Establishing Benchmarks for DOE Commercial Building R&D and Program Evaluation[1]

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ABSTRACT

The U.S. Department of Energy (DOE) Building Technologies Program and the DOE research laboratories conduct a great deal of research on building technologies. However, differences in models and simulation tools used by various research groups make it difficult to compare results among studies. The authors have developed a set of 22 hypothetical benchmark buildings and weighting factors for nine locations across the country, for a total of 198 buildings. The benchmark buildings are representative of new commercial building stock and meet the minimum requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004. The benchmark building definitions are complete descriptions suitable for whole building energy simulations and are implemented in EnergyPlus input files. The complete benchmark definitions with documentation of all inputs will be available in a technical document published near the end of 2006. The EnergyPlus input files are automatically created by preprocessor routines, which minimize errors and ensure that everyone has consistent implementation in the most recent version of EnergyPlus and the most recent version of the benchmarks.

The benchmark buildings will form the basis for research on specific building technologies, energy code development, appliance standards, and measurement of progress toward the DOE energy goals. Having a common starting point allows us to better share and to compare research results and move forward in making more energy-efficient buildings. In addition, the benchmark buildings can be used with minor modifications to evaluate other energy efficiency programs and individual buildings.

Introduction

The U.S. Department of Energy (DOE) Building Technologies (BT) program has set the aggressive goal of producing marketable net zero energy buildings (ZEBs) by 2025. The ZEB goal has been divided into intermediate goals of achieving energy savings of 30%, 50%, and 70% compared to a building built to the minimum requirements of ANSI/ASHRAE/IESNA Standard 90.1-2004 (subsequently referred to as Standard 90.1-2004) (ASHRAE 2004a). Several analysis activities that will determine the best paths forward to reach these goals are under way. Coordinating these research activities and tracking progress toward the goals is greatly simplified if we start with common reference points.

Several projects have created benchmark or prototypical buildings. The most familiar are from Lawrence Berkeley National Laboratory (LBNL), which developed a series of prototypical

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buildings over several years. Two papers by Huang and his colleagues present excellent summaries of this work and previous work (Huang et al. 1991; Huang and Franconi 1999). This project is based on some of this LBNL work. Two more recent efforts are a set of standardized energy simulation models for commercial buildings from the University of Massachusetts (Stocki et al. 2005) and a residential building benchmark from the DOE Building America program (NREL 2005). However, this project differs from previous efforts in that its purpose is to provide a baseline of new buildings that meet the minimum requirements of Standard 90.1-2004 for analyzing combinations of present and future energy efficiency technologies. Previous work focused on characterizing the energy use in existing buildings, rather than looking at the ability for future technology to achieve much lower energy buildings. Additional benchmark buildings are being developed for existing buildings based on work from LBNL in a related project. The benchmarks for new and existing buildings will be coordinated to be compatible and consistent with national building data.

These benchmark building descriptions will provide a common point of reference to measure the progress of DOE energy efficiency goals for commercial building research. They will be used for research in assessment studies, optimization work, controls, daylighting, ventilation and indoor air quality, and other areas. In addition, they may be used in the development of energy codes for buildings and building appliance standards.

The benchmarks are meant to be hypothetical ideal buildings that meet the requirements of Standard 90.1-2004; they are not meant to model the performance of real buildings. The benchmark building definitions are not intended to act as targets to rate the energy performance of individual existing or proposed buildings. They are not intended to be used with building performance rating systems. Variations of the benchmark building definitions may be created in the future by other parties for such purposes, but that is not the objective of this project.

Model Development

Our goal is to represent the building types, sizes, and locations of 70% of the new building stock. Modeling all new buildings is impractical, so we select a small number of buildings and develop weighting factors to represent the entire building stock. The approach taken for this model is to use sector-wide data to determine an appropriate, average mix of buildings and then move this set to different locations to capture climate and geographic effects. The climate-sensitive variables in each building are varied by location according to the requirements in Standard 90.1-2004. The benchmark building set is composed of two parts—the building models (which consist of the energy modeling descriptions) and the national model (which consists of the sets of building types, locations, and weighting factors).

