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Review of Pre- and Post-1980 Buildings in CBECS – HVAC Equipment

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December 2006



Pacific Northwest
NATIONAL LABORATORY

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Pacific Northwest National Laboratory
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Summary

This report analyses the content of the 2003 Commercial Building Energy Consumption Survey (CBECS) (DOE EIA 2003) to determine the most typical heating, ventilating, and air-conditioning (HVAC) equipment in use in 15 different building types. Two sets of recommended HVAC systems are developed – one for post-1980 buildings and one for pre-1980 buildings. The recommendations are listed below in tables S-1 and S-2.

Table S-1. PNNL Recommendations for Post-1980 Buildings – HVAC Equipment

Number	Type	PNNL Recommendation	
		Heating	Cooling
1	Large Office	Boiler	Chiller
2	Medium Office	Furnace	PACU
3	Small Office	Furnace	PACU
4	Warehouse	Furnace	PACU
5	Stand-alone Retail	Furnace	PACU
6	Reserved (strip mall)	NA	NA
7	Primary School	Boiler	PACU
8	Secondary School	Boiler	Chiller
9	Grocery Store	Furnace	PACU
10	Fast Food	Furnace	PACU
11	Restaurant	Furnace	PACU
12	Hospital	Boilers	Chillers
13	Outpatient Health Care	Furnace	PACU
14	Motel	ISH	IRAC
15	Hotel	Boiler	Chiller

PACU – Packaged Air Conditioning Unit ISH – Individual Space Heater
 IRAC – Individual Room Air Conditioner NA – Not Available

Table S-2. PNNL Recommendations for Pre-1980 Buildings – HVAC Equipment

Number	Type	PNNL Recommendation	
		Heating	Cooling
1	Large Office	Boiler	Chiller
2	Medium Office	Furnace	PACU
3	Small Office	Furnace	PACU
4	Warehouse	Furnace	PACU
5	Stand-alone Retail	Furnace	PACU
6	Reserved (strip mall)	NA	NA
7	Primary School	Boiler	PACU
8	Secondary School	Boiler	PACU

9	Grocery Store	Furnace	PACU
10	Fast Food	Furnace	PACU
11	Restaurant	Furnace	PACU
12	Hospital	Boilers	Chillers
13	Outpatient Health Care	Furnace	PACU
14	Motel	ISH	IRAC
15	Hotel	Boiler	Chiller
PACU – Packaged Air Conditioning Unit		ISH – Individual Space Heater	
IRAC – Individual Room Air Conditioner		NA – Not Available	

Acronyms and Abbreviations

AC	air conditioning
CAV	constant Volume
CBECS	commercial Buildings Energy Consumption Survey
DOE	U.S. Department of Energy
EER	energy efficiency ratio
FCU	fan coil units
HP	heat pump
HVAC	heating, ventilating, and air conditioning
IRAC	individual room air conditioners
ISH	individual space heater
ISH	individual space heaters
MZ	multi-zone
NA	not available
PACU	packaged air conditioning units
PHU	packaged heating units
PNNL	Pacific Northwest National Laboratory
PTAC	packaged terminal air conditioner
PTHP	packaged terminal heat pump
Res. AC	residential air conditioner
SZ	single zone
VAV	variable air volume

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1.0 Background

The U.S. Department of Energy (DOE) tasked Pacific Northwest National Laboratory (PNNL) with analyzing heating, ventilating, and air conditioning (HVAC) systems and equipment for DOE's Reference Buildings¹ based on 2003 Commercial Buildings Energy Consumption Survey (CBECS) (DOE EIA 2003) data. This report summarizes the results of PNNL's analysis of 2003 CBECS data and provides PNNL's recommendations for HVAC systems and equipment for use in the Reference Buildings.

