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A SIMPLIFIED ENERGY MODELING APPROACH FOR BUILDINGS

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ABSTRACT

This paper introduces simplified energy modeling (SEM) approaches using DOE2 and EnergyPlus and proposes a validation method for simplified energy modeling. Simplified energy modeling can allow more design teams and owners to leverage the power of energy modeling to inform their designs and lead to greater energy savings and a lower first cost because the technologies and design strategies can be thoroughly tested against models before the decisions are made. By starting a discussion on how to develop simplified energy modeling approaches and methods to validate results, we hope to increase innovation in energy modeling software while decreasing variation between modelers.

Simplified modeling is not yet widely accepted because it is unclear if the simplifications reduce the accuracy of the results. By starting an industry dialogue on a testing method for these modeling approaches, we hope to aid adoption of more streamlined tools when they can be shown to provide similar accuracy to more detailed tools. This paper discusses the need and advantages of a SEM approach and proposes a method to test simplified energy modeling programs against the Pacific Northwest National Laboratory (PNNL) prototype buildings. It builds on the testing procedure established for simulation engines by ASHRAE Standard 140. By comparing whole building and end use results from the accepted prototype buildings to any simplified modeling approach across multiple building types and climate zones we can determine if the simplifications create unwarranted error. We will present the SEM approach and results for a case study validation for a sample building types in 16 US climate zones from two such simplified energy modeling tools we can determine if simplifications create unacceptable and unwarranted error. This paper does not intend to wholly validate any given SEM tool, but to lay out a path for validating SEM tools generally.

INTRODUCTION AND PURPOSE

The intent of Simplified Energy Modeling is to provide comparative analysis to influence decision making during design for projects that are not currently using energy modeling for various reasons which could include the cost of the process of complexity of the process. By reducing the time and effort to create an energy model, while still providing a valid analysis, Simplified Energy Modeling has the promise to help drive more informed energy decisions. Energy modeling is a key enabler of energy efficiency, by allowing design teams to quantify the impact of their decisions, compare alternatives, and select the option that provides the best overall performance considering energy, design, and budget constraints. "Energy modeling supports system-level integrative design that simultaneously optimizes the building's envelope and systems to match its anticipated use profile and local conditions" (US Department of Energy, 2016). The available data indicates that energy modeling is not currently done for most buildings. The annual report of AIA 2030 indicates even for the 175 architecture firms that have voluntarily pledged to meet stringent energy goals, and report on their progress, 68% of their projects are not using energy modeling (Mella & Holdridge, 2017). This suggests that within the overall design community there is even greater opportunity as, presumably this self-selected population (AIA 2030 participants) is doing energy modeling at a higher rate than the other 20,000 architecture firms in the U.S. (Design Intelligence LLC, 2017). This paper discusses how a SEM approach can help address this issue and also proposes a validation approach for testing and verification of simulation tools that use the SEM approach.

SIMPLIFIED ENERGY MODELING CONCEPT

Simplified Energy Modeling (SEM) applications allow a user to specify a proposed building with a limited number of inputs and calculate the energy savings compared to a baseline. The inputs are limited to the key variables that impact the energy savings, The applications do this by extrapolating and interpreting the key inputs into appropriate simulation engine inputs to create a valid input file for the proposed design, and automatically generate the input file for the baseline design. This automation reduces the time and effort needed to create a model while at the same time increasing the consistency between modelers. With current practice there is substantial personal judgement that goes into creating an energy simulation of a building. One study found that with twelve professional energy modelers were given the same building, the modeled monthly energy consumption predictions ranged from 500 to 5,000 kWh (Berkeley, Haves, & Kolderup, 2015). In the US Department of Energy Multi-Year Plan for the Building Technology Office, they stated:

Inconsistency across tools pale in comparison to inconsistencies across modelers. Energy modelers are sparsely distributed, under-trained, and often poorly supported. Few architecture and mechanical engineering programs include energy modeling in their curricula and do not produce professionals with adequate building physics and modeling knowledge. Although advances have recently been made, the infrastructure for training is sparse, and few modelers seek professional certification. Further, basic modeling procedures are not documented, and best practices are slow to spread to practitioners. (US Department of Energy, 2016)

Simplified Energy Modeling has the potential to overcome several of these barriers to widespread adoption of energy modeling. It reduces the need for training, it automates the use of best practices, and produces more consistent results.

