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 review, 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 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 Energy Information Administration's Commercial Building Energy Consumption Survey. As part of an ongoing effort to expand the current set of 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 the 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 review, update processes, and providing 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 both public use. In conjunction with this effort, DOE's flagship building energy model (BEM) tools consist of the open-source EnergyPlus simulation engine and OpenStudio software development kit. These tools allow a user to modify a building, estimate energy use, and new releases are typically downloaded by over 40,000 users.

As part of DOE's support for ANSI/ASHRAE/IES Standard 90.1 (ASHRAE, 2016a) and International Energy Conservation Code (IECC) (IECC 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.

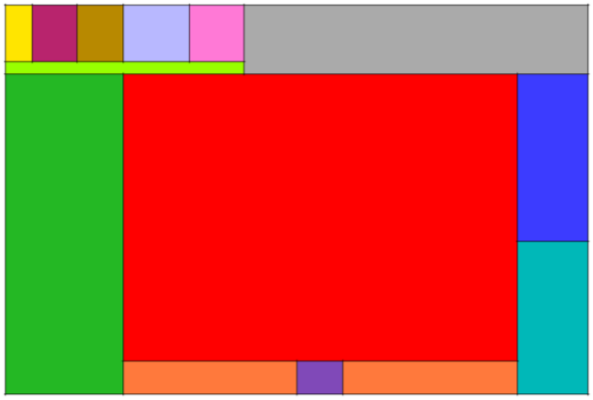
The prototype models include 16 commercial building types in 17 climate locations (across all 8 U.S. climate zones) for recent editions of Standard 90.1 and IECC. The combinations result in an overall set of 2,176 total building models (in EnergyPlus Version 8.0). Reasons that the supermarket model was excluded in the original prototype suite include: 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 system). 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 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 2003 CBECS and DOE Benchmark document (EIA 2003, DOE 2008). 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 was also used in the development of baseline model of the ASHRAE's Advanced Design Energy Guide (AEDG) for Grocery Stores (ASHRAE 2015). Figure 1 show allocated floor area for each space type in 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 more 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 supermarket is 6:00 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, stucco, or concrete) (EIA 2003) and the roof type is all insulated above deck (ASHRAE 2016a).

The new model includes a unitary rooftop unit with DX coils and natural gas heating as the HVAC system type defined by CBECS 2003. The supply fans are constant volume. The efficiency of the cooling and heating unit, including economizers, are defined per ASHRAE 90.1 requirements.

There is a major update for refrigeration systems in the prototype building model. As there were no regulations for the refrigeration system in ASHRAE standard 90.1-2004, the requirement for refrigeration system was assumed the average of nationwide standard practice design in the corresponding year. In updating refrigeration system, first, based on AEDG project committee's feedback, the original refrigeration system in the reference model was



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. Space layout and floor area per space type

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 with 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, while the medium-temperature (MT) display case models include coffin, vertical open, service and reach-in cases. For old systems (90.1-2004, 2007 and 2010) and "new" systems (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.

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 automated way. 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.

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

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 compare 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 post 1980 reference building models. The comparison shows that the overall refrigeration system's energy use increase for all climate zones as there were major update on refrigeration system, and the size (e.g., linear length of case) of the refrigeration system increases. 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 lightings and interior equipment are nearly identical. Total site energy use for the new prototype model and the original reference model were between -13% and 11%.

Total simulated energy use was also compared with real-world survey of energy use data from EIA's CBECS (EIA 2003). According to CBECS, the national average energy use (kWh) per unit floor area (m^2) for building type "food sales" is 630.2 kWh/m^2. The simulated EUI across climate zones for the new model are between 610 and 902 kWh/m^2. This appears reasonable given the CBECS includes all (i.e., old and new) existing supermakret 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 is between 233 through 298 kWh/m^2.

