USING DOE COMMERCIAL REFERENCE BUILDINGS FOR SIMULATION STUDIES

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ABSTRACT

The U.S. Department of Energy developed 256 EnergyPlus models for use in studies that aim to characterize about 70% of the U.S. commercial building stock. Sixteen building types – including restaurants, health care, schools, offices, supermarkets, retail, lodging, and warehouses – are modeled across 16 cities to represent the diversity of U.S. climate zones. Weighting factors have been developed to combine the models in proportions similar to those of the McGraw-Hill Construction Projects Starts Database for 2003-2007. This paper reviews the development and contents of these models and their applications in simulation studies.

INTRODUCTION

The U.S. Department of Energy (DOE) Building Technologies program has set aggressive energy efficiency goals for commercial and residential buildings. Making substantial progress toward these goals requires collaboration between the DOE national laboratories and the building industry. For such collaboration to be effective, projects require common points of reference (Deru et al. 2010).

The purpose of the commercial reference building modeling effort has been to develop standard energy models for the most common commercial buildings. These models can serve as starting points for energy efficiency research, as they represent fairly realistic buildings and typical construction practices. DOE, the National Renewable Energy Laboratory (NREL), Pacific Northwest National Laboratory (PNNL), and Lawrence Berkeley National Laboratory (LBNL) have agreed on 16 commercial building types that represent approximately 70% of the commercial building stock (Deru et al. 2010).

EnergyPlus and OpenStudio were used to develop the reference buildings. This paper discusses the set of models intended to represent new construction that is compliant with ASHRAE 90.1-2004 (ASHRAE 2004). They consist of 16 commercial building types:

- Offices – small, medium, large
- Schools – primary, secondary
- Retail – stand-alone, strip mall
- Supermarket
- Restaurants – quick service, full service
- Hotels – small, large
- Healthcare – hospital, outpatient facility
- Warehouse
- Midrise apartment building

Each building type has been created and simulated in each of 16 climate zones that represent the breadth of U.S. climates discussed in ASHRAE 90.1-2004. Table 1 lists the climate zones and the corresponding locations used for design days and weather files.

Table 1 Climate Zones and Locations

CLIMATE ZONE	LOCATION
1A	Miami, FL
2A	Houston, TX
2B	Phoenix, AZ
3A	Atlanta, GA
3B – Coast	Los Angeles, CA
3B	Las Vegas, NV
3C	San Francisco, CA
4A	Baltimore, MD
4B	Albuquerque, NM
4C	Seattle, WA
5A	Chicago, IL
5B	Boulder, CO
6A	Minneapolis, MN
6B	Helena, MT
7A	Duluth, MN
8A	Fairbanks, AK

SUMMARY OF INPUTS AND ASSUMPTIONS

Each model input was chosen based on referenced standard values, collaboration with colleagues in the private and public sectors (including between national laboratories), reported studies, and engineering judgment. The following subsections review the inputs and assumptions briefly. For more detailed information, refer to Deru et al. (2010).

Form

Each commercial reference building type has a different form or shape. The shape, total area, floor height, and thermal zoning of each building were determined from the 2003 Commercial Buildings Energy Consumption Survey (CBECS) dataset (EIA 2005) and other appropriate resources. For a detailed accounting of these resources, refer to Deru et al. (2010).

Table 2 lists the number of floors and gross floor area for each building type.

Table 2 Number of Floors and Gross Floor Area

BUILDING TYPE	NO. FLOORS	GROSS FLOOR AREA, FT^2 (M^2)
Small Office	1	5,500 (511)
Medium Office	3	53,628 (4,982)
Large Office	12*	498,588 (46,320)
Primary School	1	73,960 (6,871)
Secondary School	2	210,887 (19,592)
Stand-Alone Retail	1	24,962 (2,294)
Strip Mall	1	22,500 (2,090)
Supermarket	1	45,000 (4,181)
Quick-Service Restaurant	1	2,500 (232)
Full-Service Restaurant	1	5,500 (511)
Small Hotel	4	43,200 (4,013)
Large Hotel	6*	122,120 (11,345)
Hospital	5*	241,351 (22,422)
Outpatient Healthcare	3	40,946 (3,804)
Warehouse	1	52,045 (4,835)
Midrise Apartment	4	33,740 (3,135)

* Plus basement.

