

A Parametric Analysis Tool for Building Energy Design Workflows: Application to a Utility Design Assistance Incentive Program

*Andrew Parker, Kyle Benne, Larry Brackney, Elaine Hale, Dan Macumber, Marjorie Schott
and Evan Weaver, National Renewable Energy Laboratory*

ABSTRACT

Utility design assistance programs face cost-effectiveness challenges due to rising code minimums and the increased costs of the advanced energy analysis needed to design beyond-code buildings. Because of this pressure, managers of these programs are looking for ways to lower the cost of energy analysis and increase the performance of the buildings being designed. The energy consultants that perform this analysis typically use a workflow in which they define a baseline energy model, run a number of alternative design scenarios, and use the results to recommend a particular set of energy conservation measures (ECMs) for a project. Such a workflow is possible using the first version of the OpenStudio Parametric Analysis Tool (PAT), which additionally leverages the flexibility of OpenStudio Measures and the Building Component Library (BCL) to enable user-customizable, sharable parametric descriptions of ECMs.

PAT is a flexible, freely available tool, which can be used for many types of building energy simulation projects. In this paper we will focus on the use of PAT as part of the Xcel Energy Design Assistance Program and explain the particular features that were built-in to support that use case, including utility-approved measures and energy model input data, utility-specific Quality Assurance/Quality Control (QAQC) checks, automated reporting, and access to cloud computing. Xcel has found that using PAT helps its EDA program remain viable by making energy modeling cheaper while finding equal or deeper savings without sacrificing quality.

The Challenge for Energy Design Assistance Programs

Utilities use energy design assistance (EDA) programs to incentivize building owners to build more energy efficient buildings. Depending on the utility, the incentive is typically split between some combination of the building owner, the design team, and a utility-approved energy consultant (EC) who helps the building owner and design team analyze various energy conservation measures (ECMs) and incorporate them in the building design. Utilities typically fund EDA programs to meet a mandate from their regulators.

EDA programs generally reference the local energy code as the baseline above which savings are incentivized. As the ASHRAE 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE 90.1) changes and increases the minimum energy efficiency requirements for buildings, beyond-code energy savings become more difficult to achieve. About three quarters of the states in the U.S. have adopted ASHRAE 90.1-2007 or higher (OCEAN 2014). The next standard likely to be adopted by many jurisdictions is ASHRAE 90.1-2010, which decreases energy consumption by an average of 18% relative to the previous version, ASHRAE 90.1-2007 (Halverson 2011).

Xcel Energy is a large investor-owned electric and natural gas company with annual revenues of \$10.1 billion that operates in 8 Western and Midwestern states (Xcel Energy). In the case of Xcel Energy's EDA program, projects currently average 30% electricity demand savings, 28% electric energy savings, and 30% natural gas energy savings beyond ASHRAE 90.1-2007. The adoption of more stringent ASHRAE 90.1-2010 will make it more difficult for energy consultants (ECs) to find beyond-code savings. Further complicating Xcel Energy's problem was the requirement to open the EDA program to a larger group of ECs, which increased the need for more efficient Quality Assurance and Quality Control (QAQC) processes.

In order to maintain cost-effectiveness and value to rate-payers, the Xcel EDA program needed to adapt to increasingly high minimum energy efficiency standards by making energy modeling cheaper and enabling ECs to find deeper energy savings without sacrificing the quality or credibility of the program.

Selecting an Energy Modeling Platform

In order to meet their needs, Xcel decided to first identify a standardized energy modeling platform to create consistency across ECs. Xcel wanted to follow the California Energy Commission's (CEC) move to EnergyPlus as their required energy modeling engine for commercial buildings. After deciding on EnergyPlus, Xcel evaluated various modeling platforms using the engine. Xcel's evaluation criteria were that the tools be open source and transparent, enable efficient model creation, and provide flexible and extensible analysis capability. CEC's adoption of the platform along with increased application by DOE, NRCAN, and the private sector gave Xcel confidence that OpenStudio would be funded and improved for the foreseeable future. Based on these criteria, Xcel selected OpenStudio, DOE's flagship energy modeling platform (OpenStudio).

With an energy modeling platform selected, Xcel identified three key areas where it could reduce the cost of energy modeling: providing ECs with easy access to common energy modeling inputs, providing ECs with a quick method of analyzing the impact of common ECMs, and providing both ECs and Xcel tools for automating basic QAQC of models.

Distributing Standardized Measures and Modeling Input Data

Creating standardized modeling inputs was fairly easy. Xcel took key information like building constructions, spaces, internal loads, and schedules from ASHRAE 90.1, DOE's Reference Buildings, and other key references, and putting it into OpenStudio energy model format (Deru et al.). The real difficulty was distributing this content to ECs, and doing so in a manner that made the content easy to access and easy to determine whether or not the EC was using the most up-to-date content.

