

# OpenStudio: A Platform for Ex Ante Incentive Programs

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## ABSTRACT

Many utilities operate programs that provide *ex ante* (up front) incentives for building energy conservation measures (ECMs). A typical incentive program covers two kinds of ECMs. ECMs that deliver similar savings in different contexts are associated with pre-calculated “deemed” savings values. ECMs that deliver different savings in different contexts are evaluated on a “custom” per-project basis. Incentive programs often operate at less than peak efficiency because both deemed ECMs and custom projects have lengthy and effort-intensive review processes—deemed ECMs to gain confidence that they are sufficiently context insensitive, custom projects to ensure that savings are claimed appropriately.

DOE’s OpenStudio platform can be used to automate *ex ante* processes and help utilities operate programs more efficiently, consistently, and transparently, resulting in greater project throughput and energy savings. A key concept of the platform is the OpenStudio Measure, a script that queries and transforms building energy models. Measures can be simple or surgical, *e.g.*, applying different transformations based on space-type, orientation, etc. Measures represent ECMs explicitly and are easier to review than ECMs that are represented implicitly as the difference between a with-ECM and without-ECM models. Measures can be automatically applied to large numbers of prototype models—and instantiated from uncertainty distributions—facilitating the large scale analysis required to develop deemed savings values. For custom projects, Measures can also be used to calibrate existing building models, to automatically create code baseline models, and to perform quality assurance screening.

## Introduction

Many utilities operate programs that provide *ex ante* (up front) incentives for building energy conservation measures (ECMs). A typical incentive program covers two kinds of ECMs. ECMs that deliver similar savings in different contexts are associated with pre-calculated “deemed” savings values. ECMs that deliver different savings in different contexts are evaluated on a “custom” per-project basis. Savings estimates for ECMs can sometimes be calculated using normative engineering calculations, but in this work we are interested in the use of detailed (sub-) hourly whole-building energy simulation to estimate ECM impact. It is easy to justify the use of simulation to evaluate ECMs that impact multiple building systems, *e.g.*, high-performance windows, advanced HVAC systems, and operating strategies such as demand-controlled ventilation (DCV) and optimal start. Simple ECMs that affect few building systems—*e.g.*, more efficient luminaires, smart strips that reduce plug-load consumption—also benefit from detailed simulation in order to gain confidence that assumptions about context-insensitivity are valid.

Establishing and operating *ex ante* incentive programs can be costly because the simulation models used in both deemed savings for ECMs and custom projects have lengthy development and effort-intensive review processes. Performing the large-scale analyses needed to establish savings estimates and the range of contexts to which they apply can be labor-intensive and error-prone. Reviewing the experiments and their results of these large-scale analyses is similarly tedious. And whereas the development of savings estimates for custom projects is more scalable—the work is spread over a larger number of consultants—review is again more centralized and is again often a tedious, largely-manual process that requires careful inspection and “mental-differencing” of with-ECM and without-ECM models to ensure both that the ECM is both modeled correctly and that the ECM represents the only difference between the models so that additional performance is not falsely claimed. The situation is exacerbated if the simulation tools used are proprietary and the resulting savings calculations are partially or entirely opaque, engendering mistrust between claimants and program reviewers and again between program administrators and their regulators.

DOE’s OpenStudio platform can help improve the efficiency of *ex ante* incentive programs by adding transparency and automation to their processes while opening up program support to a larger number of consultants. This paper describes the relevant aspects of the OpenStudio platform—primarily the fast-growing OpenStudio Measures ecosystem—and its application to *ex ante* processes.

## **The OpenStudio Platform**

Over the past four years, DOE has supplemented its long-standing investment in EnergyPlus with a substantial investment in OpenStudio. Like EnergyPlus, OpenStudio is open-source and cross-platform. And like EnergyPlus, OpenStudio is a central component of DOE’s strategy to increase the effective use of advanced energy modeling in all aspects of building energy efficiency from design to operation to performance-rating systems, code-development, policy analysis and program support.