There are very few data from the national building stock about the parameters that affect energy use. We have used the building characteristics data from the *2003 Commercial Building Energy Consumption Survey* (CBECS) (EIA 2006) from the Energy Information Administration (EIA), population data from the 2000 Census (U.S. Census Bureau 2002), economic activity data from the 2002 Economic Census (U.S. Census Bureau 2005), and 2005 construction cost data (RSMeans 2004) to help construct the benchmark building model.

Creating energy simulation files is very time consuming and mistakes are easily made. Analysis activities of the national building sectors involve creating hundreds or even thousands of input files. Computer programs were developed to autogenerate the energy simulation input files, and the benchmark buildings were defined by sets of rules that can be easily programmed.

National Model

The national model consists of determining sets of building types, locations, and weighting factors to represent 70% of the new commercial building construction. Moving beyond 70% of the building stock quickly increases the number of the benchmark buildings to include several buildings that represent small fractions of the total population. Development of the national model was divided into three efforts: building characteristics, locations, and weighting factors. The benchmark building types, sizes, and number of floors are based on 2003 CBECS, the locations are based on U.S. census data, and the weighting factors were determined with the 2002 Economic Census and construction costs. The final set of benchmarks comprises 22 representative buildings where each is modeled in nine locations for 198 models.

The 2003 CBECS is a good source of statistical data for the characteristics of buildings in the commercial sector. It contains numerous variables for each of 4,820 buildings. However, the data set does present some problems. Modeling every building in the data set is considered too cumbersome for practical use in analyses of highly integrated technologies and practices that require detailed energy performance models be rerun numerous times. At the same time, the data set is too small to form a robust statistical representation of all commercial building types in all climates. In addition, the data set is for the existing building stock, but the benchmarks are intended to help analyze new and future construction. Finally, the 2003 CBECS data are still preliminary and did not include the energy performance data when this model was developed. The current set of benchmarks reduces the set of 4,820 to a set of 198 representative buildings. The methodology used here was selected to make maximum use of statistical data and to minimize the potential for personal bias on selecting the characteristics of buildings.

The first step in reducing the data set was to select high-level parameters to categorize the 4,820 buildings. The parameters include the year of construction, principal building activity (PBA), number of floors, and floor area. The parameters were selected in part because they have significant impact on the potential for achieving net-zero site energy use. To mimic new buildings, yet maintain a good statistical sample, only buildings constructed from 1994 to 2003 were included. Of the 18 PBAs defined in CBECS, we eliminated four and combined others to form 10 building activities. We define a split between large and small buildings to be 20,000 ft^2. The number of floors determines the types of mechanical systems, and the floor area determines roof space available for deployment of photovoltaic systems and roof daylighting devices. We divided the buildings into groups by floor area and number floors (see Table 1).

Once the sorting parameters were selected, the next step was to use the parameters to "slice" the set of newer buildings in the 2003 CBECS public use data set into 22 bins. Data in each bin were used to develop values for the average floor area and number of floors in the benchmark building models, as shown in Table 2. The percent of floor area column represents the percent of the weighted floor area in the reduced set of new buildings.

The next task was to determine a set of locations that represent the combination of new building activity and climate. After considering several methods of selecting locations, we used the following methodology to select the weather file locations.