Reviewing Simplified Energy Models is also simpler than with current detailed models. Under the current practice a modeler creates an input for both the proposed design and baseline building. A reviewer needs to verify that the model matches the design attributes found in the construction documents, and that it was modeled properly, that the baseline was properly derived from the proposed design, and that it was modeled following the rules defined in the energy code or standard. With simplified energy modeling, a reviewer's task is simplified. The verification tasks is limited to corroboration of model inputs against the design documents and verification of the prescriptive/mandatory code requirements that are not addressed by a SEM tool.

ATTRIBUTES OF A SIMPLIFIED ENERGY MODEL

There are many different techniques available to create savings calculations based on simplified inputs. This paper is focused on defining the SEM approach and the validation technique for simplifications that use physics based simulation engines (as opposed to multivariate regression models). As such, we propose the following criteria for Simplified Energy Models:

ASHRAE Standard 140 Validated Simulation Engine

A SEM tool would be built on a ASHRAE Standard 140 (ASHRAE 2014) validated simulation engine, such as DOE 2 or EnergyPlus. Tools using pre-simulated databases or regression analysis would not meet this criteria.

Automatic Generation of Baseline Building Models

SEM tools used for performance based code compliance or beyond code programs, would support the automatic generation of the baseline building model following ASHRAE Standard 90.1 Appendix G approach (ASHRAE 2013). This allows these models to be used for code compliance, as in the case of ASHRAE Standard 90.1-2016 (ASHRAE 2016), or for beyond code programs such as LEED certification or federal tax credits.

Simplified Approaches for Energy Modeling

The simplifications made by these tools should be well defined and tested, to provide a standard approach for this capability. The section below defines the minimum simplifications required for a tool to qualify as a Simplified Energy Modeling tool-

Standard Schedules and Loads

SEM tools would use standard schedules of operation and thermostat setpoint. These could be based on the COMnet Modeling Guidelines and Procedures (COMnet 2017), the Performance Rating Method Reference Manual (Goel 2017) or ASHRAE Standard 90.1-2013 Appendix C (ASHRAE 2013). Internal loads, specifically the plug loads, ventilation rates and service hot water loads, would also be prescribed based on the building use type. HVAC system performance curves would also be prescribed and not modifiable by the user.

User Interface Capabilities

A SEM tool would provide a more streamlined data entry process which prevents invalid simulation inputs (for instance, enclosed spaces or incorrectly modeling HVAC systems). It would also automatically assign the schedules and internal loads and prevent users from modifying the same. SEM tools would hence allow only valid simulation model inputs and restrict a user's ability to directly modify the energy simulation input files to prevent incorrect data entries.

Simplified Building Geometry

The SEM tool should support a simplified geometry capability which can create a geometric representation of the building with minimum variations of building footprint area, exterior surface area, building volume and fenestration area. The simplified geometry capability should support a capability which allows a user to represent their building form with less than 10% variation is gross floor area, exterior surface area, building volume and less than 5% variation for fenestration area over the entire building facade.

Automatic detailed geometry creation based on simple inputs

Thermal Zone Layout

SEM tools would allow for simplified thermal zoning which meets the following criteria

- SEM tools would allow separate thermal zones to be created for interior and perimeter spaces.
- It would allow separate zones to be created for each orientation as well as external boundary condition, i.e. zones in contact with the ground or exposed to ambient condition from adjacent zones.

Mechanical System Sizing

SEM tools would support autosizing of HVAC systems based on a sizing run. The systems would be oversized by a factor of 15% for cooling and 25% for heating.

