Integration of the CEN/ISO Monthly Building Energy Model into OpenStudio

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ABSTRACT

Modeling of the energy use of buildings is an extremely complicated endeavor. Modeling existing buildings is difficult because the model parameters must match the details of an existing building, many of which are unknown. Modeling buildings to be constructed is also difficult because many details of the building have not yet been designed. Fast and reasonably accurate building energy models allow designers and analysts to rapidly assess the inherent range of building energy consumption when many model parameters are uncertain. One such building model is the monthly model developed the by European Committee for Standardization (CEN) and the International Standards Organization (ISO). The CEN/ISO building model is the basis for the Energy Performance in Buildings Directive (EPBD) of the European Union.

The paper describes the development and application of a specific implementation of the CEN/ISO monthly energy method as C++ code that has been integrated into the OpenStudio building energy modeling platform and software development kit. The new code has the potential to greatly improve automated modeling and calibration of existing buildings, especially for buildings where limited data are available. Because the model runs extremely fast, it is also especially suitable for parametric and/or Monte Carlo studies that can be used to evaluate the possible range of energy use of a building yet to be constructed.

Introduction

The European Performance of Buildings Directive (EPBD) requires that member states establish a common methodology for estimating the energy performance of buildings. To address this requirement, the European Committee for Standardization (CEN) worked with the International Standards Organization (ISO) to develop a set of standards to be used for the required calculations. An overview of the entire set of standards can be found in the CEN EPBD "Umbrella Document", CEN/TR 15615 (CEN, 2008). A good summary of the most important standards is given by Roulet and Anderson (2006) with the single most important being ISO 13790:2007 Energy Performance of Buildings - Calculation of Energy Use for Space Heating and Cooling (ISO, 2008).

ISO 13790 defines two routes for calculating the net energy for heating and cooling: 1) simplified methods based on seasonal, monthly or hourly calculations using simplified descriptions of the building and 2) detailed calculations, typically made with dynamic energy simulation programs. While the simplified methods are limited in the types of building systems that can be modeled and the number and types of outputs from the simplified model are similarly limited, the annual heating and cooling energy for a number of typical buildings types compares well to validated dynamic energy simulation programs (Kokogiannakis, Strachan and Clarke, 2008).

OpenStudio (NREL, 2014) is a building energy simulation platform and software development kit (SDK) developed by the National Renewable Energy Lab (NREL) which uses EnergyPlus (DOE, 2014) as one of its primary energy simulation engines. It is a very capable software application for building energy modeling and versatile SDK for developing building energy modeling software.

In this paper we describe a C++ implementation of the basic monthly CEN/ISO calculation method, as described in ISO 13790 and companion documents, that has been integrated into the OpenStudio SDK. We show an application of the model to quickly analyze the uncertainty inherent in predictions of Energy Use Intensity (EUI) of a building during both the early conceptual and early schematic design phase. It should be noted that an implementation of the hourly method is currently being developed as well. The hourly method is expected to be somewhat slower than the monthly method but still orders of magnitude faster than typical dynamic simulations. The primary differences between the hourly and monthly relate to the time resolution of calculations (obviously) and how solar radiation and thermal mass are

Background

Full use of the CEN/ISO model for compliance with EPBD involves a large number of CEN/ISO standards that are specific to EPBD compliance, but the basic CEN/ISO monthly energy model is described primarily in ISO 13790 (ISO 2008a) with reference to a handful of other standards. The documents specifically referenced within the OpenStudio implementation of the ISO model are:

- ISO 13790 Energy for Heating and Cooling Loads,
- ISO 13789 Envelope Transmission Properties (ISO 2008b),
- EN 15421 Ventilation Systems (BSI 2007a),
- EN 15242 Air Flow/Infiltration (BSI 2007b) ,
- EN 15243 For Room Conditioning Systems (BSI 2007c),
- EN 15193 Lighting Systems (BSI 2007d), and
- NEN 2916 Domestic Hot Water Systems (NEN 1998).