Table 1. Categorization of 2003 CBECS Data

Bldg. No.	PBA	Floor Area, ft^2	Number of Floors
1	Office/Professional	All	1
2	Office/Professional	All	2 to 4
3	Office/Professional	> 20,000	5 or more
4	Warehouse	≤ 20,000	1
5	Warehouse	> 20,000	1
6	Warehouse	All	2 or more
7	Education	≤ 20,000	1
8	Education	> 20,000	1
9	Education	All	2 or more
10	Retail	≤ 20,000	1
11	Retail	> 20,000	1
12	Retail	All	2 or more
13	Service and Safety	All	1
14	Service and Safety	All	2 or more
15	Food Services	All	All
16	Health Care	All	1
17	Health Care	All	2 or more
18	Lodging	All	1 to 4
19	Lodging	All	5 or more
20	Assembly	All	1
21	Assembly	All	2 or more
22	Food Sales	All	All

Table 2. Benchmark Buildings for New Construction

Bldg. No.	PBA	Floor Area, ft^2	Number of Floors	Percent of Floor Area in Reduced Set
1	Office	13,006	1	3.9
2	Office	75,060	3	5.9
3	Office	598,423	12	4.6
4	Warehouse	9,974	1	8.9
5	Warehouse	157,863	1	7.9
6	Warehouse	292,667	2	6.0
7	Education	7,658	1	2.3
8	Education	122,735	1	4.3
9	Education	107,506	3	6.7
10	Retail	11,656	1	2.3
11	Retail	94,911	1	4.4
12	Retail	238,579	2	2.4
13	Service and Safety	24,039	1	6.4
14	Service and Safety	96,595	3	3.4
15	Food Services	17,834	1	3.2
16	Health Care	19,667	1	2.2
17	Health Care	241,442	4	4.2
18	Lodging	62,771	3	4.0
19	Lodging	285,493	8	2.5
20	Assembly	24,209	1	4.5
21	Assembly	162,301	3	7.4
22	Food Sales	23,902	1	2.6

We choose the nine census divisions as the level of granularity, which is the finest geographic granularity available in the 2003 CBECS. CBECS only reports building information by census division to hide the identity of specific buildings. The next step was to determine the most appropriate weather file location, or site where typical year weather data (TMY2) are available, within each Census Division. This was done in the following manner:

- A Graphical Information System (GIS) was used to associate 2000 census blocks to the nearest TMY2 site. The 2000 census population data were then aggregated by TMY2 site and state. All 216 TMY2 sites in the lower 48 states are included. A single TMY2 site may cross census division boundaries; this is accounted for by including the state lines in the organization of the data set.
- The heating degree-day (base 65ºF) (HDD65) and cooling degree-day (base 50ºF) (CDD50) data for each TMY2 site were then assembled with the population data and used to determine the population-weighted, mean values for HDD65 and CDD50 for each of the nine census divisions. Table 3 shows the mean results.

The specific TMY2 site that most closely matches the mean values for HDD65 and CDD50 were found by minimizing a combined error signal. The error signal was formulated by comparing the absolute value of the deviations between mean degree-days and the degree-days for each weather site. The combined error signals were calculated for all possible choices of weather sites within a census division and the one with the lowest error signal was chosen as the best match. This method does not take into account solar insolation, which is important for ZEB analysis. Table 3 shows the locations selected and the combined error signal.

Table 3. Population-Weighted Weather Location Assignments by Census Division

Census Division	Mean HDD65 ºF-days	Mean CDD50 ºF-days	City	State	90.1-2004 Climate Zone	Combined Error Signal ºF-days
1 New England	6,176	2,665	Providence	RI	5A	370
2 Middle Atlantic	5,232	3,100	Atlantic City	NJ	4A	161
3 East North Central	6,430	2,897	South Bend	IN	5A	122
4 West North Central	6,496	3,340	Des Moines	IA	5A	32
5 South Atlantic	2,794	5,619	Columbia	SC	3A	256
6 East South Central	3,412	4,946	Huntsville	AL	3A	180
7 West South Central	2,211	6,448	Fort Worth	TX	3A	202
8 Mountain	4,425	3,908	Albuquerque	NM	4B	641
9 Pacific	2,727	4,017	Sacramento	CA	3B	478

Finally, we needed weighting factors for the 198 models to characterize the number of buildings that are similar to the benchmarks for each location. The 2003 CBECS appears to provide the data to develop values for the weighting factors; however, attempts to use these data failed because there are too few buildings to determine the geographic distribution of benchmarks. For example, 27 of the 198 models result in weights of zero because 2003 CBECS had no sample buildings. We therefore turned to the 2002 Economic Census (U.S. Census Bureau 2005) and cost models from *2005 Square Foot Costs* (RSMeans 2004) to characterize the geographic distribution of new additions to the commercial building stock.

