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NATIONAL IMPACT OF ANSI/ASHRAE/IES STANDARD 90.1-2016

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ABSTRACT

ANSI/ASHRAE/IES Standard 90.1 is the U.S. national commercial building model energy code and it has a significant impact on many programs and policies that impact energy savings across the United States and the world. Determining the energy savings from the latest edition of Standard 90.1 relative to previous editions is critical for beyond code programs and for others setting energy performance targets. Pacific Northwest National Laboratory developed prototype building models to determine the energy savings from 90.1-2016 standard. This paper presents the rigorous modeling and development process that PNNL has established and its applications. In addition, the energy savings results of Standard 90.1-2016 are described.

INTRODUCTION

ANSI/ASHRAE/IES Standard 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings is an ANSI-approved, consensus-based standard (ASHRAE 2016). It establishes minimum energy efficiency requirements for the design and construction of new buildings, alterations and major renovations in commercial and multi-family residential buildings. Standard 90.1 has been a benchmark for commercial building energy codes in the United States and a key basis for codes and standards around the world for more than 35 years.

In 2007 ASHRAE and DOE jointly set a goal to develop 90.1-2010 achieving 30% energy savings compared to 90.1-2004. The 30% energy savings goal led to a dramatic increase in the level of activity and enhancement of Standard 90.1. For the first time in the history of the Standard, an energy goal was set for developing the new edition. Prior to the development of 90.1-2010, the previous three updates of Standard 90.1 to 2001, 2004 and 2007 editions generated 34, 32 and 44 approved addenda, respectively. By the time 90.1-2010 was published in October 2010, 109 addenda to 90.1-2007 were approved and incorporated in the new version. Figure 1 illustrates the improvement of Standard 90.1 over the last 30 years. At the start of each code cycle, the Standard 90.1 Committee sets an energy savings target for that cycle. The goal for the 2016 Standard was 35-40% savings compared to the 2004 edition. No long term energy savings targets for future ASHRAE 90.1 editions have not been established.

Pacific Northwest National Laboratory (PNNL) provided technical leadership in support of this initiative under the U.S. Department of Energy's (DOE's) Building Energy Codes Program. To closely measure the progress towards the goal, PNNL developed a new metric and process named the "Progress Indicator" (PI). The PI process was used to quantitatively measure progress toward the 30% improvement goal for 90.1-2010 relative to the baseline 90.1-2004. Using the PI, PNNL periodically reported the energy and cost saving impacts for the approved addenda to DOE and the Standard 90.1 committee during the three-year Standard development cycle. The PI methodology and over one thousand prototype building models were peer-reviewed and published at DOE's codes website for free download (www.energycodes.gov).

This paper describes the PI methodology and the energy simulation infrastructure. It also presents the broad application of prototype building models and model enhancements. The paper concludes with the 90.1-2016 energy saving results and discussions.

PROGRESS INDICATOR

PI is an analytical process that PNNL developed to evaluate the potential energy savings from the application of new editions of Standard 90.1 to building design and construction compared to its predecessors. The PI process was implemented using state-of-the-art energy simulation software—*EnergyPlus*—for the quantitative analysis. PNNL developed a suite of 16 prototype building models based on DOE's Commercial Reference Building Models (Deru et al. 2011), with substantial modifications during the PI. The prototype buildings are simulated in all climate zones in the United States. These models provide a solid basis for reaching conclusions about the potential energy savings of applying Standard 90.1.

Prototype Building Models

The prototype buildings were developed to represent a cross section of the most common commercial building types. The prototype buildings correspond to a classification scheme established in the Commercial Building Energy Consumption Survey (CBECS 2003). The CBECS data are organized around 14 principal building activities. Figure 2 illustrates the annual energy consumption in trillions of Btus by the principal building activities, ranked from the most energy usage to the least. The prototype buildings cover the first seven principal building activities, representing 76% of the building energy usage of commercial buildings. Multi-family housing buildings more than three stories are not included in CBECS but are covered by Standard 90.1. Consequently, PNNL developed mid-rise and high-rise multi-family prototype buildings to add to the suite of prototype buildings. The characteristics of the mid-rise and high-rise multi-family buildings were developed using data from a separate study by PNNL (Gowri et al. 2007).

