Chapter 6
OpenStudio Measures

6.1 Introduction to OpenStudio Measures

Chapter 1 briefly mentioned the concept of OpenStudio Measures. These small scripts written in the Ruby[1] programming language are a unique feature of OpenStudio and are key to the platform's extensibility. Measures are most often used to implement model transformations that correspond to Energy Efficiency (EE) measures – hence their name. However, as we shall see, they can be used to query and transform OpenStudio models and associated data in a variety of ways. Throughout this text, whenever you see the word Measure capitalized, know that we're referring to an OpenStudio script as opposed to an EE measure.

Like their namesake, Measures are frequently used to apply an EE technology to a building Model in a simple, self-contained operation. For example, if a designer wishes to assess the potential for Energy Recovery Ventilation (ERV) to save energy in a building, they can select the ERV Measure and apply it to their Model. Figure 6.1 illustrates and HVAC system before and after the Measure is applied. Other examples include modification of an HVAC system's coefficient of performance (COP), alterations to window-to-wall ratio (WWR), and alteration of insulation thermal resistance (R-Values).

Simple parametric substitutions are generally within the capability of other modeling tools and scripting languages. Since OpenStudio Measures are written in the full-featured Ruby scripting language, and have access to components in OpenStudio's Object Model, Measures can do much more. One of the most significant examples is shown in Fig. 6.2.

[1] https://www.ruby-lang.org/en/

The original version of this chapter was revised. A correction to this chapter can be found at https://doi.org/10.1007/978-3-319-77809-9_10

Electronic Supplementary Material: The online version of this chapter (https://doi.org/10.1007/978-3-319-77809-9_6) contains supplementary material, which is available to authorized users.

L. Brackney et al., *Building Energy Modeling with OpenStudio*,
https://doi.org/10.1007/978-3-319-77809-9_6

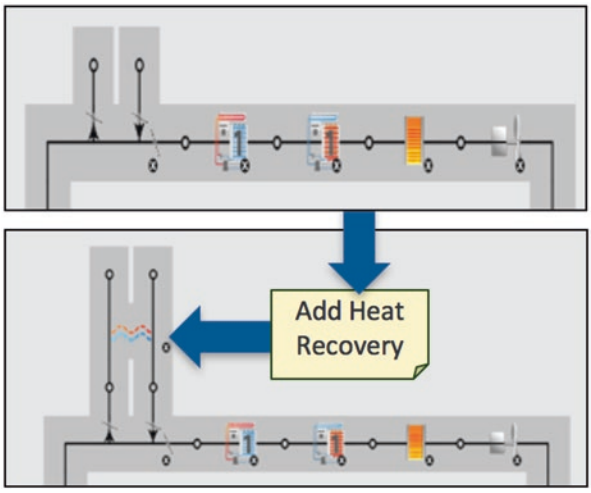


Fig. 6.1 Measure used to add heat recovery to an HVAC system (https://bcl.nrel.gov/node/39440)

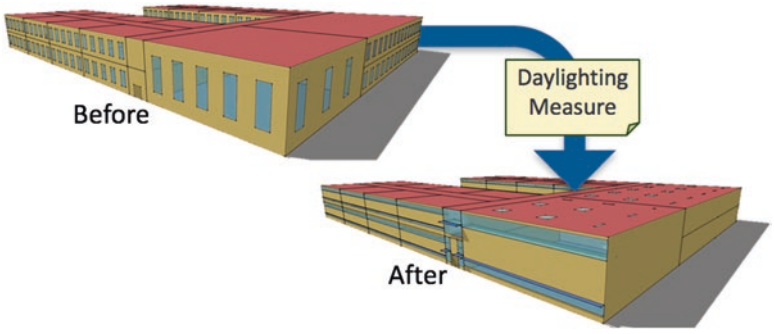


Fig. 6.2 Measure used to apply a complete daylighting solution to a school (https://bcl.nrel.gov/node/39783)

In this example, a complete daylighting solution is applied to an arbitrary primary school Model with a single operation. This particular Measure is based on design guidance in the ASHRAE Advanced Energy Design Guide (AEDG) for K-12 schools[2] that includes:

- Removal of all existing fenestration,
- Addition of daylight and view glass to South-facing facades,
- Addition of daylight redirection devices (light shelves),
- Placement of daylight sensors and controls,
- Addition of skylights to spaces that benefit from top-lighting, and
- Addition of shading devices for glare control.

Note that the daylighting Measure "intelligently" traverses spaces within the Model, applying design elements surgically – e.g. skylights are added to a cafeteria

[2] ASHRAE (2011).

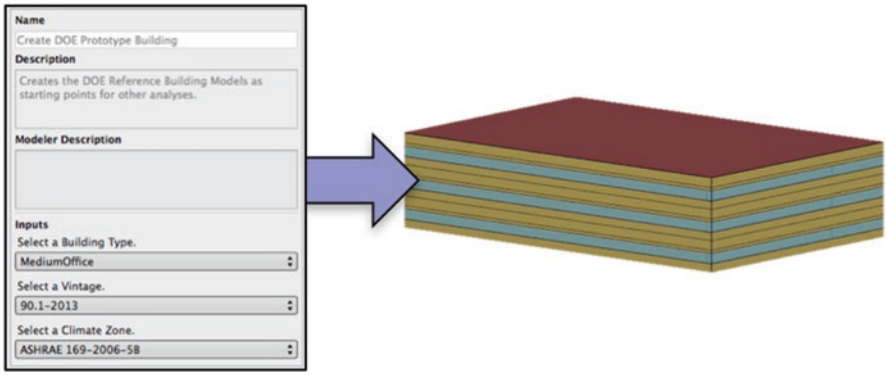


Fig. 6.3 DOE prototype building Measure (https://bcl.nrel.gov/node/83591) dialog and result

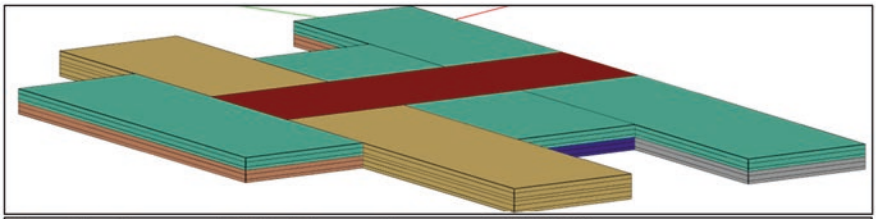
and gymnasium, but not in classrooms where top-lighting would interfere with projection Equipment. The Measure script embodies an expert modeler's knowledge of how to approach a good daylighting design; enabling a less experienced modeler to evaluate the Measure with far greater confidence than if they attempted to modify a Model by hand. Encapsulation of "best practice" for EE modeling is a powerful capability for increasing both speed and consistency of energy modeling.

Because Ruby is such a capable scripting language, OpenStudio Measures are not limited to modeling the application of EE technologies to buildings. They can also operate on an empty Model, using Ruby code along with the OpenStudio Standards Gem[3] to generate models from scratch. One example is the "Create DOE Prototype" Measure, which creates a Model procedurally from three Measure inputs: building type, vintage, and climate zone (Fig. 6.3). Behind scenes, this Measure (along with the Standards Gem) encapsulates a large amount of model input data and modeling heuristics corresponding to various building energy codes and standards. The net result from a user's perspective is that an incredibly sophisticated series of modeling operations are packaged within a deceptively simple interface.

Another type of OpenStudio Measure focuses on querying the data associated with the energy Model to produce customized reports or data exports. Although we didn't mention it, the standard OpenStudio reports we have reviewed in previous chapters are actually generated by a Measure, which enables easy customization and expansion. Other popular "reporting Measure" applications include interactive 3D visualizations for building geometry, automated Model quality checking, and HVAC psychrometric charts. Figure 6.4 presents html renderings for three reporting Measures.

Chapter 9 will cover the anatomy and creation of Measures in greater detail. The remainder of this chapter focuses on utilizing Measures to automate common modeling tasks.

[3] https://github.com/NREL/openstudio-standards. A Ruby Gem is a packaged library of Ruby code. The OpenStudio Standards Gem contains a collection of Ruby scripts that are useful for applying energy standards and input assumptions to models.



Austin Energy EDA Reporting and QAQC

Name	Category	Flags	Description
EUI Reasonableness	General	0	Check EUI for model specific building type against DOE prototype buildings with Austin Energy specific tolerance.
Weather Files	Austin Energy	0	Check weather file, design days, and climate zone against Austin Energy list of allowable options.
End Use by Category	General	2	Check end use by cateogry against DOE prototype buildings with Austin Energy specific tolerance.
Mechanical System Part Load Efficiency	General	0	Check 40% and 80% part load efficency for the following compenent types: ChillerElectricEIR, CoilCoolingDXSingleSpeed, CoilCoolingDXTwoSpeed, CoilHeatingDXSingleSpeed. Checking EIR Function of Part Load Ratio curve for chiller and EIR Function of Flow Fraction for DX coils.
Internal Loads	Baseline	0	Check Space-by-space load checks for LPD, ventilation rates, occupant density, plug loads, and equipment loads against ASHRAE standards and DOE Prototype buildings.
Schedules	Baseline	0	Check schedules for lighting, ventilation, occupant density, plug loads, and equipment based on DOE reference building schedules in terms of full load hours per year.
Mechanical System Efficiency	Baseline	0	Check per 90.1 Tables 6.8.1 A-K. The following component types are checked: ChillerElectricEIR, CoilCoolingDXSingleSpeed, CoilCoolingDXTwoSpeed, CoilHeatingDXSingleSpeed, BoilerHotWater, FanConstantVolume, FanVariableVolume, PumpConstantSpeed, PumpVariableSpeed
Envelope R-Value	Baseline	1	Check per ASHRAE 90.1 Table 5.5.-2 per Table G2.1.5 b,c,d,e (with reflectance = 0.55), Section 5.5.3.1.1a.
Domistic Hot Water	Baseline	1	Rule-of-thumb check per ASHRAE standards.

