate Zones
NA	SubArctic	Zone 8
1	VeryCold	Zone 7
	Cold	Zone 5 and 6
2	Mixed-Humid	4A and 3A counties above warm-humid line*
	Mixed-Dry	Zone 4B
3	Hot-Humid	2A and 3A counties below warm-humid line*
	Hot-Dry	Zone 2B and 3B
5	Marine	All counties with a "C" moisture regime
7	N/A Data withheld for confidentiality	

* warm-humid line roughly divides zone 3a, where warm-humid climates are defined as those where the wet bulb temperature is either: a) ≥ 67° F for 3,000 hours or more; b) ≥ 73° F for 1,500 hours or more.

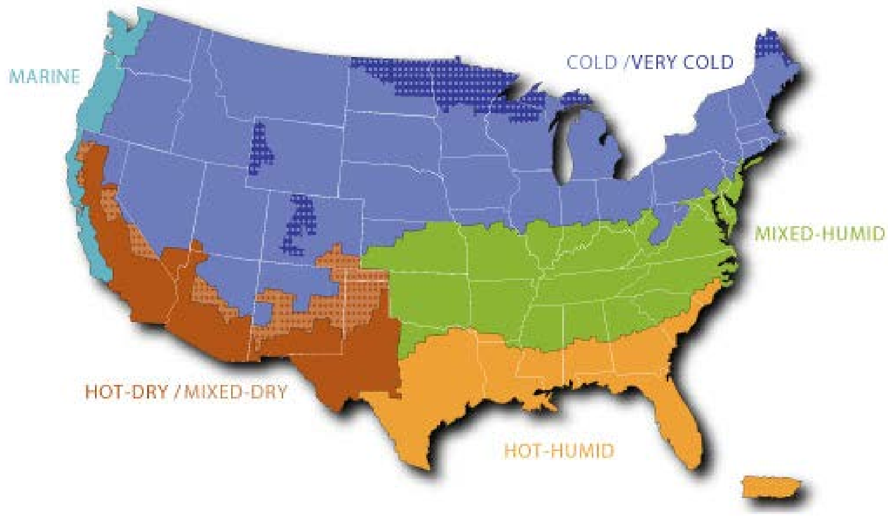

Figure D.1. Building America Climate Zones and CBECS Pubclim (courtesy EIA)[1]

Since climate data in the form of the Pubclim variable as well as geographic location data in the form of Census division are captured in CBECS 2012, it is possible to provide a breakout of unique *geo-climate* combinations that each map to a distinct set of ASHRAE climate zones. For each Pubclim value, Table D.2 shows which Census divisions are included, and a range of possible 90.1 climate zones found in the geo-climate combination. Most ASHRAE Standard 90.1 climate zones can be mapped to more than one geo-climate region. This table should provide insight on the electric heating energy use described in this appendix. In addition, a map of the U.S. Census divisions is provided in Figure D.2.

Table D.2. Geo-Climate Characterization of CBECS 2012 Building Record Variables with ASHRAE Climate Zones

PUBCLIM Value	Census Division No.	Census Division Name	Possible Climate Zones
1	1	New England	5A, 6A, 7
	2	Middle Atlantic	5A, 6A
	3	East North Central	5A, 6A, 7
	4	West North Central	5A, 6A, 7
	5	South Atlantic	NA
	6	East South Central	NA
	7	West South Central	NA
	8	Mountain	5B, 6B
	9	Pacific	7
2	1	New England	NA
	2	Middle Atlantic	4A
	3	East North Central	4A
	4	West North Central	4A
	5	South Atlantic	3A*, 4A
	6	East South Central	3A*,4A
	7	West South Central	3A*
	8	Mountain	NA
	9	Pacific	NA