Table 1 shows the 16 prototype buildings, including 14 with the applicable principal building activity categories from CBECS and two added apartment activity types. The prototypes include characteristics of buildings that do not vary between editions of Standard 90.1 or climate zone. Characteristics include building size and shape, type of building activity and occupancy, and mechanical system type. Most of these characteristics were derived from the CBECS data to best represent the typical building design and construction practices in the United States.

During development and assessment of multiple editions of Standard 90.1, the prototype building models were reviewed extensively by building industry experts from the Standard 90.1 committee. These prototype models, their detailed characteristics, and their development are published on DOE's Building Energy Codes Program web site. A detailed description of the prototypes can also be found in a technical report published by PNNL, *Energy and Cost Savings Analysis of ASHRAE Standard 90.1-2010* (Thornton et al. 2011).

Table 1 Prototype Buildings

BUILDING TYPE	PROTOTYPE
Office	Small office
	Medium Office
	Large Office
Retail	Stand-Alone Retail
	Strip Mall
School	Primary School
	Secondary School
Healthcare	Outpatient Health Care
	Hospital
Lodging	Small Hotel
	Large Hotel
Warehouse	Non-Refrigerated Warehouse
Food Service	Quick Service Restaurant
	Full Service Restaurant
Apartment	Mid-rise Apartment
	High-rise Apartment

Climate Zones

Building models were analyzed in standardized climate zones described in ASHRAE Standard 169, which is incorporated into Standard 90.1 by reference. Standard 169 was recently updated to the 2013 edition, which resulted in changes to climate zone assignments for some locations in Standard 90.1, as well as the incorporation of a new Climate Zone 0. While the revision of Standard 169 is not the focus of the analysis, this change indirectly affects how climate zones are defined and applied through Standard 90.1. A discussion of the impact of Standard 169-2013 on building energy codes and energy efficiency can be found in PNNL's previous study (Athalye et al. 2016).

Standard 169-2013 includes nine thermal zones and three moisture regimes. To develop the prototype models, a specific climate location (city) was selected as a representative of each of the climate zones found in the United States. Table 2 lists the climate zones and representative cities. These are the same set of representative cities approved by the Standard 90.1 committee for setting the criteria for 90.1-2016.

Table 2 Climate Zones and Weather Locations

CLIMATE ZONE	MOISTURE REGIME	WEATHER LOCATION
1A	Moist	Honolulu, HI
2A	Moist	Tampa, FL
2B	Dry	Tucson, AZ
3A	Moist	Atlanta, GA
3B	Dry	El Paso, TX
3C	Marine	San Diego, CA
4A	Moist	New York, NY
4B	Dry	Albuquerque, NM
4C	Marine	Seattle, WA
5A	Moist	Buffalo, NY
5B	Dry	Denver, CO
5C	Marine	Port Angeles, WA
6A	Moist	Rochester, MN
6B	Dry	Great Falls, MT
7	N/A	International Falls, MN
8	N/A	Fairbanks, AK

Construction Weighting Factors

PNNL developed construction weighting factors that allow aggregation of the energy impact from an individual building and climate zone level to the national level. The weighting factors were based on five years of construction data purchased from McGraw Hill. Details of their development are discussed in a PNNL report (Jarnagin and Bandyopadhyay 2010). Table 3 lists the resulting weighting factors by prototype building used in the PI analysis. These data are used to develop the relative fractions of new construction floor space represented by prototype building and within the 16 climate zones.

Analyze Results

The primary measurement reported for the PI is the national aggregated energy and energy cost savings for each edition of the standard compared to a 2004 baseline. These savings are the percentage savings for the entire set of prototypes across all U.S. climate zones. The simulation provides a break-down of energy end uses such as lighting, cooling, heating, fan, service hot water,