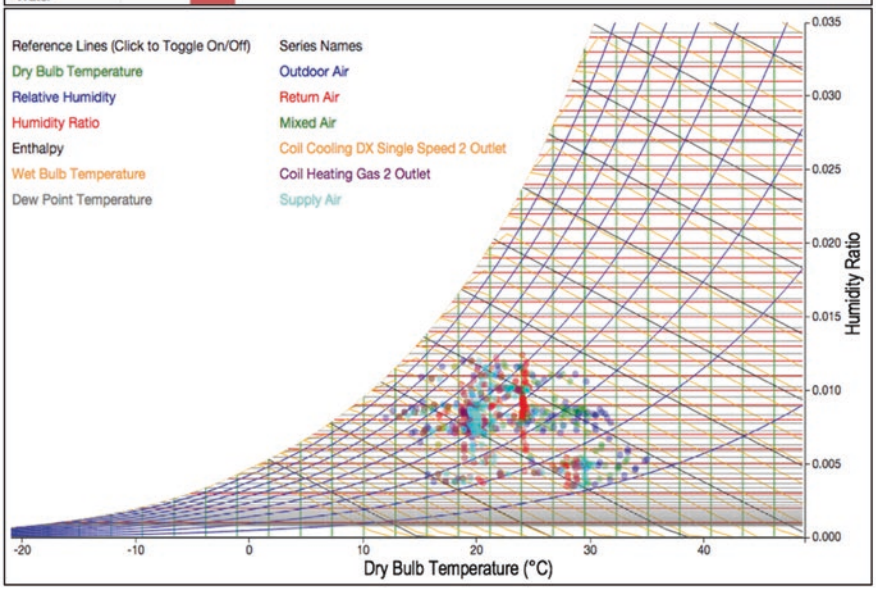


Fig. 6.4 OpenStudio reporting Measure examples (https://bcl.nrel.gov/node/82771, https://bcl.nrel.gov/node/83647, https://bcl.nrel.gov/node/83307)

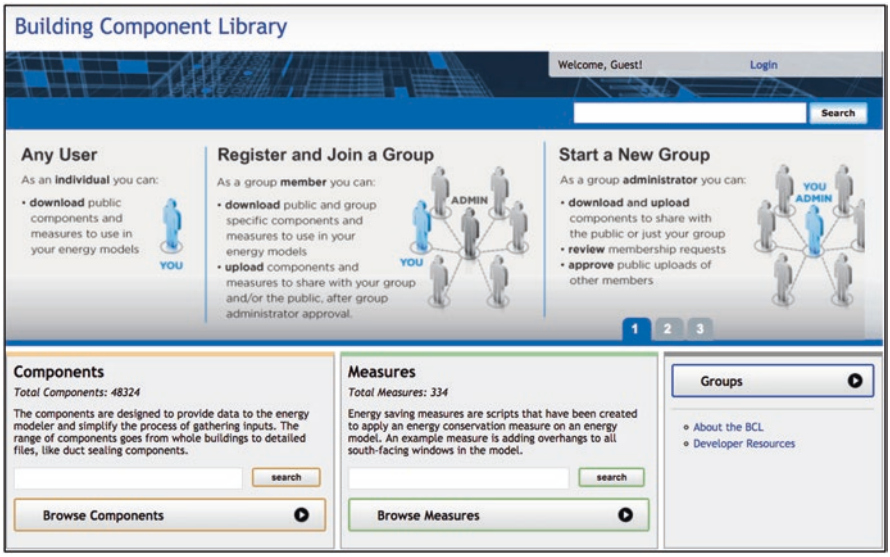


Fig. 6.5 Landing page of http://bcl.nrel.gov

6.2 Accessing and Using Measures

Since Measures are such an important part of the OpenStudio ecosystem, it stands to reason that ensuring they are easily accessible is an important feature of the platform. Measures are stored in an online repository called the Building Component Library (BCL).[4,5] The BCL can be accessed through a web browser, and includes integral search functionality to quickly locate content of interest. Figure 6.5 shows the landing page of http://bcl.nrel.gov.

An integrated search engine allows users to quickly identify content of interest – e.g. HVAC Measures (Fig. 6.6). The left side of the BCL window enables narrowing of search results using a combination of attributes.

Clicking on a specific entry brings up more information that can help the modeler determine if a particular Measure is right for the task. Figure 6.7 is the BCL entry for the ERV Measure we highlighted above. Eagle-eyed readers will note that this Measure has a specific URL (Uniform Resource Locator) that is unique to the Measure. Footnotes associated with Figs. 6.1, 6.2, 6.3, and 6.4 call out the respective URLs for the illustrated Measures, facilitating citation and sharing of specific content used in any given analysis. We'll revisit these Unique Identifiers (UIDs) along with the rest of a Measure's descriptive information in Chap. 9, but for the time being note the descriptive text and a Button that allows the Measure to be downloaded.

[4] http://bcl.nrel.gov

[5] Fleming et al. (2012).

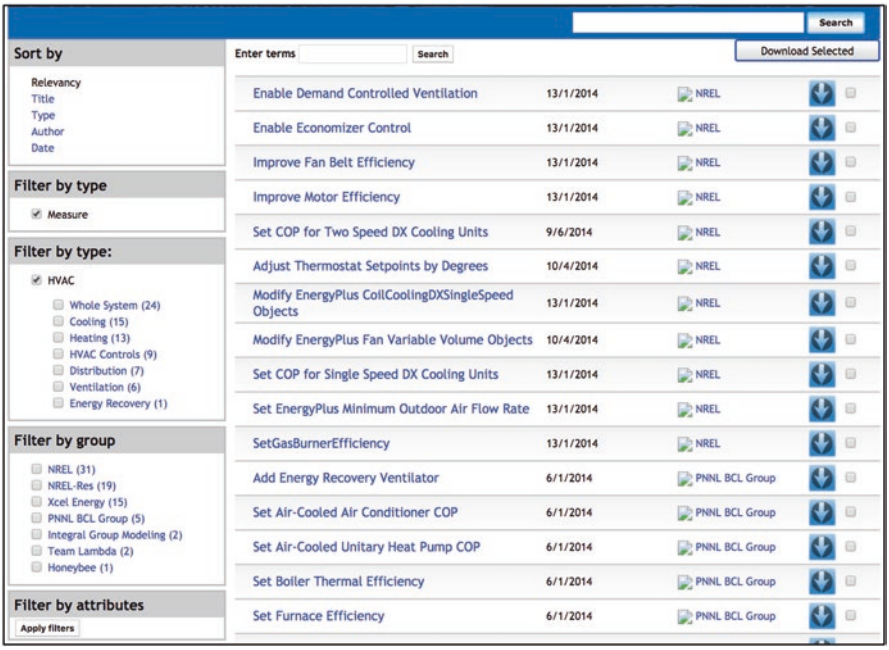


Fig. 6.6 HVAC Measures on the BCL

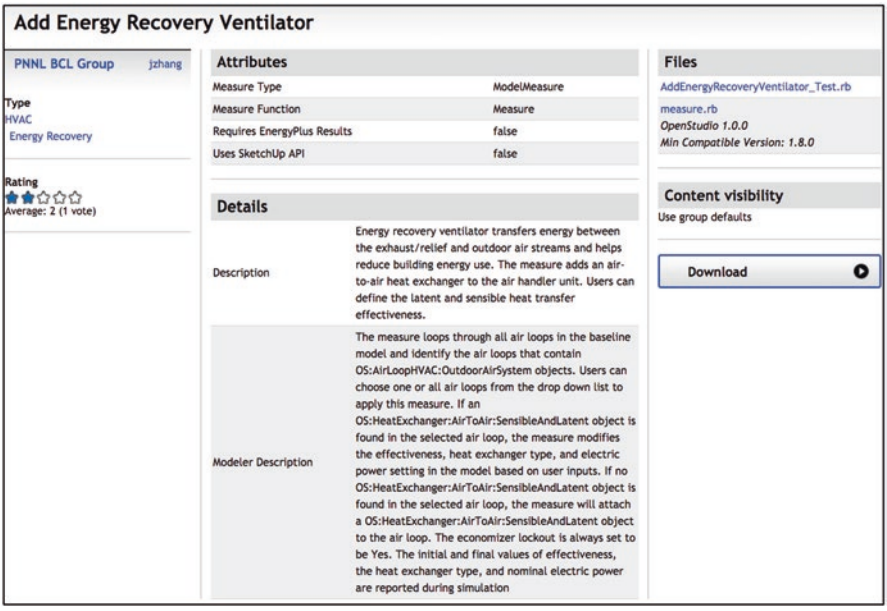


Fig. 6.7 BCL web page for ERV Measure

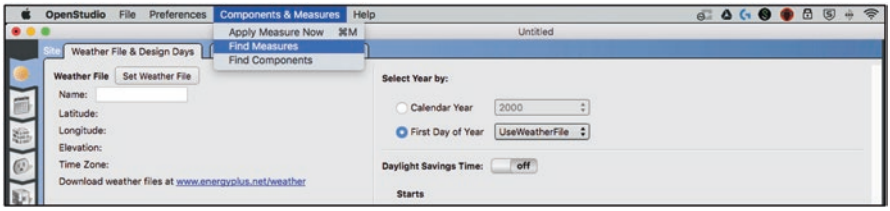


Fig. 6.8 Accessing the BCL from within the OpenStudio Application

6.3 Using Measures Within the OpenStudio Application

While the BCL web page provides a convenient means of identifying and downloading Measures, OpenStudio utilizes the BCL's API to integrate that search and download functionality directly in its applications. Not only does this improve convenience for the modeler, but it also allows OpenStudio applications to identify when a more recent version of the Measure is available for use. In the OpenStudio Application, the BCL is accessed from the "Components & Measures" menu (Fig. 6.8).

Once selected, a new BCL dialog pops up to allow search and selection of Measures. Measures already downloaded appear with a gray checkbox next to them. Clicking the checkbox next to one or more Measures and scrolling to the bottom of the list reveals a download Button that may be used to add additional content to a user's computer. In Fig. 6.9 we can see that the ERV Measure has already been downloaded and installed for use in an energy Model.

6.3.1 Applying a Measure Immediately to a Model

The OpenStudio Application offers two ways to use Measures: the "Apply Measure Now" menu option and via the Measure ( ) Tab. "Apply Measure Now" is located in the same menu used to open the BCL dialog (Fig. 6.8) and is used to select and apply a Measure to the active Model. As an example, consider the energy Model with a single Zone served by a packaged rooftop unit shown in Fig. 6.10.