A web tool called the Building Component Library (BCL) that is part of the OpenStudio modeling platform (accessible at bcl.nrel.gov) helped Xcel address this need. The BCL is an online database to store and share modeling input data and Measures. (For the duration of this paper, the term Measure refers to a small, self-contained OpenStudio script which can procedurally alter energy models to represent a given ECM). The BCL allows anyone to create a group, upload content, and share content by either making that content public or sharing the content with other members of their group (for which they control membership). Users of the OpenStudio Application and Parametric Analysis Tool can access BCL content directly from the GUI. In Figure 1 below, a user is searching for Measures related to "Electric Lighting Controls."

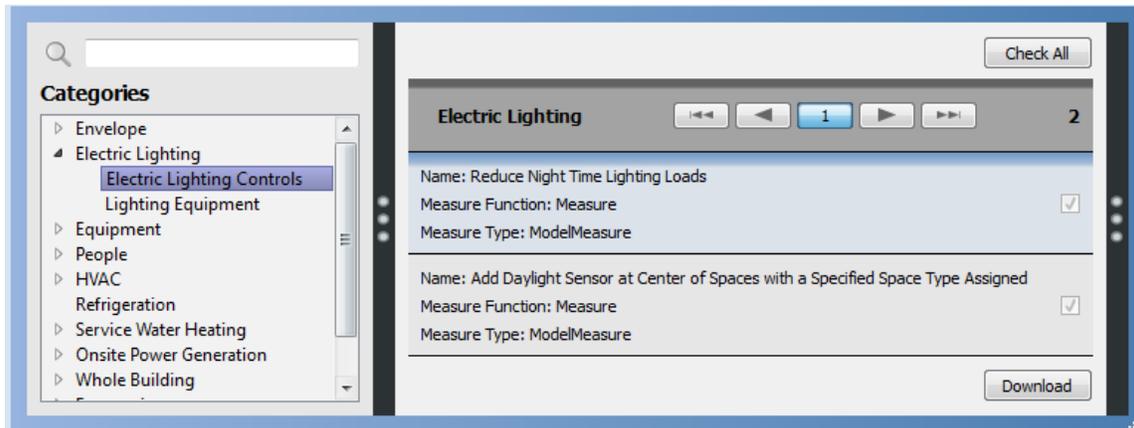


Figure 1. Accessing Measures on the BCL from PAT.

One of BCL's key features, versioning of content, is very important for Xcel. If an EC finds a mistake in an existing Measure, Xcel can quickly change the Measure to fix the mistake and upload it to BCL. From that point onward, whoever downloads the Measure will get the latest, corrected version. Also, ECs who already have an older version can simply go into PAT and see a notification that this Measure has a new version available, and can click a button to update the Measure in their existing analysis. This ability to instantaneously disseminate energy modeling content in a format that is immediately accessible to ECs directly in their modeling platforms enables utilities to communicate information without the tremendous overhead of traditional methods.

Parametric Analysis of Energy Conservation Measures

Running parametric studies to determine the impact of various ECMs early in the design process is where an EC provides the most value, and where experience has shown that most modeling time is spent. Historically, the process has been limited to either:

1. Manually hand-editing the baseline and saving the new model as a variation.
2. Using a limited set of built-in ECMs to run simple parametric studies.
3. Using text-substitution scripts to parametrically modify the input files.

Each of these variations has its own drawback; manually hand-editing files is slow and tedious, built-in ECMs are by their nature not easily modified and therefore limit to the user to investigating a small number of fixed design options, and text-substitution scripts, while powerful and flexible, can be difficult for a small EC firm to create and maintain, and are often limited to value-substitution ECMs as opposed to major changes like swapping out entire HVAC systems. Outcomes can also vary significantly based on the modeler's expertise, and best practices for modeling specific ECMs can be difficult to share within a firm, let alone across firms.

The solution Xcel was looking for needed the ease-of-use and speed of built-in ECMs combined with the power and flexibility of the text-substitution scripts. These needs were well aligned with the extensible model transformation capability contained within OpenStudio, and

they provided a market-driven set of requirements to define a formal structure for OpenStudio Measures and the OpenStudio Parametric Analysis Tool (PAT) that would use them.

An Introduction to PAT

OpenStudio is a Software Development Kit (SDK) designed for energy modeling. It is a library of energy-modeling-specific programming commands that can be used to efficiently create or modify models, manage individual or multiple simulations, and visualize results. After reviewing Xcel and other stakeholders' need for an easy-to-use yet customizable way to communicate ECMs, the OpenStudio team defined a standardized template for a small program, or Measure, written using SDK commands, that could modify an energy model to reflect the application of an ECM. Measures written in this way may be directly used by PAT, OpenStudio's graphical user interface (GUI) for assessment of their energy and economic performance.