Table 3 Prototype Building Construction Weights

BUILDING TYPE	PROTOTYPE	FLOOR AREA (FT²)	FLOOR AREA (%)
Office	Small office	5,502	5.61
	Medium Office	53,628	6.05
	Large Office	498,588	3.33
Retail	Stand-Alone Retail	24,692	15.25
	Strip Mall	22,500	5.67
School	Primary School	73,959	4.99
	Secondary School	210,887	10.36
Healthcare	Outpatient Health Care	40,946	4.37
	Hospital	241,501	3.45
Lodging	Small Hotel	43,202	1.72
	Large Hotel	122,120	4.95
Warehouse	Non-Refrigerated Warehouse	52,045	16.72
Food Service	Quick Service Restaurant	2,501	0.59
	Full Service Restaurant	5,502	0.66
Apartment	Mid-rise Apartment	33,741	7.32
	High-rise Apartment	84,360	8.97
Total		1,515,674	100.00

and plug loads. Annual site energy usage is reported in the PI as site energy usage intensity (EUI) values – energy use per unit floor area per year, kBtu/ft²-yr. This includes electricity and natural gas converted by straight unit conversion to the kBtu unit. Energy usage by utility energy type is determined during the simulation, and national average utility rates for electricity and natural gas usage are used to calculate energy cost. Energy cost is reported per unit area, an energy cost index similar to the energy usage index described above. Source energy is the energy required to generate and deliver energy to a building site. Source energy is also calculated from site energy reported using conversion factors from EIA's Annual Energy Outlook.

Comparisons of the actual energy use of buildings constructed to the various codes to that predicted by the prototype models have not been made, but some differences are expected. The prototype building models assume not only full compliance with each code from a design and construction perspective, but also that the buildings are operated and maintained at that level over the long term. Actual reality may be quite different. ASHRAE is currently funding a research project (1814-TRP) that is intended to compare modeled results to those obtained from real buildings constructed in accordance with the 2004 and 2010 editions of Standard 90.1. Feedback from that research project may be useful in calibrating the prototype models.

SIMULATION INFRASTRUCTURE

The PI primarily depends on conducting extensive building energy simulation to quantitatively evaluate the potential energy savings among various editions of Standard 90.1. *EnergyPlus* is the computer simulation software used to evaluate the energy savings. *EnergyPlus* is a whole-building energy simulation program for modeling building heating, cooling, lighting, ventilation, and other energy uses in buildings. To run *EnergyPlus* simulations, the user needs to prepare a detailed input file, the idf file, to specify building characteristics as well as the requirements of different versions of Standard 90.1. An *EnergyPlus* input data file can easily have thousands of lines for numerous object blocks, which make the manual preparation both tedious and error-prone. During development of the PI, thousands of *EnergyPlus* simulations were run. Each of the 16 prototype buildings has a corresponding *EnergyPlus* simulation model, which consists of all the values needed to run *EnergyPlus* simulation. Most of the objects and their values are the characteristics of the prototype buildings, which are standard-and-climate-zone-independent, but others vary with the standards and climate zone (e.g., insulation of walls and equipment efficiencies).

By assigning standard-dependent values, the model of each of the prototype building expands into several different *EnergyPlus* models to comply with various editions of Standard 90.1, including 2004, 2007, 2010, 2013 and 2016 editions. Further considering the selected 16 climate locations, the five *EnergyPlus* models for each prototype are expanded into 80 sets of *EnergyPlus* models per building type. With all the combinations of the 16 prototypes, 5 versions of the 90.1 standard, and 17 climate locations, a total of 1280 *EnergyPlus* models are in each single batch of simulation run.

The massive numbers of *EnergyPlus* simulation runs present a challenge in preparing the idfs, conducting *EnergyPlus* simulations, and post-processing the output files to assemble building energy consumption information and to assess energy savings of the advanced standards against the baseline standard. To facilitate the automatic creation of the large number of *EnergyPlus* idfs, the prototype models were parameterized by splitting the prototype model into two separate but related associated file pairs called *template* and *parm* files. All energy simulations were completed within a PNNL High Performance Computer energy simulation infrastructure, which automatically manages inputs and outputs of the *EnergyPlus* simulations. This infrastructure includes creating *EnergyPlus* idfs, submitting input files to a super computing cluster for batch simulation, and extracting energy end-use results. Figure 3 is a flow diagram of these procedures as described in PNNL's report (Thornton et al. 2011).

OTHER APPLICATIONS

Although originally developed for the ASHRAE Standard 90.1 PI, the prototype building models have been used extensively by DOE and others for analyzing and quantifying building energy efficiency. This section describes some of the uses.