The CEN/ISO monthly model is a quasi-steady state whereby the monthly average temperature, wind speed, and average solar radiation on the façade are combined with hourly variations of the temperature and global horizontal solar radiation averaged for each month to develop the exterior building loads. These exterior loads are combined with internal lighting, equipment, and occupant heat generation to compute the average monthly heating and cooling loads for the building. The building envelope is treated as a composite assembly with total R values for walls and roofs and total U values and solar heat gain coefficients (SHGC) for fenestration. Thermal absorptivity and emissivity of the outer surfaces, exterior and interior shading of the fenestration, and heat capacity and infiltration through the envelope are also included

Heating, ventilation, and air conditioning (HVAC) and domestic hot water systems are not modeled in detail at all, but their contribution to energy use are included through the use of overall or average efficiencies and loss factors for the distribution systems and utilization factors that attempt to account for dynamic effects of solar radiation transfer and energy storage of the building mass. This lack of detail limits the applicability of the monthly model but is a key part of both the speed of the monthly model and the ability to use the monthly model with limited information about the building systems.

A diagram of the basic inputs and outputs for the monthly model are shown in Figure 1 below. The reader is referred to ISO 13790 and the papers cited in the introduction above for more complete descriptions of the monthly model. The model has a number of fixed inputs that describe the basic building program, the envelope characteristics and geometry, equipment and systems. The model has one variable input, monthly weather data. The model then estimates the monthly average energy heating and cooling load and from that monthly energy use in many end use categories.