Fabric

The fabrics (the materials comprising the envelope) of the buildings vary with building type and climate. Fabric elements include the roofs, foundations, exterior walls, and exterior windows. No exterior shading or window shading elements appear in the reference buildings.

Roofs

Most reference building types have built-up, flat roofs with the insulation entirely above the roof deck (IEAD). Exceptions include the full-service restaurant, quick-service restaurant, and small office, which have attic roofs, and the warehouse, which has a metal roof. In the models with attic roofs, the assembly thermal conductance values apply to the attic floor surface.

ASHRAE 90.1-2004, Section 5 requires the roof type and the principal space type to determine the allowable thermal conductance of the roof assembly. The reference building roofs use the "non-residential" space type values, except for the large hotel, small hotel, and midrise apartment building, which use the "residential" values, and the warehouse, which uses the "semiconditioned" values.

For a given roof type and principal space type, roof assembly thermal conductance values vary according to climate in the specifications of ASHRAE 90.1-2004, Section 5. Table 3 provides the roof type and primary space conditioning type for each reference building type.

Table 3 Roof Assembly Types and Primary Space Conditioning Types[a]

BUILDING TYPE	ROOF TYPE	SPACE TYPE
Small Office	Attic Roof	Non-residential
Medium Office	IEAD[b]	Non-residential
Large Office	IEAD[b]	Non-residential
Primary School	IEAD[b]	Non-residential
Secondary School	IEAD[b]	Non-residential
Stand-Alone Retail	IEAD[b]	Non-residential
Strip Mall	IEAD[b]	Non-residential
Supermarket	IEAD[b]	Non-residential
Quick-Service Restaurant	Attic Roof	Non-residential
Full-Service Restaurant	Attic Roof	Non-residential
Small Hotel	IEAD[b]	Residential
Large Hotel	IEAD[b]	Residential
Hospital	IEAD[b]	Non-residential
Outpatient Healthcare	IEAD[b]	Non-residential
Warehouse	Metal Roof	Semi-conditioned
Midrise Apartment	IEAD[b]	Residential

a) The roof assembly types and primary space conditioning types listed here are, in conjunction with a building's ASHRAE climate zone, for use with ASHRAE 90.1-2004, Section 5, in determining the overall roof assembly thermal conductance value.
b) Built-up flat roof with IEAD.

Foundations

Ground heat transfer is modeled separately with EnergyPlus's auxiliary Slab program, which produces average ground temperatures for inclusion in the main simulation input file (EnergyPlus 2009). Most of the reference buildings include 4-inch (10-cm) heavyweight concrete slabs-on-grade. Only the warehouse models have a slab-on-grade thickness of 8 inches (20 cm). The office, school, lodging, and apartment building models also have a layer of carpet.

Three reference building types – the hospital, the large office, and the large hotel – are modeled with a basement. In these models, the underground walls are given thermal properties per ASHRAE 90.1-2004, Section 5.

Exterior Walls

ASHRAE 90.1-2004 differentiates between four types of wall systems – steel frame, mass wall, wood frame, and metal building wall. Each reference building type has a wall system that most accurately reflects the findings of the 2003 CBECS dataset (Deru et al. 2010).

As with roof assemblies, ASHRAE 90.1-2004, Section 5 requires both the exterior wall type and the space type to determine the allowable thermal conductance of the exterior wall assembly. All reference building walls use the "non-residential" values, except the large hotel guest room walls, small hotel, and midrise apartment building, which use the "residential" values, and the warehouse, which uses the "semiconditioned" values.

For a given exterior wall type and space type, exterior wall assembly thermal conductance values vary according to climate in the specifications of ASHRAE 90.1-2004, Section 5. Table 4 provides the exterior wall type and space conditioning type for each of the 16 reference building types.

Some models contain exterior swinging doors, and the warehouse contains exterior overhead doors. The thermal conductance of these elements is determined by ASHRAE 90.1-2004, Section 5 and is not included in the overall thermal conductance of the exterior wall assembly.