One difficulty in working with three data sets is that each has a different classification system. Therefore, we had to map between the three data sets, which leads to some loss of information. For instance, the economic census contains nine construction types, and all the buildings were placed into these nine types. The construction costs for each type were determined by averaging the RSMeans costs that were mapped to each census construction type. The national cost data were then adjusted to each state by a cost modifier, which was determined from city data published in RSMeans.

An initial test of the validity of this approach was completed. Using national average cost models and no regional modifiers, the area of new construction in 2002 came out to 2.06 billion ft^2. Data tables from EIA's *AEO 2005* listed new floor area additions in 2002 at 2.09 billion ft^2; therefore, we concluded that we could approach the calculations in this way.

The next step was to model the distribution of the benchmark buildings within each group of categories for the type of construction used in the 2002 Economic Census with the percent of floor area data listed in Table 2 (derived from 2003 CBECS). The limitation of this approach is that the distribution of building types, within a type of construction group, is not sensitive to geographic location. However, there does not appear to be a robust way of capturing this with currently available statistical data.

Finally, the weighting factors for the benchmark models were calculated from the 2002 Economic Census data and RSMeans cost models and shown in Table 4. The nationwide new additions from this model correspond to 2.14 billion square feet, which is consistent with AEO 2005 data. In addition, the percentage of total construction by census division matches closely with the economic value of construction by census division from Reed Construction Data (2005).

Table 4. National Sector Model Weighting Factors

Bldg. No.	New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific
1	523	1314	1311	960	2526	481	1279	947	1603
2	137	345	344	252	662	126	335	248	420
3	13	34	34	25	65	12	33	24	41
4	253	769	1040	596	1387	361	766	870	1219
5	14	43	58	33	78	20	43	49	68
6	6	18	24	14	32	8	18	20	28
7	716	1242	1486	700	2100	451	1207	776	1128
8	84	145	173	82	245	53	141	91	132
9	149	258	308	145	436	94	250	161	234
10	192	451	635	351	980	291	500	450	584
11	45	106	149	82	230	68	118	106	137
12	10	23	32	18	50	15	26	23	30
13	258	608	857	473	1323	392	675	607	788
14	34	80	113	63	175	52	89	80	104
15	174	410	577	319	892	265	455	409	531
16	140	330	453	271	603	251	337	223	293
17	22	51	70	42	94	39	52	35	46
18	97	92	112	65	291	53	122	164	157
19	13	13	15	9	40	7	17	23	22
20	99	187	415	202	507	159	365	200	276
21	24	46	102	50	124	39	90	49	68
22	106	248	350	193	540	160	276	248	322

Building Descriptions

Detailed energy models of buildings require many details that are not available from standard data sources. Appendix G in Standard 90.1-2004 provides guidance on envelope and equipment when creating a baseline building that meets the minimum requirements of the standard. However, many assumptions not covered in the standard have to be made to complete the modeling of the buildings. These assumptions include thermal zoning, aspect ratio, orientation, number of floors, window to wall ratios, HVAC types, and schedules. We have divided the building input into program, form, fabric, and equipment, which are shown in Table 5 with some of the building parameters.