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

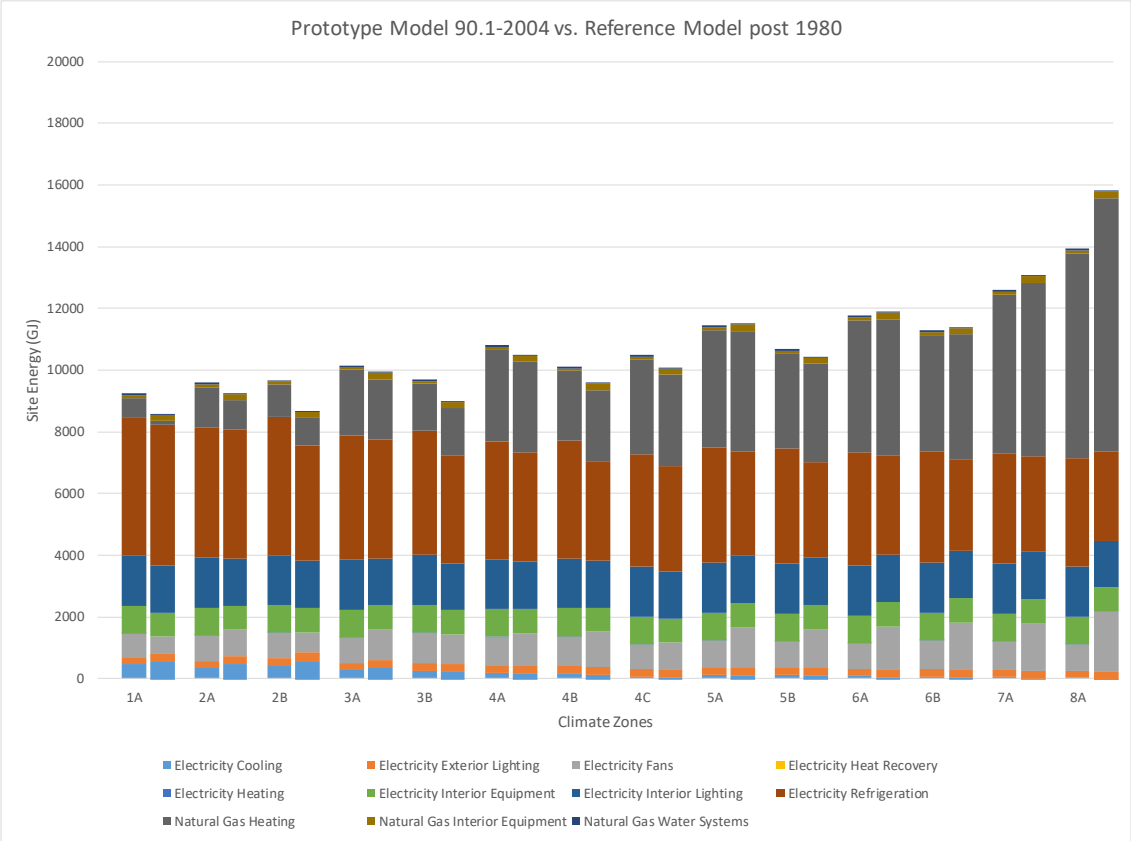


Figure 2. Annual site energy for 2004 prototype building models (left) vs. post 1980 reference building models (right)

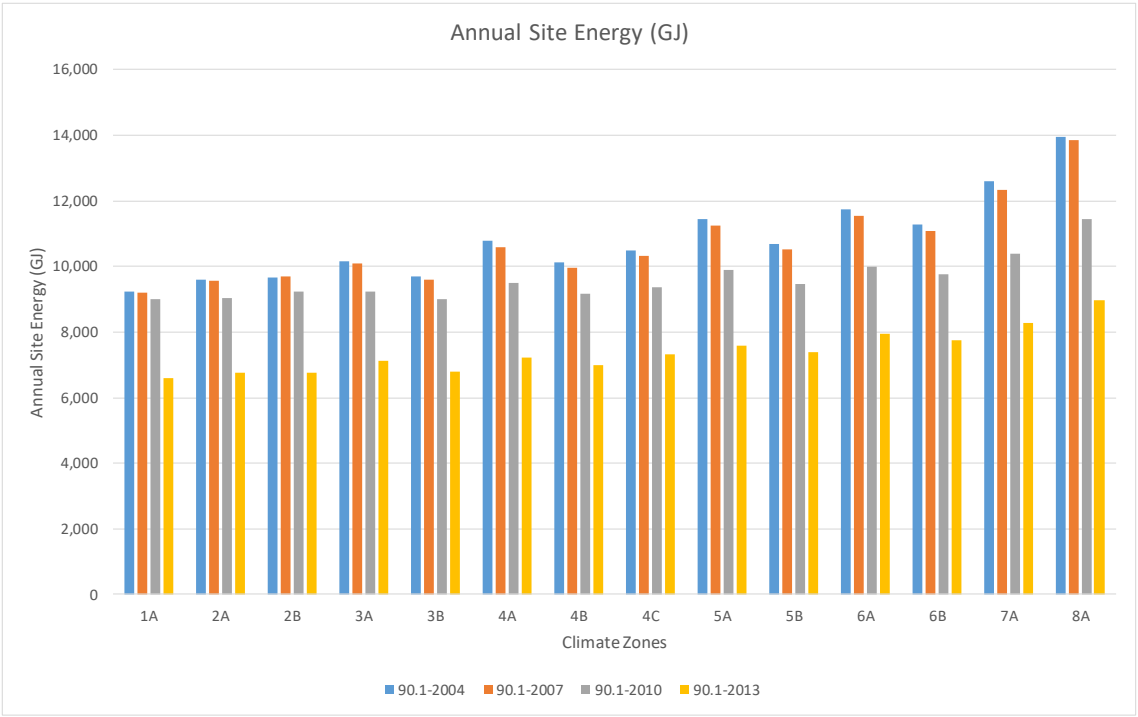


Figure 3. Annual site energy for ASHRAE 90.1-2004, 2007, 2010, and 2013 models.

DISCUSSIONS AND CONCLUSIONS

As an effort to expand the current set of Commercial Building Prototype Model suite, this paper presents the procedure and result of developing prototype supermarket building model. The final set of prototype models includes the 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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