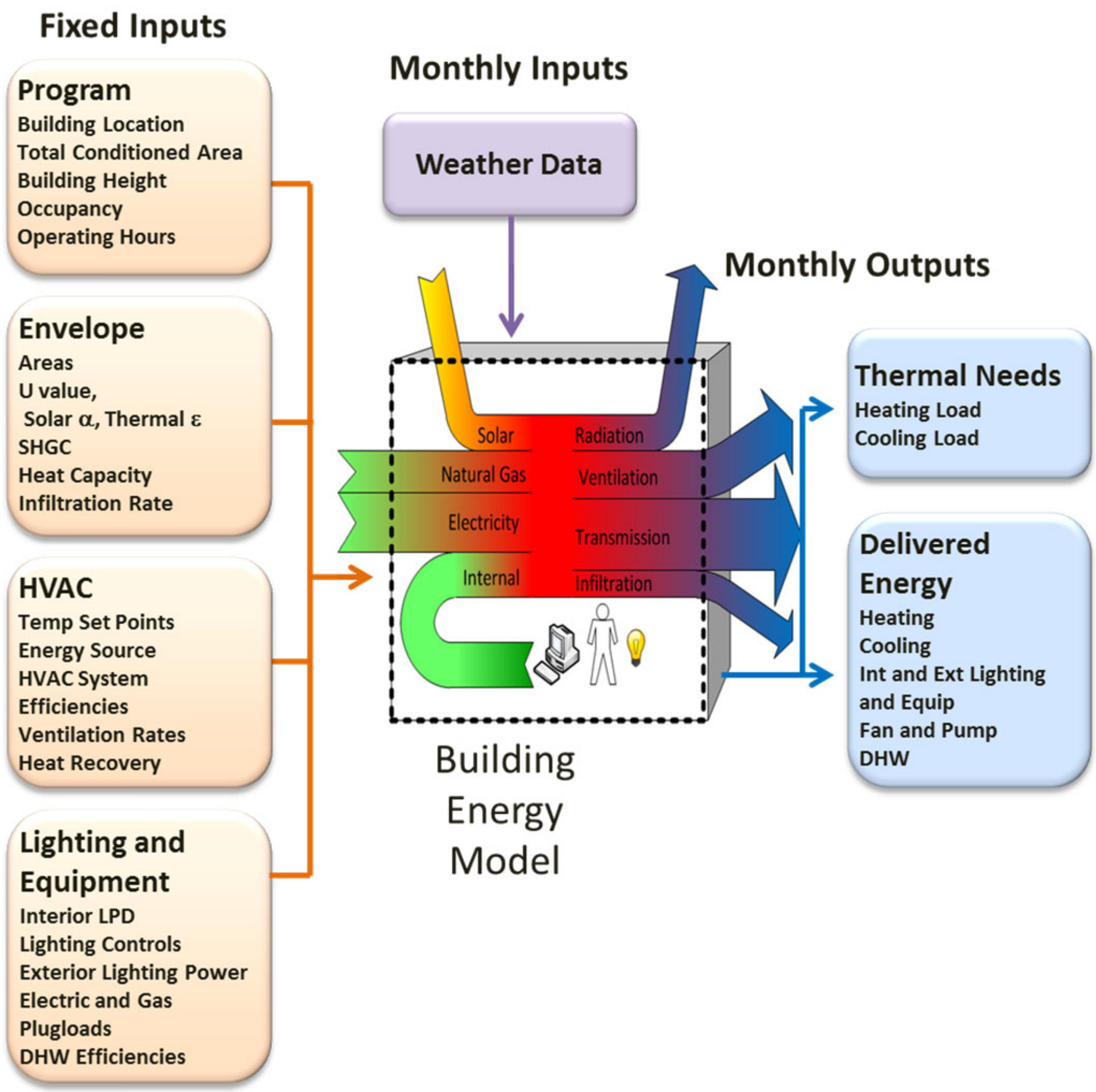

Figure 1. Inputs and outputs of the CEN/ISO building energy model.

CEN/ISO Model SWOT Analysis

The weaknesses and limitations of using the monthly method are well balanced by strengths and opportunities that result from the speed of execution and limited need for HVAC system details as described in the Strengths/Weaknesses/Opportunities/Threats (SWOT) analysis chart seen in Figure 2 below. In particular, the speed of analysis allows for fast parametric and Monte Carlo uncertainty analysis for early design studies as well as for uncertainty analysis when trying to model existing buildings with limited knowledge of building parameters. In many early design scenarios, absolute accuracy of the energy predictions is not particularly important, but it is an accurate comparison of relative energy use of design choices or energy conservation measures (ECMs) that is needed. The CEN/ISO model is particularly suited to this sort of design choice analysis.

Because this implementation is part of the open source OpenStudio SDK, programmers, engineers, and architects have the ability to develop links between their early design tools of choice and the CEN/ISO energy model and generate real-time estimates of monthly energy use as building geometry is modified. Users can also make use of the OpenStudio ability to import gbXML and IDF files for generating CEN/ISO energy models.