Exterior Windows

ASHRAE 90.1-2004 differentiates between two types of vertical exterior windows – fixed and operable. Engineering judgment was used to determine whether the vertical exterior windows in each model are fixed or operable. Some models have both types.

As with roof and exterior wall assemblies, ASHRAE 90.1-2004, Section 5 requires both the vertical exterior window type and the space type to determine the allowable thermal conductance and solar heat gain coefficient (SHGC) of the window assembly. The window assembly includes the frame.

For given window and space types, window assembly thermal conductance values and SHGC values vary according to climate in the specifications of ASHRAE 90.1-2004, Section 5. Table 5 provides the vertical exterior window type and space conditioning type for each reference building type.

Table 4 Exterior Wall Assembly Types and Space Conditioning Types[a]

BUILDING TYPE	WALL TYPE	SPACE TYPE
Small Office	Mass	Non-residential
Medium Office	Steel Frame	Non-residential
Large Office	Mass	Non-residential
Primary School	Steel Frame	Non-residential
Secondary School	Steel Frame	Non-residential
Stand-Alone Retail	Mass	Non-residential
Strip Mall	Steel Frame	Non-residential
Supermarket	Mass	Non-residential
Quick-Service Restaurant	Wood Frame	Non-residential
Full-Service Restaurant	Steel Frame	Non-residential
Small Hotel	Steel Frame	Residential
Large Hotel	Mass	Residential for guest room walls, non-residential for other walls
Hospital	Mass	Non-residential
Outpatient Healthcare	Steel Frame	Non-residential
Warehouse	Metal Building	Semi-conditioned
Midrise Apartment	Steel Frame	Residential

a) The exterior wall assembly types and space conditioning types listed here, in conjunction with a building's ASHRAE climate zone, are for use with ASHRAE 90.1-2004, Section 5, in determining the overall exterior wall assembly thermal conductance value.

Skylights

Skylights appear in only two reference buildings – the primary school and secondary school. In both models, they comprise 4.5% of the roof area over the gymnasium zones. To determine the overall thermal conductance and SHGC for these skylights, the reference buildings use the values in ASHRAE 90.1-2004, Section 5, that correspond with plastic skylights with curbs for non-residential space types.

Infiltration

Infiltration is modeled identically for all reference building types. Although EnergyPlus includes a method for modifying infiltration design flow to account for changes in outdoor-indoor temperature differential and outdoor windspeed, the infiltration modeling has been kept simple in the reference building models. An attempt to estimate these effects would presume a more detailed knowledge of an individual building's conditions than can be afforded to a generic prototype.

Table 5 Vertical Exterior Window Types and Space Conditioning Types[a]

BUILDING TYPE	WINDOW TYPE	SPACE TYPE
Small Office	Fixed	Non-residential
Medium Office	Fixed	Non-residential
Large Office	Fixed	Non-residential
Primary School	Fixed	Non-residential
Secondary School	Fixed	Non-residential
Stand-Alone Retail	Fixed	Non-residential
Strip Mall	Fixed	Non-residential
Supermarket	Fixed	Non-residential
Quick-Service Restaurant	Fixed	Non-residential
Full-Service Restaurant	Fixed	Non-residential
Small Hotel	Operable in guest rooms, others fixed	Residential for guest rooms, non-residential for others
Large Hotel	Operable in guest rooms, others fixed	Residential for guest rooms, non-residential for others
Hospital	Fixed	Residential for patient rooms, non-residential for others
Outpatient Healthcare	Fixed	Non-residential
Warehouse	Operable	Semi-conditioned
Midrise Apartment	Operable	Residential

a) The vertical exterior window types and space conditioning types listed here, in conjunction with a building's ASHRAE climate zone, are for use with ASHRAE 90.1-2004, Section 5, in determining the overall window assembly thermal conductance and SHGC values.