2.0 HVAC Information Available in 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 responder was asked to identify the main cooling and main heating equipment. The categories for response are as follows:

- 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
 - swamp coolers or evaporative coolers
 - some other cooling equipment
- 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 heating units (PHUs)
 - some other heating 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 here refer to % floor space) by specific equipment categories. The latter data collected are in a similar form to the main cooling and main heating categories:

- percent cooled by:
 - PACU
 - Central AC

¹ DOE Reference Buildings were developed as part of DOE's Commercial Building Initiative. The Reference buildings provide typical building models for approximately 70% of the commercial buildings in the US. See http://www1.eere.energy.gov/buildings/commercial_initiative/reference_buildings.html for more detail.

- IRAC
- Heat pumps
- District chilled water
- Central chillers
- Swamp coolers
- Other cooling equip
- percent heated by:
 - Furnace
 - Boiler
 - PHU
 - ISH
 - Heat pumps
 - District steam/hot water
 - Other heating equip

Where heat pumps are used, the survey asks additional questions regarding the type of heat pumps (e.g., water source, ground source, air source, packaged, split system, individual room) used for heating and cooling in the building. CBECS also presents data on whether the building uses a variable air volume (VAV) system and the main and secondary heating or cooling fuel types.

3.0 CBECS Limitations in Terminology

Unfortunately, not all the CBECS responses regarding equipment categories are mutually exclusive. Two potential responses in particular that can cause trouble are PHUs and IRACs.

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 2003 glossary, the responses captured in the survey are for packaged cooling units or PHUs. PHUs are simply “boxes that provide heating” to many occupants. Identifying what that box is, be it a furnace, a boiler, or a heat pump, is beyond the interest or knowledge of some occupants, and so PHU could also mean any of these three categories. The most common PHU is expected by the authors to be a gas furnace installed as part of packaged rooftop cooling unit. However, hydronic coils 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 reply could refer to a gas or electric furnace in a packaged rooftop unit, a standalone gas or electric furnace, or a gas or electric furnace with a direct expansion coil—as with a residential split system furnace/air handler.

Based on these two definitions, it is clear that a large overlap exists between the categories of PHU and furnace that cannot be easily disaggregated through other survey responses.

Individual (room) air conditioner is another term that could cause some confusion in earlier versions of CBECS (such as DOE EIA 1995), as responders showed some uncertainty regarding whether packaged terminal air conditioners (PTACs) should be classed under IRAC or packaged cooling units. The 2003 CBECS clarifies that IRACs are direct expansion units (as opposed to fan coil units [FCU]) and that all packaged terminal equipment is clearly to be categorized as IRAC or individual room heat pumps.

Heat pump is another term that was more problematic in previous versions of CBECS. In the 2003 CBECS, the definitions and follow-on questions help to 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 many cases chillers). Heat pumps can potentially also be interpreted as package heating units.

4.0 CBECS Limitations on Percent of Floor Space Heated and Cooled

While CBECS does provide estimates of the fraction of floor space heated or cooled by the different equipment categories, analysis of the data shows that it is quite common for the sum of the estimates to exceed 100 percent (around 14 percent of the post-1980 buildings exceed 100 percent for heating equipment). For simple buildings, it may be relatively easy to define one heating or cooling equipment type for each portion of floor space such that this is not an issue. However, for other buildings with multiple systems serving multiple spaces or with poorly defined or unknown zoning, assigning a floor area to a particular system may be very difficult.

5.0 CBECS 2003 Analysis

To examine HVAC system selection, PNNL extracted data for all 2003 CBECS buildings in two sets—construction in 1980 and before and construction post-1980. Tables 1 and 2 show the result of this extraction. The tables show the most common HVAC types by Reference building type², viewed on both number of represented buildings and on total represented floor area.

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

Table 2 exhibits three special points of interest (in bold text): the high percentage of unheated and uncooled warehouses, the significant fraction of district heating and cooling in secondary schools and hospitals, and the surprising large segment of hospitals that report other cooling systems than those explicitly identified in the CBECS survey.