Selecting the Apply Measure Now option, the user is first prompted to save their Model before proceeding to the Measure selection dialog (Fig. 6.11). Navigating the same categories used on the BCL, we can quickly locate the "AddEnergyRecoveryVentilator" Measure discussed previously. The OpenStudio icon and blue BCL text indicate this Measure has been downloaded from the BCL. Selecting that Measure updates the window with a description of the Measure and several Measure-specific inputs that can be customized. In this example, we have selected only the Packaged Rooftop Air Conditioner air loop for the Measure to act on and accept the default values for the remaining inputs related to heat exchanger efficiency.

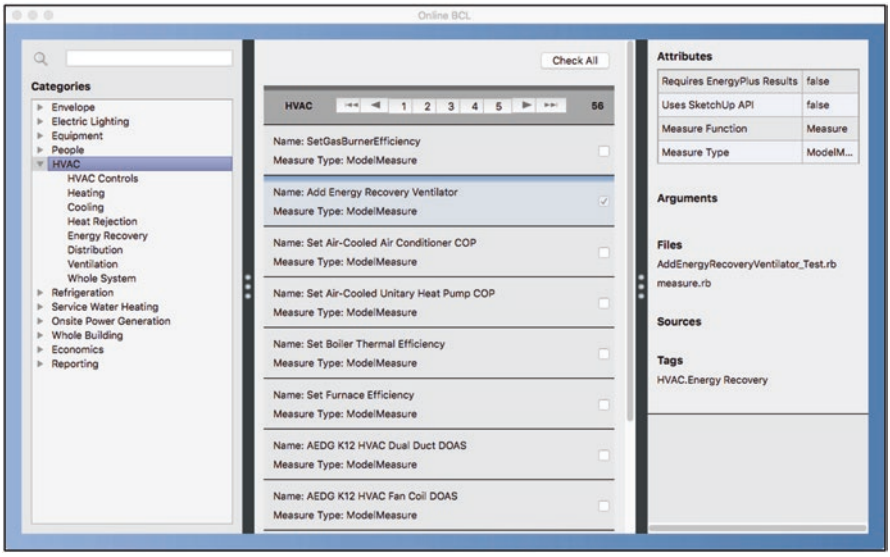


Fig. 6.9 The BCL interface within the OpenStudio Application

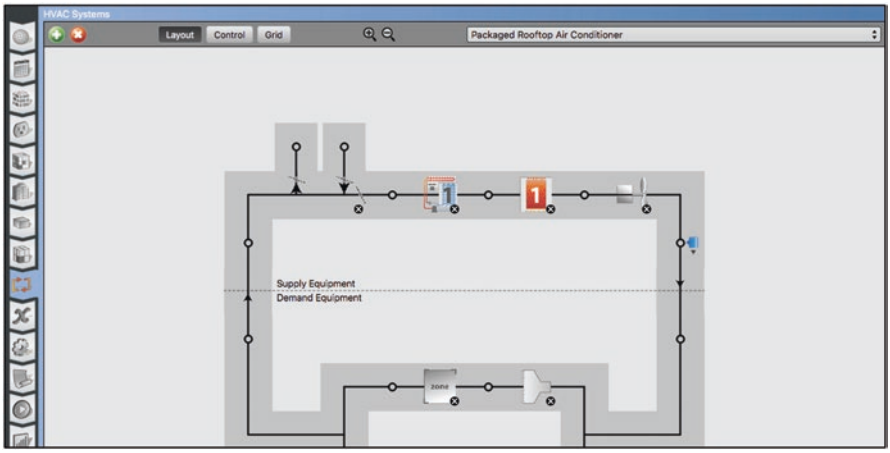


Fig. 6.10 Model HVAC air loop prior to applying Measure

Clicking the "Apply Measure" Button transitions to a progress indicator while the Measure is applied to the Model. After a brief wait, a new dialog appears containing the Measure's "output." Just as Measure inputs vary, so do outputs. In this case, the ERV Measure reports what it did to the Model: reporting how many air loops it may have structurally modified along with Model parameters that have been set or altered (Fig. 6.12). This dialog would also report any errors that may have occurred when applying the Measure. This feedback allows the user to determine if the Measure behaved as expected, accepting those changes to the Model, or rejecting the modification with the Cancel Button.

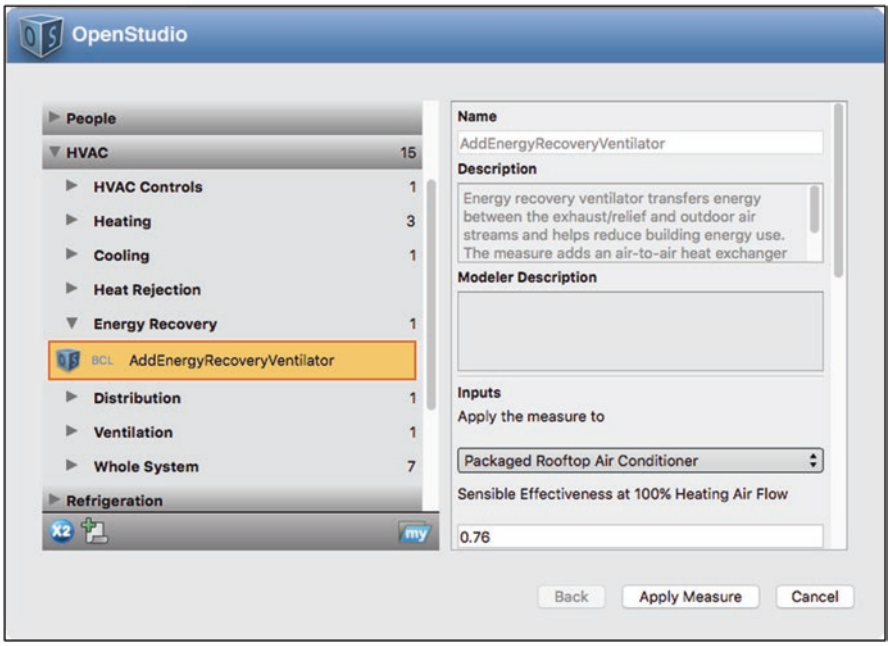


Fig. 6.11 Apply Measure Now window with ERV Measure selected

Figure 6.13 shows the OpenStudio HVAC ( ) Tab after the Measure was applied, allowing us to visually confirm that the Measure added an ERV to the Packaged Rooftop Air Conditioner loop and that the parameters for the ERV were set as expected. Saving the Model once more will make this alteration permanent.

6.3.2 *Adding Measures to an OpenStudio Application Workflow*

The second method of applying Measures to a Model utilizes the Application's Measures ( ) Tab (Fig. 6.14). The fundamental difference between this method and using "Apply Measure Now" is that the Measures ( ) Tab does not permanently modify the building Model. Measures are applied to the Model and affect simulation results, but the Model itself is left untouched. This can be useful in seeing the effect of a Measure without fully committing to that as a design feature in the building Model.

Note that the Measures ( ) Tab has sections for three "types" of Measures. They are OpenStudio Measures, EnergyPlus Measures, and Reporting Measures. Each has a unique icon, and on the right side of the Tab, we note that several of the available Measures have matching icons. To understand the meaning of these three categories, it is important to understand what OpenStudio does when we push the Button on the Run Simulations ( ) Tab. This run process or "workflow" is illustrated in Fig. 6.15.

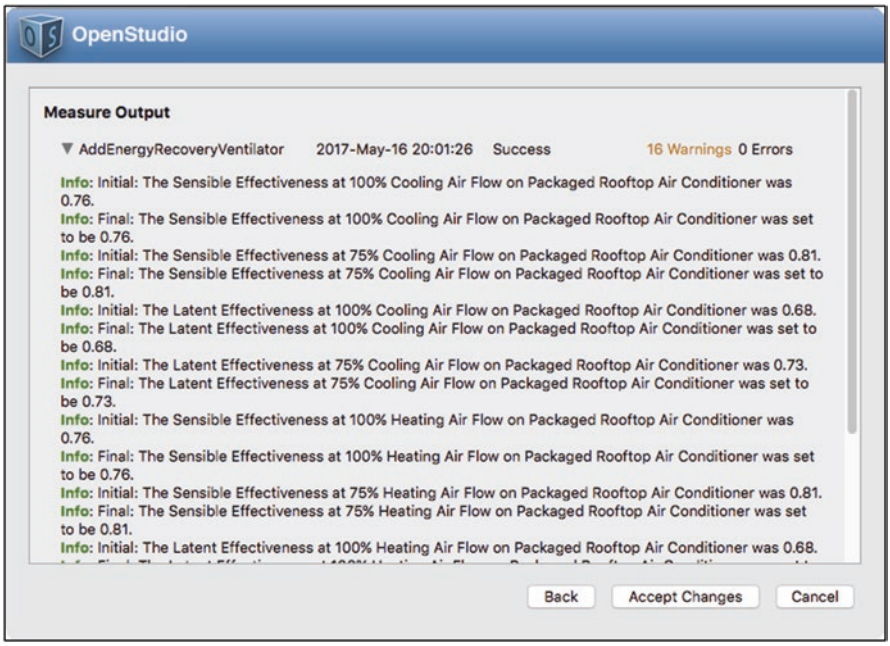


Fig. 6.12 Report from ERV Measure after application

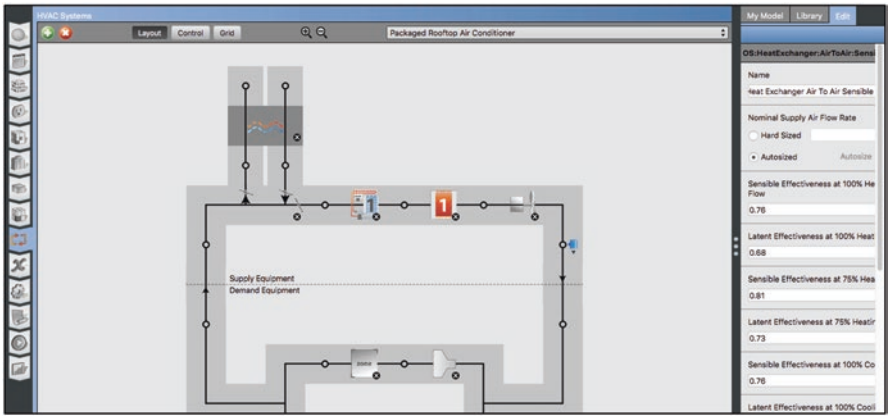


Fig. 6.13 Model HVAC air loop after applying Measure

As one would expect, the process begins with the OSM. The first Measures to be applied to the Model are OpenStudio Measures, Measures that make full use of OpenStudio's Object Model and data inheritance. An OpenStudio Measure that removes an HVAC air loop removes not only the loop, but all of the objects within it and any associated Zone or Plant Loop Connections. Similarly, an OpenStudio Measure could alter a space type definition, simultaneously changing all of the space's underlying definitions for loads, occupancy, schedules, etc. OpenStudio Measures are the preferred means of modifying an OpenStudio Model.