The infiltration design flow is calculated based on exterior wall area. A flow rate of 0.4 cfm/ft^2 (2 L/s/m^2) of exterior wall area, measured at a pressure differential of 0.3 in.w.c. (75 Pa), is the basis for the calculation. Because EnergyPlus accepts inputs for use at typical pressure differential conditions, a flow exponent of 0.65 is used to determine the flow rate at 0.016 in.w.c. (4 Pa). Equation 1 demonstrates the conversion of the flow rate at the higher differential to one at a lower differential.

$$Q_{inf,1} = Q_{inf,2} \cdot (\Delta p_1 / \Delta p_2)^n \qquad (1)$$

$Q_{inf,1}$ = infiltration flow [cfm/ft^2] at Δp_1
$Q_{inf,2}$ = infiltration flow [cfm/ft^2] at Δp_2
Δp_1 = reference pressure differential [in.w.c.]
Δp_2 = measured pressure differential [in.w.c.]
n = infiltration flow exponent

The resulting infiltration design flow at the reference condition of 0.016 in.w.c. (4 Pa) is 0.059 cfm/ft^2 (0.302 L/s/m^2). For most reference building models, the infiltration flow is assumed to equal 25% of this peak flow when the ventilation system is on and 100% of the peak flow when the ventilation system is off. Any attic zones are exceptions: they are modeled with 1 ACH infiltration flow for all hours of the year. Refer to Deru et al. (2010) for more details.

Internal Loads

The use of ASHRAE standards as sources for internal loads has homogenized the reference building models to some degree. However, there is considerable variation from one building type to another. Decisions about internal load levels have been made and reviewed by NREL, PNNL, and LBNL, with significant input from ASHRAE technical committees, Advanced Energy Design Guide (AEDG) documents (ASHRAE 2009), industry-specific design guides, and user feedback.

Occupancy

A variety of sources inform the occupancy levels for the different space types in the reference buildings. The 2003 CBECS dataset does include occupancy information; however, a close review of the data shows a wide range of values, some more representative of a "typical" building than others.

The two principal sources of occupancy levels are ASHRAE 62-1999 (ASHRAE 1999) (used because ASHRAE 90.1-2004 calls for this vintage of the standard) and DOE's AEDG documents. Peak occupant densities by space type for all building types appear in Deru et al. (2010).

Lighting

The reference building models include interior and exterior lighting.

Most interior lighting power densities (LPDs) come from ASHRAE 90.1-2004. Some healthcare space types are not represented as well in that standard, so the hospital and outpatient facility models took some LPDs from GGHC (2007). All interior lighting calculations employ the space-by-space method except for the office models, which use the building-area method (ASHRAE 2004).

Exterior lighting power in the reference building models includes façade lighting by area, lighting for main and other doors, lighting for canopies, and lighting for drive-through windows. LPDs for each of these surface types derive from ASHRAE 90.1-2004.

Plug and Process Loads

ASHRAE 90.1-2004 does not contain requirements for plug and process loads, and measured data are scarce. The reference buildings draw from a variety of sources to obtain reasonable plug and process load levels, or equipment power densities (EPDs). Most EPDs originate from ASHRAE 90.1-1989 recommendations (ASHRAE 1989), work by Huang et al. (1991), and DOE's AEDG series.

Table 6 provides a snapshot of the primary source of EPD levels in each reference building model.

Table 6 Plug and Process Load Sources

BUILDING TYPE	SOURCE
Small Office	Huang et al. 1991
Medium Office	Huang et al. 1991
Large Office	Huang et al. 1991
Primary School	AEDG series
Secondary School	AEDG series
Stand-Alone Retail	Engineering judgment
Strip Mall	Engineering judgment
Supermarket	Engineering judgment
Quick-Service Restaurant	Multiple, see Commercial Reference Buildings Technical Report (Deru et al. 2010)
Full-Service Restaurant	Multiple, see Deru et al. (2010)
Small Hotel	AEDG series
Large Hotel	Huang et al. 1991
Hospital	AEDG series, GGHC 2007
Outpatient Healthcare	AEDG series, GGHC 2007
Warehouse	AEDG series
Midrise Apartment	Building America Benchmark definition (Hendron 2007)

The estimation of certain types of process loads – elevators, commercial kitchen equipment, and refrigeration – has received special attention. A discussion of the determination of these loads appears in Deru et al. (2010).

HVAC Systems

This section provides a summary of the HVAC system inputs in the reference buildings. For more detailed descriptions and information about the choice of these inputs, refer to Deru et al. (2010).