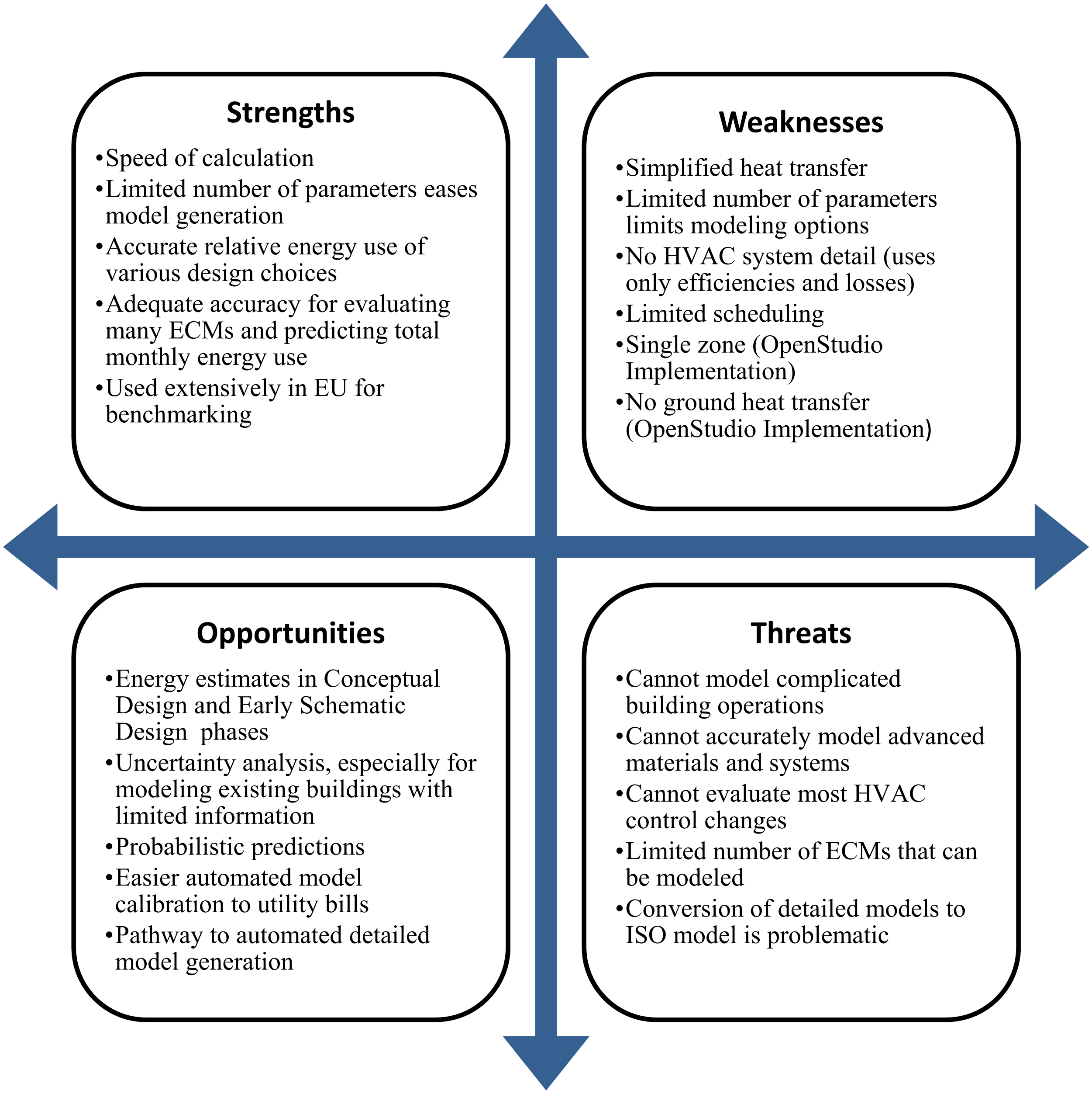

Figure 2. Strengths/Weaknesses/Opportunities/Threats (SWOT) Analysis Chart for the CEN/ISO Model.

OpenStudio and the OpenStudio ISO Model Implementation

OpenStudio is both an analysis platform and a software development kit. As an analysis platform, OpenStudio acts as "middle ware" between software that generates building geometry and a building simulation engines such as EnergyPlus. For building energy modeling, most users would generate geometry in some other software package or using the Sketchup plug-in, add system details and scheduling in OpenStudio and then run analysis in EnergyPlus or Radiance (or both). For users who are doing early stage design, OpenStudio can automatically add default schedules and systems to models so users can do early stage analysis after only generating basic geometry. However, EnergyPlus is not a particularly fast energy simulation program and the execution time of OpenStudio native models converted to EnergyPlus makes parametric or uncertainty analysis of such models slow and costly. It is for this reason that a version of the CEN/ISO model was integrated into OpenStudio.

The current OpenStudio implementation of the CEN/ISO monthly model (hereafter referred to as the OpenStudio ISOmodel) implements much of the model as described in ISO 13790 but with a number of limitations. As currently implemented, the model is single-zone, so users who want to model multi-zone buildings need to model the separate zones as separate buildings. The current OpenStudio ISOmodel does not include ground heat transfer so the accuracy prediction for low-rise buildings, where ground heat transfer is more important, is limited. The current OpenStudio ISOmodel envelope geometry is limited to eight uniform walls in the eight main cardinal directions (North, South, East, West, Northwest, Northeast, Southeast, and Southwest) with one window on each wall and one roof. Buildings with more complex walls and window constructions must be modeled using area weighted average properties. Infiltration (envelope leakage) is modeled as a whole building single value input as the whole building infiltration volume flow rate per unit area of building envelope at a 75 Pa pressure difference across the envelope.

HVAC systems are modeled by a coefficient of performance (COP) for cooling systems, an efficiency for heating systems, and by three system loss factors: cooling system loss, heating system loss, and a waste factor (losses from simultaneous heating and cooling). The user can find tables of typical values for these losses for various system types in the CEN/ISO standards. Domestic hot water systems are modeled by a system efficiency and distribution efficiency.

The current OpenStudio ISOmodel outputs monthly energy use for both gas and electricity in eight end use categories: heating, cooling, interior lights, exterior lights, interior equipment (plug loads), fans, pumps, and domestic hot water.

The OpenStudio ISOmodel is fully integrated into the OpenStudio SDK as an OpenStudio object which is accessible to users through the Ruby, C#, and python bindings as well as through Ruby “measures” that can be run from the main OpenStudio application or the Parametric Assessment Tool (PAT). Users can either define an OpenStudio ISOmodel directly or use a forward translator which will analyze a standard OpenStudio model and create an “equivalent” OpenStudio ISOmodel. Unfortunately, the current translator is quite limited in functionality. Basic building geometries and wall constructions are translated well, but non-flat roofs and attic spaces are currently not converted properly. Buildings with advanced technology windows are not well converted. Buildings with schedules that do not vary from week-to-week are translated well but buildings with schedules that change from week-to-week are not. Perhaps most importantly, HVAC system types are not identified and so proper assignment of HVAC losses and utilization factors are left to the user. Occupancy and daylighting controls are not always properly identified. As a result, conversions with the current forward translator for anything but simple buildings need to be checked and possibly corrected by users before the energy prediction results can be trusted.