### **EnergyPlus and Radiance**

OpenStudio’s value derives from the access it provides to EnergyPlus (Crawley et al., 2000; 2016a), DOE’s whole-building energy simulation engine. EnergyPlus is an advanced simulation program that is capable of modeling the designs, envelopes, mechanical systems, and operational strategies that are needed for energy-efficient buildings and that utilities are trying to promote and incentivize. As a publically funded tool, EnergyPlus is open-source and thoroughly documented, providing a degree of transparency that is important in many applications, including *ex ante* incentive program development and operation. As energy-efficiency standards tighten, the role of daylighting and advanced fenestration and shading grows. The same OpenStudio model that is translated to EnergyPlus input can also be translated to input for the advanced open-source lighting engine Radiance (Ward, 1994) to calculate detailed lighting metrics.

### **Graphical Application and Software Development Kit (SDK)**

OpenStudio (2016b) is known primarily as a graphical application for model creation and editing, including a plug-in for Trimble’s 3D drawing program SketchUp. However, this is only

the visible “tip of the iceberg” and not the focus of DOE’s investment. Underneath is a non-graphical software development kit (SDK) that provides programmatic access to the model and simulation results as well as a large library of functions that automate common modeling, simulation, and results processing tasks. The OpenStudio SDK reduces the effort required to develop energy modeling applications (Weaver et al., 2012). The OpenStudio application itself demonstrates this development productivity which has been leveraged by other applications including DOE’s Asset Score, NORESKO’s CBECC-Com (Energy Design Resources, 2014), and Concept3D’s Simuwatt Energy Auditor application (Macumber et al., 2014), among others.

## OpenStudio Measures

The SDK and its value for application development constituted the original value proposition of OpenStudio. In retrospect, as much if not more value derives from the fact that the SDK is accessible from popular scripting languages like Ruby, Python, C#, and JavaScript and that OpenStudio can interpret these scripts at runtime. The result is a flexible facility that resembles Microsoft Excel’s Visual Basic macros and which is having similar impact on OpenStudio. These scripts are referred to as “OpenStudio Measures” because their most common use is the programmatic application of energy conservation measures (ECMs) to building models (Roth et al., 2015).

Figure 1 shows the “working” code snippet from the OpenStudio Measure `occupancy_sensors_for_lighting`. Following ASHRAE Standard 90.1-2010, application of this measure is defined as a 5% reduction in lighting power for affected space types including Office, Conference, BreakRoom, RestRoom, and Stairs. The Measure loops over all space types in the model, and performs the proper power adjustment for only the designated space types.

```
# space-types affected by occupancy sensors (this is a comment, not code)
affected_space_types = ["BreakRoom", "Conference", "Office", "RestRoom", "Stair"]

# power reduction of 5% from ASHRAE 90.1-2010 Table 9.6.2
power_reduction = 0.05

# iterate over all space-types in model
model.getSpaceTypes.each do |st|

  # only adjust lighting power in affected space-types
  if affected_space_types.include? st.standardsSpaceType.to_s

    # calculate new lighting power from current lighting power
    area = st.floorArea
    people = st.getNumberOfPeople(area)
    power = st.getLightingPower(area, people)
    power_new = power * (1 - power_reduction)

    if st.lightingPowerPerFloorArea.is_initialized
      st.setLightingPowerPerFloorArea(power_new / area)
    elsif st.lightingPowerPerPerson.is_initialized
      st.setLightingPowerPerPerson(power_new / people)
    end # set new power
  end # if space-type is affected
end # iterate over space-types in model
```

Figure 1. A snippet from OpenStudio Measure "occupancy\_sensors\_for\_lighting" written in the popular scripting language Ruby. The code iterates over all space-type description objects in the model. For space-types whose canonical type is on the affected type list, lighting power is reduced by 5% according to ASHRAE-90.1-2010.

This example demonstrates several advantageous characteristics of OpenStudio Measures. First, Measures are compact and readable. Second, whereas EnergyPlus only provides a thermal-zone abstraction, OpenStudio also includes space and space-type abstractions, automatically rolling up space-level inputs to zone-level inputs. This allows Measures to implement space- and space type- level transformations cleanly and easily—many ECMs have standard definitions that vary by space-type—further enhancing readability and transparency. Third, Measures can use context information such as space-type, façade orientation, and climate-zone to apply transformations selectively and surgically, making them both powerful and robust.