System Types

Although ASHRAE 90.1-2004, Appendix G, might seem to be the most logical resource in determining which system type belongs in which model, given the frequent references mentioned to this ASHRAE standard, the system types it calls for do not always reflect the systems installed in real buildings of a given primary building activity. In an effort to accurately represent the system types common to the activities included in the reference buildings, we chose the system types in accordance with a study of those shown in an analysis of the 2003 CBECS dataset performed by Winiarski et al. (2006). The ASHRAE Standard 90.1 Mechanical Subcommittee has also provided important guidance in the selection of system types (Deru et al. 2010).

Table 7 shows the types of heating, cooling, and air distribution equipment included in each of the 16 reference buildings.

Economizers are operated under the guidelines identified in ASHRAE (2004).

Ventilation

Ventilation amounts in most spaces follow the guidance of ASHRAE (1999). The 1999 vintage of the ASHRAE 62 standard is used because ASHRAE 90.1-2004 calls for it, instead of for the 2004 vintage (ASHRAE 2004). GGHC (2007) gives more specific guidance for some healthcare spaces. Therefore, ventilation amounts in some spaces in the hospital and outpatient facility models deviates from the typical ASHRAE 62-1999 resource and follows these guidelines. Demand-controlled ventilation does not appear in the reference building models.

Equipment Efficiencies

Fan powers, heating efficiencies, and cooling efficiencies all coincide with the maximum/minimum allowable values presented in ASHRAE (2004). In the case of fan power, slight differences may occur because of the difference between what the standard specifies and what EnergyPlus requires in input files.

Exhaust fans and the fans in unit heaters, packaged terminal air conditioner units (PTACs), and fan-coil units (FCUs) do not follow the ASHRAE 90.1-2004 rules for maximum allowable fan power. Instead, the reference buildings use the properties shown in Table 8 for these fan types.

Service Water Heating

Service water heating (SWH) is modeled in most of the reference buildings. All SWH systems in the models consist of a natural gas-fired storage tank kept at 140°F (60°C).

The AEDG series, ASHRAE 90.1-2007 (ASHRAE 2007), Gowri et al. (2007), and engineering judgment were used to calculate the SWH flows by space type and the temperature required at the fixtures. Table 9 provides the SWH peak use rate and fixture temperature by space type. Peak flows are multiplied by fractional schedules to obtain hourly flows in EnergyPlus.

Table 7 HVAC Equipment Types

BUILDING TYPE	HEATING[a]	COOLING	AIR-SIDE[b]
Small Office	Furnace	Packaged DX	SZ CAV
Medium Office	Boiler	Packaged DX	MZ VAV
Large Office	Boiler	Chiller, water-cooled	MZ VAV
Primary School	Boiler	Packaged DX	SZ CAV and MZ CAV
Secondary School	Boiler	Chiller, air-cooled	SZ CAV and MZ CAV
Stand-Alone Retail	Furnace	Packaged DX	SZ CAV
Strip Mall	Furnace	Packaged DX	SZ CAV
Supermarket	Furnace	Packaged DX	MZ CAV
Quick-Service Restaurant	Furnace	Packaged DX	SZ CAV
Full-Service Restaurant	Furnace	Packaged DX	SZ CAV
Small Hotel	Gas furnace and electric heating	Packaged DX AC and PTAC units	SZ CAV
Large Hotel	Boiler	Chiller, air-cooled	MZ VAV and FCU
Hospital	Boiler	Chiller, water-cooled	MZ CAV and MZ VAV
Outpatient Healthcare	Furnace central heat, hot water reheat from natural gas boiler	Packaged DX	MZ VAV
Warehouse	Furnace and unit heaters	Packaged DX	SZ CAV
Midrise Apartment	Furnace	Packaged DX split system	SZ CAV

a) All heating equipment is fueled by natural gas, unless noted otherwise.
b) SZ = single zone, MZ = multi-zone, CAV = constant air volume, VAV = variable air volume, FCU = fan-coil unit

USES AND LIMITATIONS

By creating these 256 commercial building models, DOE intends to provide a set of common starting points for a wide variety of possible simulation studies.

