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Development of a Supermarket Prototype Building Model

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ABSTRACT
The U.S. Department of Energy supports the development of commercial building energy codes and standards by participating in industry reviews, update processes, and providing technical analyses to support both published model codes and potential changes. In support of ANSI/ASHRAE/IES Standard 90.1 and the International Energy Conservation Code, 16 commercial prototype building models were developed that cover 80% of the commercial building floor area in the United States for new construction, including both commercial buildings and mid- to high-rise residential buildings, across all U.S. climate zones. However, the current set of commercial prototype building models does not include a supermarket building type, which is one of major building types defined in the Energy Information Administration's Commercial Building Energy Consumption Survey. As part of an ongoing effort to expand the current Commercial Building Prototype Model suite, this paper presents the procedure used to develop the prototype supermarket building model based on multiple studies as well as a previously developed reference building model. The final set of prototype models includes 68 models for different vintages of ASHRAE Standard 90.1 (i.e., 2004, 2007, 2010, and 2013) and for 17 ASHRAE climate zones.

KEYWORDS
Commercial Building Prototype Model, EnergyPlus, OpenStudio, Supermarket

INTRODUCTION
The U.S. Department of Energy (DOE) supports the development of commercial building energy codes and standards by participating in industry reviews and update processes, and provides technical analyses to support both published model codes and potential changes. DOE publishes its findings to ensure transparency and to make its analysis available for public use. In conjunction with this effort, DOE's flagship building energy modeling (BEM) tools consist of the open-source EnergyPlus simulation engine and the OpenStudio software development kit. These tools allow a user to modify a building and estimate energy use. New releases of these tools are typically downloaded by over 40,000 users.

As part of DOE's support for ANSI/ASHRAE/IES Standard 90.1 (ASHRAE, 2016a) and the International Energy Conservation Code (IECC) (ICC, 2015), researchers at Pacific Northwest National Laboratory (PNNL) apply a suite of prototype buildings covering approximately 80% of the U.S. commercial building floor area (Goel et al., 2014; Deru et al., 2011). These buildings include new and existing construction, mid- to high-rise residential buildings and span all U.S. climate zones. These prototype buildings–derived from DOE's Commercial Reference Building Models[1]–cover all Reference Building types except for supermarkets, and an additional prototype representing high-rise apartment buildings. Since Standard 90.1 and IECC are updated every three years, PNNL modifies the commercial

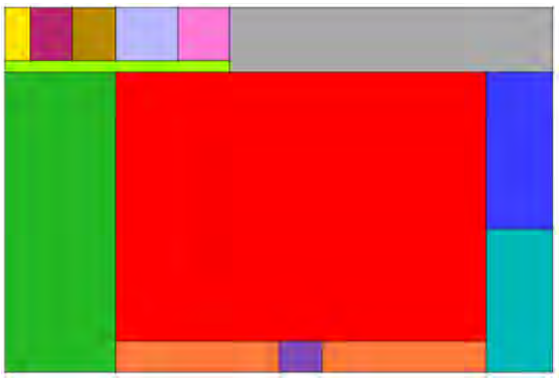
[1] Available in https://www.energy.gov/eere/buildings/commercial-reference-buildings

prototype building models with extensive input from ASHRAE 90.1 Standing Standards Project Committee (SSPC) members and other building industry experts.

The prototype models include 16 commercial building types in 17 climate locations (across all 8 U.S. climate zones) for recent editions of Standard 90.1 and IECC. The combinations result in an overall set of 2,176 total building models (in EnergyPlus Version 8.0). The supermarket model was excluded from the original prototype suite for the following reasons: 1) the building type covers a relatively small percentage of total commercial floor area (EIA, 2003), 2) the refrigeration equipment/system was not regulated by earlier versions of ASHRAE Standard 90.1, and 3) there was insufficient data regarding common design practice. Newer versions of ASHRAE Standard 90.1 include regulations for refrigeration systems, and more data is now available for supermarket building characteristics (especially for refrigeration systems). This study leveraged multiple sources to develop the OpenStudio supermarket prototype building model. This paper presents the research conducted to define the building and system characteristics for prototype supermarkets, and the final prototype building energy models for supermarkets.