A single run of the OpenStudio ISOmodel takes about 5 milliseconds when called from Ruby (the scripting language used by the OpenStudio SDK). This represents a 1000x – 1000000x speed increase over a single run of the EnergyPlus model from OpenStudio, depending upon the complexity of the building design. The forward translation of the OSM to the ISOmodel takes hundreds of milliseconds so users who are considering very large parametric or Monte Carlo analysis are encouraged to write scripts that translate an OpenStudio model to ISOmodel once and then directly iterate changes on the ISOmodel for parametric or Monte Carlo analysis rather than iterate changes on the OpenStudio model and convert to an ISOmodel after each manipulation.

Example

As one example of the use of the OpenStudio ISOmodel, consider the prediction of the energy use for a building in the conceptual and early schematic design phases. In the conceptual design phase, most building system parameters are unknown and systems types and construction materials may not have even been selected. The designers often want to know possible range of overall yearly energy use intensity (EUI) given the possible types and combinations of envelope materials, building systems and variations in both interior equipment loads and scheduling. At the schematic design phase, the range of possibilities has been greatly narrowed as many materials and system types have been eliminated; however there are still some uncertainties in most parameters because details of the implementation are not yet known. Both of these design scenarios can be analyzed by parametric sweeps or Monte Carlo analysis.

The example building we analyze here is a 32 story office building located in Chicago, IL, USA, as shown in Figure 3 below. The building is a typical high-rise office building with a floor-to-floor height of 4 m, and a window-to-wall ratio of 40%. A “baseline” building was as a starting point for uncertainty analysis. The baseline building had exterior insulated steel stud walls with a composite U value of 0.33 W/(m^2K), a roof assembly with a U value of 0.23 W/(m^2K), simple double glaze window assemblies with an overall U value of 2.6 W/(m^2K) and, the HVAC system consists of many packaged VAV systems with 80% efficient gas heat and a COP of 2.7 with fixed heating and cooling temperature set points of 24 °C and 28 °C respectively. The entire OpenStudio model including geometry, constructions, schedules, and HVAC systems, was generated through Ruby scripts. As generated, the OpenStudio model has 160 total thermal zones (5 per floor) and one packaged rooftop unit per floor. The OpenStudio ISOmodel, as mentioned earlier, combines all thermal zones from the standard OpenStudio model into a single thermal zone.

Running OpenStudio on this baseline building resulted in annual EUI prediction of 87 kWh/m^2 for electricity use and 93 kWh/m^2 for gas use. Running the ISOmodel on the file converted from the OpenStudio model to ISOmodel using the current forward translator resulted in an annual EUI prediction of 78 kWh/m^2 for electricity use and only 27 kWh/m^2 for gas use. Inspection of the translated ISOmodel revealed that the infiltration rate, thermostat schedules, HVAC loss factors, internal mass, and some window properties were mistranslated for this model. These values were adjusted through hand calculation of the ISO model equivalents and with updated values, the ISOmodel EUI predictions were 80 kWh/m^2 for electricity and 84 kWh/m^2 for gas.