² This analysis uses the U.S. National Renewable Energy Laboratory approach for defining Large, Medium, And Small Offices, 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 these would presumably influence the relative equipment usage statistics for these office benchmarks

Table 1. Post-1980 Buildings in 2003 CBECS

Number	Type	By Number of Buildings		By Floor Area	
		Heating	Cooling	Heating	Cooling
1	Large Office	Boiler 40% PHU 20% District 7%	PACU 43% Chiller 39% District 5%	Boiler 29% PHU 18% District 16%	Chiller 50% PACU 27% District 12%
2	Medium Office	Furnace 34% PHU 25% HP 23%	PACU 39% Res AC 25% HP 23%	PHU 30% Boiler 22% Furnace 18%	PACU 59% HP 14% Chiller 11%
3	Small Office	PHU 39% Furnace 33% HP 20%	PACU 43% Res AC 33% HP 20%	PHU 38% Furnace 32% HP 19%	PACU 49% Res AC 26% HP 18%
4	Warehouse	None 57% Furnace 19% PHU 10%	None 61% PACU 17% Res AC 13%	Furnace 29% PHU 27% None 27%	PACU 45% None 26%
5	Stand-alone Retail	Furnace 43% PHU 31%	PACU 42% Res AC 28%	PHU 42% Furnace 30%	PACU 73%
6	Reserved (strip mall)	No Data	No Data	No Data	No Data
7	Primary School	PHU 28% Furnace 28% HP 16% ISH 10% Boiler 9%	PACU 36% Res AC 21% HP 17% Chiller 9%	Boiler 32% HP 23% PHU 18% Furnace 15%	PACU 37% Chiller 26% HP 18% Res AC 10%
8	Secondary School	Furnace 27% HP 24% PHU 17% Boiler 11% District 10%	HP 24% PACU 21% Chiller 14% District 12%	Boiler 37% District 20% Furnace 13% PHU 12% HP 9%	Chiller 37% PACU 21% District 20% HP 10%
9	Grocery Store	PHU 42% Furnace 37%	PACU 56% Res AC 15%	Furnace 47% PHU 45%	PACU 68% Res AC 10%
10	Fast Food	PHU 60% Furnace 24%	PACU 73% Res AC 22%	PHU 63% Furnace 20%	PACU 74% Res AC 24%
11	Restaurant	PHU 43% Furnace 28%	PACU 64%	PHU 51% Furnace 24%	PACU 65%
12	Hospital	Boiler 71%	Chiller 54% PACU 33%	Boilers 69%	Chiller 68% PACU 13%
13	Out Patient Health Care	Furnace 43% PHU 22% HP 21% Boiler 9%	PACU 40% Res AC 36% HP 21%	Furnace 28% PHU 23% HP 22% Boiler 22%	PACU 43% HP 23% Res AC 19%
14	Motel	ISH 43% HP 26%	IRAC 60% HP 23%	ISH 36% HP 22%	IRAC 55%
15	Hotel	ISH 45% HP 19% Boiler 12%	IRAC 47% HP 18% Chiller 11%	Boiler 44% ISH 21%	Chiller 39% IRAC 25%

PACU – Packaged Air Conditioning Unit
 IRAC – Individual Room Air Conditioner
 PHU – Packaged Heating Unit

ISH – Individual Space Heater
 Res AC – Residential Air Conditioner
 HP – Heat Pump