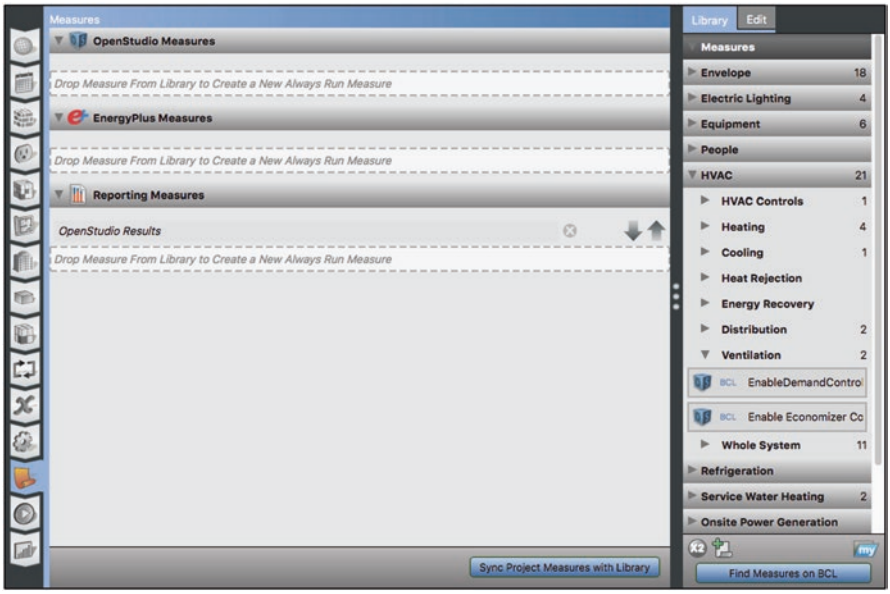


Fig. 6.14 OpenStudio Application Measures Tab

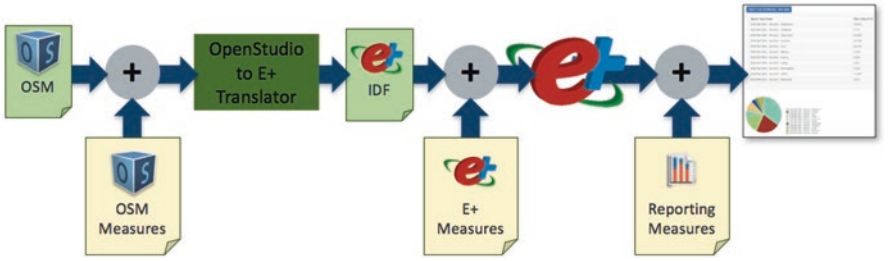


Fig. 6.15 High level OpenStudio workflow with Measures

After all, OpenStudio Measures are applied to the Model, OpenStudio translates the Model from an OSM to an EnergyPlus IDF in preparation for actually running the simulation. At this point, EnergyPlus Measures can be applied to the IDF. EnergyPlus Measures are most often used to make specific alterations to the EnergyPlus IDF that may not yet be supported within the OpenStudio Object Model. These might include new, experimental, or esoteric EnergyPlus features that OpenStudio has yet to support. Examples at the time of writing include Measures that add utility tariffs to the Model or modify EnergyPlus Energy Management System (EMS) control logic. EnergyPlus Measures do not enjoy the benefits of the OpenStudio Object Model, and are best suited for simple, well-defined text additions or substitutions in the IDF file. Because of their limitations, EnergyPlus Measures should be used sparingly.

Following the application of any EnergyPlus Measures, OpenStudio invokes the EnergyPlus simulation engine itself. This produces both high level summaries

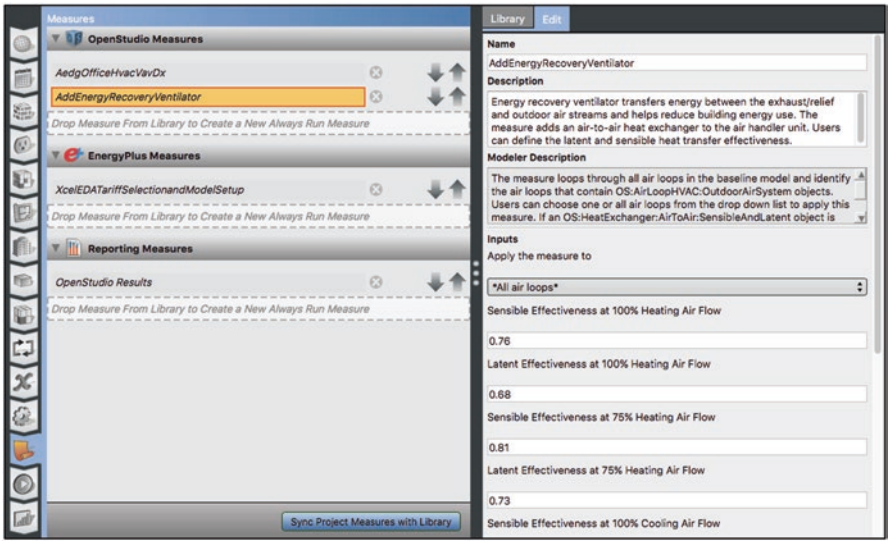


Fig. 6.16 Measures added to a simulation workflow

of the simulation results in an EnergyPlus eplustbl.htm file, along with a SQLite database containing detailed time series results from the simulation. These (and other) EnergyPlus output files are the subjects of the final class of Measures, Reporting Measures. Reporting Measures can parse and format simulation results for a number of purposes ranging from creating simple Model summaries to applying automated quality check heuristics against the simulation results. Reporting Measures allow the user to customize the simulation output to produce static or interactive content suited to specific analysis needs or the target audience.

Figure 6.16 shows the Measures ( ) Tab after several different Measures have been "dragged and dropped" into the three categories. In this example, we apply two OpenStudio Measures that modify the HVAC systems in the building, one EnergyPlus Measure that adds a utility rate tariff, and a Reporting Measure that produces the standard OpenStudio HTML report. As with the Apply Measure Now method, the user can select a Measure and modify all of its inputs on the right side of the window. It is also important to note the Buttons just to the right of the Button that allows a Measure to be removed from the workflow. These arrows allow Measures to be reordered. This is important because Measures are generally non-commutative or order dependent. Consider this example where the "AEDGOfficeHvacVavDx" Measure operates on the Model before "AddEnergyRecoveryVentilator." In this case, the first Measure removes all existing HVAC systems from the Model, replacing them with VAV systems before ERVs are added. If the order is reversed, an ERV is first added to the Model's existing HVAC systems. This modification is then eradicated when those systems are replaced by VAV systems – quite likely not the intended result.

6.4 Introduction to Parametric Analysis

In practice, we wish to compare the performance of various building designs including individual EE measures or combinations thereof. The previous section showed how Measures might be applied to an OpenStudio Model to create Design Alternatives. While Measures make the process of altering the Model fast and repeatable compared to manually altering it, comparison of results would still be cumbersome; perhaps involving setup and management of multiple simulations and transcription of relevant outputs into a spreadsheet. Comparative analysis of Measure-based Design Alternatives is the role of another OpenStudio example application, the Parametric Analysis Tool (PAT).

PAT allows the user to quickly try out and compare specified combinations of measures, optimize designs, calibrate models, perform parametric sensitivity analysis, and much more. This section focuses on utilizing Measures to manually construct Design Alternatives that can be simulated using local computing resources. Chapter 7 delves more deeply into PAT's ability to explore design spaces utilizing a variety of sampling and search algorithms that can be run on dedicated computing hardware or in the cloud.

6.4.1 Starting PAT

When first launching PAT from the OpenStudio installer package the user has the option to create a new project or open an existing project (Fig. 6.17). An OpenStudio project represents a particular analysis comparing results from multiple models and resulting simulations.

To create a new project:

- Click the "Make New Project" Button.
- Type the name[6] for the project and click "Continue" as shown in Fig. 6.18.
- Browse to the directory where the project should be saved and click the "Open" Button (Fig. 6.19). PAT will create a new directory for the project at this location.

The user may also open an existing PAT project when first launching PAT, or from PAT's file menu. In either case a dialog will open to locate the Project directory. There is no file to select, just browse to the top-level of the project directory. Figure 6.20 illustrates selecting a previous project called "Office_HVAC."

As with most modern software applications, PAT's File menu also allows the user to create a new project, open an existing project, save a project, or save a copy of a project under a new name. Saving a copy of a project creates a new directory structure containing all of the project's resources.

[6] Important note – project names should not include spaces.