A fundamental design goal of PAT was to make application of Measures “drag and drop” simple, with comparison of design alternatives presented in an easy to understand format. PAT's interface utilizes a tabbed workflow that leads the user through key tasks that include specifying the model and measures, defining design alternatives, running simulations, and viewing key results.

The first step in creating a parametric analysis using PAT is to select a baseline OpenStudio energy model input file. Baseline models can be created using a number of OpenStudio-based tools including the DOE Asset Score Tool, concept3D's simuwatt mobile auditing tool, or the OpenStudio SketchUp Plug-In and Application. Measures are included in the analysis by dragging and dropping them from the library pane of the GUI. In Figure 2 the user drags in the Measure called “Replace Forced Air System with Baseboard Heaters.” The user may drag in multiple copies of the Measure to specify a range of inputs. For example, a user could include several copies of a Measure to lower lighting power density, and set their respective user inputs to 10%, 20%, and 30% reduction.

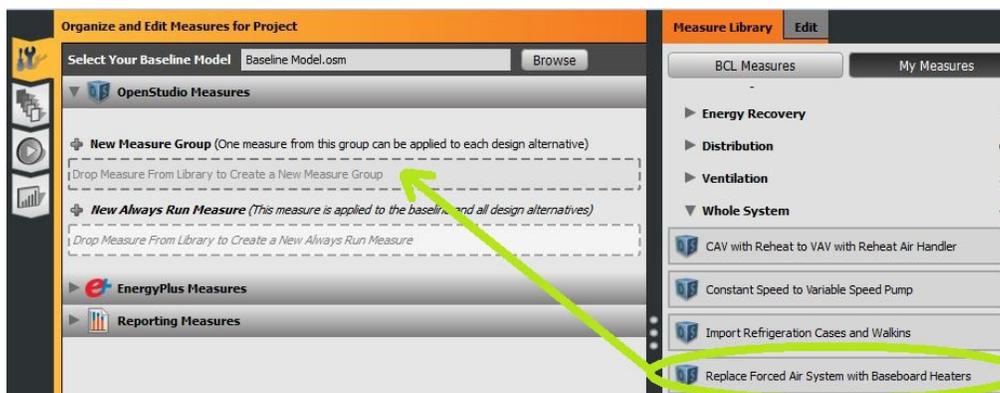


Figure 2. Adding a Measure to an analysis.

Once the Measure has been added to the project, the user can set the inputs that the author of the Measure made available. Measure arguments vary and will often include a combination of engineering and economic inputs that are used by the simulation and life cycle economic analysis. In Figure 3 the user can input the name of the air system to be replaced with electric baseboard heaters. Additional air systems that may exist in the model will not be affected.

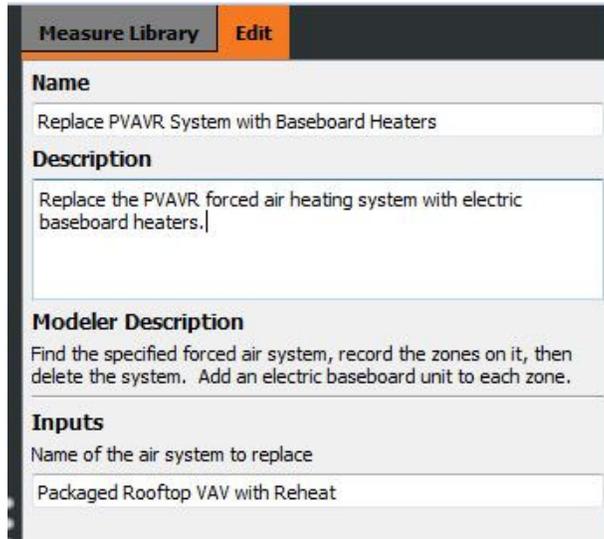


Figure 3. Setting user inputs for a Measure.

After adding all Measures to be considered, the user proceeds to PAT’s second tab and defines design alternatives comprised of the baseline model with one or more Measures. It is important to note that the user can create design alternatives with as few or many Measures as desired, and in a variety of combinations. A single button press enables the rapid creation of one design alternative for each Measure applied to the baseline. Groups of measures may be applied simultaneously by selecting multiple measures and pressing the “Create One With Selected Measures” button. In Figure 4 the user has created one design alternative including the “Reduce Building LPD by 22%” Measure, and another design alternative including that Measure plus the “Replace PVAVR System” Measure. The initial interface design deliberately avoided adding a “Make Design Alternatives for Every Combination of Measures” button, as the full factorial analysis problem quickly becomes unmanageable, but this capability is possible through the underlying SDK.