METHODS

The new supermarket prototype building model was developed based on extensive review of existing literature and resources as well as the original, post-1980 supermarket reference model. The basic building size, shape, and window distribution of the new prototype follows the original reference model, consisting of a one-story building, 4,181 m^2 floor area, floor-to-floor height of 6.10 meters, and window area of 130 m^2. This building form was originally defined based on the *2003 Commercial Buildings Energy Consumption Survey* (CBECS) and DOE Benchmark documents (EIA, 2003; DOE, 2008). Subsequently, the space types and their internal layout were updated based on the *Grocery Store 50% Energy Savings Technical Support Document* (Leach et al., 2009). The updated space types in this report were also used in the development of the baseline model found in ASHRAE's *Advanced Energy Design Guide (AEDG) for Grocery Stores* (ASHRAE, 2015). Figure 1 shows allocated floor area for each space type in the newly-developed prototype building model. The original reference model consists of 6 space types, whereas the updated prototype building consists of 13 space types. With the additional space types, the model more accurately reflects actual supermarket buildings. In addition, the corresponding space attributes (including occupancy density, lighting power density, plug load and ventilation rate) are defined for each space type to represent properties based on surveys of supermarket buildings. These space attributes are in alignment with the requirements from each vintage of ASHRAE Standard 90.1 and ASHRAE Standard 62.1 (ASHRAE, 2016b). The operating hours for the prototype supermarket are 6:00



Space Type	Floor Area (m^2)	Percent of Total
Main Sales	2,082	49.8%
Perimeter Sales	215	5.1%
Produce	711	17.0%
Deli	225	5.4%
Bakery	209	5.0%
Enclosed Office	28	0.7%
Meeting Room	47	1.1%
Dining Room	47	1.1%
Restroom	63	1.5%
Mechanical Room	56	1.3%
Corridor	49	1.2%
Vestibule	28	0.7%
Active Storage	422	10.1%
Total	4,181	100.0%

Figure 1. Supermarket space layout and floor area per space type

am through 10:00 pm, Monday through Sunday, with occupancy and lighting schedules defined in accordance with ASHRE 90.1-1989. The dominant wall type is mass (e.g., brick, stone, or concrete) (EIA, 2003) and the roof type is all insulated above deck (ASHRAE, 2016a).

The heating, ventilation, and air conditioning (HVAC) system for the new model consists of a unitary rooftop unit with direct expansion (DX) coils and natural gas heating, as defined by CBECS (EIA, 2003). The supply fans are constant volume. The efficiency of the cooling and heating units, including economizers, are defined per ASHRAE 90.1 requirements.

Major updates were made to the refrigeration system in the new prototype building model. Since there were no regulations for the refrigeration system in ASHRAE Standard 90.1-2004, the requirements for the refrigeration system were assumed to be the average of nationwide standard design practice in the corresponding year. In updating the refrigeration system, first, based on the AEDG project committee's feedback, the original refrigeration system in the reference model was modified with longer display cases and increased walk-in cooler/freezer space. The original reference model has 6 refrigerated display cases, 5 refrigerated walk-ins, and 4 compressor racks, while the updated model has 26 refrigerated display cases of 7 different types, 10 refrigerated walk-ins, and 4 refrigeration systems. The low-temperature (LT) display case models include specifications for coffin ice cream, coffin frozen food, reach-in ice cream and reach-in frozen food cases, while the medium-temperature (MT) display case models include coffin, vertical open, service and reach-in cases. For "old" systems (ASHRAE 90.1-2004, 2007 and 2010) and "new" systems (ASHRAE 90.1-2013), typical values for the rated capacity, fan power, lighting power, anti-sweat heater power, defrost type and power, and evaporator temperature of these display case types (for both "old" and "new" vintage cases) were defined, based on statistical analysis of refrigeration system manufacturers' data. A summary of the display case types and their specifications are given in Table 1. Furthermore, walk-in cooler/freezer cooling capacity was defined in terms of walk-in floor area, based on a least-squares fit of walk-in manufacturers' performance data. In the prototype supermarket models, the total length of the display cases is 225.2 m, and the total insulated floor area for the walk-ins is 321 m^2.

Table 1. Summary of selected display case performance parameters.