Being clearly separate from the models they apply to makes OpenStudio Measures valuable for large-scale analyses. A Measure can be written once and applied automatically many times. Separation also provides transparency benefits. An OpenStudio Measure defines its intended transformation explicitly, precisely, and succinctly. In the absence of OpenStudio Measures, intended transformations can be defined in (English) pseudo-code, which is less precise or as the implicit difference between a set of with-and-without models, which is less succinct and transparent.

OpenStudio Measures are quite easy to both write and share. Both EnergyPlus and the OpenStudio SDK are large code-bases that evolve relatively slowly to fixed and pre-planned release schedules using rigorous standards and processes for documentation, testing, and code review. This is proper for core software that underpins commercial products. By contrast, Measure development is much lighter-weight. Not only are Measures written using higher-level and more productive scripting languages like Ruby and using the high-level functionality of the OpenStudio SDK, they are also for the most part not included in the OpenStudio distribution. Instead, Measures are housed in a version and provenance (i.e., ownership) tracking online repository called the Building Component Library (BCL) (Fleming et al., 2012, 2016c). Anyone can author OpenStudio Measures, upload them to the BCL, and share them either within their organization or with all modelers. A number of consultants already have Measure writing capability, and more are developing it. Many of the over 200 Measures currently on the BCL were written by consultants.

## **OpenStudio Prototype Buildings and Baseline Measures**

Large-scale analysis is usually performed using prototype models such as the DOE commercial building reference and prototype models. OpenStudio versions of these models are now available for the 16 commercial building types, 16 ASHRAE climate zones, and six vintages—pre-1980, 1980-2004, and ASHRAE 90.1-2004, 2007, 2010, and 2013. The left side of Figure 2 shows the user dialog for invoking the prototype building Measure. The prototypes themselves are created using a successive application of Measures: `load_geometry`, `add_constructions`, `add_loads`, `add_hvac`, etc. The data that parameterizes these Measures—e.g., loads and schedules, lighting levels, insulation levels, infiltration and ventilation rates, system types, and equipment efficiencies—resides in an easy-to-read and extend spreadsheet. This structure simplifies the creation of variants of existing prototypes and provides a template for the creation of new prototypes. It also facilitates the use of alternative stock modeling methodologies. For instance, for residential modeling, DOE creates a sample of home models from tables of probability distributions for location, floor area, construction type, heating and cooling system type, etc. rather than using fixed pre-defined prototypes.

The prototype model “build-up” Measures serve a second useful purpose. When (variants of) these Measures are applied to existing full models, they effectively perform the code-baseline

transformation—e.g., the ASHRAE 90.1 Performance Rating Method or “Appendix G” transformation—on those models. This baseline-generation functionality is similar to the one provided by NORESO’s CBECC-Com for California Title 24 and by several software packages including Trane TRACE and IES Virtual Environment for ASHRAE 90.1. Like CBECC-Com baselining “rulesets”, OpenStudio baselining Measures are open-source and concise, supporting transparency. Unlike rulesets, baselining Measures, may be chained together with ECM Measures to create a wide range of workflows spanning one-off custom project analyses to portfolio-scale technology potential assessments.