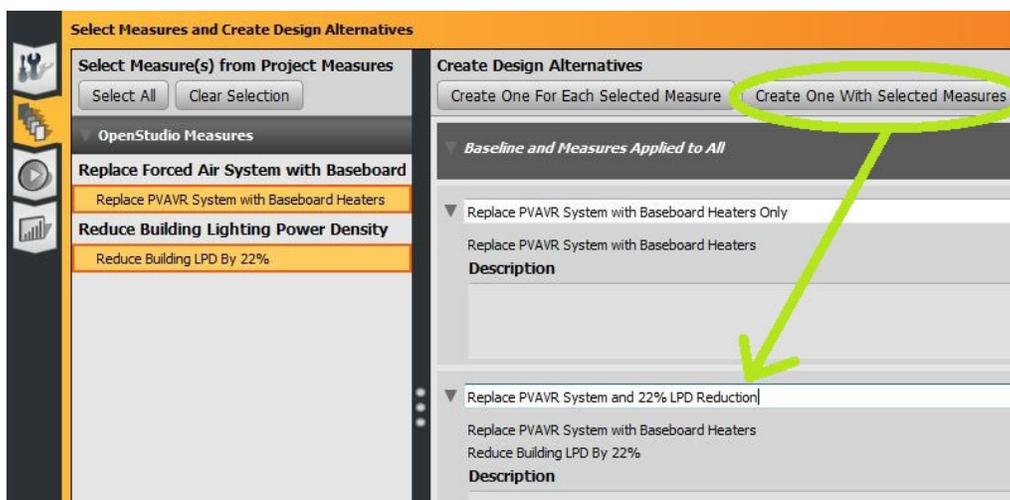


Figure 4. Creating design alternatives including one or more Measures.

Once the design alternatives have been created, the user proceeds to PAT’s third tab to run the simulations. At its simplest, this tab allows the user to press a “start” button to run parallel simulations across multiple cores on the user’s computer. A progress bar and messages related to each design alternative are updated as the analysis progresses as shown in Figure 5.

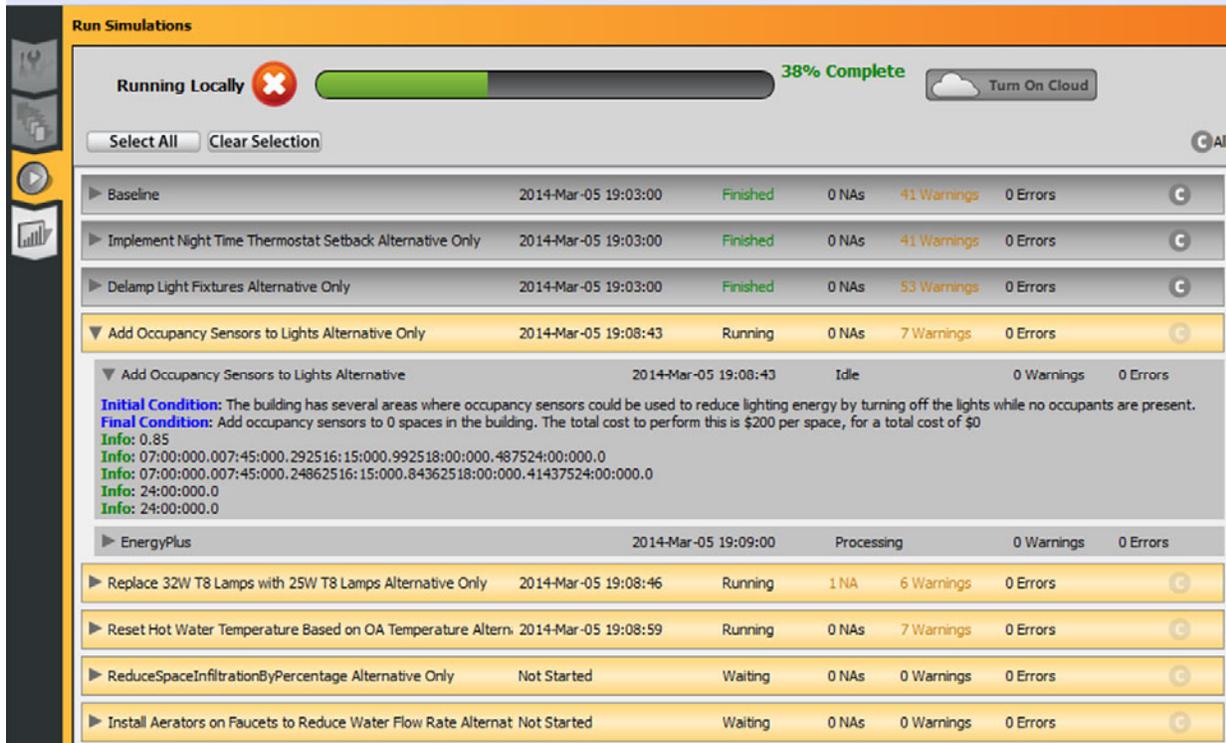


Figure 5. Simulating design alternatives and assessing progress.