Automated Standard Reports

SEM tools would include a capability to write out automated standard reports that document all model inputs, standard assumptions, system sizes and efficiency values. It should include standard validation checks like unmet heating and cooling load hours, system design airflows, outdoor air flows etc.

PROPOSED VALIDATION APPROACH

The validation of any SEM tool would require testing and verification of its results through a two step process:

- Simplification Validation: Validate variability in simulation results due to simplifications made by the tool
- Application Validation: Validate variability in simulation results based on the application of the SEM tool.

The simplification validation would be a mandatory verification that each SEM tool would be required to do. This test would identify the variation in energy use by end use results arising due to the simplifications made by the tool. This test has been further described in the section below.

The application validation would be based on the application of the SEM tool. It would depend on the purpose to which the SEM tool would be applied (code compliance, green building certification program or utility incentive programs). A SEM application could submit to be approved for all PNNL prototype building types, or a subset of these building types, depending on the tool's modeling capabilities. A few scenarios for application validation have also been discussed below.

A rating authority would review a SEM application and approve it for general use, or under specific circumstances to either claim code compliance, beyond baseline performance, or submit for utility incentives. The SEM application reviewer would need some level of expertise in energy modeling to review results for certifying the use of the SEM tool.

Simplification Validation

The purpose of the simplification validations is to identify the variability of simulation results arising due to the simplified modeling approach, use of standard assumptions and schedules, simplified thermal zoning and autosizing of HVAC systems. These test would be carried out using the PNNL prototype buildings.

For energy codes development and evaluation, PNNL has developed a suite of 16 building prototypes representing 80% of new construction floor area in the United States (Thornton et al 2011). The prototypes are publicly available. Because these models cover a variety of HVAC system types and common energy efficiency measures, they are used to benchmark the modelled performance results from Asset Score. The prototype building models (Thornton et al. 2011) cover a range of energy efficient design practices and the characterization of the same through the SEM tools tool have been tested through this analysis. The analysis would compare the energy use by end use of the simplified models, against the energy use by end use of the building models for all 17 climate zones, modeled to meet requirements of Standard 90.1-2013.

Through this validation process, energy use differences are expected due to two reasons:

- Model Simplifications: SEM tools simplify the energy model definition, as discussed in the previous section. These simplifications result in variations in energy use by end use results, as seen in Figures 1 through 8.
- Schedules and Loads: The ventilation rates, operation schedules and plug loads vary between the SEM models and Prototypes. These result in in variations in energy use as well. A second set of analysis can be carried out to normalize for the differences in the schedules of operations, and ventilation loads and compare the results of the modified prototypes against energy use from the SEM tools. This helps distinguish the energy use variations occurring to the model simplifications versus the variations due to different operating assumptions.

The acceptance criteria for this testing have been proposed to be:

- Total site energy consumption within either 10% or 5 kBtu/ft^2, whichever is greater.
- End-use site energy consumption within 20% or 3 kBtu/ft^2, whichever is greater

Results for two SEM tools have been discussed in the following sections. The details of the prototype buildings (Table 1) are entered into the SEM tools, to create the simplified energy model. The results from the SEM tools have been compared against the results of the detailed models for variations in the energy use by end use. This analysis has been carried out for 17 climate zones (Briggs et al. 2003), listed in Table 2. Energy uses by end use results are compared between the prototype model and the simplified model to identify differences in results. In a second set of tests, the prototype building models were modified to have the same infiltration and ventilation rates as the simplified models. They have also been modified to use the same schedules of operation as the simplified models. These include the occupancy, lighting, infiltration, equipment, thermostat and HVAC operation schedules. There remaining sources of variation between the prototypes and SEM tools include geometry assumptions, automatic sizing and thermal zoning, simulation engines, modeling interpretation, and any other assumptions or derived inputs that are created by the SEM tools.