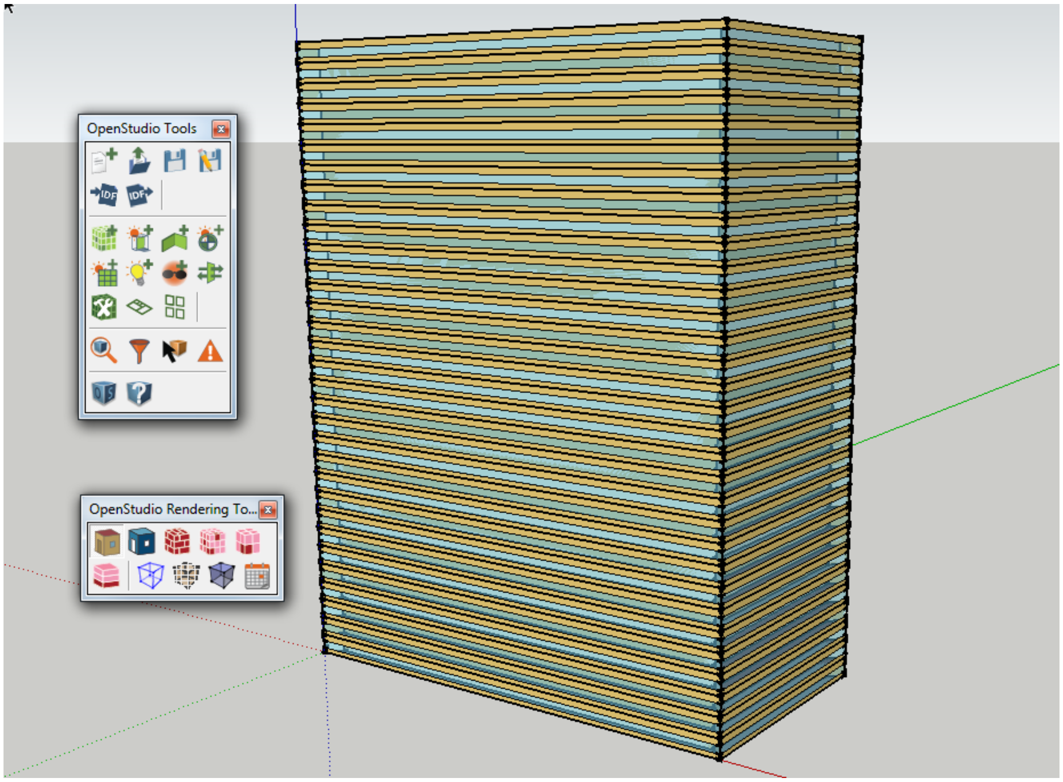

Figure 3. Example 32 story office building as rendered using the OpenStudio Sketchup Plugin.

In the conceptual phase of design the values of many building parameters are completely unknown as materials and systems have often not yet been selected. These uncertain model parameters can then be represented by uniform uncertainty distributions with maximum and minimum values determined from knowledge of the types of systems to be considered. In the early schematic phase of design, there are still many unknown parameters, but some potential systems and constructions will have been eliminated and thus the uncertainty range for most parameters is reduced. For some parts of the design, systems or constructions may have been broadly selected, but there is still uncertainty in the exact implementation. For yet other parts of the design, distributions can be used to simulate the natural variability about the design points that comes from the fact that the system is not fixed.

In particular, parameters such as lighting and plug load power densities, occupant densities, and occupant heat load, should all be considered as uncertain variables. Parameters such as these which have some highly probable value and a reduced probability away from that value can be represented by a triangle distribution where the mode (most probable value) of the distribution represents the expected value and the range of the distribution representing the range of possible values. Parameters where only a range is known are better modeled by a uniform distribution. Generic plots of the probability $p(x)$ as a function of x for both the uniform and triangle distributions are shown in Figure 4 below.

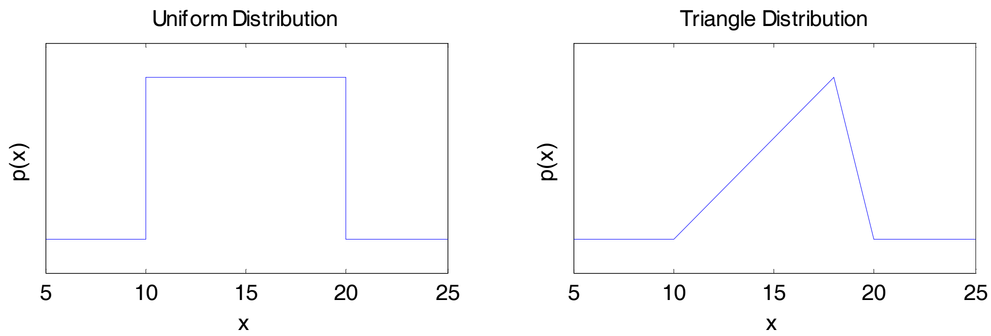

Figure 4. Plot of a generic uniform and triangular distribution. The uniform distribution has an equal probability between 10 and 20 and the triangle distribution ranges from 10 to 20 with a most probable value of 18.