In addition to modifying energy models to reflect the impact of an ECM, Measures may be written to help energy modelers quickly and reliably visualize key results or find modeling errors. When properly authored, Measures may report errors directly in the PAT Run tab. By expanding an entry for a design alternative, as shown in Figure 6, the user can quickly see the state of a particular simulation along with what changes (if any) the Measure made to the baseline model. This becomes a valuable diagnostic tool for the modeler.

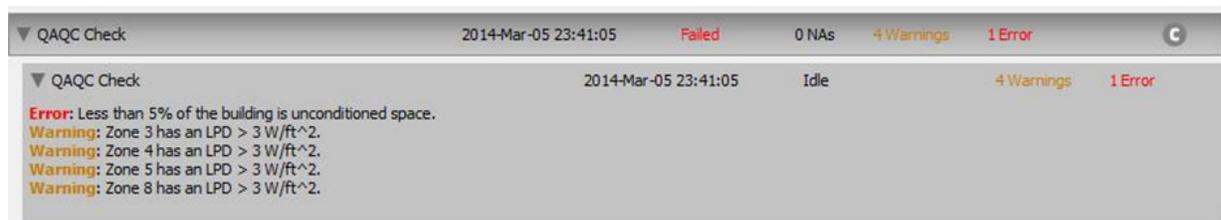


Figure 6. Output messages from a Measure.

For larger analyses, PAT includes the capability to manage simulations on the Amazon Elastic Compute Cloud (EC2). For roughly \$2.00/hr, users can rent one compute node with 16 processors (typical laptops and desktops have 2 to 8 processors). A single node is reserved for use as a server that distributes tasks to worker nodes, stores results in a database, communicates

with the PAT client, and supports a light web service for monitoring the status of an analysis. Users may rent up to 19 compute nodes at a time. Using this capability, users can run large parametric studies (16 x 19) = 304 simulations in parallel) in a fraction of the time it would take on their own computer, and at a fraction of the cost of the user's own time. This feature gives energy modelers access to computational capability that might otherwise be too expensive for them to purchase and maintain on their own, and is key in avoiding the simulation time bottleneck that users often cite as a major barrier to adoption of tools based on the EnergyPlus simulation engine.

Once the simulations have finished, users can proceed to the last tab of PAT to review summary results. In Figure 7, users can see the impact of each Measure on the performance of the baseline model. Users can also open the resulting models in the OpenStudio Application or the OpenStudio SketchUp Plugin to review the models to make sure the Measures worked as intended.

The screenshot shows a software interface titled "Create and View Reports" with a sidebar on the left containing icons for a person, a building, a play button, and a bar chart. The main area has a "View:" dropdown set to "Standard" and a "Calibration" button. Below this are two tables. The first table compares a "Baseline" against various energy metrics. The second table compares two "Design Alternative Only" measures against the same metrics, including "Simple Payback (years)" and "Total LCC Savings (\$)".

Design Alternative Name	Energy Use Intensity (kBtu/ft ² -yr)	Peak Electric Demand (kW)	Electricity Consumption (kWh)	Natural Gas Consumption (Million Btu)	District Cooling Consumption (Million Btu)	District Heating Consumption (Million Btu)	First Year Capital Cost (\$)	Annual Utility Cost (\$)	Total LCC (\$)
Baseline	17	31	90,436	0	0	0	0	10,039	292,218

Design Alternative Name	Energy Use Intensity Reduction (kBtu/ft ² -yr)	Peak Electric Demand Reduction (kW)	Electricity Savings (kWh)	Natural Gas Savings (Million Btu)	District Cooling Savings (Million Btu)	District Heating Savings (Million Btu)	First Year Capital Cost Increase (\$)	Annual Utility Cost Savings (\$)	Simple Payback (years)	Total LCC Savings (\$)
Implement Night Time Thermostat Setback Alternative Only	0 0%	0 0%	8 0%	0 --	0 --	0 100%	0 --	1 0%	0	14 0%
Delamp Light Fixtures Alternative Only	4 26%	10 31%	23,761 26%	0 --	0 --	(0) (8%)	4,675 --	2,638 26%	2	41,391 14%

Figure 7. Comparing baseline and design alternative simulation results.

Using Measures for Reporting and QA/QC

OpenStudio Measures take on a broader meaning when we consider that they may not only transform building models, but also the data associated with them. In the previous section, we described how Measures can “self report” the actions they have taken. Another class of Measures exists; these Reporting Measures post-process simulation results. Such Measures can be applied within a simulation workflow to produce outcomes that supplement standard results reporting from EnergyPlus. These can include anything from sophisticated analysis of time series data to custom plots that enhance the modeler's understanding of a simulation's behavior as illustrated in Figure 8.