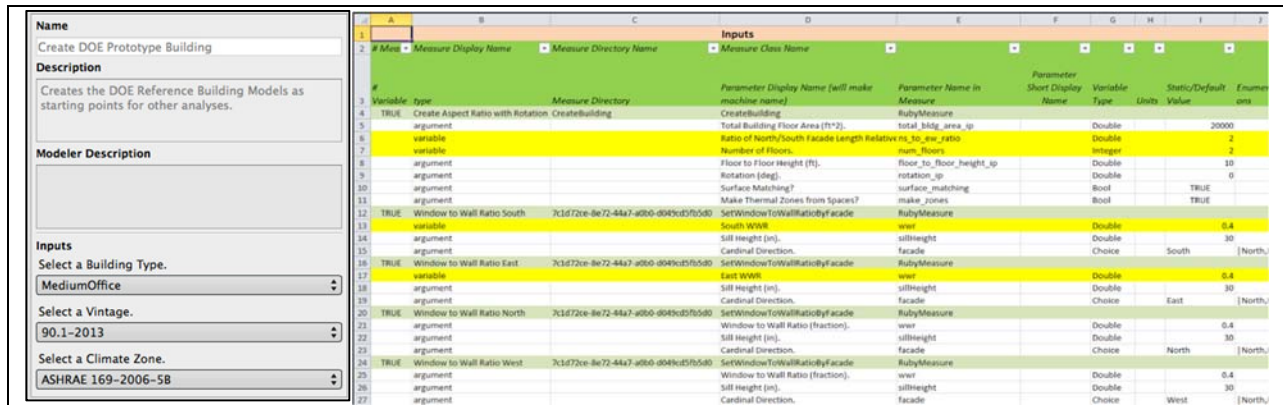


Figure 2. Two components of the OpenStudio Measure ecosystem. Left: OpenStudio prototype building generation Measure user dialog. This Measure takes three input parameters—building type, code vintage, and climate-zone—and builds up the corresponding prototype building model. Right: OpenStudio Server input spreadsheet. The spreadsheet specifies the baseline building model and a set of Measures—including arguments, which may be fixed, sets, or distributions—to apply to it. OpenStudio Server parses the spreadsheet, creates the corresponding models, and runs them on the cloud.

## OpenStudio Server

OpenStudio Measures make it easy to create large numbers of model variants. OpenStudio Server makes it easy to run the corresponding simulations (Long et al., 2014). OpenStudio Server analyses are specified using a spreadsheet as shown on the right side of Figure 2. The spreadsheet specifies baseline model(s) along with lists of OpenStudio Measures—including Measure inputs which can be fixed values, sets of values, or distributions—as well as specifications for how baseline models and measures are to be combined. One example specification is “all combinations of one baseline model and one measure”; another is “1,000 samples of a baseline model and packages of up to five randomly chosen measures.” Full-factorial analysis, probabilistic sampling problems, and multivariate optimizations can all be specified depending upon the problem of interest.

OpenStudio Server itself is a pre-configured Amazon Machine Image (AMI) that includes EnergyPlus, Radiance, and the OpenStudio SDK; and that can be used on Amazon’s Elastic Compute Cloud (EC2) to perform large-scale simulation quickly and cheaply (about \$0.10 per processing hour). On a 16-core machine, OpenStudio Server can run 1,000 simulations in about 4 hours and for roughly \$8.

## Reporting, Quality Assurance, and Workflow Measures

Applying ECMs and building up models are the intuitive applications, but Measures are more generally useful. Via the OpenStudio SDK, Measures have full access to both the model and the results of the simulation. Measures can create custom reports and visualizations, to perform quality assurance checks and to “semantically” compare models to one another. Two popular and recently posted reporting measures are `view_model` and `view_data` which, respectively, display color-coded static (e.g., construction type, space type, zone) and dynamic (e.g., surface temperature, space temperature) data on a 3D image of the model that can be viewed, zoomed, and rotated in a web browser. Automated quality assurance checking measures are of special value to custom incentive programs, in that they can substantially reduce the effort and cost associated with rigorous engineering review of submissions.

Measures are written in Ruby, a general-purpose language that provides full access to the local machine and Internet resources. These languages also have large and ever-expanding collections of free libraries for performing common tasks, for reading and writing different file formats, and for interacting with various software packages and devices. This generality enables Measures that connect OpenStudio to other tools and for general workflow automation. One innovative example leverages the Nest thermostat Application Program Interface (API) to extract occupancy schedules from a building and automatically apply them to a model.

## OpenStudio and Deemed Savings

The OpenStudio platform can improve the operations of energy-efficiency *ex ante* programs by supporting process automation, improving transparency, making project review more efficient, and expanding the pool of program support options.

### Current Processes

The deemed or pre-calculated savings approach is typically used when savings estimates are insensitive or robust—e.g., vary by 10% (relative) or less—within a given context. To meet this variation criterion, a deemed savings analysis context is usually parameterized by independent variables that minimally include climate-zone, building-type, and project-type (i.e., new construction, deep retrofit, or minor upgrade), the latter determines whether savings are calculated against prevailing code-level performance or building-stock level performance. Additional parameters can include building physical and operational characteristics relevant to the ECM, the presence of other potentially interacting ECMs, and characteristics of the ECM itself. For a given ECM, deemed savings are usually presented as a (flattened) multi-dimensional table. Choosing the appropriate value for a given project is a table lookup.