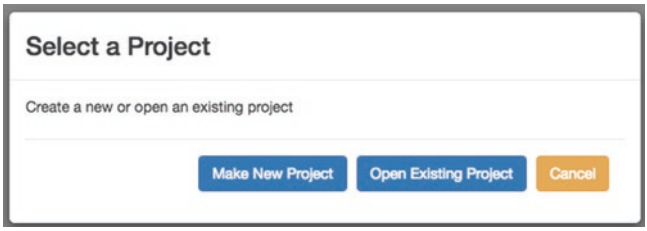


Fig. 6.17 Starting OpenStudio's Parametric Analysis Tool (PAT)

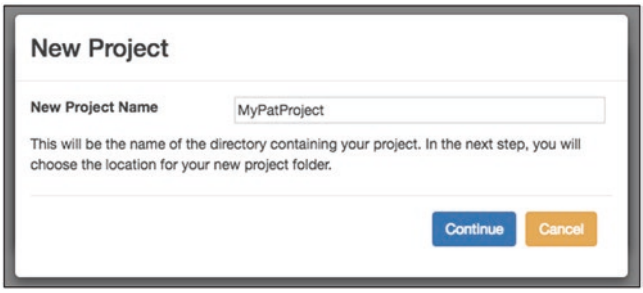


Fig. 6.18 PAT new project dialog

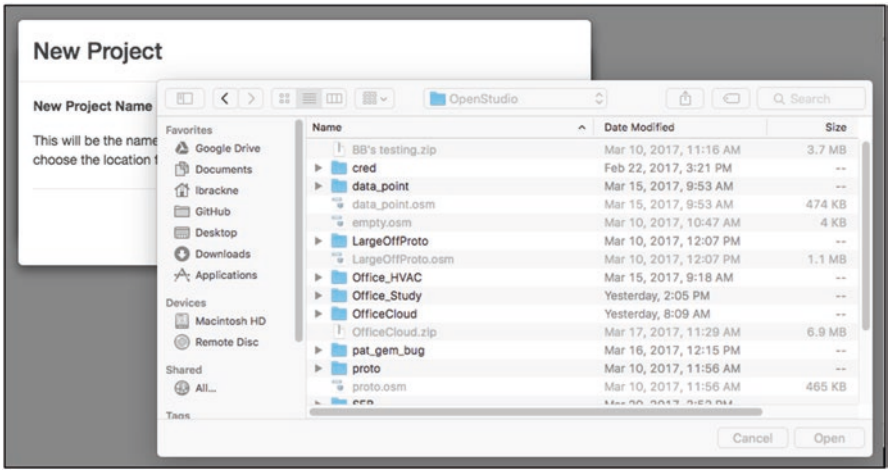


Fig. 6.19 Specifying a new PAT project's location

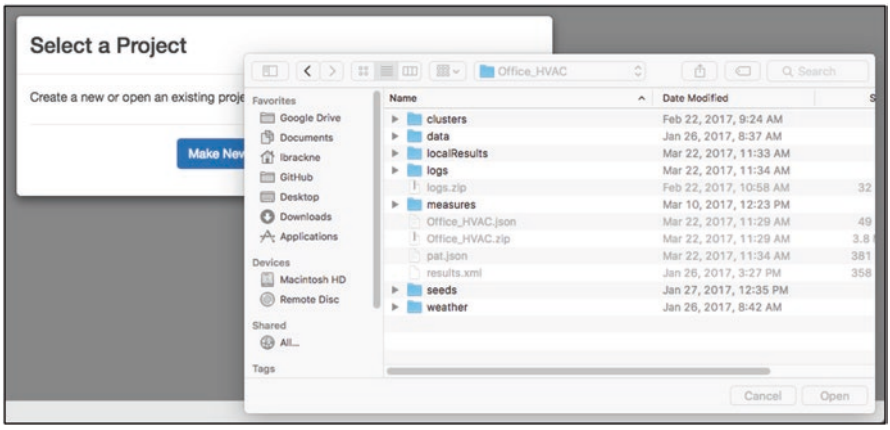


Fig. 6.20 Opening the "Office_HVAC" project in PAT

6.4.2 Managing Measures in PAT

Like the OpenStudio Application, PAT's functionality is broken down into Tabs located along the left side of the window. The Tabs include:

- **Analysis** – Used to specify the analysis mode, seed models, weather files, Measures, and Measure options;
- **Design alternatives** – Used to establish Design Alternatives;
- **Outputs** – Specifies outputs for algorithm-based analysis;
- **Run simulations** – Runs an analysis and manages the analysis server;
- **Compare results** – Used to view comparison reports; and
- **Analysis server** – Allows the user to view and interact with the underlying analysis server.

In general, a PAT workflow moves through the six vertical Tabs from top to bottom. PAT allows the user to specify Design Alternatives manually or automate the process using a selection of algorithms. The analysis mode is selected at the top of the Analysis ( ) Tab (Fig. 6.21). The choice of mode dictates whether the Design Alternatives ( ) or Outputs ( ) Tabs are used along with the types of computing resources (local or cloud) that may be selected on the Run Simulations ( ) Tab. This section focuses on PAT's "manual" mode. Algorithm-driven analyses are the subject of Chap. 7.

Just below the analysis mode selector are fields to identify a default "seed" Model and weather file. At this point, the weather file is self-explanatory. The seed Model is the initial Model that Measures in the project will be applied to. Clicking on the symbol allows the user to select the seed Model and weather file. Note that PAT supports specifying multiple seed and weather files that may all be used within a project for certain types of analyses.

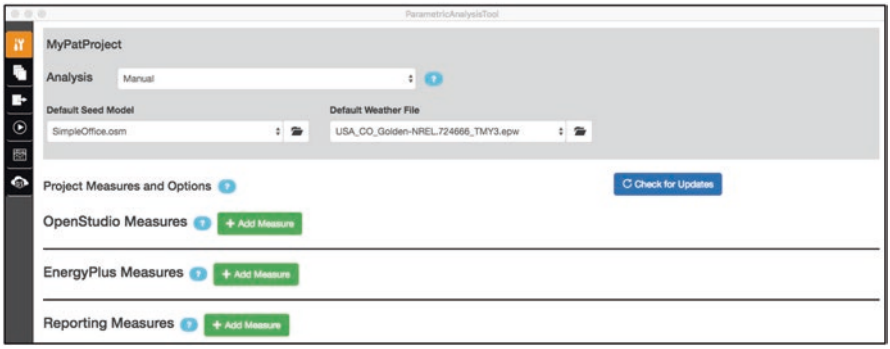


Fig. 6.21 Specifying an analysis in PAT

Fig. 6.22 PAT's Measure Library dialog for the "Office_HVAC" project

As with the OpenStudio Application, PAT allows the selection of all three Measure types. Click the + Add Measure Buttons by the OpenStudio, EnergyPlus, or Reporting Measure text to add Measures of that type to your project. The resulting Measure Library dialog is structurally similar to the BCL dialog we used in the OpenStudio Application. It provides the same search, download, and add functionality discussed in the previous section with a few additions. Figure 6.22 shows the dialog for an existing project that serves as a useful example in expanding our understanding of Measures.

The Measure Library dialog allows the user to filter by Measure location, type, category, and sub-category. When it first opens the dialog will have all locations checked except for BCL (Online). It will also have only one Measure type checked, based on which + Add Measure Button was clicked. The category and sub-category options are identical to the categories discussed in the previous section and are helpful in locating a Measure more rapidly.

OpenStudio Measures are located in one of four distinct locations:

1. My Project – Measures that have already been added to the current PAT project. Such Measures will be denoted with a under the "Add" column to indicate they've been added to the project.
2. Measure Directory – Measures stored in a user configurable "MyMeasures" directory on your computer. This topic will be discussed further in Chap. 9, but this directory generally will contain Measures that the user has customized or intends to customize. These Measures will have a "My" label next to the Measure name and may be added to the project by clicking the Button.
3. Local – Includes any BCL Measures that may have already been downloaded. These Measures will have a "BCL" label next to the Measure name and may be added to the project by clicking the Button.
4. BCL (Online) – Contains all publicly available Measures located in the online BCL that have yet to be downloaded.

Only Measures stored in Local or MyMeasures may be added to a PAT project, and only Measures added to the project may be used to create Design Alternatives for comparison. BCL Measures cannot be added until they are first downloaded – hence the reason the BCL selector is initially unchecked in the Measures Library dialog. Figure 6.23 shows the same project Measure Library dialog with the BCL selector turned on and the Envelope/Fenestration subcategory selected. Downloading a Measure from the BCL to Local is as easy as clicking the relevant Button.

Once downloaded, PAT will check to see if an updated version of a Measure is available in the BCL each time the project is opened. Available updates will be indicated with a symbol in the "updates" column. Simply click the to download the latest version to your local library.

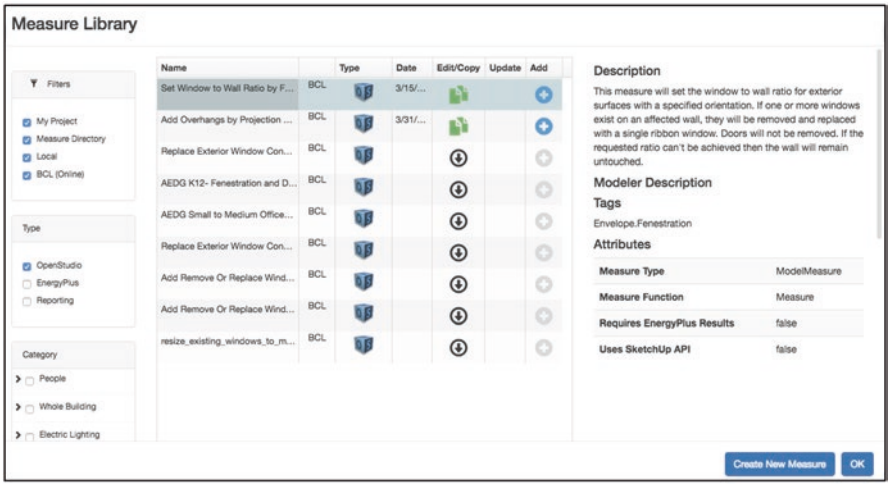


Fig. 6.23 PAT's Measure Library with BCL fenestration content shown

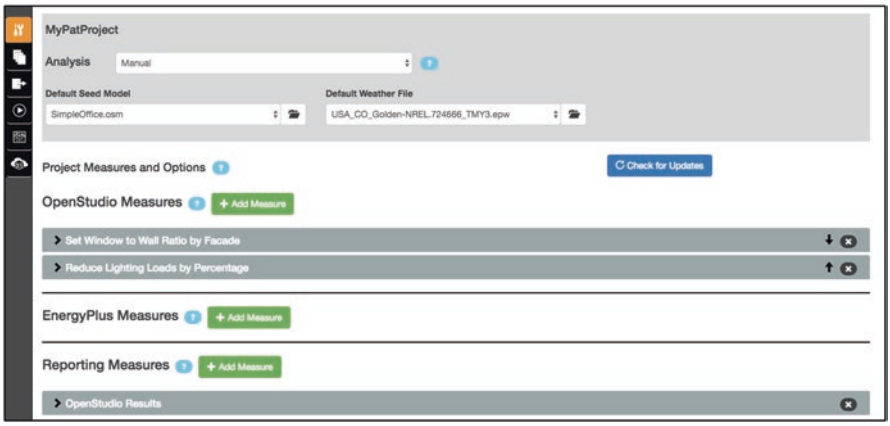


Fig. 6.24 Three Measures added to a PAT project

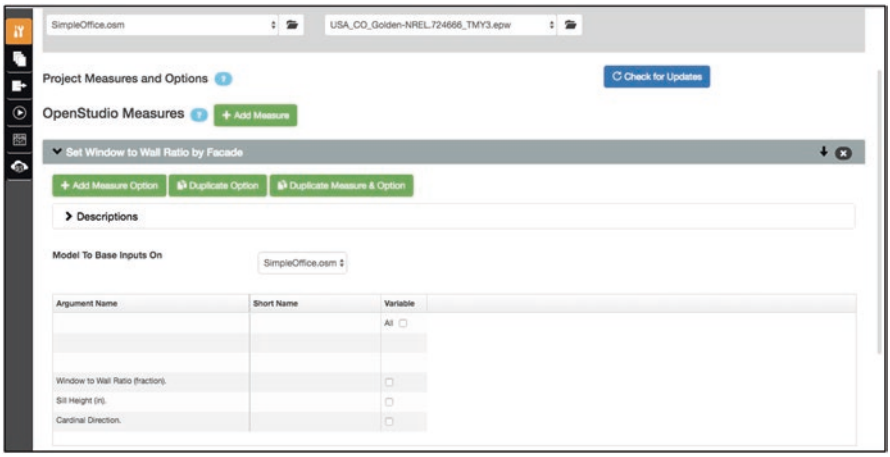


Fig. 6.25 Set window to wall ratio by Façade Measure expanded

After making the desired selections with ⊕ and closing the BCL dialog, our Measures are now loaded into the project. In the example shown in Fig. 6.24, three measures have been added.