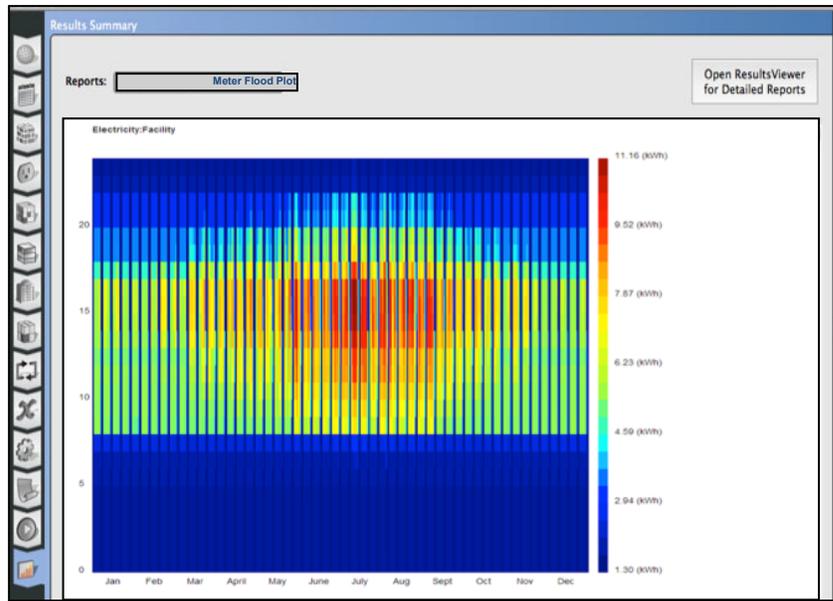


Figure 8. Output from a heat map Reporting Measure displayed in the OpenStudio application.

Codifying energy modeling QAQC knowledge from experts into a format that can be easily and consistently used by beginner and expert modelers is an obvious application for OpenStudio Measures. Lack of confidence in results due to a lack of standardized QAQC procedures is widely considered a problem by the energy modeling community (RMI 2011). One of Xcel’s goals was to automate not only “best practice” model quality checks, but also the regulator-mandated protocols for their EDA program. Automated QAQC enabled by an appropriate Measure informs not only the modeler, but also Xcel engineers who must review a large number of submissions to the EDA program. Figure 6 depicts the results on a typical QAQC check applied in Xcel’s standard workflow (Long 2013).

Measures and Integration with the Xcel EDA Program

Xcel’s EDA program has leveraged Measures extensively. The first step was encouraging the ECs to use the Measures already created by NREL for modeling common ECMs such as reducing lighting power density, improving the performance of the building envelope, etc. To use these Measures, ECs simply drag Measures from their library, fill in a few inputs, and run the analysis. The programming logic for the Measure is available for the EC to review and modify, but generally this is not necessary.

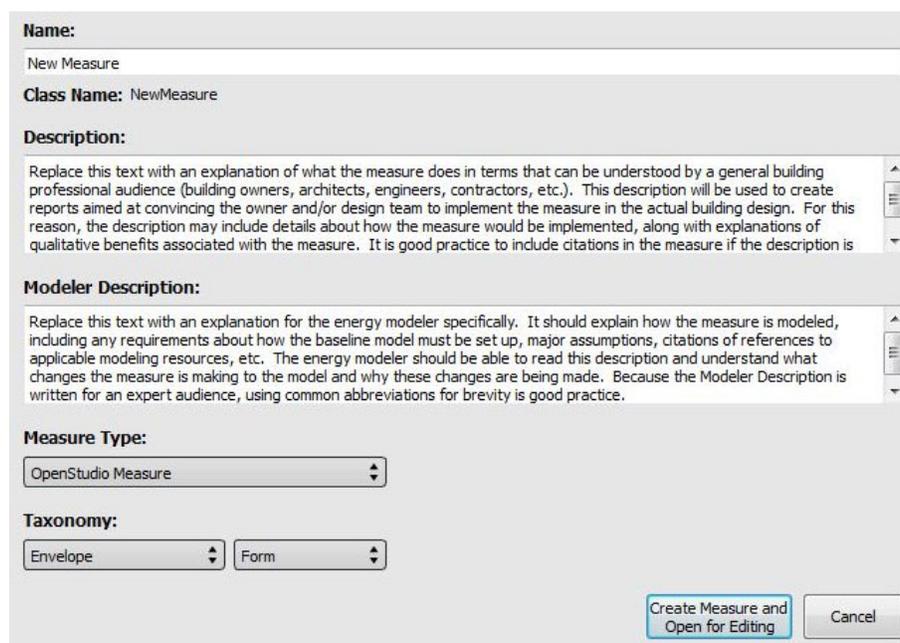
Beyond the initial set of Measures created by NREL, Xcel and DOE are partnering to create a set of Measures to reflect the ECMs suggested by the ASHRAE K-12 School and Office 50% Advanced Energy Design Guides (ASHRAE 2010). These Measures will help ECs who are working on these common building types consider the deeper, more complex ECMs recommended by experts who regularly design high performance buildings. Xcel sees long-term value in paying one expert modeler to create a vetted Measure for an ECM that typically yields high savings, and then distributing this Measure to all of its ECs.