For this example analysis we have decided to treat the following input parameters as uncertain: infiltration rate, thermostat settings, cooling system COP and IPLV ratio, heating efficiency, HVAC waste factors, occupant density, lighting and plug load power density, HVAC heat recovery, and thermal mass. Unfortunately, as currently written, the uncertainty measure cannot uniformly change all window and wall parameters and therefore they were not varied in this example. For the conceptual design scenario, uniform distributions were used for all variables. The ranges for these distributions were determined from an inspection of the values for common construction and system types used for the selected building type.. For the early schematic design phase scenario, the range of distributions was reduced, as described above, and several parameters were converted to triangle distributions, namely the lighting and plug load power densities, occupant density and heat load, and the HVAC loss factors. Table 1 below lists the distribution types and ranges of the parameters for both the conceptual design phase scenario and the early schematic design phase scenario. Argonne is developing a library of uncertainty values that is expected to be integrated into the Building Component Library system (NREL 2014b) in the near future.

For the example uncertainty analysis, 25,000 runs were made in a basic Monte Carlo fashion updating the value of each uncertain variable using random sampling from the uncertainty distributions on each run. The resulting EUI were saved to files and post processed to generate probability density function (PDF) and cumulative density functions (CDF) of the annual total EUI using the statistically robust nonparametric kernel density method of Botev et al. (2010). The raw data were further analyzed to determine the mean, median, mode, and 5% and 95% confidence intervals. The PDF and CDF are shown in Figure 5 below.

Analysis of the conceptual design phase probability distribution reveals the mean of the distribution to be 143 W/m^2, the median to be 142 W/m^2, and the mode (highest probability) to be 139 W/m^2. Analysis of the cumulative distribution reveals the 5% and 95% confidence intervals to be 121 $W/m^2$and 169 W/m^2 meaning there is a 90% chance of the EUI being between those two values. Analysis of the early schematic design phase distribution yields a mean and median of 127 W/m^2 a mode of 128 W/m^2 and 5% and 95% confidence intervals of 113 W/m^2 and 140 W/m^2.

Table 1. Uncertainty Information

	Conceptual Design Phase			Early Schematic Design Phase			
Parameter	Dist[1]	Min	Max	Dist[1]	Min	Mode	Max
Infiltration ($m^3/h/m^2$)	U	5	20	U	5	-	15
Lighting Power Density (W/m^2)	U	4	11	T	4	6	8
Plugload Power Density (W/m^2)	U	4	11	T	4	6	8
Occupant Density (m^2/person)	U	15	30	T	18	22	28
Occupant heat Gain (W/person)	U	80	120	T	80	100	120
HVAC Waste Factor	U	0	0.1	T	0	0.04	0.08
HVAC System Heating Loss Factor	U	0	0.36	T	0.0	0.1	0.2
HVAC System Cooling Loss Factor	U	0	0.1	T	0	0.01	0.05
Cooling COP	U	2.5	5	U	4		5
Heating Temperature Setpoint Occupied (°C)	U	20	26	U	23		25
Heating Temperature Setpoint Unoccupied (°C)	U	20	26	U	15		20
Cooling Temperature Setpoint Occupied (°C)	U	24	30	U	27		29
Cooling Temperature Setpoint Unoccupied (°C)	U	24	35	U	30		32
Heat Recovery Fraction	U	0	0.6	U	0.3		0.6
Interior Heat Capacity (J/K/m2)	U	8.0E4	2.5E5	U	1.0E5		2.5E5
Envelope Heat Capacity (J/K/m2)	U	1.0E4	20E5	U	1.5E4		5.0E4

[1] Distribution Types: U = Uniform, T = Triangle

Each of the 25000 run scenarios took approximately 450 seconds to run, 120 seconds of which were actual model simulation time. Thus each ISOmodel run takes approximately 5 milliseconds. Because the ISOmodel is single zone and uses a limited wall and window description, all ISOmodels run at the same speed. The complete 32 story, 160 zone OpenStudio model takes approximately 1100 seconds to run in EnergyPlus on the same computer with the same background tasks going on and thus for this building, the ISOmodel runs over 5 orders of magnitude faster than the OpenStudio model in EnergyPlus.