**Error! Reference source not found.** shows a screenshot of a typical deemed savings lookup table. The table is from the Database of Energy Efficient Resources (DEER) (Cullen et al., 2006; Energy Design Resources, 2014), which is used by the California investor owned utilities, and shows values for interior lighting measures. The savings table uses five independent (i.e., “lookup”) variables. Building type (BldgType), project type (BldgVint), and climate zone (BldgLoc); each encoded in individual columns and selected using Excel selection widgets. Lighting type (Linear Fluorescent, CFL, exit, and high-bay) and occupancy-sensor type (none,

building-level, and space-level) are encoded into the measure column (EnergyImpactID) and selected by scrolling. The section of the table shown in the Figure corresponds to CFLs and building-level occupancy sensors. Deemed savings over pre-existing conditions per Watt of lighting power reduction are given on both an end-use (EU) and whole-building (WB) basis for three metrics—annual electricity use (kWh), peak electricity use (kW), and annual gas use (therm). Savings over code level performance are shown in the table, but not in the figure for space reasons. For instance, replacing 100 60W incandescent bulbs with 20W CFLs yields 4,840 kWh of annual lighting end-use electricity savings and reduces peak lighting electricity demand by 0.92 kW—these numbers are computed by multiplying 100 bulbs by 40W power reduction per bulb by 1.21 kWh/W and 0.00023 kW/W, respectively. Whole-building savings can be smaller if the lighting power reduction must be compensated for by an increase in heating as in CZ01 (coastal northern California) or larger if the increase in heating requirements is more than offset by a reduction in cooling requirements as in other California climate zones.

EnergyImpactID	BldgType	BldgVin	BldgLoc	Above Pre-Existing Impacts (per delta Watt)					
				End Use Values			Whole Building Values		
				APreEUkWh	APreEUkW	APreEUtherm	APreWBkWh	APreWBkW	APreWBtherm
Com-iltg-dWatt-CFL_OSbldg	Asm	Ex	CZ01	1.21	0.00023	0	1.15	0.000267	-0.0215
Com-iltg-dWatt-CFL_OSbldg	Asm	Ex	CZ02	1.21	0.000231	0	1.25	0.000271	-0.0125
Com-iltg-dWatt-CFL_OSbldg	Asm	Ex	CZ03	1.21	0.000231	0	1.24	0.000271	-0.0137
Com-iltg-dWatt-CFL_OSbldg	Asm	Ex	CZ04	1.21	0.000231	0	1.27	0.00027	-0.0101
Com-iltg-dWatt-CFL_OSbldg	Asm	Ex	CZ05	1.21	0.00023	0	1.27	0.000276	-0.0118
Com-iltg-dWatt-CFL_OSbldg	Asm	Ex	CZ05	1.21	0.000231	0	1.27	0.000276	-0.0118
Com-iltg-dWatt-CFL_OSbldg	Asm	Ex	CZ05	1.21	0.00023	0	1.27	0.000276	-0.0118
Com-iltg-dWatt-CFL_OSbldg	Asm	Ex	CZ06	1.21	0.00023	0	1.32	0.000286	-0.00631
Com-iltg-dWatt-CFL_OSbldg	Asm	Ex	CZ06	1.21	0.00023	0	1.32	0.000286	-0.00631
Com-iltg-dWatt-CFL_OSbldg	Asm	Ex	CZ06	1.21	0.00023	0	1.32	0.000286	-0.0063

Figure 3. A deemed savings table for commercial lighting from California’s Database of Energy Efficiency Resources (DEER). Independent (input) variables are building type, building vintage, and climate zone. The dependent (output) variables shown are annual energy consumption (in kWh) and peak power demand (in kW) savings over pre-existing baseline per Watt of lighting power reduction.

### Streamlining and Enhancing Current Processes

OpenStudio makes it easy to develop deemed savings tables. OpenStudio prototype buildings can be created to model both code and existing-stock efficiency levels, supporting savings calculations for both new construction and retrofit projects. The OpenStudio prototype buildings spreadsheet makes it straightforward to create model variants that represent a region or service territory. Regardless of the size and construction of the underlying building stock model, an OpenStudio Measure can be automatically and consistently applied to every individual model in it. OpenStudio Server then simulates the resulting models quickly and cost-effectively.