[1] https://www.eia.gov/consumption/commercial/maps.php

PUBCLIM Value	Census Division No.	Census Division Name	Possible Climate Zones
3	1	New England	NA
3	2	Middle Atlantic	NA
3	3	East North Central	NA
3	4	West North Central	NA
3	5	South Atlantic	1A, 2A, 3A**
3	6	East South Central	2A, 3A**
3	7	West South Central	2A, 3A**, 2B, 3B, 4B
3	8	Mountain	2B, 3B, 4B
3	9	Pacific	2B, 3B, 4B
5	1	New England	NA
5	2	Middle Atlantic	NA
5	3	East North Central	NA
5	4	West North Central	NA
5	5	South Atlantic	NA
5	6	East South Central	NA
5	7	West South Central	NA
5	8	Mountain	NA
5	9	Pacific	1A, 3C, 4C, 5C
7	1	New England	Any
7	2	Middle Atlantic	Any
7	3	East North Central	Any
7	4	West North Central	Any
7	5	South Atlantic	Any
7	6	East South Central	Any
7	7	West South Central	Any
7	8	Mountain	Any
7	9	Pacific	Any

*3A north of warm-humid line in IECC maps
**3A south of warm-humid line in IECC maps
NA = Not Applicable

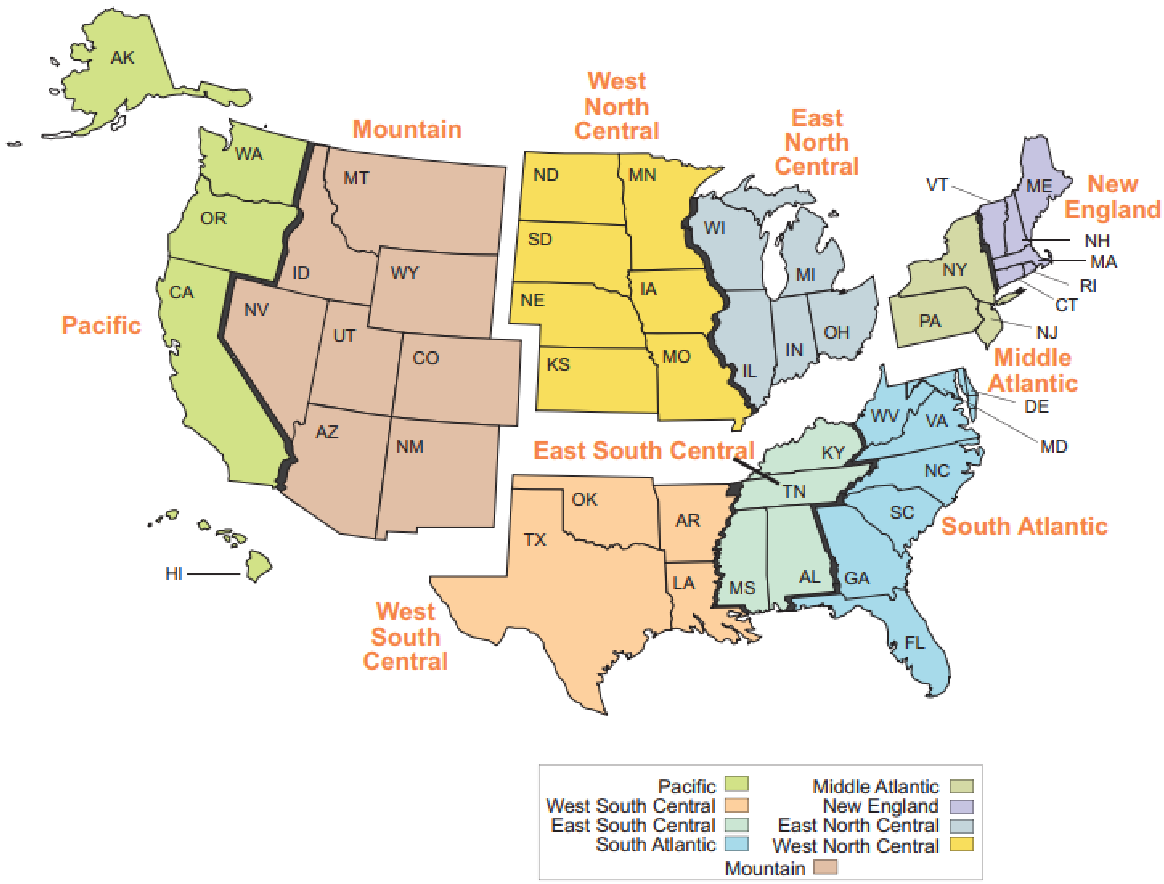

Figure D.2. U.S. Census Divisions (courtesy EIA)[1]