DOE Determination

ASHRAE Standard 90.1 is recognized by the U.S. Congress as the national model energy code for commercial buildings under the Energy Conservation & Production Act (ECPA), as amended. With each new edition of Standard 90.1, DOE is required to make a *determination* as to whether the update would improve energy efficiency in commercial buildings. To facilitate that determination, PNNL has traditionally performed a quantitative analysis of the energy efficiency of each new edition of the standard and compared it to the previous edition. Since 2007, this analysis has relied on whole-building energy simulation using the sixteen prototype building models. If the analysis shows that on aggregate, buildings constructed to the newer version will use less energy than those constructed to the previous version, a positive determination is issued. Based on recent analysis, DOE has issued a determination that Standard 90.1-2016 would achieve greater energy efficiency in buildings subject to the code. Compared to the 2013 Standard, the 2016 Standard is estimated to save approximately 8.3% energy cost, 7.9% source energy, and 6.8% site energy (DOE 2017).

Support to States Adopting Energy Codes

As states consider adopting new versions of the model energy code, there is a need for both the energy savings impacts and cost effectiveness of code adoption. Using an established methodology relying on the prototype building models, DOE and PNNL have provided this data on both a national and state-specific level. Energy and energy cost savings taken from the PI results are paired with the incremental cost of building construction and ongoing maintenance due to compliance with the updated code. Developing the incremental costs relies on extracting detailed information from the prototype building models. For example, the added cost for an increase in the efficiency requirements for heat pumps requires knowing the size and quantity of heat pumps in each climate zone for each impacted building type, while an increase in wall insulation requirement costs is impacted by the net opaque wall area. While these types of data are easily extracted from the building models, more in-depth data such as lighting fixture descriptions and counts not typically included in a building model are taken from the detailed assumptions that were developed to create the prototype models. Standard engineering economic analysis procedures are then used to determine the cost effectiveness of a new code. This entire process is documented in DOE's Cost-Effectiveness Analysis Methodology report (DOE 2015). The cost-effectiveness analysis of Standard 90.1-2013 can be found in another PNNL report (Hart et al. 2015). In addition, a similar process is used to provide state-specific cost-effectiveness data. The national results are modified to apply state-specific building new construction weightings, utility costs, and construction cost modifiers.

Code Development

When energy codes are updated, there is typically a requirement to demonstrate cost effectiveness for new provisions, or to at least determine their energy impact. The prototype building models have been used by PNNL and others for this function. Recently PNNL has provided analysis using prototype models to accompany proposals to the International Energy Conservation Code, the proposed Washington, D.C. energy code (Rosenberg et al. 2017), the State of Washington's energy code, and the New York Stretch Code (Liu et al. 2018).

PROTOTYPE MODEL ENHANCEMENTS

Since the first generation of prototypes was developed for analysis of the 2010 Standard, a number of updates and enhancements have occurred which are documented in a PNNL technical report (Goel et al. 2014). Those enhancements were made for several reasons: (1) to change or improve prototype design assumptions; (2) to improve simulation accuracy; (3) to improve simulation infrastructure; and (4) to add additional detail to the models needed to better capture certain energy impacts. Some of these enhancements were identified by PNNL researchers, some by public users of the posted prototypes, and others by request of a working group of Standard 90.1 committee members tasked with recommending improvements to the prototype buildings. For example, this working group recognized that many larger office buildings these days contain significant centralized computing resources which were not accounted for in the original prototype buildings. At their request, a 380 kW data center was added to the basement of the large office prototype. Enhancements to improve simulation accuracy include updates to more recent versions of *EnergyPlus*, updates to newer representative weather files, improvements to the calculation procedure for determining ventilation air for multizone HVAC systems, and detailed assumptions for space type breakdowns so requirements for occupancy sensors, lighting power, demand controlled ventilation, and other measures could be more accurately simulated.

ANALYSIS RESULTS

Using the PI approach described previously, PNNL assesed the energy and energy cost improvement of Standard 90.1-2016 compared to the Standard 90.1-2004 baseline. This involved starting with the Standard 90.1-2013 prototype models and incorporating the changes between those and the 2016 standard that directly impact energy consumption.

There were a total of 121 addenda to the 2013 Standard approved for the 2016 Standard, but only 51 (42%) of those have direct energy impacts. The impactful addenda are those that modify the prescriptive and mandatory design requirements. The remaining 70 include addenda that are clarifications, administrative, updates to references, or those that impact one of the optional performance paths in the standard. Of the impactful addenda, 23 (45%) are captured in the PI. There are various reasons why impactful addenda may not be incorporated. For example, some addenda improve systems or equipment not included in the prototypes like swimming pools, air conditioned vestibules, or variable refrigerant flow systems. Others implement what had already been considered standard practice such as a requirement to limit outdoor air ventilation to 135% of that required by ASHRAE's ventilation standard (Standard 62.1). Finally, several addenda only apply to building retrofits which are not considered in the PI.