Table 2. Pre-1980 Buildings in 2003 CBECS

Number	Type	By Number of Buildings		By Floor Area	
		Heating	Cooling	Heating	Cooling
1	Large Office	Boiler 63% District 17%	Chiller 52% PACU 23%	Boiler 53% District 28%	Chiller 66% PACU 20%
2	Medium Office	Furnace 45% Boiler 22% PHU 14%	PACU 36% Res AC 33% IRAC 13%	Boiler 32% Furnace 26% PHU 20%	PACU 43% Res AC 17% Chiller 16%
3	Small Office	Furnace 51% PHU 25%	PACU 42% Res AC 35% IRAC 10%	PHU 38% Furnace 36%	PACU 61% Res AC 18%
4	Warehouse	Furnace 33% None 32%	None 47% PACU 21%	Furnace 34% ISH 13% Boiler 13% None 12%	PACU 33% None 32%
5	Stand-alone Retail	Furnace 52% PHU 15%	PACU 43% IRAC 19% Res AC 19%	Furnace 48% PHU 18% Boiler 8%	PACU 48% IRAC 15% Res AC 13%
6	Reserved (strip mall)	No Data	No Data	No Data	No Data
7	Primary School	Boiler 33% PHU 25% Furnace 24%	PACU 36% IRAC 23% HP 9%	Boiler 61% PHU 17% Furnace 14%	PACU 33% IRAC 22% Chiller 18%
8	Secondary School	Furnace 27% Boiler 20% District 17% PHU 12% ISH 12%	IRAC 26% PACU 25% Res AC 12% HP 11% Chillers 8% District 6%	Boiler 54% District 21%	PACU 33% Chiller 26% IRAC 15% District 11%
9	Grocery Store	Furnace 32% None 25% ISH 14%	PACU 39% Res AC 18% IRAC 13%	Furnace 38% PHU 30%	PACU 61% Res AC 16%
10	Fast Food	PHU 42% HP 16%	PACU 60% HP 16%	PHU 59% HP 14%	PACU 68%
11	Restaurant	Furnace 53% PHU 20%	PACU 47% Res AC 26%	Furnace 47% Boiler 21% PHU 20%	PACU 45% Res AC 21%
12	Hospital	Boilers 76%	Chillers 39% Other 26%	Boilers 76% District 17%	Chillers 58% District 12% Other 12%
13	Out Patient Health Care	Furnace 53% PHU 17%	PACU 46% Res AC 39%	Boiler 33% Furnace 32% PHU 14%	PACU 46% Res AC 33%
14	Motel	ISH 37% PHU 27% Boiler 23%	IRAC 45% PACU 28%	ISH 37% Boiler 23% PHU 21%	IRAC 52% PACU 20%
15	Hotel	Boiler 32% PHU 24% ISH 21%	IRAC 46% PACU 30%	Boiler 37% PHU 14% Furnace 13%	Chiller 45% IRAC 33%

PACU – Packaged Air Conditioning Unit

ISH – Individual Space Heater

IRAC – Individual Room Air Conditioner
PHU – Packaged Heating Unit

Res AC – Residential Air Conditioner
HP – Heat Pump

As discussed, it is difficult to draw a clear distinction between PHUs and furnaces and to some extent between PHUs and heat pumps. Judging from the CBECS responses and PNNL’s findings, PHU and furnace should be considered synonymous. However, where the building use might indicate a large fraction of heat pumps, some non-trivial fraction of the PHUs may be, in fact, heat pumps. In addition, when considering the use of district cooling or district heating, PNNL believes that for the purposes of developing the benchmarks, the most important consideration is that these systems are hydronic systems. If the primary heating or cooling equipment source (boiler or chiller) is assumed to be in the building such that we can capture the energy efficiency of that equipment when modeling, then these district systems are probably best categorized by lumping district cooling with chillers and district heating with boilers.

Based on Table 1, PNNL recommends using the heating and cooling equipment that has the highest fraction of floor area for each benchmark. This approach attempts to most reasonably capture the floor space served by the various equipment types. For most building types, the most typical classes of equipment/systems, expressed in terms of fraction of buildings served, match the most common classes of equipment/systems in terms of floor space served, and the choice of selection method is not important. In both the pre-1980 and post-1980 buildings there are three notable exceptions: primary schools, secondary schools, and hotels.

5.1 In Post-1980 Buildings

In primary schools, the most common heating system by number of buildings is furnace. However, the most common heating system by floor space is boiler.

In secondary schools, the most common heating system appears to be furnace; however, the nearly equal fraction of heat pump responses suggest that it could also be heat pump—depending on what fraction of the classification of the PHUs might be a heat pump versus a furnace. Additionally, heat pumps are shown as the most common equipment for cooling and the combination of all direct expansion equipment (heat pump and PACU) predominates over the hydronic system. However, in terms of floor space served the hydronic chiller/boiler systems appears dominant.