OpenStudio Measures not only help automate evaluation, they also facilitate the review process by making the assumptions associated with an ECM and its application explicit and succinct. The code in Figure 1 shows all relevant aspects of the `occupancy_sensors_for_lighting` Measure: the target space types, the assumed lighting power reduction, and the calculation method for lighting power adjustments on both per-area and per-occupancy basis. If necessary, the documentation and source code for OpenStudio SDK methods used in the Measure (e.g., `setLightingPowerPerFloorArea`) can be examined. Documentation and source code for the relevant underlying EnergyPlus objects and their operation—in this case, the `Lights` object—are also available.

By reducing the effort needed to develop deemed savings values, OpenStudio allows the existing paradigm to be efficiently replicated. The combination of Measures and OpenStudio

Server also allows the breadth and depth of deemed savings analysis to be greatly expanded. One straightforward use is to explore additional independent variables to provide refined savings estimates—especially whole-building savings estimates—or in some cases to quantify savings estimates in the presence of uncertainty to assess deemed savings robustness criteria. Example independent variables include window-to-wall ratio, insulation levels, fenestration characteristics, and HVAC system types and efficiencies. Independent variables that do not significantly impact savings can be omitted from the final product, but lend additional confidence to the assumption that savings are robust. OpenStudio Server’s web interface facilitates interactive navigation of larger multi-dimensional spaces in addition to flat file export suitable for spreadsheet analysis. Additional uncertainty analysis could simply provide confidence in the robustness of the estimate, but it could also be explicitly exposed and integrated into the incentive process. For instance, premiums could be paid for ECMs with narrow uncertainty bands whereas ECMs with more variable outcomes could be incentivized at reduced levels.

A more ambitious use of additional model creation and simulation capacity is to expand the deemed savings path to cover ECM packages. This is especially valuable for packages of interacting ECMs. One of the well-known limitations of the deemed savings approach is the difficulty of handling interactive effects. Rather than providing savings values for individual ECMs along with “correction factors” for interactive effects, savings values could be calculated for packages, improving estimates, and reducing complexity for the end user by eliminating the need for correction factors and other downstream calculations. Providing a deemed savings for some ECM packages could help utilities more effectively incentivize these packages, achieve deeper savings, and meet their regulatory obligations.

## **OpenStudio for Custom Projects**

OpenStudio Measures simplify processes associated with deemed savings calculations, but may have even greater impact on custom projects. Xcel Energy of Colorado has been using OpenStudio, a set ECM, reporting, and quality-assurance Measures, and the OpenStudio-Measure based EDAPT (Energy Design Assistance Project Tracker) to implement and administer its Energy Design Assistance (EDA) for new construction program since 2013. The use of quality-assurance and reporting Measures reduces project administration costs by 15%. Office and educational projects that use pre-approved packages Measures that correspond to ASHRAE 50% Advanced Energy Design Guide (AEDG) (ASHRAE, 2016) recommendations see cost reductions of 50% (Elling et al., 2014). Other utilities including Austin Energy and Energy Trust of Oregon are now adopting the platform for their EDA programs.

### **Current Processes**

The custom project *ex ante* path is used for either existing or new buildings when deemed savings values for key ECMs are not available, when interacting ECMs are used, or—especially for new construction—for comprehensive designs that cannot be reduced to individual ECMs.

The custom project *ex ante* process resembles the process used for performance-path code compliance and green certification. It involves developing two models, a proposed or upgraded building model and a baseline model that corresponds to code level for new buildings and “deep” retrofits or to the existing building for more limited upgrades. The incentive is proportional to the modeled savings, which is calculated from the difference of the simulated



annual energy use of the two models. Many utilities supplement the incentive by subsidizing the modeling process for custom projects.

Whereas model development is the bottleneck for deemed savings, model review is the bottleneck for the custom path. Model development is done by project engineers or consultants; the reviewer pool is typically smaller. For custom projects, the dual models are inspected to ensure that the proposed building is modeled faithfully, that the baseline was created properly from the proposed model, and that savings are properly attributed and claimed.