D.2 Electric Heating Characterization for Buildings

Analysis of prototype building heating fuel identified buildings by primary heated energy as reported in the CBECS 2012 dataset. The ratio of electric heating energy (CBECS 2012 field ELHBTU) to total heating energy (Calculated as the sum of all reported heating fuel consumption)[2] was calculated for each building record in the post-1990 Prototype building set.[3]

After examination, it was determined that simply aggregating buildings in bins of low, medium and high electric heat fractions provided reasonable building characterization for those buildings which are primarily electric or fossil fuel heated.

[1] https://www.eia.gov/outlooks/aeo/pdf/f1.pdf

[2] Total heating energy is the sum of electric (CBECS 2012 field ELHTBTU), natural gas (CBECS 2012 field NGHTBTU), fuel oil (CBECS 2012 field FKHBTU), and district heat (CBECS 2012 field DHHBTU).

[3] Heating energy use data in CBECS is derived data and not based on sub-metered heating energy usage.

- Low electric heat fraction was used for buildings where the ratio of electric to total heating Btus was 0.33 or less.
- Medium electric fraction was used for building where the ratio of electric to total heating Btus was greater than or equal to 0.33 but less than or equal to 0.66.
- High electric fraction was used for building where the ratio of electric to total heating Btus was greater than 0.66.

In addition, some buildings report no heating fuel use. These buildings are indicated as to have no heating reported (CBECS variable HT1, "Energy Use for Main Heating" indicates no energy used for main heating) in some instances. Warehouses are the most common building type in CBECS reported as unheated. However, in other instances, the energy use for main heating may correspond to one in which the heating energy is not captured in CBECS data (e.g., wood, coal, solar, and propane). The latter complicates the analysis as these heating energy sources, particularly propane, may be indicated as a fuel used in the building, but it is not captured in terms of heating energy use, even when no other heating energy is identified.

Table D.3 analyzes the buildings identified as prototypes using the combinations of the CBECS (Pubclim aggregations) and the prototype building category. For each combination of Pubclim variable and building prototype, Table D.3 shows:

- The number of samples (where heat energy was declared used in the building),
- The number of samples where heating Btus were recorded by CBECS 2012,
- The fraction of buildings falling into each electric heat category defined previously, by building population
- The fraction of buildings falling into each electric heat category defined previously, by building floor space.

Many, but not all of the buildings where heating energy (heating Btus) were not recorded reflect buildings that may use propane, wood, coal, or solar as a main heating source, with propane likely the most common. Thus, some significant number of these records could be considered low electric heat fraction buildings. Examination of the data suggests that the fraction of buildings or building floor space with heating not recorded is not substantial enough to impact the relative predominance of electric or fossil fuel heated buildings.

While no detailed statistical examination of the data in Table D.3 was conducted, rows indicating small numbers of samples (e.g. less than 20) are likely less representative of the overall building population and therefore should not be relied on exclusively to describe the building prototype heating fuels.

Table D.4 provides analysis of the buildings identified as prototypes using the combinations of the CBECS (Pubclim aggregations) and Census division data, aggregating all the prototype observations together. For each combination of Pubclim variable and Census division, Table D.4 shows:

- The number of samples (where heat energy was declared used in the building),
- The number of samples where heating Btus were recorded by CBECS 2012,
- The fraction of buildings falling into each electric heat category defined previously, by building population, and
- The fraction of buildings falling into each electric heat category defined previously, by building floor space.

Examination of the data shown in Table D.4 suggests that the fraction of buildings or building floor space with heating energy is presumed in the building, but not recorded, is not substantial enough to impact the relative predominance of electric or fossil fuel heated buildings. A limited review of the data in Table D.3 and D.4 shows the following:

- In Pubclim zone 1, fossil fuel heating appears dominant across all Census divisions when considering all commercial prototype building square footage (Table D.4), and across all building prototypes individually (Table D.4).