In hotels, individual space heaters and individual air conditioners are the most common in terms of number of buildings serviced, but boilers and chillers dominate hotels in terms of floor space served.

5.2 In Pre-1980 Buildings

In primary schools, the most common heating system by number of buildings is furnace. However, by floor space the most common heating system is boiler.

In secondary schools, the most common main heating system is furnace; however, boiler/hydronic systems clearly dominate floor space heating. For cooling systems, the most common system, individual air conditioners, have a slight edge over packaged air conditioning units in terms of number of buildings, but packaged air conditioners clearly dominate in terms of total floorspace served. Secondary schools also commonly use residential type AC for cooling. Note that each of these cooling system types are

direct expansion systems, with the most important differences likely related to the fan energy use and the effective energy efficiency ratio (EER) due to different equipment standards as a function of equipment capacity and whether single or three-phase. In terms of floor space, the total amount of floor space served by DX systems is higher than that served by hydronic (chiller or district cooling) systems.

Finally, in hotels, individual space heaters and IRAC are the most common in terms of number of buildings serviced, but boilers and chillers dominate in terms of floor space served.

6.0 PNNL Recommendations

This section contains PNNL’s recommendations for Post-1980 and Pre-1980 Reference buildings. These Reference buildings are based on the review of the CBECS data, PNNL’s interpretations of the most likely meaning of PHUs, the desire to lump hydronic systems (chiller/district cooling and boiler/district heating) together, and the desire to capture the most floor space served within benchmark categories.

Table 3. PNNL Recommendations for Post-1980 Buildings – HVAC Equipment

Number	Type	PNNL Recommendation	
		Heating	Cooling
1	Large Office	Boiler	Chiller
2	Medium Office	Furnace	PACU
3	Small Office	Furnace	PACU
4	Warehouse	Furnace	PACU
5	Stand-alone Retail	Furnace	PACU
6	Reserved (strip mall)	NA	NA
7	Primary School	Boiler	PACU
8	Secondary School	Boiler	Chiller
9	Grocery Store	Furnace	PACU
10	Fast Food	Furnace	PACU
11	Restaurant	Furnace	PACU
12	Hospital	Boilers	Chillers
13	Outpatient Health Care	Furnace	PACU
14	Motel	ISH	IRAC
15	Hotel	Boiler	Chiller

PACU – Packaged Air Conditioning Unit ISH – Individual Space Heater
 IRAC – Individual Room Air Conditioner NA – Not Available

Table 4. PNNL Recommendations for Pre-1980 Buildings – HVAC Equipment

Number	Type	PNNL Recommendation	
		Heating	Cooling
1	Large Office	Boiler	Chiller
2	Medium Office	Furnace	PACU
3	Small Office	Furnace	PACU
4	Warehouse	Furnace	PACU
5	Stand-alone Retail	Furnace	PACU
6	Reserved (strip mall)	NA	NA
7	Primary School	Boiler	PACU
8	Secondary School	Boiler	PACU
9	Grocery Store	Furnace	PACU
10	Fast Food	Furnace	PACU
11	Restaurant	Furnace	PACU
12	Hospital	Boilers	Chillers
13	Outpatient Health Care	Furnace	PACU
14	Motel	ISH	IRAC
15	Hotel	Boiler	Chiller

PACU – Packaged Air Conditioning Unit ISH – Individual Space Heater
IRAC – Individual Room Air Conditioner NA – Not Available

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 VAV system. Unfortunately, CBECS does not state which cooling systems this response applies to within a building or how much of the building the VAV system covers. In addition, there is no information in CBECS to help directly indicate the fraction of floor space covered by 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 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 on whether or not to recommend a VAV system in a particular reference building is further complicated by the fact that VAV systems may be common in a building type, but not necessarily common in the “most typical” system in that building type (See footnotes to Tables 6 and 7 regarding schools, grocery stores, hospitals, outpatient healthcare, and hotels). When examining the “most typical” system one must decide whether to consider the CBECS categories independently or to presume that PACU also includes other direct expansion system types. PNNL first examined what fraction of the total building floor space is in buildings reporting the use of VAV systems. These results are shown in Table 5.