Recall from the previous section that the ordering of Measures matters. As in the OpenStudio Application, Measures in PAT run from top to bottom in the user interface, and they may be reordered using the ↑ or ↓ arrows at the right. The ⊗, may be used to delete a Measure from the project. Note that each Measure also has an › just to its left. This is used to expand and collapse the Measure, allowing the user to specify Measure input arguments and more (Fig. 6.25).

Every Measure in a manual analysis project needs at least one Measure "option." An option describes a Measure and particular set of Measure arguments that will be applied to create a specific Design Alternative. For example, a generic fan efficiency

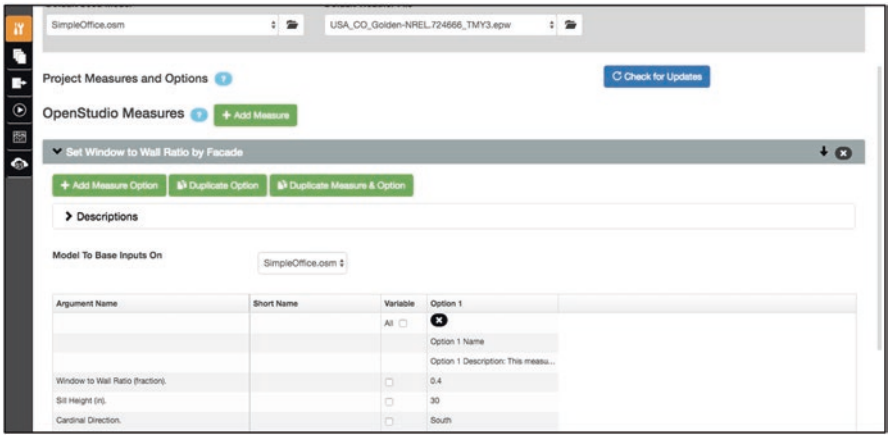


Fig. 6.26 A newly created Measure option

Measure would likely have an efficiency argument. Applying that generic Measure with a specific value for efficiency would constitute an option representing a specific fan product.

Clicking the + Add Measure Option Button adds a column to the right side of the grid for the Measure. Newly created options have a generic option name, description, and inherit any default values specified by the Measure. Figure 6.26 depicts a newly created "Set Window to Wall Ratio by Façade" Measure option with the Measure's default values.

The variable column and associated checkboxes are used to specify which arguments will vary across design options. Each option must be given a unique (and meaningful) name that will be referenced when constructing Design Alternatives. The option description field is free form and can be used to capture notes regarding the option that may be used by reporting Measures. In Fig. 6.27, three design options have been created with variable window to wall ratios.

The standard OpenStudio Results Measure must be added to every project as an option for each Design Alternative (Fig. 6.28). Manual project reports and most algorithmic workflows rely on outputs defined by this Measure to work properly. PAT will run without this Measure and an associated Measure option, but comparison results will not appear correctly.

6.4.3 Creating Design Alternatives in PAT

The Design Alternatives ( ) Tab is used to create Design Alternatives consisting of a seed Model, weather file, and some combination of Measure options. Design alternatives may be based on multiple seed models, allowing for the inclusion of modeled alternatives for which no Measure exists. Buttons near the top of the window are used to create and copy individual alternatives. A Button to automatically create

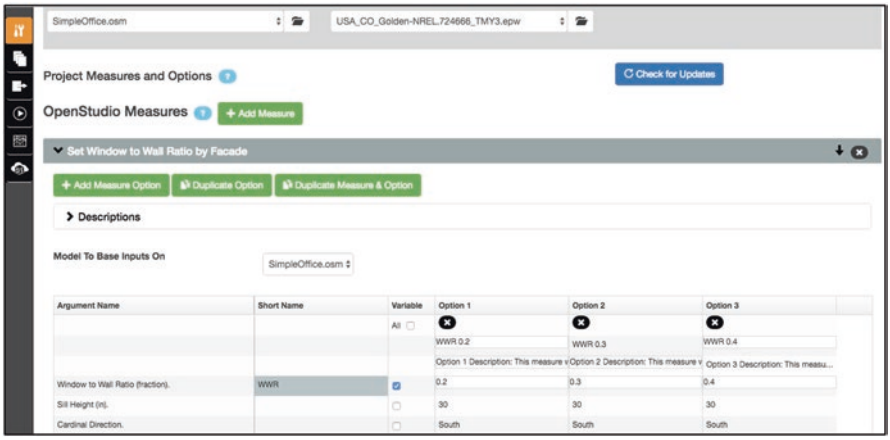


Fig. 6.27 Window to wall ratio Measure with three design options

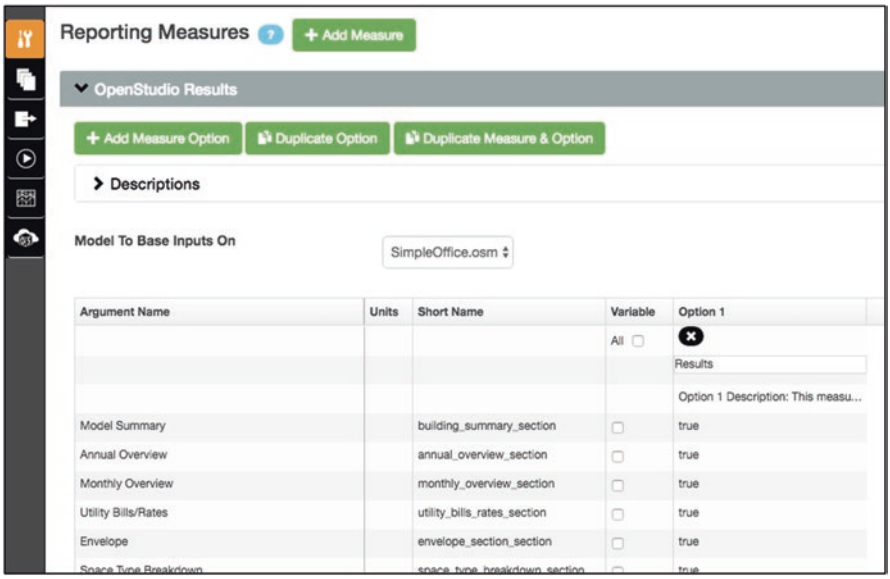


Fig. 6.28 Ensuring the OpenStudio Results Measure is included with an option

a design with each Measure option applied independently is also available. Repeatedly pressing + Add Alternative creates sequentially named alternatives based on the default seed Model and weather file with no options defined.

Figure 6.29 illustrates this Tab with eight Design Alternatives specified. The Tab's grid layout allows for rapid inspection, alteration, and naming of alternatives. Clicking most of the fields brings up a menu that is automatically populated with available choices. Design alternative name and description fields are free from text. It is considered a best practice to enter meaningful descriptions in these fields to document the project.

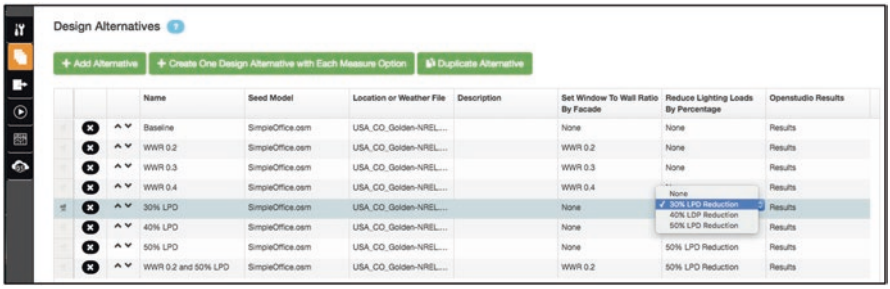


Fig. 6.29 PAT's design alternatives Tab

Design alternatives may be deleted using the Button on the left side of the screen. Rows may be rearranged manually using the Buttons or sorted alphabetically by clicking the grid headings. The order of Design Alternatives on this Tab has no bearing on simulation order or results reporting and is simply used as an aid to the modeler in defining the analysis.

Useful Tip: Quickly set multiple options for a Measure by highlighting the first option, typing the first letter of the desired option, tapping the down arrow, and repeating. This is useful for quickly selecting things like the OpenStudio Results Measure in this example by repeatedly pressing the "R" and down keys.

6.4.4 Running an Analysis in PAT

PAT configures a "mini server" on your computer to perform local analysis. This is essentially the same server that is used to run large-scale cloud analyses that will be discussed in Chap. 7. PAT's server architecture enables it to easily migrate projects between scalable computing systems. The local server begins to start up as soon as you launch PAT and is usually ready to perform analysis within a minute. This is indicated by a Server Status message at the top of PAT's Run Simulations ( ) Tab shown in Fig. 6.30.

For a manual analysis, leave "Run Locally" selected. Pressing the Run Entire Workflow Button starts running simulations using all available CPU cores less one for PAT itself. In Fig. 6.31 we see that my meager laptop has four cores and is able to run three simulations at a time. As Design Alternative simulations (data points) are completed; associated rows are updated with run times, status, an active report selector , and indicators showing that the final Model and results are available for review.