- In Pubclim zone 2, fossil fuel heating appears dominant across all commercial prototype building square footage (Table D.4) with the exception of in the Mid-Atlantic Census division, which was electric heating dominant. When considering building prototypes individually (Table D.4), large office, grocery store, quick-service restaurant and the one sample shown for small hotel were dominated by electric heating. The small sample sizes for grocery and small hotel make it difficult to say that simply based on this data that the sample is representative. However, in the case of the choice of IRAC and ISH for small hotel, electric heating would likely be considered representative regardless. This argument would apply in all climate zones.

- In Pubclim zone 3, electric heating is dominant when considering all commercial prototype square footage (Table D.4) with the exception of the buildings in the Pacific Census division. By square footage in the prototype categories, all buildings with the exception of medium office, strip mall, stand-alone retail, secondary school, and grocery store were electric heat dominant.

- In Pubclim zone 5, which lies entirely within the Pacific Census division, fossil-fuel heating is indicated as dominant when considering all commercial prototype square footage (Table D.4) and the 55 building samples captured. By square footage in the prototype categories, all building types with the exception of warehouse and small hotel were dominated by fossil-fuel heat. Sample sizes are very low and may or may not be representative of the true population by building type.

Table D.3. Electric Heat Fraction by CBECS Pubclim and DOE Prototype (By Total Building Population and Total Building Area)*

Pub-Clim	DOE Prototype	Samples	Samples with Heating Btu	Electric Heating Fraction (%) by Total Building Population				Electric Heating Fraction (%) by Total Building Square Footage			
				No Heat Energy	Low	Med	High	No Heat Energy	Low	Med	High
1	Large Office	19	19	0%	59%	0%	41%	0%	59%	0%	41%
	Medium Office	51	51	0%	80%	0%	20%	0%	83%	0%	17%
	Small Office	50	48	5%	70%	4%	21%	5%	70%	9%	17%
	Warehouse	70	66	8%	68%	0%	24%	2%	86%	1%	12%
	Stand-alone Retail	56	51	17%	65%	2%	17%	7%	83%	3%	7%
	Strip Mall	32	32	0%	93%	6%	1%	0%	90%	7%	2%
	Primary School	44	43	3%	66%	0%	31%	2%	83%	0%	15%
	Secondary School	47	47	0%	97%	0%	3%	0%	97%	0%	3%
	Grocery store	11	11	0%	80%	2%	18%	0%	90%	4%	6%
	Quick Service Restaurant	8	7	6%	53%	0%	40%	12%	53%	0%	35%
	Full Service Restaurant	23	21	10%	66%	0%	24%	5%	71%	0%	24%
	Hospital	28	28	0%	100%	0%	0%	0%	100%	0%	0%
	Outpatient Health Care	31	31	0%	83%	0%	17%	0%	80%	0%	20%
	Small Hotel	6	5	26%	12%	0%	62%	16%	57%	0%	27%
	Large Hotel	24	23	5%	1%	43%	51%	2%	4%	43%	52%
	All	**500**	**483**	**6%**	**71%**	**2%**	**21%**	**2%**	**80%**	**4%**	**14%**