Table 8 Fan Properties for Fans Not Following ASHRAE 90.1-2004

FAN TYPE[a]	PRESSURE RISE, IN.W.C. (PA)	TOTAL EFFICIENCY
Exhaust	0.5 (125)	22.5%
Unit heater	0.2 (50)	53.6%
PTAC and FCU	1.33 (330)	52.0%

a) PTAC = packaged terminal air conditioning unit, FCU = fan-coil unit

Table 9 Service Hot Water Peak Flows and Fixture Temperatures

MODEL/SPACE TYPE	PEAK FLOW RATE, GAL/H (L/H)	FIXTURE TEMP., °F (°C)
Small office	3.0 (11.4)	110 (43)
Medium office (per floor)	9.9 (37.5)	110 (43)
Large office (per floor)	21.3 (80.6)	110 (43)
Primary school kitchen	100.0 (379.0)	120 (49)
Primary school restrooms	56.5 (214.0)	110 (43)
Secondary school gym	189.5 (717.2)	110 (43)
Secondary school kitchen	133.0 (503.0)	120 (49)
Secondary school restrooms	104.4 (395.0)	110 (43)
Supermarket bakery	5.0 (19.0)	120 (49)
Supermarket deli	5.0 (19.0)	120 (49)
Quick service kitchen	40.0 (151.0)	120 (49)
Full-service kitchen	133.0 (503.0)	120 (49)
Small hotel guest room	1.8 (6.6)	110 (43)
Small hotel laundry	67.5 (255.5)	140 (60)
Large hotel guest room	1.3 (4.7)	110 (43)
Large hotel kitchen	133.0 (503.0)	120 (49)
Large hotel laundry	156.6 (592.8)	140 (60)
Hospital ER waiting	1.0 (3.8)	120 (49)
Hospital kitchen	150.0 (568.0)	120 (49)
Hospital lab	2.0 (7.6)	120 (49)
Hospital OR	2.0 (7.6)	120 (49)
Hospital patient room	1.0 (3.8)	120 (49)
Outpatient facility	40.0 (155.0)	110 (43)
Apartment	3.5 (13.2)	110 (43)

The breadth of primary building activity types lends itself to sector-wide studies, or studies of one building type across many climates. For example, one could use only the restaurant models to examine the effect nationwide of using more energy-efficient kitchen equipment. Another example might involve demand-controlled ventilation in schools, using the primary school and secondary school models.

Alternatively, including all representative U.S. climate zones allows for regional simulation studies across several building types. Studies of this type could compare the effects of an energy design measure across several building types for a given region. For instance, one could vary cooling efficiencies for several building types across the Southeast and compare the results to varying heating efficiencies in those same building types across the Midwest.

Many other options may be used as applications for the reference building models in simulation studies; however, these have limitations. The models represent prototypical buildings, so not every building design is accurately approximated by a reference building. And although a breadth of primary building activities is covered, not all can fall into one of the 16 categories.

SAMPLE APPLICATIONS

To demonstrate how the commercial reference buildings can be useful for simulation studies, this section presents a variety of examples of studies currently under way.

Evaluation of ASHRAE Standards

ASHRAE Standard 90.1 is updated every three years. As this standard is frequently referenced by building codes, changes to it present opportunities to save energy in commercial building stock. The updates usually consist of aggregating comments and changes to individual systems without much regard to the effect on the final performance of the standard. The performance of the standard is determined after and not during its development.

For the 2010 version, ASHRAE has set a performance goal for Standard 90.1 of 30% improvement over 90.1-2004. This aggressive goal has forced the use of energy simulations to inform the development and progress toward the efficiency goal. PNNL has conducted studies for the ASHRAE 90.1 standard committee to estimate energy savings from 90.1-2004 to 90.1-2007 to 90.1-2010 (proposed). These studies use the reference buildings and aggregate them with the weighting factors discussed previously. The aggregate results afford the committee a straightforward way to understand the impact of each subsequent standard, as one percentage savings number.

NREL recently conducted a similar analysis, using the reference buildings to estimate the aggregate savings of ASHRAE Standard 189.1 compared to 90.1-2004 and 90.1-2007. The ASHRAE subcommittee for Standard 189.1 had set a target of 30% energy consumption reduction over 90.1-2007. Simulations with the reference buildings, plus postprocessing with weighting factors, showed the committee that the first iteration of the proposed standard would not reach this target. Further modifications were made, and the next round of simulations resulted in 30% savings.