The results of the 2016 PI show that buildings meeting the requirements of Standard 90.1-2016 exhibit 34.2% energy and energy cost savings compared to Standard 90.1-2004 on a national basis. Figure 4 shows the national weighted site energy savings for each prototype building and the overall savings.

CONCLUSION

An analytical approach, called the Progress Indicator, was developed to capture the national impact of Standard 90.1. This approach uses prototypical building energy models representing the national commercial building stock that are simulated across all climate zones within the country. The results from the simulations are then aggregated to the national level using building construction weights. This approach was used to analyze the impact of Standard 90.1-2016 relative to Standard 90.1-2004 and showed that buildings meeting the requirements of Standard 90.1-2016 exhibit 34.2% energy and energy cost savings compared to Standard 90.1-2004 on a national basis. The simulation infrastructure developed to support the PI process enables the execution of several other DOE analyses, including the Standard 90.1 determination, state code cost-effectiveness, and future development of energy codes. In addition, prototype models developed during the PI process are a valuable resource used by industry and academia to perform numerous other analyses.

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REFERENCES

ASHRAE. 2016. ANSI/ASHRAE/IESNA 90.1-2016, Energy Standard for Buildings Except Low-Rise Residential Buildings. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta, Georgia.

Athalye, R., Taylor, Z.T., Liu, B. 2016. Impact of ASHRAE Standard 169-2013 on Building Energy Codes and Energy Efficiency. ASHRAE and IBPSA-US SimBuild Buidling Performance Modeling Conference, August 8-12, 2016, Salt Lake City, UT.

CBECS. 2003. Commercial Buildings Energy Consumption Survey 2003. Energy Information Administration, U.S. Department of Energy, Washington, D.C.

Deru, M., Field, K., Studer, D., Benne, K., Griffith, B., Torcellini, P., Liu, B., Halverson M., Winiarski, D., Yazdazian, M., Huang, J., Crawley, D. 2011. U.S. Department of Energy Commercial Reference Building Models of the National Building Stock. NREL/TP-5500-46861, National Renewable Energy Laboratory, Golden, Colorado.

DOE. 2015. Commercial Energy and Cost Analysis Methodology. U.S. Department of Energy, Washington, D.C.

DOE. 2017. Energy Savings Analysis: ANSI/ASHRAE/IES Standard 90.1-2016. U.S. Department of Energy, Washington, D.C.

Goel, S., Athalye, R.A., Wang, W., Zhang, J., Rosenberg, M.I., Xie, Y.L., Hart, P.R., Mendon, V. V. 2014. Enhancements to ASHRAE Standard 90.1 Prototype Building Models. PNNL-23269, Pacific Northwest National Laboratory, Richland, WA.

Gowri, K., Halverson, M., and Richman, E. 2007. Analysis of Energy Saving Impacts of ASHRAE 90.1-2004 for New York. PNNL-16770, Pacific Northwest National Laboratory, Richland, WA.

Hart, P.R., R.A. Athalye, M.A. Halverson, S.A. Loper, M.I. Rosenberg, Y.L. Xie, and E.E. Richman. 2015. National Cost-effectiveness of ANSI/ASHRAE/IES Standard 90.1-2013. PNNL-23824. Pacific Northwest National Laboratory, Richland, WA.

Jarnagin, R.E. and Bandyopadhyay, G.K. 2010. Weighting Factors for the Commercial Building Prototypes Used in the Development of ANSI/ASHRAE/IES 90.1-2010. PNNL-19116, Pacific Northwest National Laboratory, Richland, WA.

Liu, B., Zhang, J., Chen, Y., Edelson, J., Lyles, M. 2018. Energy Savings Analysis of the Proposed NYStretch-Energy Code 2018. PNNL-ACT-10062, Pacific Northwest National Laboratory, Richland, WA.

Rosenberg, M.I., Athalye, R., and Hart, P.R.. 2017. Energy Savings Analysis of the Proposed Revision of the Washington D.C. Non-Residential Energy Code. PNNL-27081, Pacific Northwest National Laboratory, Richland, WA.