PAT's status will continue updating to apprise the user of progress. Changing Tabs during active simulation is prevented to avoid accidentally altering an analysis mid-run. As data points complete, the user can inspect results from the Run

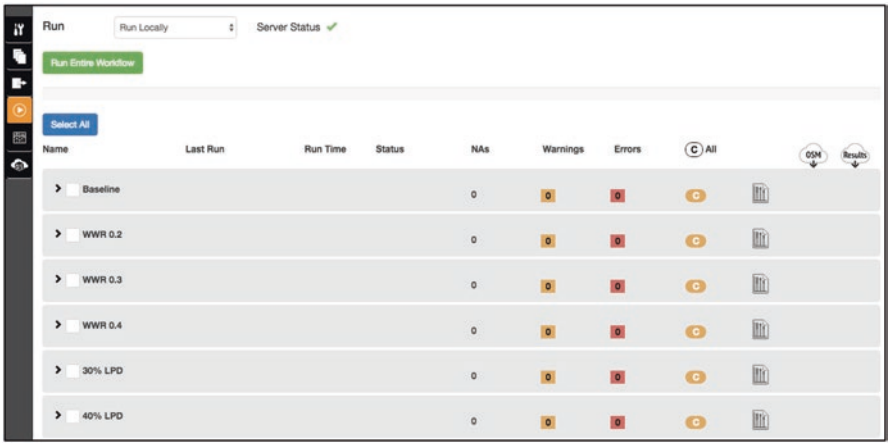


Fig. 6.30 PAT's Run Tab indicates it is ready to simulate

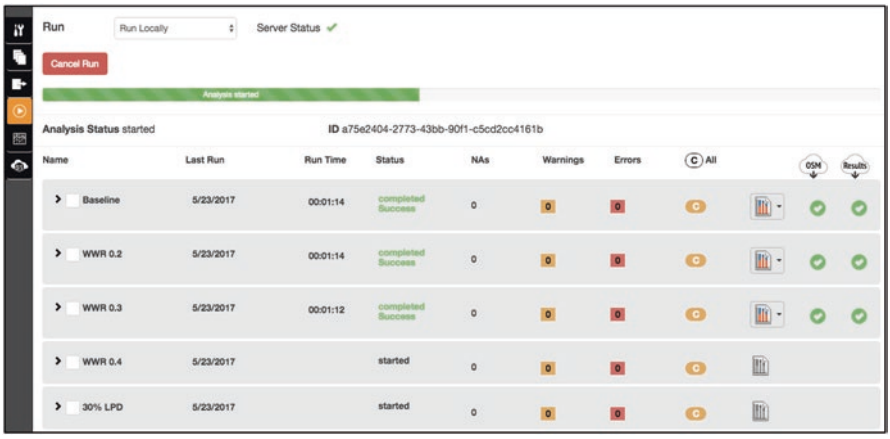


Fig. 6.31 PAT analysis in progress

Simulations ( ) Tab by clicking on the report selector icon (Fig. 6.32). In this case, the user may select from the default EnergyPlus tabular report or the OpenStudio Results Measure that was added as an option for all the Design Alternatives.

Each data point may also be expanded by clicking on the › Button on the left side of the Tab. Figure 6.33 shows the WWR 0.2 data point expanded revealing the Measure output messages for that alternative. Here we see that the window to wall ratio Measure changed the South-facing façades from 0.4 to 0.2 at no cost since we didn't enter a cost input. The lighting loads were unchanged since that option was set to "None" for this alternative. The OpenStudio Results Measure also states that it generated a report for the data point. **This output should be the first recourse for any user faced with a data point that has failed for one reason or another.**

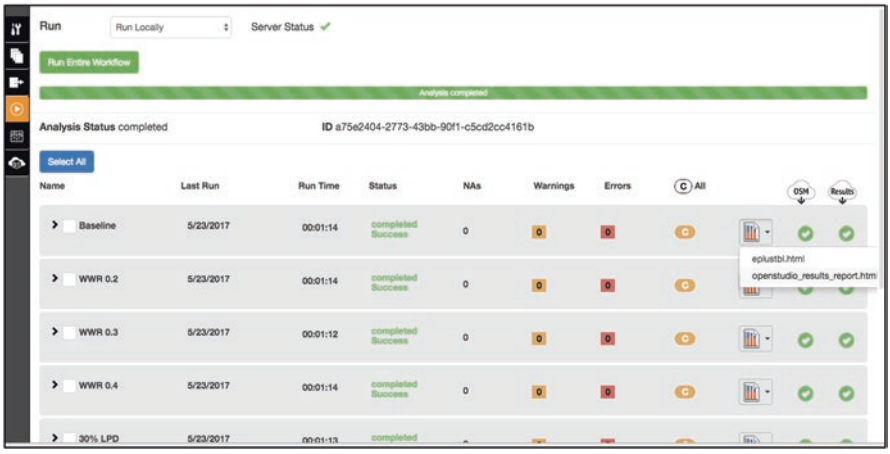


Fig. 6.32 PAT completed analysis

Fig. 6.33 An individual PAT data point expanded

In the event that a problem with a data point is corrected or the alternative is modified in some way, PAT allows individual data points to be re-run without repeating the entire set of simulations. A checkbox next to each Design Alternative's name allows the user to specify which data points are to be re-run. In Fig. 6.34 the "WWR 0.4" alternative has been selected for repeat simulation. Note that an additional Run Selected option appears at the top of the window when any checkboxes are ticked.

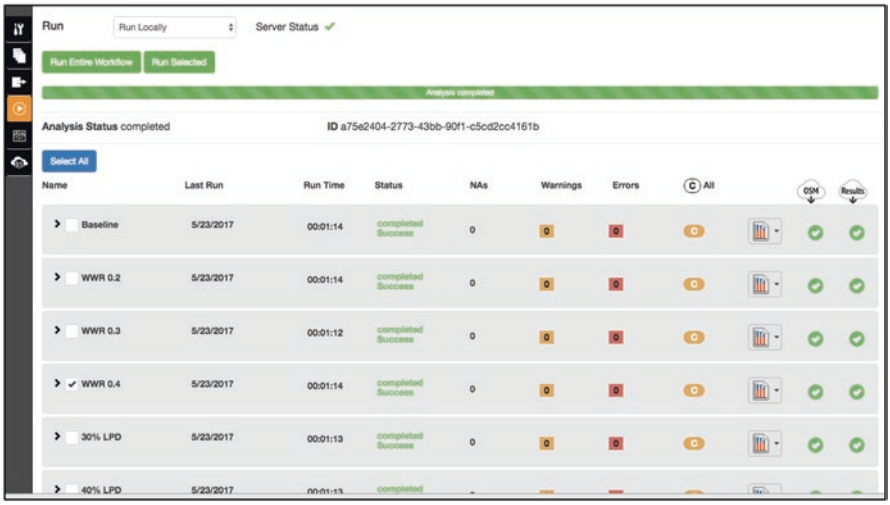


Fig. 6.34 Re-running a single data point

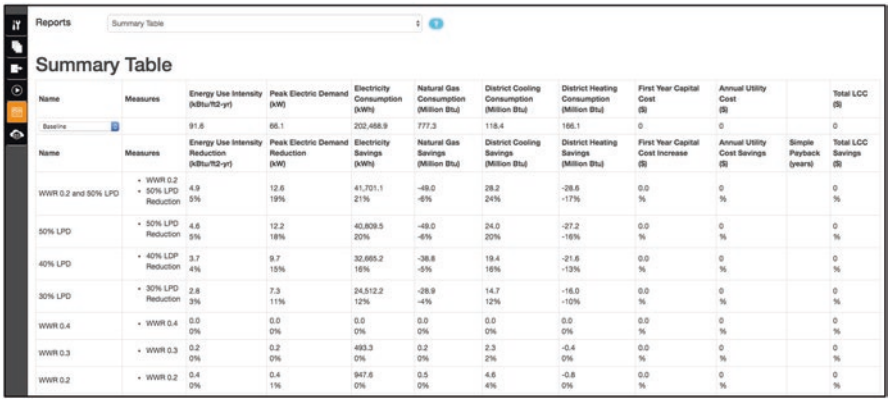


Fig. 6.35 PAT summary table on the reports Tab

6.4.5 Comparing Results in PAT

PAT includes three built-in reports in its Compare Results ( ) Tab that help the user compare Design Alternatives. The default summary table compares consumption, demand, and economic metrics for all of the Design Alternatives. A selection field near the top of the table allows the user to specify which of the alternatives is to be used as the datum for performance comparison. Analysis results shown in subsequent rows are relative to the datum's modeled values. Figure 6.35 contains results for our example problem with the Baseline data point (seed Model + no Measures) used as a datum. Note that the cost columns are all

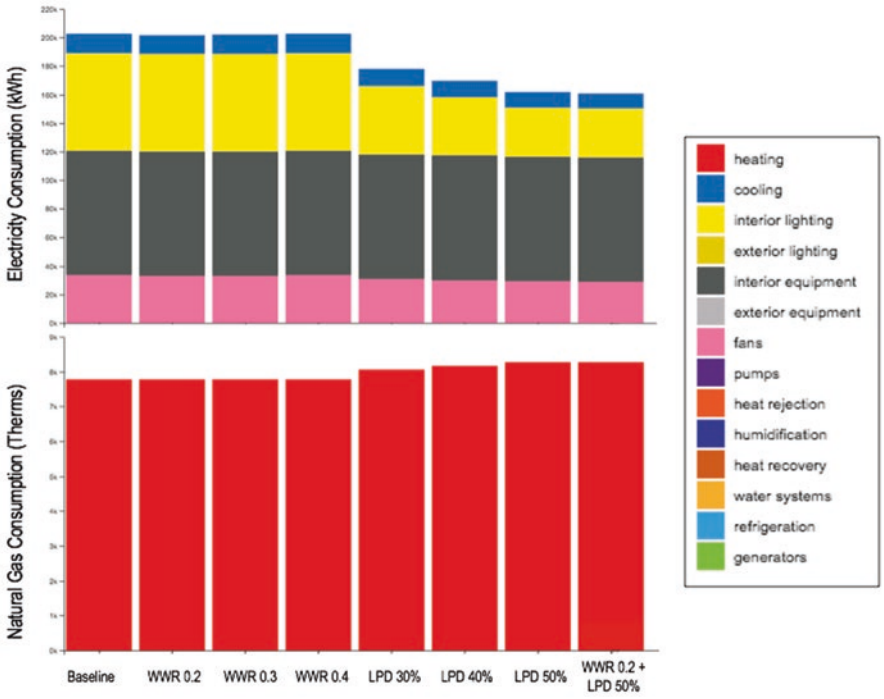


Fig. 6.36 End user comparison chart

empty in this example because we did not specify a utility tariff Measure or any capital costs for the window to wall ratio or lighting power reduction changes to the building.