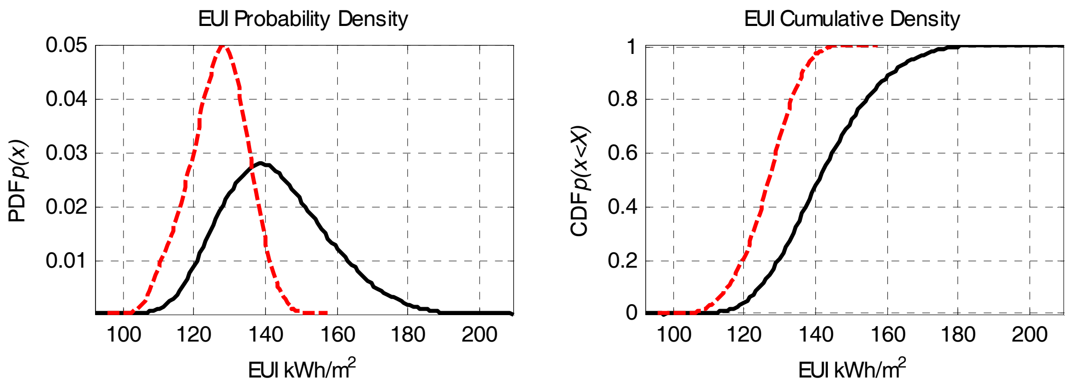

Figure 5. Probability density functions (PDF) (left) and Cumulative density function (CDF) (right) for the example analysis. The solid black line (—) is the EUI PDF/CDF for conceptual design phase and the red dashed line (– –) is the PDF/CDF for early schematic design phase.

Future Work

While a working version of the basic monthly CEN/ISO model has been integrated into OpenStudio and is available for use by "adventurous" modelers, there is a large amount of future work planned for improvement of the OpenStudio ISOmodel. This work includes:

- Improving the forward translator to better map OSM model to ISO model inputs,
- Developing a methodology to use full EnergyPlus runs from OpenStudio to estimate system loss factors for buildings where detailed system models have been created,
- Adding additional components of the CEN/ISO monthly model not yet implemented, including ground heat transfer and multiple zones,
- Improving the current methods used for estimating infiltration, fan energy, and pump energy
- Creating and integrating a C++ version of the hourly CEN/ISO to complement the monthly version which will allow for the use of more complicated schedules and provide rough estimates of peak demand with only a moderate decrease in speed,
- Creating GUIs for easier input of uncertainty information and more detailed control of the uncertainty calculations,
- Integrating a more complete uncertainty library with improved uncertainty information about a wider range of parameters and building types,
- Integrating ISOmodel Ruby scripts and OpenStudio measures with RServe (an interface for programs to access the statistical software package "R") for more efficient sampling and more advanced result analysis,
- Integrating functionality of the Bayesian Calibration method which Argonne is currently developing for OpenStudio to allow for calibration of models with uncertainty to measured building energy use and using the Bayesian Calibrator to improve the forward translator,
- Creating a reverse model translator to generate basic OSM models from ISO models.

Conclusions

A version of the CEN/ISO monthly building energy model has been integrated into the OpenStudio Software Development Kit. The model has a limited number of inputs and outputs and a limited range of applicability but outputs are computed very quickly. The speed of computation makes it particularly suitable for parametric simulation where large sweeps of many parameters need to be explored and for Monte Carlo analysis using uncertainty about the model input parameters to develop a probabilistic energy use prediction. A list of the CEN/ISO standards from which the model is derived is presented along with a brief description of the model inputs and outputs. A SWOT analysis chart is presented to help users quickly assess the strengths and limitations of the model. The main strengths of the model are the speed of execution and the need for limited inputs. The main weaknesses of the model are the inability to model system details or advanced materials/equipment/control systems. The current state of the OpenStudio implementation of the ISO model is described. While basic monthly prediction functionality is available now, additional development, especially of the forward translator from OpenStudio model to the ISOmodel, is planned. Finally, an example of the use of the model for early design of a 32 story high rise office building was presented. EUI probability and cumulative density functions were created using 25000 Monte Carlo runs with high levels uncertainty of many model parameters corresponding to a typical early conceptual design scenario and with reduced levels of uncertainty of the same parameters corresponding to a typical early schematic design scenario. The ISO model ran over 5 orders of magnitude faster than the EnergyPlus model from which it was derived.

Acknowledgments

The authors would like to thank, Godfried Augenbroe, Fei Zhou, Sang Hoon Lee, Yeonsook Heo, and the other graduate students at Georgia Tech who developed the spreadsheet version of the CEN/ISO model which was the inspiration for the version that has been implemented within OpenStudio. The authors would also like to thank the entire NREL OpenStudio development team for their ongoing development of the OpenStudio SDK.

This work was supported by the U. S. Departement of Energy under Contract No. DE-AC02-06CH11357 with Argonne National Laboratory and under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory.

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