Pub-Clim	DOE Prototype	Samples	Samples with Heating Btu	Electric Heating Fraction (%) by Total Building Population: No Heat Energy	Low	Med	High	Electric Heating Fraction (%) by Total Building Square Footage: No Heat Energy	Low	Med	High
2	Large Office	38	38	0%	6%	1%	94%	0%	18%	4%	78%
	Medium Office	45	45	0%	53%	3%	44%	0%	56%	6%	38%
	Small Office	51	51	0%	45%	0%	55%	0%	61%	3%	37%
	Warehouse	69	69	0%	60%	0%	40%	0%	71%	1%	29%
	Stand-alone Retail	48	45	8%	42%	3%	47%	5%	51%	3%	41%
	Strip Mall	35	35	0%	47%	9%	44%	0%	57%	16%	26%
	Primary School	47	46	1%	53%	3%	43%	1%	73%	4%	22%
	Secondary School	28	27	14%	49%	0%	37%	1%	82%	0%	16%
	Grocery store	6	5	5%	48%	0%	47%	25%	19%	0%	56%
	Quick Service Restaurant	19	19	0%	48%	0%	52%	0%	42%	0%	58%
	Full Service Restaurant	27	27	0%	51%	3%	46%	0%	50%	11%	39%
	Hospital	41	41	0%	94%	0%	6%	0%	90%	0%	10%
	Outpatient Health Care	24	24	0%	62%	0%	38%	0%	55%	0%	45%
	Small Hotel	1	1	0%	0%	0%	100%	0%	0%	0%	100%
	Large Hotel	18	18	0%	39%	2%	59%	0%	49%	3%	49%
	All	**497**	**491**	**2%**	**50%**	**2%**	**46%**	**1%**	**62%**	**4%**	**33%**
3	Large Office	17	17	0%	45%	0%	55%	0%	38%	0%	62%
	Medium Office	41	41	0%	51%	7%	42%	0%	61%	4%	35%
	Small Office	52	52	0%	21%	1%	78%	0%	23%	4%	73%
	Warehouse	91	90	7%	23%	1%	69%	1%	25%	4%	70%
	Stand-alone Retail	31	31	0%	24%	0%	76%	0%	51%	0%	49%
	Strip Mall	45	45	0%	48%	1%	51%	0%	62%	2%	36%
	Primary School	79	79	0%	30%	0%	70%	0%	37%	0%	63%
	Secondary School	27	26	14%	42%	1%	43%	1%	48%	7%	45%
	Grocery store	3	3	0%	61%	0%	39%	0%	6%	0%	94%
	Quick Service Restaurant	12	11	13%	21%	0%	65%	6%	26%	0%	68%
	Full Service Restaurant	19	19	0%	36%	6%	58%	0%	36%	6%	58%
	Hospital	39	39	0%	71%	1%	28%	0%	89%	2%	9%
	Outpatient Health Care	18	18	0%	22%	0%	78%	0%	10%	0%	90%
	Small Hotel	5	5	0%	12%	0%	88%	0%	22%	0%	78%
	Large Hotel	22	22	0%	8%	23%	69%	0%	15%	19%	65%
	All	**501**	**498**	**2%**	**29%**	**1%**	**67%**	**0%**	**40%**	**3%**	**56%**
5	Large Office	8	8	0%	63%	0%	37%	0%	59%	0%	41%
	Medium Office	9	9	0%	85%	2%	14%	0%	68%	5%	27%
	Small Office	2	2	0%	42%	0%	58%	0%	64%	0%	36%
	Warehouse	3	3	0%	0%	83%	17%	0%	0%	35%	65%

Pub-Clim	DOE Prototype	Samples	Samples with Heating Btu	Electric Heating Fraction (%) by Total Building Population				Electric Heating Fraction (%) by Total Building Square Footage			
				No Heat Energy	Low	Med	High	No Heat Energy	Low	Med	High
	Stand-alone Retail	9	9	0%	80%	3%	17%	0%	84%	13%	3%
	Strip Mall	3	3	0%	95%	0%	5%	0%	85%	0%	15%
	Primary School	2	2	0%	100%	0%	0%	0%	100%	0%	0%
	Secondary School	1	1	0%	100%	0%	0%	0%	100%	0%	0%
	Grocery store	1	1	0%	100%	0%	0%	0%	100%	0%	0%
	Quick Service Restaurant	1	1	0%	100%	0%	0%	0%	100%	0%	0%
	Full Service Restaurant	2	2	0%	100%	0%	0%	0%	100%	0%	0%
	Hospital	7	7	0%	100%	0%	0%	0%	100%	0%	0%
	Outpatient Health Care	4	4	0%	100%	0%	0%	0%	100%	0%	0%
	Small Hotel	1	1	0%	0%	0%	100%	0%	0%	0%	100%
	Large Hotel	2	2	0%	47%	0%	53%	0%	64%	0%	36%
	All	**55**	**55**	**0%**	**74%**	**7%**	**19%**	**0%**	**75%**	**6%**	**19%**
7**	Large Office	10	10	0%	55%	0%	45%	0%	54%	0%	46%
	Warehouse	5	5	0%	100%	0%	0%	0%	100%	0%	0%
	Inpatient Health Care	16	16	0%	100%	0%	0%	0%	100%	0%	0%
	Hotel	3	3	0%	93%	7%	0%	0%	93%	7%	0%
	All	**34**	**34**	**0%**	**80%**	**1%**	**18%**	**0%**	**80%**	**1%**	**19%**