Here the expectation is for all climate zones to meet the acceptance criteria. The following section discusses results from two SEM tools which were used to analyze the original and modified prototype buildings.

Table 1 Prototype Building Types

Apartment (High-rise)	Outpatient (Health Care)
Apartment (Mid-rise)	Restaurant (Fast Food)
Hospital	Restaurant (Sit Down)
Hotel (Large)	Retail (Standalone)
Hotel (Small)	Retail (Strip Mall)
Office (Large)	School (Primary)
Office (Medium)	School (Secondary)
Office (Small)	Warehouse

Table 2 Climate Zones Analyzed

CZ		CZ	City, State
1A	Miami, FL	4B	Albuquerque, NM
1B	Riyadh, Saudi Arabia	4C	Salem, OR
2A	Houston, TX	5A	Chicago, IL
2B	Phoenix, AZ	5B	Boise, ID
3A	Memphis, TN	5C	Vancouver, BC
3B	El Paso, TX	6A	Burlington, VT
3C	San Francisco, CA	6B	Helena, MT
4A	Baltimore, MD	7	Duluth, MN
		8	Fairbanks, AK

<u>Test Results for SEM Tool 1</u>

Initial comparison of the original prototype models and the SEM results (represented as NEO in the results) were within the acceptable range for total energy use, but not within the acceptable range for heating and cooling energy consumption. Updates were made to the prototype buildings to normalize for operation parameters (including setpoint schedules, lighting schedules etc.) to remove schedules as a parameter contributing to this variation and identify the variations caused by using the simplified approach instead.. With the normalization, all criteria were met except for cooling in Houston and Miami (2 of the 17 climate zones).Simplification of the modeling approaches results in overestimation of energy consumption, as was seen in these two climate zones. This is because simplified approaches are not able to represent all parameters of a detailed energy modeling tool. For instance, SEM approach is restricted to a perimeter and core thermal zoning or a single zone per floor approach which contributes to some of the variations seen when compared to a detailed energy model.

The results for this analysis are shown in the figures below. The total energy consumption in all climates met the acceptance criteria, as well as the heating and cooling EUIs for all climates, and 185 of the 187 end use permutations. We propose that this sufficiently matches the acceptance criteria to show that SEM can validly be used to demonstrate energy performance for a small hotel.