Besides running parametric studies of ECMs, experience has shown that documenting the modeling process and modeling results is the second most time-consuming part of energy modeling. To speed up this step, Xcel has integrated the Xcel EDA-specific reporting and QAQC

Measure described above with a web service called the Energy Design Assistance Project Tracker, or EDAPT (Elling 2014). PAT has the ability to package key results calculated by the Xcel reporting Measure into a singular output file summarizing all of the design alternatives. This output file is uploaded to EDAPT (Elling 2014), which uses the data to populate its own internal reports, but also to generate a template Word document that standardizes modeling results into tables, figures, and boilerplate text extracted from the Measures used in each design alternative. This eliminates the need for the EC to transfer simulation results into a spreadsheet, create tables or plots, and cut and paste them into a document manually. The template document was designed in partnership with the ECs to ensure their need to communicate recommendations to the customer was addressed.

Writing New Measures

OpenStudio's Measure capability was designed to be extensible by practitioners. By clicking the "New Measure" button in PAT, the dialog shown in Figure 9 pops up to gather basic information about a new Measure. This information is used to determine the Measure's location within the BCL taxonomy, but also to capture a high level description of what the measure is intended to do along with a detailed technical description of the modeling implementation. User responses generate a collection of template Measure files that the user may complete to create new modeling capability. The user may also elect to copy an existing Measure as a starting point for a new one.



Name:
New Measure

Class Name: NewMeasure

Description:
Replace this text with an explanation of what the measure does in terms that can be understood by a general building professional audience (building owners, architects, engineers, contractors, etc.). This description will be used to create reports aimed at convincing the owner and/or design team to implement the measure in the actual building design. For this reason, the description may include details about how the measure would be implemented, along with explanations of qualitative benefits associated with the measure. It is good practice to include citations in the measure if the description is

Modeler Description:
Replace this text with an explanation for the energy modeler specifically. It should explain how the measure is modeled, including any requirements about how the baseline model must be set up, major assumptions, citations of references to applicable modeling resources, etc. The energy modeler should be able to read this description and understand what changes the measure is making to the model and why these changes are being made. Because the Modeler Description is written for an expert audience, using common abbreviations for brevity is good practice.

Measure Type:
OpenStudio Measure

Taxonomy:
Envelope Form

Create Measure and Open for Editing Cancel

Figure 9. New Measure dialog.

Measures consist of two main parts. First, the author of a measure defines user inputs. These give the user some flexibility without needing to modify the code of the Measure. Figure 10 below shows the user input for a Measure to replace a forced air heating system with electric baseboard heaters. The author can expose user inputs for things like cost and equipment performance as well.

```

#define the user inputs
def arguments(model)
  inputs = OpenStudio::Ruleset::OSArgumentVector.new

  #user input for the name of the air system to remove
  air_sys_name = OpenStudio::Ruleset::OSArgument::makeStringArgument("air_sys_name", true)
  air_sys_name.setDisplayName("Name of the air system to replace")
  inputs << air_sys_name

  return inputs
end

```

Figure 10. Example user input for a Measure.

The second part of a measure is the logic to define how the model will be altered when the Measure is applied. This logic can be as simple or sophisticated as the author desires. Because all of the inputs to the energy model are programmatically accessible, and because the OpenStudio commands greatly simplify complex actions, Measures can move beyond the realm of text-substitution scripts into complex ECMs like replacing whole HVAC systems or modifying building geometry. Figure 11 illustrates application of a daylighting measure to a model of a school. In this example, the measure removes existing fenestration, replacing it with a combination of daylight and view glass on appropriate façades, adds overhangs and light shelves for glare control, creates skylights for appropriate spaces, and adds daylighting controls.