Table 5 shows the relative fraction of floor space in each building type using a VAV. However, DOE recognized that when a given equipment type is specified as the “most representative” for that building type, the relative fraction of floor space using VAV as well as use that equipment type could be different from the Table 5 results. To examine this, for each building type, DOE did a separate analysis which examined the fraction of floor space served by VAV systems only those buildings which indicated that they were served by the equipment types identified in Table 3 and Table 4 (with the presumption that

hydronic cooling could be classified as chiller and hydronic heating could be classified under boiler for the purpose of identifying the relative fraction of floor space using a VAV air distribution system). This subsequent analysis showed that even though the relative fraction of identified floor space using VAV or not using VAV for the defined equipment differed from the values in Table 5, the particular buildings types where the majority of the floor space indicated the use of VAV air distribution did not change.

Table 5. Total Floor Space in Buildings Reporting Use of VAV Systems

Number	Type	Post-1980 Fraction of Floor space reported with VAV ^(a)	Pre-1980 Fraction of Floor space reported with VAV ^(a)
1	Large Office	84%	71%
2	Medium Office	53%	26%
3	Small Office	24%	11%
4	Warehouse	22%	12%
5	Stand-alone Retail	12%	10%
6	Reserved (strip mall)	NA	NA
7	Primary School	44%	27%
8	Secondary School	70%	40%
9	Grocery Store	31%	8%
10	Fast Food	12%	40%
11	Restaurant	28%	19%
12	Hospital	95%	67%
13	Outpatient Health Care	45%	23%
14	Motel	13%	8%
15	Hotel	50%	34%

(a) Fraction of those responding to question

NA – Not Available

Unfortunately, the authors' experience is that two building types in particular, hospitals and hotels, commonly rely on multiple systems. Virtually all hospital buildings in the CBECS survey use VAV systems. However, hospitals are complicated buildings and multiple distribution system types are both likely and common. Patient areas commonly have FCUs with individual heating control. In other areas, such as operating areas, most systems are likely constant volume (CAV) systems or a single zone with fan control, primarily for pressurization issues. Multi-zone VAV systems, while likely prevalent for office areas, are less likely used elsewhere in the building. CBECS provides little guidance here. The 2003 ASHRAE Applications Handbook (Chapter 7) presents a good review of system designs and concerns for hospital buildings.

Hotels are similar to hospitals in that they typically use a variety of systems, but the individual room areas of the hotel are more likely to be served by FCUs, IRAC units (PTAC/package terminal heat pump (PTHP), or water loop heat pumps. Inspection of the CBECS “% cooled by” data shows that only 3 of 19 post-1980 buildings that report the use a VAV system also report chillers as the main cooling type, and none indicate district cooling. Another 13 buildings show a smattering of DX equipment (IRAC, heat pumps, PACU, and even residential type AC units) as the main cooling type. Only 3 buildings report the “% cooled by” central AC at all. Given this and the relative preponderance of hydronic (e.g., chiller boiler) systems in hotels, it seems prudent to consider other data sources for determining a typical distribution system for hotels. At this stage, PNNL recommends a multiple system type with FCUs to serve the residential spaces (let hotel rooms) and kitchens, and either FCUs or possibly a VAV system to serve lobby and other rooms.

In addition, it is important to address whether the buildings predominantly use single- or multi-zone systems. As stated, this information is not in CBECS. For the 15 benchmark building categories, PNNL used “professional judgment” to decide on single- or multi-zone systems. Table 6 and Table 7 show PNNL’s initial recommendations of system types based on the CBECS data, including assumptions on single- or multi-zone systems. Tables 6 and 7 are identical to Tables 3 and 4, but include an extra column for air distribution.