Table 5. Input Categories with Partial Parameter Lists

Program	Form	Fabric	Equipment
Location	Number of floors	Exterior walls	HVAC system types
Total floor area	Aspect ratio	Roof	Component efficiency
Schedules	Window fraction	Windows	Control settings
Plug and process loads	Window locations	Interior partitions	Lighting fixtures
Lighting densities	Shading	Internal mass	Lamp types
Ventilation needs	Floor height		Daylighting controls
Occupancy	Orientation		

Building program. Some of the program parameter values are shown in Table 6. The activities and locations were determined in the process of analyzing the national building data as shown in Table 1. The occupancy rates in Table 6 are from Standard 90.1-1989 (ASHRAE 1989), except for the small warehouse and service and safety buildings, which were determined based on assumption. Ventilation requirements are determined from ASHRAE Standard 62.1-2004 (ASHRAE 2004b). The building area method was used to determine lighting power densities from Standard 90.1-2004. Some of the benchmark buildings combine building types that have different lighting power allowances. In these cases, the most likely value was chosen. Determining the plug load intensity is difficult because there are very few data on this number. Thus, several assumptions had to be made based on experience with a small number of buildings and from previous work by Huang and Franconi (1999).

The operating parameters in Table 6 are controlled with hourly schedules. Setting schedules is another problematical task; however, the benchmark buildings will be used in comparison to other simulations with the same schedules, which lower the importance of getting them exactly right. As a starting point, we use the schedules in the *ANSI/ASHRAE/IESNA Standard 90.1-2004 User's Guide* (ASHRAE 2004c), which are slight modifications of the schedules included in Standard 90.1-1989. Experience with monitoring real buildings has shown that night and weekend plug loads are much higher than predicted by these schedules (Torcellini et al. 2004). We created separate schedules for plug loads and increased the plug load schedules during unoccupied periods by an additional 20% to 40%, depending on the building type.

Fuel sources were limited to natural gas and electricity for the benchmark buildings. Utility costs are used to help analyze the effectiveness of energy efficiency and on-site energy production technologies. Utility rate schedules vary widely across the country, and capturing this variability is difficult. We have chosen to use the utility rate schedule for each benchmark location as an approximation. These rates are picked automatically by EnergyPlus. Finally, tax rates on utilities vary at the city and county government levels, and most utility companies do not publish tax rates with their tariffs because they vary within the service territory. We assumed that energy taxes are equal to the state sales tax rate plus 2%.

Table 6. Benchmark Building Program Parameters

Number	Principal Building Activity	Floor Area (ft^2)	Occupancy (ft^2/person)	Ventilation (cfm/person)	Lighting (W/ft^2)	Plug Loads (W/ft^2)
1	Office	13,006	275	17	1.0	1.3 [1]
2	Office	75,060	275	17	1.0	1.3 [1]
3	Office	598,423	275	17	1.0	1.3*
4	Warehouse	9,974	5,000*	0.06 cfm/ft^2	0.8	0.1*
5	Warehouse	157,863	15,000	0.06 cfm/ft^2	0.8	0.1*
6	Warehouse	292,667	15,000	0.06 cfm/ft^2	0.8	0.1*
7	Education	7,658	75	15	1.2	0.8**
8	Education	122,735	75	15	1.2	0.8**
9	Education	107,506	75	15	1.2	0.8**
10	Retail	11,656	300	16	1.5	0.5*
11	Retail	94,911	300	16	1.5	0.5*
12	Retail	238,579	300	16	1.5	0.5*
13	Service and Safety	24,039	300*	19*	1.0	1.0*
14	Service and Safety	96,595	300*	19*	1.0	1.0*
15	Food Services	17,834	100	10	1.5	2.25**
16	Health Care	19,667	200	25	1.0	2.2**
17	Health Care	241,442	200	25	1.2	2.2**
18	Lodging	62,771	250	11	1.0	0.7**
19	Lodging	285,493	250	11	1.0	0.7**
20	Assembly	24,209	50	6	1.2	0.4**
21	Assembly	162,301	50	6	1.2	0.4**
22	Food Sales	23,902	300	15	1.5	1.5*

* Assumption

** Huang and Franconi 1999

Building form. The floor area and number of floors were determined from the weighted average values for each bin, as shown in Table 2. Obtaining robust statistical data on the other parameters is difficult, so we must generate the additional detail using assumptions (see Table 7). We define aspect ratio as the overall length in the east-west direction divided by the overall length in the north-south direction. Assumptions were used to create aspect ratios, floor-to-floor height, and plenum height where sufficient data were not available. A uniform distribution with five-degree increments was used to obtain values for the rotation parameter by random selection. Thermal zones were set up with one to five zones per floor. The glazing fractions were set to the values used by Huang and Franconi (1999), except where they exceeded the maximum values specified in Standard 90.1-2004 Table G3.1. The window locations are determined by the sill height, which is set to 3.6 ft, and the edge offset, which was fixed at 0.16 ft.