Thornton, B.A., Wang, W., Cho, H., Xie, Y.L., Mendon, V.V., Richman, E., Zhang, J., Athalye, R., Rosenberg, M.I., and Liu, B. 2011. Achieving 30% Goal: Energy and Cost Saving Analysis of ASHRAE/IES Standard 90.1-2010. PNNL-20405. Pacific Northwest National Laboratory, Richland, WA.

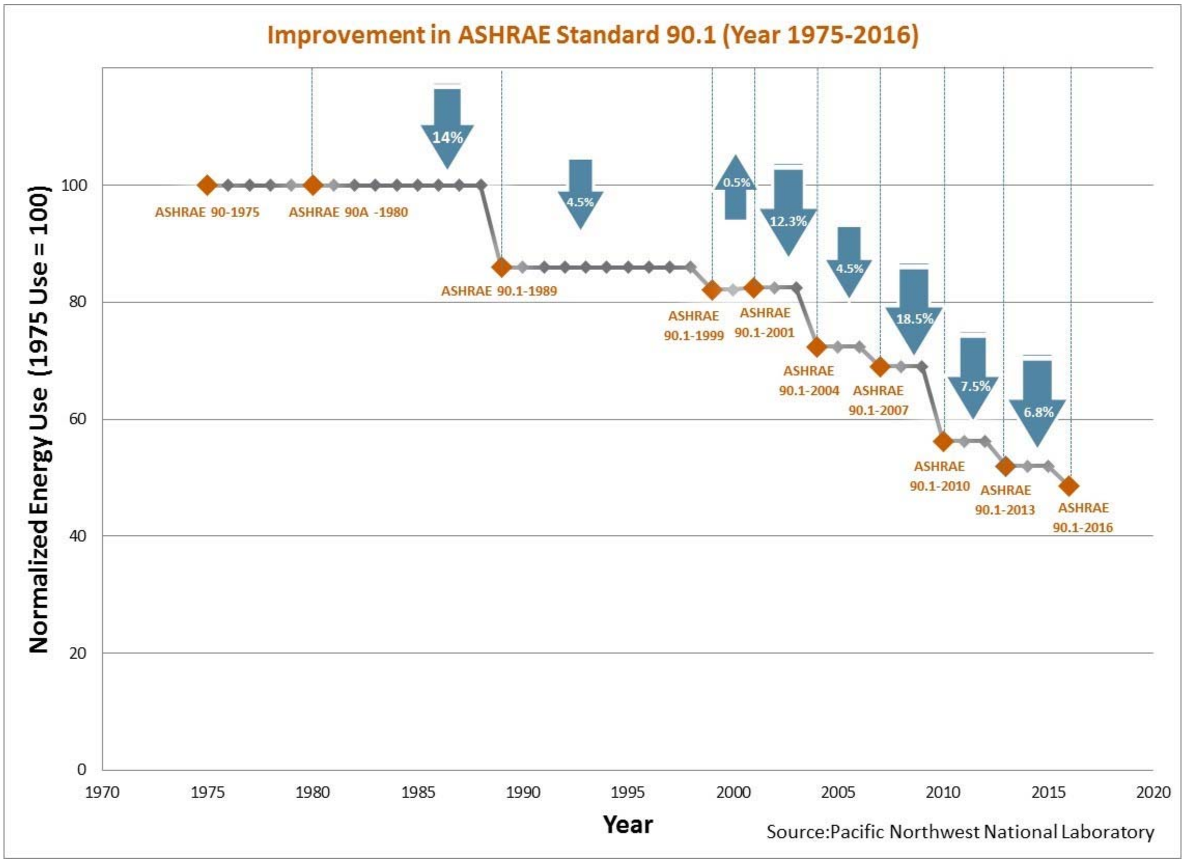

Figure 1 Standard 90.1 Improvement

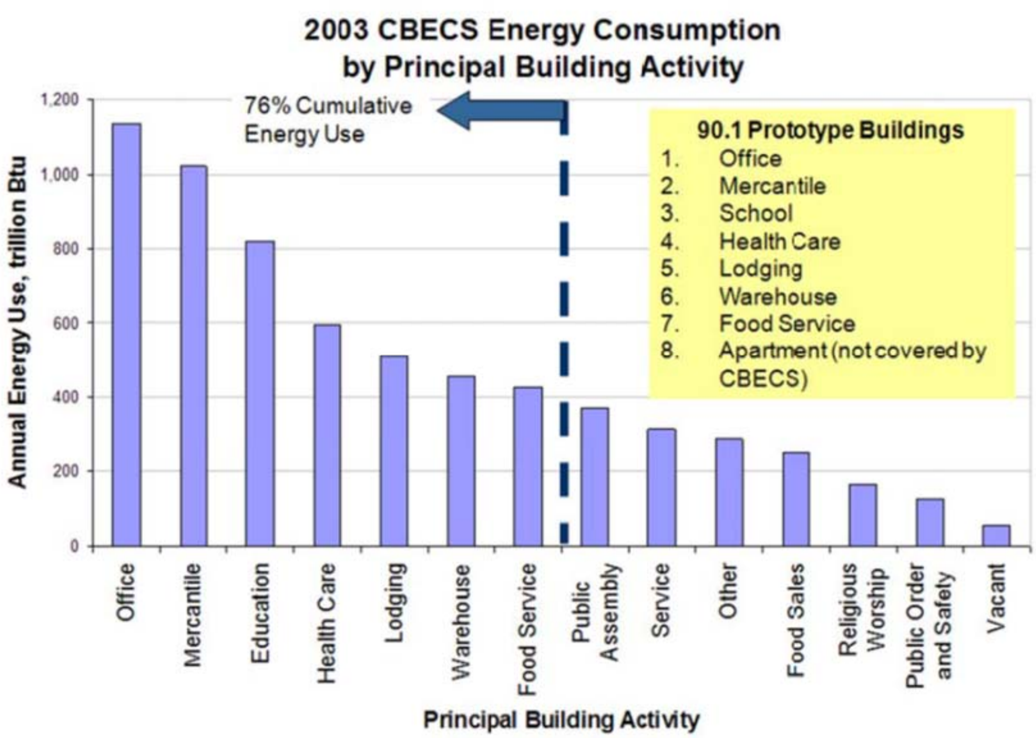