Case Type	**Rated Cooling Capacity (W/m)**		**Defrost Type**		**Evaporator Temperature (°C)**	
	Old	New	Old	New	Old	New
LT Cases						
Coffin Ice Cream	695	521	Electric	Electric	-28.9	-32.2
Coffin Frozen Food	589	436	Electric	Electric	-25.6	-26.7
Reach-in Ice Cream	618	462	Electric	Electric	-28.3	-27.4
Reach-in Frozen Food	584	425	Electric	Electric	-23.9	-23.3
MT Cases						
Coffin	1250	303	Off cycle	Electric	-6.1	-6.4
Vertical Open	1438	1143	Off cycle	Off cycle	-6.1	-3.1
Service	404	599	Off cycle	Off cycle	-7.8	-6.4
Reach-In	--	309	--	Off cycle	--	-0.8

Generic compressor performance maps are provided for modeling "old" compressor racks (using reciprocating compressors) and "new" compressor racks (using scroll compressors). Compressor racks utilize air-cooled condensers, and condenser fan power has been fit to compressor heat rejection capacity based on condenser manufacturers' data. To simplify the model development, only limited number of inputs value were entered, and other required input parameters were automatically calculated based on further study from refrigeration system manufacturers' data and statistical analysis.

Once all the building characteristics for the prototype supermarket building were defined, the prototype building model was generated in an automated fashion. An OpenStudio Measure was used to automatically generate the supermarket prototype building for 16 climate locations and 4 building standards (Roth et al., 2016). This measure, OpenStudio-Standards, provides mechanisms to add new building types, such as the supermarket, and its building characteristics. Additionally, the measure automatically assigns and models all 90.1 building standard requirements. By using an OpenStudio Measure, the OpenStudio-Standards can be used to generate OpenStudio Prototype Buildings using all OpenStudio workflows.

RESULTS

Based on the procedure described above, the final set of 68 prototype supermarket models were created covering different vintages of ASHRAE Standard 90.1 (i.e., 2004, 2007, 2010, and 2013) and for 17 ASHRAE climate zones. We compared the models for ASHRAE Standard 90.1-2004 to the original, post-1980 vintage reference building. Figure 2 presents the annual site energy by end use for the prototype building models and the post-1980 reference building models. The comparison shows that the overall refrigeration system energy use increased for the new prototype models in all climate zones since there were major updates to the refrigeration system, and the size (e.g., linear length of case) of the refrigeration system increased. The reduction in cooling energy use in warmer climates and heating energy use in colder climates is primarily due to improved building envelope systems and reduced infiltration rates. Other end uses such as interior/exterior lighting and interior equipment are nearly identical. The difference in total site energy use between the new prototype model and the original referent model ranged from -13% to 11%.

Total simulated energy use was also compared with real-world surveys of energy use data from EIA's CBECS (EIA, 2003). According to CBECS, the national average energy use per unit floor area for the building type "food sales" is 630.2 kWh/m^2. The simulated energy use intensity (EUI) across climate zones for the new supermarket model are between 610 and 902 kWh/m^2. These simulation results appear reasonable given that CBECS includes all (i.e., old and new) existing supermarket buildings. The largest energy use within the supermarket is attributed to "Refrigeration", and CBECS shows the EUI for refrigeration energy use is about 299 kWh/m^2, close to the simulated refrigeration use, which ranges from 233 to 298 kWh/m^2.

Figure 3 shows the total site energy use of the prototype supermarket model for different climate zones and different ASHRAE 90.1 vintages. As shown, the total energy use decreases for newer vintages, but there is a larger decrease for the 2013 vintage. This is primarily due to the reduced refrigeration energy use since the refrigeration system in 2004, 2007, and 2010 was defined as an "old system", while the system for 2013 model was defined as a "new system". The total energy use for the 2013 model is about 29 to 36% lower than the 2004 model.