### **Streamlining and Enhancing Current Processes**

OpenStudio Measures help streamline and automate the processes involved in developing and reviewing models for custom projects. For minor upgrades, the existing building is the baseline for savings calculations and the modeling process starts by modeling existing conditions. OpenStudio helps here because the combination of selected uncertainty distributions and OpenStudio Server objective function can implement automated model input calibration—tuning of model input parameters to better match modeled to measured energy use—improving the fidelity of the existing building model to desired levels, e.g., ASHRAE Guideline 14 (ASHRAE, 2002), and identifying remaining inputs that have both high impact and high uncertainty (Hale, et al., 2014). This residual uncertainty can be reduced via on-site inspections or, more likely, propagated through the savings analysis to produce a range of savings estimates.

Given a calibrated baseline model, the upgraded building model can possibly be generated by applying a combination of OpenStudio ECM Measures. In this case, the review process is simplified because rather than reviewing both the baseline and upgraded models and their differences, the only things requiring review are the baseline model—which has been calibrated to measured consumption—and the Measures. Measures can be shared across projects and can be reviewed and approved once for all projects. Furthermore, if Measures are deemed savings Measures, they have already been reviewed.

If the upgraded model cannot be created from the baseline using ECM Measures, and must instead be created manually, the simplified Measure-based review option is not available. However, OpenStudio Measures can still help by automating some basic checks such as ensuring that baseline and upgraded models have identical occupancy, lighting, plug-load and set-point schedules, as well as some program-specific checks, for instance, any restrictions on fuel-switching. Measures can also be used to create custom reports. OpenStudio Measures not only streamline the project model review process, they also improve review transparency producing less contentious and more predictable results. If quality-assurance and other review Measures are published, project consultants can execute them before submission. In doing so, they avoid submitting (some) models that will fail review—saving both frustration and reviewer time. Building energy model quality-assurance and reporting—especially for utility incentive programs—is a fast growing application of OpenStudio Measures.

For new buildings and major upgrades, the savings baseline is typically an energy-efficiency code (and vintage) selected by the utility. This custom project path resembles the handcrafted upgrade model path, but in reverse. In this case, there is no model of the existing building to start with. And while it is possible to start with a prototypical-building model and add ECMs, the more common workflow is to model the proposed building and then create the code-level baseline from it. A number of software programs can do this automatically; in OpenStudio, this functionality is provided by baselining Measures. The use of open and “pre-reviewed” baselining Measures eliminates the need to review the baseline model. Quality-assurance and

program-rule Measures can be developed and applied to the proposed building model to automate its review.

As with deemed savings calculations and existing building upgrades, the opportunity exists to use OpenStudio to perform uncertainty analysis by perturbing the proposed building model prior to baseline generation to gauge savings estimate robustness. Future *ex ante* programs may prescribe specific uncertainty analyses and adjust incentives according to the results.

## An OpenStudio-Based Ex Ante Ecosystem

The OpenStudio platform holds potential benefits for both deemed savings and custom project *ex ante* incentive programs. But its greatest benefit is in putting these two largely separate paths on the same platform, allowing them to effectively share development and review resources and to reinforce one another, and providing building energy-efficiency projects a set of interoperable incentive paths that encourage program participation and increase energy savings. The resulting ecosystem is shown partially and schematically in Figure 4.