* Buildings Reporting Using Energy for Heating
** Not mapped to climate zone

Table D.4. Electric Heat Fraction by CBECS Pubclim and Census Division (By Total Building Population and Total Building Area)*

				Electric Heating Fraction (%) by Total Building Population				Electric Heating Fraction (%) by Total Building Square Footage			
PubClim	**Census Division**	**Samples**	**Samples with Heating Btu**	**No Heat Energy**	**Low**	**Med**	**High**	**No Heat Energy**	**Low**	**Med**	**High**
1	1	46	42	16%	71%	0%	12%	3%	92%	0%	5%
	2	86	82	7%	59%	5%	29%	2%	75%	5%	18%
	3	170	170	0%	88%	3%	9%	0%	85%	3%	12%
	4	71	64	19%	44%	0%	37%	8%	68%	1%	23%
	8	82	80	2%	86%	1%	11%	2%	84%	8%	6%
	9	45	45	0%	41%	5%	54%	0%	62%	10%	28%
	All	**500**	**483**	**6%**	**71%**	**2%**	**21%**	**2%**	**80%**	**4%**	**14%**
2	2	40	39	8%	75%	1%	16%	0%	18%	4%	78%
	3	26	25	1%	65%	1%	33%	0%	56%	6%	38%
	4	38	38	0%	44%	1%	55%	0%	61%	3%	37%
	5	272	269	2%	43%	2%	54%	0%	71%	1%	29%
	6	56	56	0%	50%	0%	50%	5%	51%	3%	41%
	7	65	64	3%	66%	4%	27%	0%	57%	16%	26%
	All	**497**	**491**	**2%**	**50%**	**2%**	**46%**	**1%**	**62%**	**4%**	**33%**
3	5	70	70	0%	0%	0%	100%	0%	4%	0%	96%
	6	19	19	0%	17%	0%	83%	0%	43%	0%	57%
	7	168	165	7%	24%	3%	66%	1%	38%	7%	55%
	8	49	49	0%	16%	3%	81%	0%	33%	4%	63%
	9	195	195	0%	47%	1%	52%	0%	56%	1%	43%
	All	**501**	**498**	**2%**	**29%**	**1%**	**67%**	**0%**	**40%**	**3%**	**56%**
5	9	55	55	0%	74%	7%	19%	0%	75%	6%	19%
	All	**55**	**55**	**0%**	**74%**	**7%**	**19%**	**0%**	**75%**	**6%**	**19%**
7**	2	4	4	0%	72%	0%	28%	0%	72%	0%	28%
	3	7	7	0%	100%	0%	0%	0%	100%	0%	0%
	4	1	1	0%	100%	0%	0%	0%	100%	0%	0%
	5	8	8	0%	79%	0%	21%	0%	79%	0%	21%
	6	3	3	0%	87%	13%	0%	0%	87%	13%	0%
	7	6	6	0%	46%	0%	54%	0%	46%	0%	54%
	8	3	3	0%	100%	0%	0%	0%	100%	0%	0%
	9	2	2	0%	40%	0%	60%	0%	40%	0%	60%
	All	**34**	**34**	**0%**	**80%**	**1%**	**18%**	**0%**	**80%**	**1%**	**19%**

* Buildings Reporting Using Energy for Heating
** Not mapped to climate zone

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