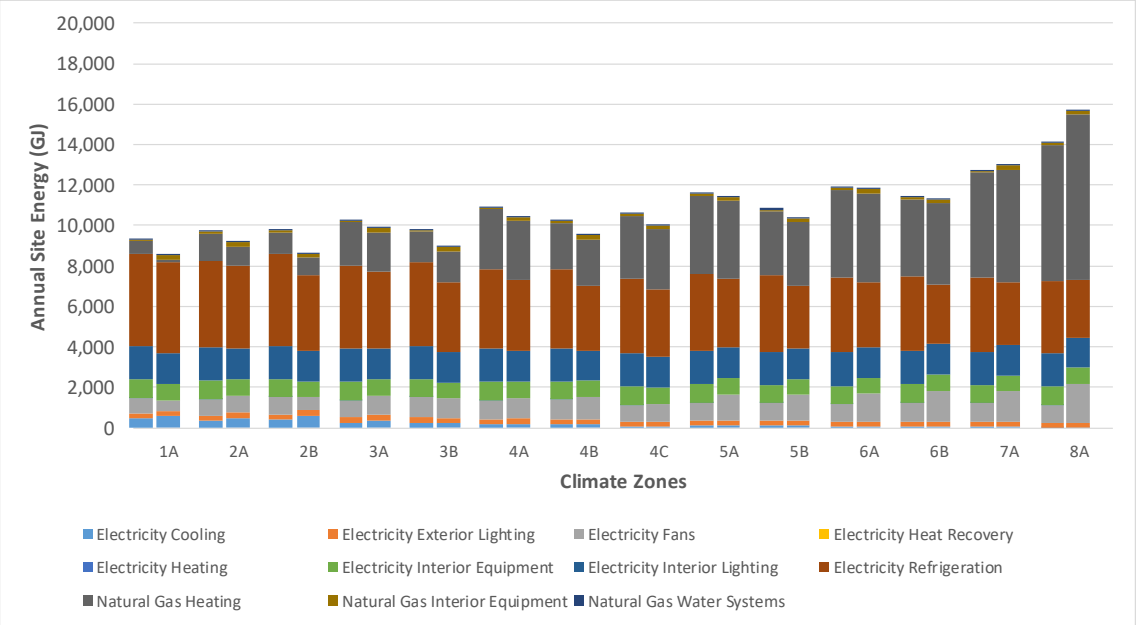


Figure 2. Annual site energy for the 2004 prototype supermarket models (left) vs. the post-1980 reference supermarket models (right)

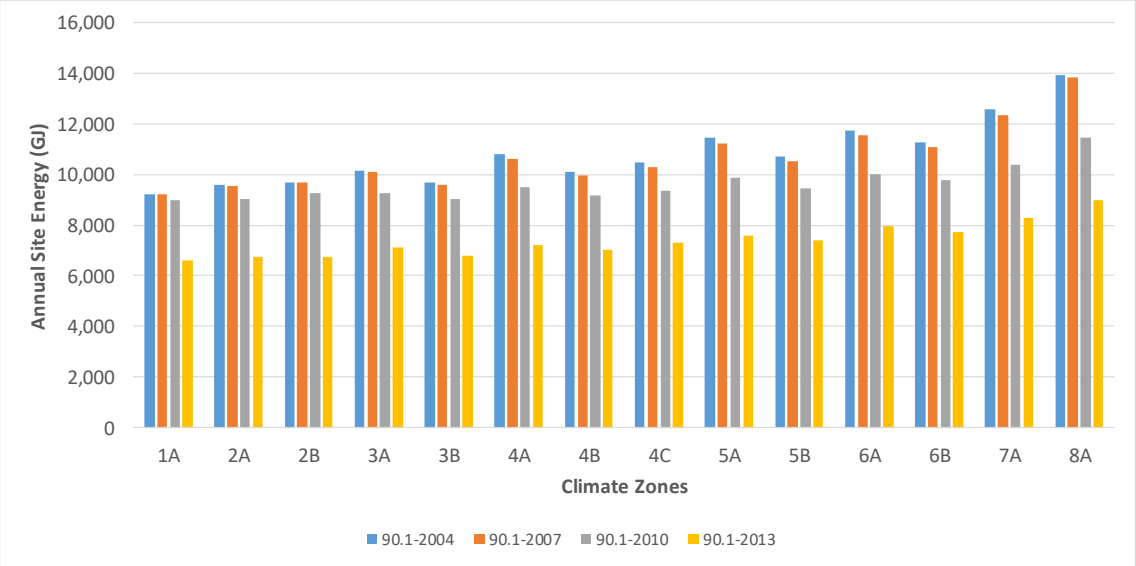


Figure 3. Annual site energy for the supermarket models corresponding to ASHRAE 90.1-2004, 2007, 2010, and 2013.

DISCUSSIONS AND CONCLUSIONS

As an effort to expand the current Commercial Building Prototype Model suite, this paper presents the procedure and results of developing a prototype supermarket building model. The final set of prototype models includes 68 models for different vintages of ASHRAE Standard 90.1 (i.e., 2004, 2007, 2010, and 2013) and for 17 ASHRAE climate zones, and the modelled energy uses are consistent with existing data from multiple sources.

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