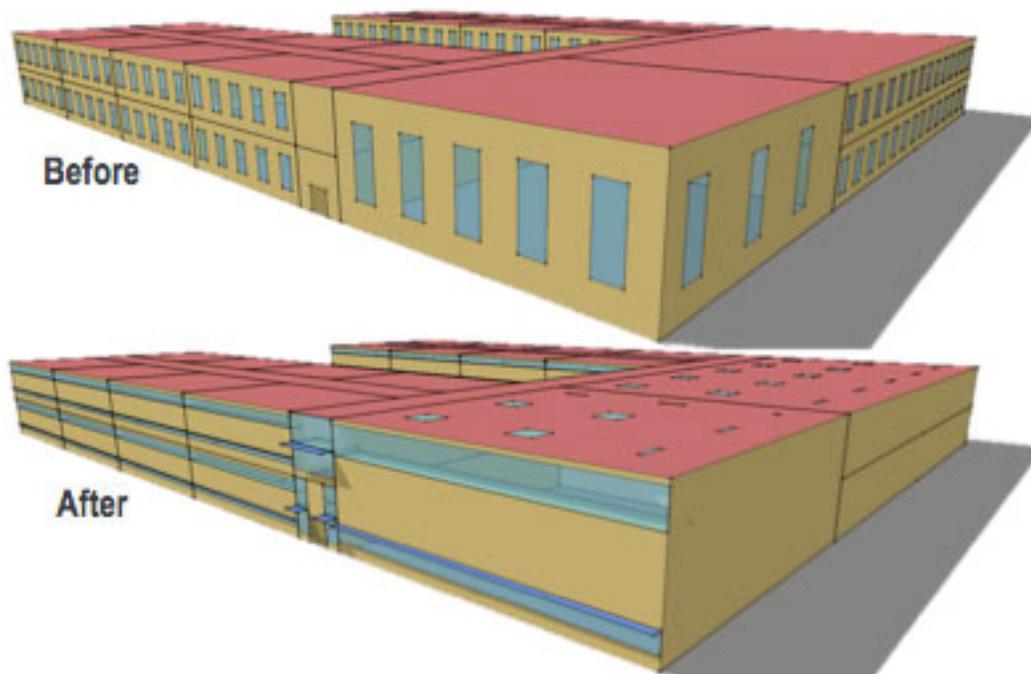


Figure 11. A single OpenStudio Measure applies a variety of daylighting Measures to a school.

Figure 12 below contains the Ruby code for an HVAC measure. This example shows the body of a simple Measure that replaces a forced air heating system with electric baseboard heaters.

```
#define what happens when the measure is run
def run(model, runner, user_arguments)
  super(model, runner, user_arguments)

  #assign the user inputs to variables
  air_sys_name = runner.getStringArgumentValue("air_sys_name",user_arguments)

  #find the air system in the model
  air_sys = model.getAirLoopHVACByName(air_sys_name).get

  #log the zones on the air system, then remove it
  zones = air_sys.thermalZones
  air_sys.remove

  #loop through the zones, create a bb heater, add it to the zone, log action
  zones.each do |zone|
    elec_bb = OpenStudio::Model::ZoneHVACBaseboardConvectiveElectric.new(model)
    elec_bb.addToThermalZone(zone)
    runner.registerInfo("added elec bb heater to #{zone.name}")
  end

  return true
end
```

Figure 12. Measure logic to replace a forced air system with electric baseboard heaters.

Xcel's Experience with PAT and Measures

Thus far, the ECs using PAT and OpenStudio Measures have found that when Measures exist to represent the ECMs they want to analyze, the process works well and saves time. Since many of them were accustomed to using eQuest, the transition to OpenStudio and EnergyPlus came with a learning curve, but the ECs have found that the tools become more comfortable after one or two projects. The greater challenge is in learning to write custom Measures when they do not yet exist. This requires more effort, and pushes some ECs out of their comfort zone. That said, several ECs have learned how to write their own Measure within the space of their first project and successfully modeled major HVAC system swaps. ECs who already had experience with simple programming (such as Excel VBA macros) have fared best in this regard. As the number of publicly-accessible Measures created by NREL, other National Laboratories, universities, and other parties grows, there will be more ECMs already covered and more example Measures that may be modified in the case that an ECM hasn't yet been modeled.

Conclusions and Future Work

As minimum energy efficiency standards increase, EDA programs are finding it more difficult to achieve cost-effective energy savings. In order to retain value, the utilities and their ECs must learn how to perform energy modeling more cheaply and effectively. Based on initial analysis of the first few months of using this new system, Xcel has found that using Measures and PAT helps its EDA program remain viable by making energy modeling cheaper while finding equal or deeper savings without sacrificing quality.

Near-term, OpenStudio's optimization and uncertainty quantification capability will be made available. These features are being built on top of the same Measures infrastructure used by PAT, and will enable ECs to perform sophisticated analyses not easily performed through any current energy modeling programs. As the margins for finding savings shrink, these more sophisticated types of analysis are one potential avenue for ECs to identify deeper savings.

Acknowledgements

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