Figure 2 CBECS 2003 Energy Consumption

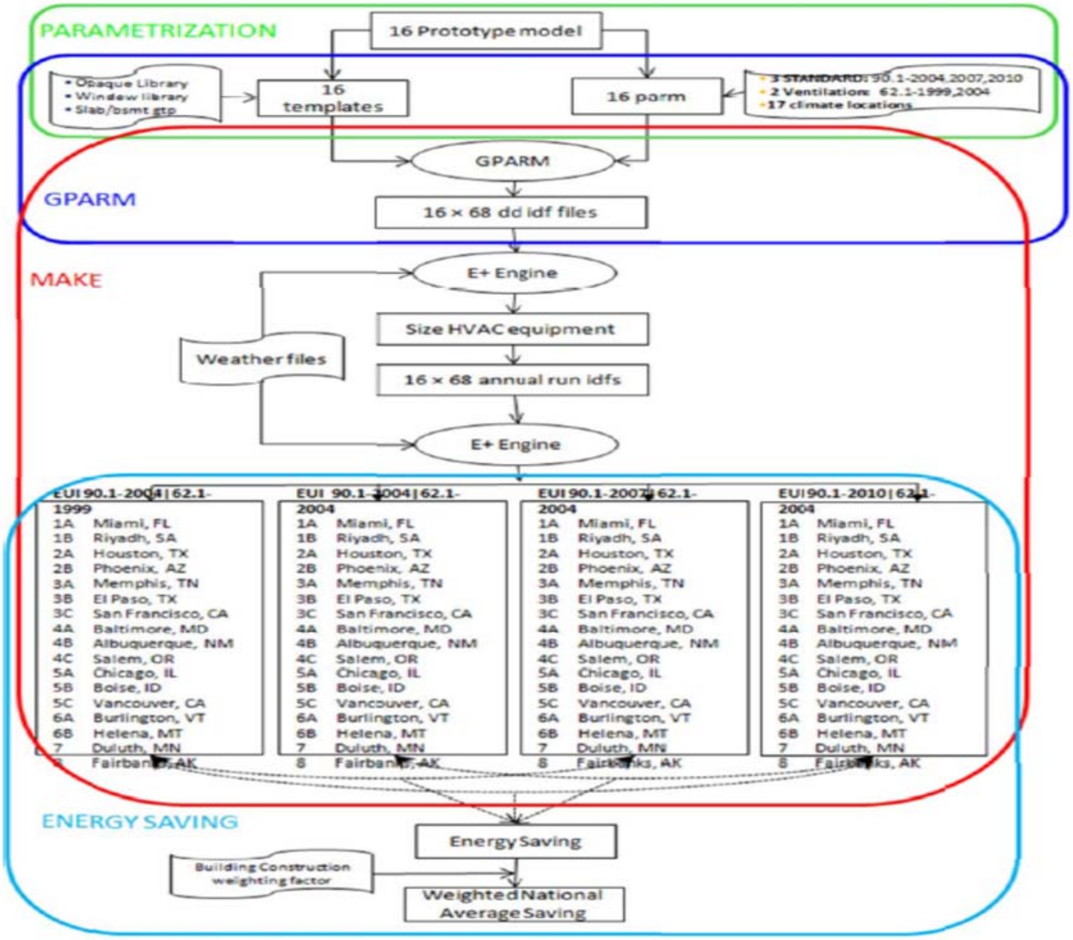

Figure 3 Flow Diagram of PI Simulation Framework

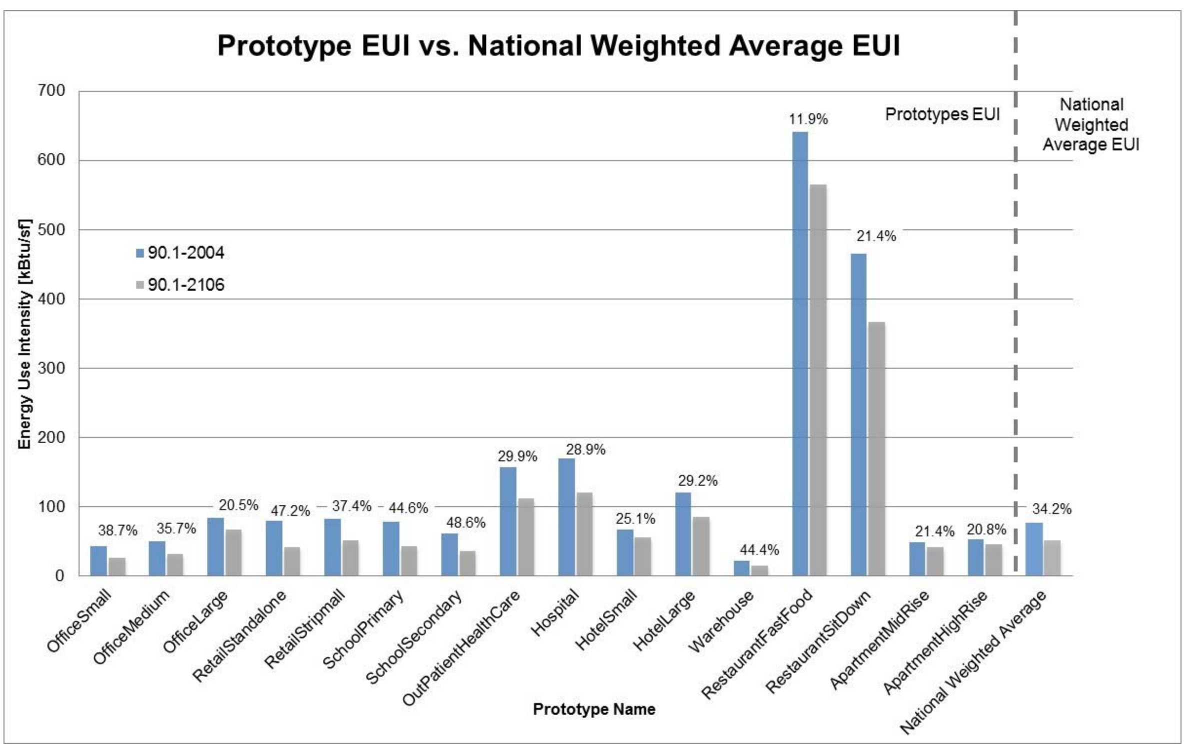

Figure 4 90.1-2016 Energy Savings by Building Type