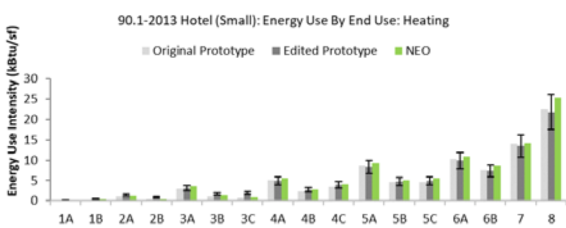

Figure 1 Small Hotel Heating Energy Use Comparison

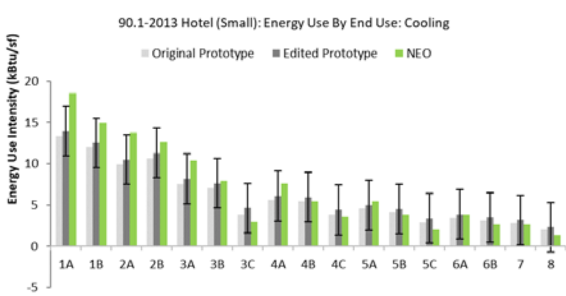

Figure 2 Small Hotel Cooling Energy Use Comparison

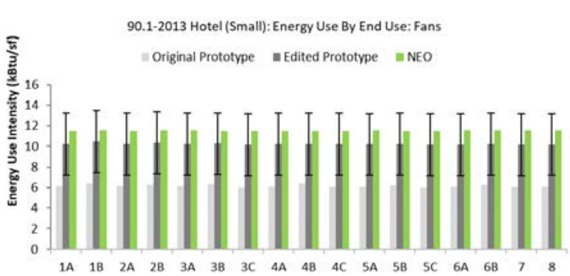

Figure 3 Small Hotel Fan Energy Use Comparison

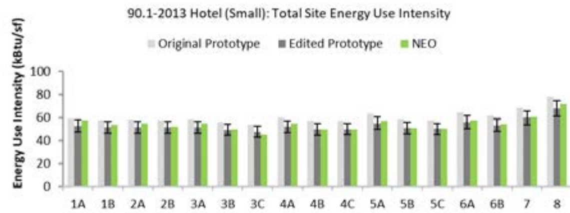

Figure 4 Small Hotel Total Site Energy Use Comparison

<u>Test Results for SEM Tool 2</u>

Similar to the previous analysis, an additional SEM tool (represented as 'AS Model) was analyzed against the small office and standalone retail prototype building. The tool's user interface was used to model the prototype building and the results were compared against the detailed building run. An additional comparison was done where the prototype buildings were modified to use the same schedules, internal loads, infiltration and ventilation rates as the SEM tool and were compared against the results from the simplified building. The results fall within the acceptance criteria in all climate zones, except climate zone 8.