Building fabric. The fabric of the building includes the construction type and thermal properties of the walls, roof, floor, and windows. Construction types are defined from Standard 90.1-2004 Table G3.1 and the thermal properties are from Tables 5.5-1 to 5.5-8.

Building equipment. Standard 90.1-2004 Appendix G specifies HVAC equipment to use for baseline buildings in Tables G3.1.1A and G3.1.1B. This information is repeated in Table 8 for each benchmark building, with the assumption that all buildings use natural gas as a heating fuel. There are two exceptions in the current benchmark buildings from the Appendix G recommendations. Benchmark building numbers 5 and 11 are assigned packaged single zone systems, which is common practice for these building types.

Table 7. Building Form Parameters

Bldg. No.	Aspect Ratio	Azimuth	Floor-to-Floor Height (ft)	Plenum Height (ft)	Zones per Floor	Perimeter Zone Depth (ft)	Glazing Fraction
1	1.2	295	13	4	5	15	0.40*
2	2.2	40	13	4	5	15	0.40*
3	1.2	235	13	4	5	15	0.40*
4	1.1	295	15	N/A	1	N/A	0.03**
5	2.2	55	20	N/A	5	20	0.03**
6	2.2	295	15	N/A	5	20	0.03**
7	1.1	195	13	4	5	N/A	0.18**
8	5.0	275	13	4	5	20	0.18**
9	3.0	350	13	4	5	20	0.18**
10	1.1	30	15	N/A	1	N/A	0.15**
11	2.2	160	23	N/A	5	20	0.15**
12	1.5	195	18	N/A	5	20	0.15**
13	2.2	245	18	N/A	5	15	0.15†
14	1.5	170	15	N/A	5	15	0.15†
15	1.3	20	13	4	5	20	0.175**
16	3.5	260	13	4	5	15	0.25**
17	2.0	185	13	4	5	15	0.25**
18	3.5	45	12	3	5	20	0.21**
19	2.5	255	12	3	5	20	0.35**
20	1.2	5	18	3	5	20	0.15†
21	3.0	250	15	3	5	20	0.15†
22	1.5	170	20	N/A	5	15	0.15**

* Limits of Standard 90.1-2004 Table G3.1
** Huang and Franconi 1999
†Assumption

Equipment sizing is determined according to Standard 90.1-2004 Section G3.1.2.2. Minimum, nominal coefficient of performance values are taken from Standard 90.1-2004. Performance curves and HVAC system models are used to model how performance might vary when operating away from the nominal operation point using the models available in EnergyPlus. Minimum theoretical efficiencies are taken from Standard 90.1-2004, and the efficiency of gas heating coils is set to 0.80. Economizer operation is determined from building size and climate zone per Section G3.1.2.6. The minimum ventilation rates were determined from ANSI/ASHRAE Standard 62.1-2004 Table 6-1.

Preliminary Validation of the Benchmarks

This benchmark model was compared to a larger sector model from an earlier study, referred to as the Assessment (Griffith et al. 2006). The Assessment study created EnergyPlus simulation files for 5,375 building models that corresponded directly with the buildings in the 1999 CBECS public use data set (all activities except refrigerated warehouses). The routines from the Assessment were used to make a comparison between these models and the benchmark models to generate several EnergyPlus input files. There are some differences in these models and the benchmark models—primarily in the HVAC systems. The "LZEB 2005" scenario uses routines that alter the base models by applying a comprehensive package of year 2005 efficiency technologies and practices and PV systems. Table 9 provides a summary of key characteristics along with results from EnergyPlus simulations.