There are four differences between Tables 6 and 7: 1) use of PACU instead of chiller in pre-1980 secondary schools, 2) use of CAV instead of multi-zone VAV in pre-1980 secondary schools, 3) use of single-zone CAV instead of multi-zone VAV in medium office, and 4) use of FCU and multi-zone CAV in hotels. Because professional judgment forms the basis for choosing whether a single-zone or multi-zone distribution system is most representative, both situations are likely common in both vintages of buildings. DOE may choose to make an executive decision that would make the pre- and post-1980 benchmarks equipment and or system choices identical in all vintages.

Table 6. PNNL Recommendations for Post-1980 Buildings – HVAC Equipment and Air Distribution

Number	Type	PNNL Recommendation		
		Heating	Cooling	Air Distribution
1	Large Office	Boiler	Chiller	MZ VAV
2	Medium Office	Furnace	PACU	MZ VAV
3	Small Office	Furnace	PACU	SZ CAV
4	Warehouse	Furnace	PACU	SZ CAV
5	Stand-alone Retail	Furnace	PACU	SZ CAV
6	Reserved (strip mall)	NA	NA	NA
7	Primary School	Boiler	PACU	CAV ^(a)
8	Secondary School	Boiler	Chiller	MZ VAV
9	Grocery Store	Furnace	PACU	CAV ^(a)
10	Fast Food	Furnace	PACU	SZ CAV
11	Restaurant	Furnace	PACU	SZ CAV
12	Hospital	Boiler	Chiller	FCU, CAV and VAV ^(b)
13	Outpatient Health Care	Furnace	PACU	CAV ^(a)
14	Motel	ISH	IRAC	SZ CAV
15	Hotel	Boiler	Chiller	FCU and VAV ^(c)

(a) Unclear if single zone or multi-zone
(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 here and other sources should be consulted.
(c) Hotels may be 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 fan coil systems may be common for living areas. In some hotels, some amount of multi-step or continuous fan control for these fan coils may also exist.

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
NA – not available

Table 7. PNNL Recommendations for Pre-1980 Buildings – HVAC Equipment and Air Distribution (bold italic text shows differences from post-1980 recommendations)

Number	Type	PNNL Recommendation		
		Heating	Cooling	Air Distribution
1	Large Office	Boiler	Chiller	MZ VAV
2	Medium Office	Furnace	PACU	<i>SZ CAV</i>
3	Small Office	Furnace	PACU	SZ CAV
4	Warehouse	Furnace	PACU	SZ CAV
5	Stand-alone Retail	Furnace	PACU	SZ CAV
6	Reserved (strip mall)	NA	NA	NA
7	Primary School	Boiler	PACU	CAV ^(a)
8	Secondary School	Boiler	<i>PACU</i>	<i>CAV^(a)</i>
9	Grocery Store	Furnace	PACU	CAV ^(a)
10	Fast Food	Furnace	PACU	SZ CAV
11	Restaurant	Furnace	PACU	SZ CAV
12	Hospital	Boiler	Chiller	FCU, CAV and VAV ^(b)
13	Outpatient Health Care	Furnace	PACU	CAV ^(a)
14	Motel	ISH	IRAC	SZ CAV
15	Hotel	Boiler	Chiller	<i>FCU and MZ CAV^(c)</i>

(a) Unclear if single zone or multi-zone

(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 here and other sources should be consulted. CBECS Buildings reporting VAV are significantly less common in pre-1980 buildings (67% versus 95% in post-1980 hospitals).

(c) Hotels may be 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 fan coil systems may be common for living areas.

Bold Italics – Indicates pre-1980 recommendations that are different from post-1980 recommendations.

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 units

NA – not available

7.0 References

DOE EIA 1995. 1995 Commercial Building Energy Consumption Survey. DOE Energy Information Administration. Washington, DC. All released data on the 1995 CBECS may be found at <http://www.eia.doe.gov/emeu/cbecs/>.

DOE IEA 2003. 2003 Commercial Building Energy Consumption Survey . DOE Energy Information Administration. Washington, DC. All released data on the 2003 CBECS may be found at <http://www.eia.doe.gov/emeu/cbecs/>.



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