ASHRAE Standard 100, which aims to improve the performance of existing buildings, has also used the reference buildings in its development. Building performance in this standard is measured against existing building data gathered in the 2003 CBECS (EIA 2005). Some buildings may not be well represented in CBECS because of their primary building activities, locations, or both. The results of the reference building simulations can be used to map the consumption of well-represented areas to that of poorly represented areas, because the reference building results span 16 building types and all 16 typical U.S. climates.

Pending further analysis, ASHRAE Standard 100 may also take the effects of operating hours into account. If simulations of the reference buildings yield significantly different energy use intensities (EUIs) when a building's operating hours are modified, then the committee working on Standard 100 will likely use the reference buildings to identify EUIs for a variety of building operating hours.

For example, in the application of Standard 100 to a large office building, the office building in question may have double the hours of operation per week than the buildings examined in CBECS. Some office buildings, because of the nature of their work, employ workers on multiple shifts. Their EUIs will naturally increase based on their extended operations. To avoid penalizing these buildings unnecessarily, simulation analysis would be used to calculate a more appropriate EUI against which to compare the building in question. The large office reference building would be simulated, in the applicable climate, with hours representative of CBECS data and then with hours representative of the building's actual energy use. Comparing both simulations would create a multiplier indicating the increase in EUI associated with the increase in operating hours. This multiplier would then be applied to the CBECS EUI, and the office building in question would be compared to an EUI more appropriate to its use.

Comparing Building Vintages

In its work with the reference buildings, NREL has also created two vintages of existing building models – one representing 1980s and 1990s construction and one representing construction before 1980. These models use the reference buildings described in this paper as starting points and vary a few key parameters to represent buildings of the appropriate vintage:

- Increased infiltration for leakier construction
- Increased LPDs

- Modified HVAC efficiencies
- For some, changed system types
- Decreased envelope thermal resistance

For more details about the selection of existing building inputs, see Deru et al. (2010). These models, in conjunction with those described in this paper for new construction, can be used to predict the impact of energy design measures on existing building stock as opposed to new designs.

Ice Storage Modeling

Ice Energy is a private sector company with considerable experience in the manufacture, testing, design, and installation of ice storage systems. In its ongoing research and development efforts, it has developed in-house software analysis tools to evaluate the performance of its products.

The actual performance of an ice storage system depends on the load characteristics of the building for which it is installed. Ice Energy has used the reference buildings to obtain reasonable hourly load profiles for a variety of building types in a variety of climates. These profiles serve as inputs to Ice Energy's in-house software. Having pregenerated load profiles allows its research to focus less on load forecasting and more on product enhancements.

Comparison of Natural Gas Furnace Types

The reference buildings can be used to test the impacts of equipment efficiency on a variety of building types and primary building activities. The Gas Technology Institute (GTI) has used them to estimate the effect of high-efficiency rooftop unit furnaces compared to standard efficiency furnaces. Because initial capital cost increases are associated with the high-efficiency units, the GTI needs to understand their potential for savings to persuade building owners to make this investment.

This research has benefited from the use of the reference buildings for three reasons:

- Developing full-scale hourly building simulations falls outside the scope of GTI research projects. Researchers have preferred having representative energy models already created and vetted so that they could focus on the areas more suited to their expertise.
- Being able to model a variety of commercial building types means that the results of the GTI study will not be limited to one sector of their market.
- The results of the GTI research will depend on climate. The reference buildings vary envelope properties with climate and take into account the effects of different loads on the equipment efficiencies allowed by ASHRAE 90.1-2004. The reference buildings cover the 16 typical U.S. climates, so this research can provide results appropriate to different climate zones.

CONCLUSION

The EnergyPlus inputs of the commercial reference building models embody a large collection of buildings research. The information included therein has been vetted by multiple national laboratories, ASHRAE technical committees, industry design professionals, academics, and other EnergyPlus users. Others are encouraged to use this common collection of buildings knowledge to avoid duplicating foundational work in their simulation studies.

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