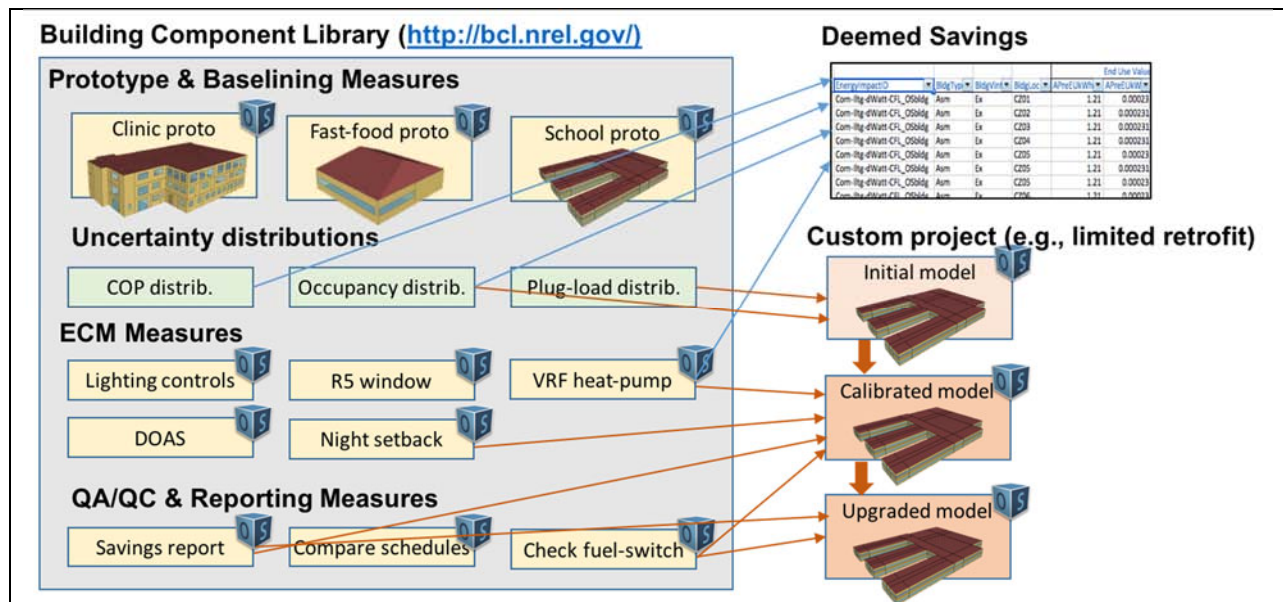


Figure 4. An OpenStudio Measure ecosystem for *ex ante* energy-efficiency programs. OpenStudio Measures are housed in the online Building Component Library (BCL) repository where they can be shared within organizations or more broadly. Shown using blue arrows, prototype building Measures, ECM Measures, and (optionally) uncertainty distributions on key ECM and model inputs, are used to develop deemed savings tables. Orange arrows show the same components applied to a custom project workflow. Uncertainty distributions used to create a calibrated model of an existing building to which ECM Measures are then applied to evaluate upgrades. Quality-assurance and reporting measures to the pre- and post-upgrade models.

The basis for this economy and synergy is the use of OpenStudio Measures to define and implement ECMs, prototype buildings and baselining procedures, and model review. Each of these components plays multiple roles. In the figure, blue arrows show contributions to the deemed savings process; orange arrows correspond to a custom project workflow, in this case a limited retrofit. ECM Measures support the development and review of deemed savings values; they can also be used in custom projects, typically for small upgrades as in the figure. Uncertainty distributions on key model and ECM inputs can help increase confidence in the

robustness of deemed savings values; they also play a role in model input calibration. Prototype building measures are used in the deemed savings development process; they double as baseline generation Measures for custom new building projects. Quality-assurance and program-logic Measures automate project screening; they also enable self-screening.

The transparency and accessibility of OpenStudio Measures mean that all *ex ante* actors—program administrators, reviewers, and project consultants—can contribute to improving the ecosystem. Project consultants can develop new ECM Measures and share them with other consultants. They can submit them for review and “pre-approval” for use in custom projects. Approved Measures can also be evaluated for the deemed savings path, in isolation or in packages. Reviewers can develop quality-checking measures to streamline their own workflows, share them with other reviewers and project consultants, and submit them for inclusion in the formal custom project process. And sharing need not be limited to a single utility-program or utility. The OpenStudio platform and its Measures facility allow a utility to leverage work done by other utilities for their programs. It even allows utilities to leverage work done in the service of no utility program at all.

One relevant OpenStudio-based project utilities may want to leverage is Scout, a national impacts assessment tool developed by DOE’s Building Technologies Office for technology portfolio management, specifically for performance and cost target setting (Harris, et al., 2016). Scout evaluates ECMs on OpenStudio prototype models and applies the savings—together with tunable adoption assumptions—to an evolving “stock-and-flow” model of the national building stock. Scout is used to project future savings for technologies both individually and “competitively”, i.e., against one another. Scout can also deal with technology packages. Utilities can use the Scout framework—as well as the over 50 ECM Measures developed for it, including the `occupancy_sensors_for_lighting` measure shown in Figure 1—to explore target costs for different ECMs and to help develop incentive portfolios.

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