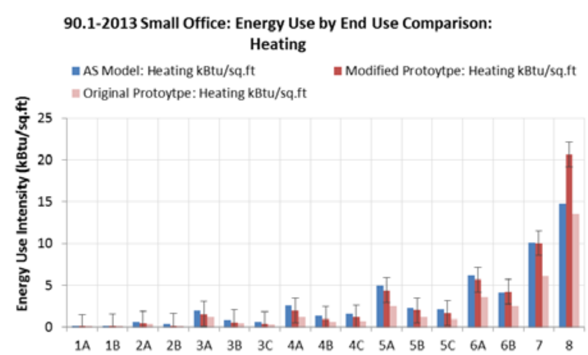

Figure 5 Small Office Heating Energy Use Comparison

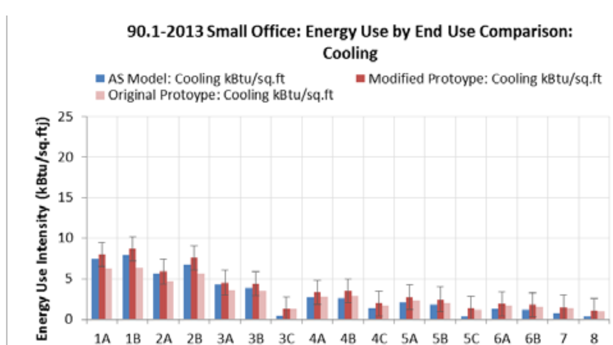

Figure 6 Small Office Cooling Energy Use Comparison

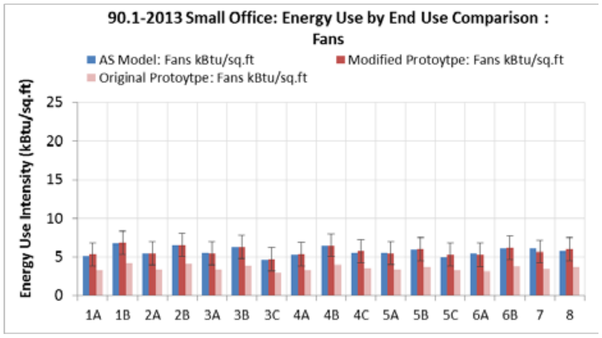

Figure 7 Small Office Fan Energy Use Comparison

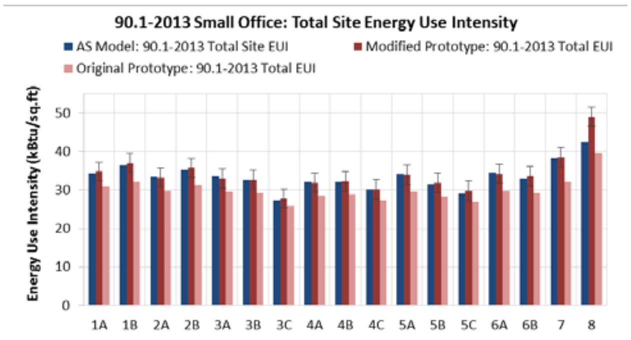

Figure 8 Small Office Site Energy Use Comparison

Application Validation

The application validation criteria would be developed to be specific to the application of the SEM tool. For instance, if the SEM tool is used to identify potential candidates for utility incentive programs, then the validation process would include testing of typical energy efficiency measures using the SEM tool and comparison of the resultant savings of the measure against a detailed modeling tool. For such a use case, the SEM tool will need to provide documentation on any energy efficiency, renewable energy, or mechanical systems it wishes to be able to claim savings credit for by providing sample results including input and results files from the simulation engine, and savings for each such strategy and mechanical system.

Similarly, in the use case of SEM tools being applied as an alternate compliance option for green building certification systems, a validation criteria based on verification of the automatically generated baseline system would need to be applied. The validation process would include some standard tests for verifying the Appendix G baseline rules such as the window to wall ratio limitations, fan power limitations, number and efficiency of HVAC systems etc. In addition to the standard tests, the validating authority shall provide 5 to 8 sample design scenarios for identifying the variations in energy savings predicted through the detailed energy model, as compared to the simplified energy model. The acceptance criteria for the application validation would be dependent on the application itself and would need to be developed in conjunction with the authority implementing the SEM approach.

POTENTIAL APPLICATIONS

With Simplified Energy Modeling showing promise that it can produce results consistent with detailed modeling, and the majority of projects being done even by the self-selected group interested in sustainability enough to report on their 2030 Challenge progress not getting modeled, there is ample opportunity for simplified energy modeling to benefit projects that are currently receiving no energy modeling.

Informing Design Decisions

Various forms of simplified modeling, including “shoe box models”, adjusting previous detailed models to reflect new buildings, or using prototype models have been used by modelers to provide quick answers to design decisions. SEM provides a way to make that work more consistent, and more flexible. A SEM could be used early in design to decide the mechanical system type, or the energy impacts of a package of measures. Because a SEM can be completed in a few hours to a day, that feedback can be much quicker than building a detailed model

Green Building Rating Systems

SEM would provide several benefits to green building rating systems. SEM would make the modeling more consistent, and reduce the time to review models by limiting review to a smaller number of inputs. SEM can also make modeling cost effective for smaller buildings than it currently is.

Code Compliance

With the adoption of Addendum BM to ASHRAE 90.1-2013, code compliance can now be demonstrated by achieving a percent improvement beyond ASHRAE 90.1-2004 that is adjusted for each new version of ASHRAE 90.1. SEM could be used to find the most cost effective way to be code compliant for a specific building, in a specific climate. This provides a better, and more cost effective fit between the technologies and their specific use case in a given climate and anticipated building use.

Utility Demand Side Management (DSM) Programs

Many utilities in the United States are required by state regulators to invest in energy efficiency. These program often use prescriptive rebates based on average savings for a given technology rather than building specific energy modeling. SEM has been used by utilities in 12 states to provide DSM programs that allow building specific savings and paybacks to be calculated in a cost effective manner for buildings as small as 5,000 sf. With SEM, some of the programs are getting 70% of all commercial new construction in their service territory to have energy modeling during design development.

NEXT STEPS

The authors are presenting these ideas in hopes of receiving feedback on them and suggested refinements. Our ultimate goal is to create a sound, and accepted method for software developers to have simplified energy modeling tools vetted and accepted for use to inform design, calculate savings, and ultimately save more energy by having the custom solutions developed for buildings. We are presenting this idea for the first time here to the modeling community, and hope to also present it to the policy community, and to the design communities. It is our belief that SEM will enable increased adoption of energy modeling, and allow greater savings in a cost effective manner by allowing design professionals to find HVAC systems and efficiency and renewable energy strategies that are well matched for their building and climate.

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