Table 8. Building HVAC Equipment

Bldg. No.	System Type	Fan Control	Cooling Type	Heating Type
1	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
2	Packaged VAV with reheat	VAV	direct expansion	hot water fossil fuel boiler
3	VAV with reheat	VAV	chilled water	hot water fossil fuel boiler
4	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
5	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
6	VAV with reheat	VAV	chilled water	hot water fossil fuel boiler
7	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
8	Packaged VAV with reheat	VAV	direct expansion	hot water fossil fuel boiler
9	VAV with reheat	VAV	chilled water	hot water fossil fuel boiler
10	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
11	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
12	VAV with reheat	VAV	chilled water	hot water fossil fuel boiler
13	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
14	Packaged VAV with reheat	VAV	direct expansion	hot water fossil fuel boiler
15	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
16	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
17	VAV with reheat	VAV	chilled water	hot water fossil fuel boiler
18	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
19	VAV with reheat	VAV	chilled water	hot water fossil fuel boiler
20	PSZ-AC	constant volume	direct expansion	fossil fuel furnace
21	VAV with reheat	VAV	chilled water	hot water fossil fuel boiler
22	PSZ-AC	constant volume	direct expansion	fossil fuel furnace

Table 9. Comparison of Benchmark and Assessment Sector Models

Characteristics and Results	Benchmark Model	Assessment Model
Scope	New construction in 2002	Existing stock as of 1999
Number of models	198	5,375
Number of weather locations	9	77
Weighted floor area (billion ft^2)	2.09	66.46
Weighted roof area (billion ft^2)	1.33	39.96
Ratio of roof area to floor area	0.64	0.60
Base average EUI (kBtu/ft^2·yr)	49.3	49.7
LZEB 2005 average total EUI (kBtu/ft^2·yr)	33.1	29.3
LZEB 2005 average net EUI—includes PV (kBtu/ft^2·yr)	14.6	15.7
LZEB 2005 average percent savings in total site EUI (%)	33.7	39.5
LZEB 2005 average percent savings in net site EUI (%)	74.0	82.4

The results show that the response of the two sector models is similar. For the base case scenario, the average EUIs differ by only 0.4 kBtu/ft^2·yr. For the LZEB 2005 scenario, the total EUIs differ by 3.8 kBtu/ft^2·yr and the net EUIs differ by 1.1 kBtu/ft^2·yr or 13% higher and 7% lower. The Assessment sector model tends to produce higher efficiency improvements and lower PV production. The results are encouraging in that the smaller set of benchmark models performs similarly to the larger Assessment set. There is no "truth" standard here, only a comparison of two sector models that employ hundreds or thousands of simulations. However, more research is needed to ensure that the benchmark sector model will perform adequately in the ZEB context.

Conclusions

Energy modeling as a representation of the entire commercial building sector is a complex task; however, with some simplifying assumptions and current computing power, reasonable models can be made of this large set of buildings. DOE research goals require that we use extensive energy simulations to assess the energy use and energy efficiency potentials on a national basis instead of on individual buildings. We have established a set of benchmark buildings and weighting factors to represent new commercial buildings in the United States. The benchmark building descriptions have been established as set of rules that can be expanded into EnergyPlus input files by two computer programs. These programs provide rapid and consistent implementation of the benchmark building descriptions, and allow unlimited variations to be implemented to analyze different technologies.

We recognize that this benchmark model is not perfect and could be improved. Complete data for developing the benchmark buildings are simply not available and several assumptions have to be made. More data are needed on the current building stock and on operations within the buildings to minimize the number of assumptions and improve the models. This set of benchmark buildings is intended to be viewed as version 1; updated versions will be developed as more building data are made available, as more analysis is completed with the benchmarks, and as analysis requirements change.

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