The reports selection field at the top of the window may also be used to produce end use stacked bar charts broken down by fuel type like the one shown in Fig. 6.36.

PAT includes a third reporting option that is used by professionals working in some utility programs that offer incentives for high performance buildings. That topic is beyond the scope of this textbook, but those interested can learn more about how PAT works with these programs at http://eda-pt.org.

6.4.6 The OpenStudio Analysis Server Tab

The Analysis Server ( ) Tab (Fig. 6.37) provides a view into PAT's underlying OpenStudio Server. While this Tab is generally not necessary for manual analyses, it provides our first glimpse at OpenStudio's deep capacity for large-scale analysis including sampling and optimization – the topics of Chap. 7.

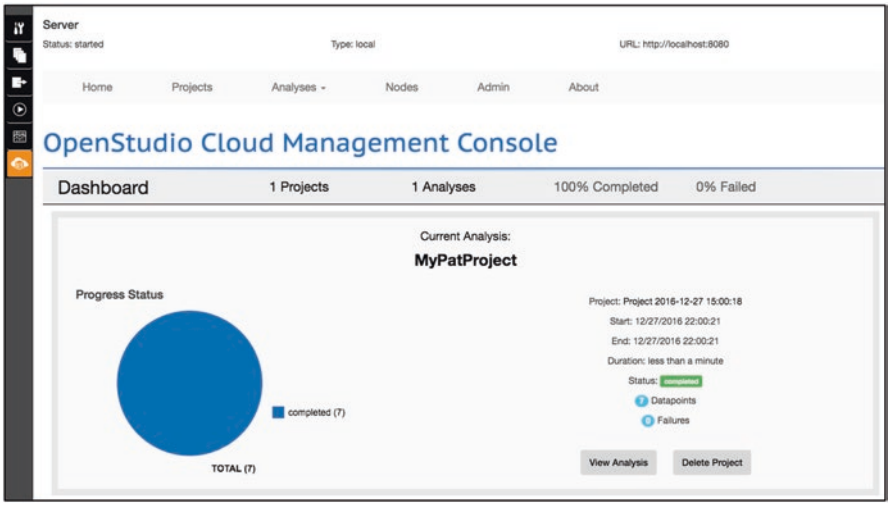


Fig. 6.37 PAT's OpenStudio Cloud Management Console Tab

6.5 Checkpoint Nine: Introduction to Parametrics

For our next checkpoint exercise, let's revisit our Primary School Model from Chap. 4 as the subject of an introductory study using OpenStudio Measures. Use the initial PAT dialog window to create a new project called "MyPATSchoolProject." Remember that the directory you select indicates where the PAT project's directory will be created. In the Analysis ( ) Tab select Chap. 4 MyPrimarySchoolHVAC.osm as the default seed Model and the weather file you have used in previous exercises as shown in Fig. 6.38.

Unlike the OpenStudio Application, the OpenStudio Results Measure is not automatically included in a PAT workflow. Click the + Add Measure Button in the Reporting Measures section to bring up the Measure Library dialog window (Fig. 6.39). Locate the Results Measure and click the Button to add it to your project.

Once the standard reporting Measure has been added to the project, create a Measure Option for it with the + Add Measure Option Button. Name the new Option "Report." Also, make sure that at least one of the Result Measure's arguments is checked as a variable as shown in Fig. 6.40. This is not normally needed, but we are going to test run our seed Model by itself in PAT, which needs at least one variable to run an analysis. You can come back later and uncheck this as a variable (or not) once we have added proper EE Measures and variables to the project.

Proceed to the Design Alternatives ( ) Tab to create a baseline for our analysis. This data point will consist of our seed Model and the Results Measure. Click the + Add Alternative to add the alternative shown in Fig. 6.41.

Save your project before moving on to PAT's Run Simulations ( ) Tab. Once you see Server Status ✓ at the top of the window, you can press the Run Entire Workflow Button to run the baseline data point. Figure 6.42 illustrates the baseline simulation in process.

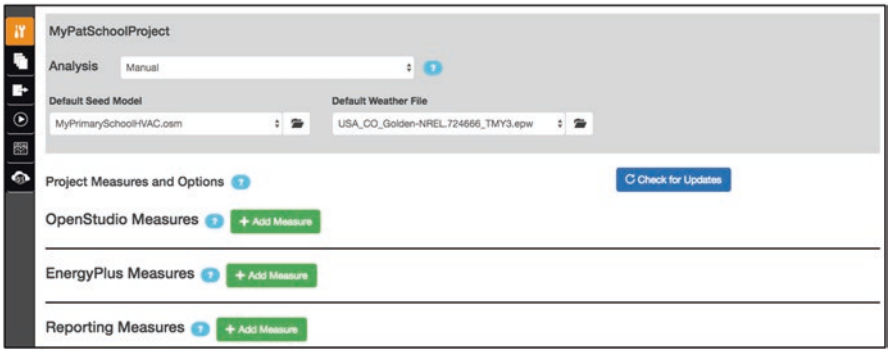


Fig. 6.38 Creating a new primary school PAT project

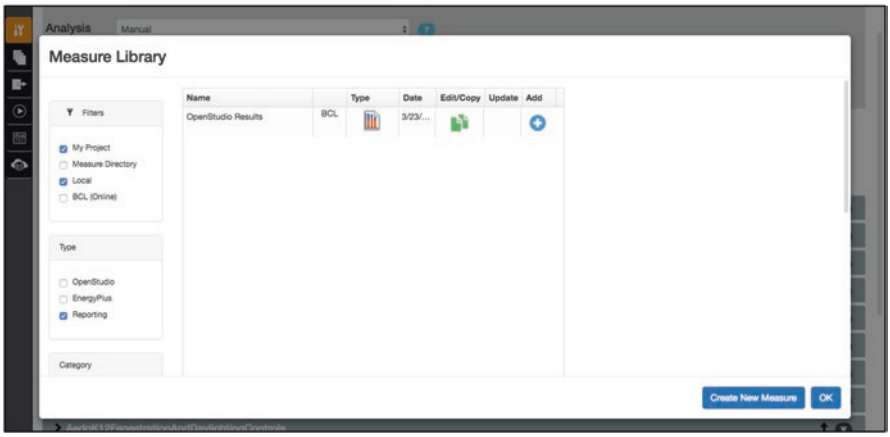


Fig. 6.39 Adding the OpenStudio Results Measure to the project

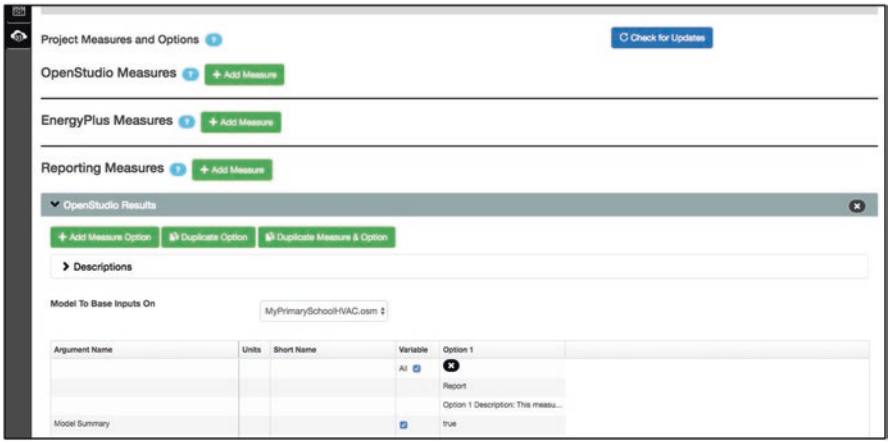


Fig. 6.40 Creating a Report Option for the project

Fig. 6.41 Creating the baseline Design Alternative in the project

Fig. 6.42 Running the project containing only the baseline

Fig. 6.43 Examining the baseline data point

When the simulation is complete, the Run Simulations ( ) Tab should look like the window shown in Fig. 6.43. Note that the data point can be expanded to show steps in the associated workflow. The reports pull down menu offers the EnergyPlus standard report along with the OpenStudio Results Measure output (Fig. 6.44) we added as an option for the data point.

The Compare Results ( ) Tab is shown as Fig. 6.45. This particular comparison table isn't particularly interesting since it only contains the single baseline data point. Nevertheless, we can see from the OpenStudio Report and the comparison table that the baseline Model did run properly, and we can proceed to adding EE Measures to perform a proper comparison of Design Alternatives.

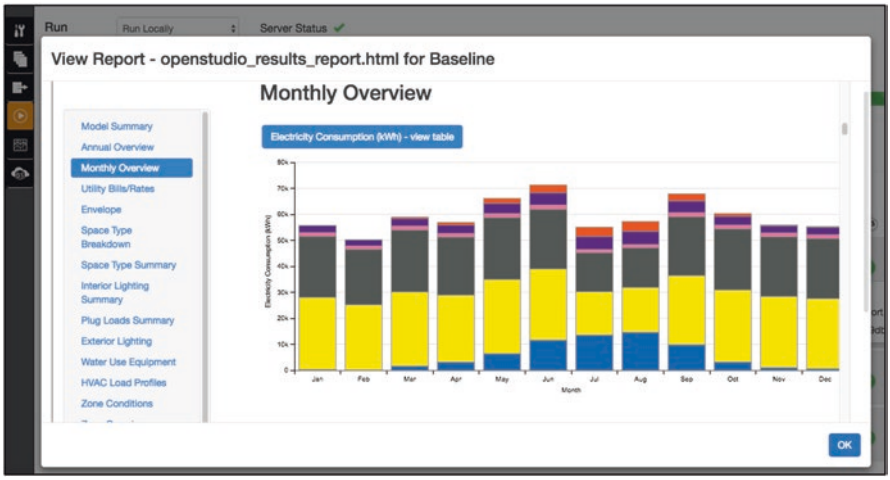


Fig. 6.44 Reviewing the monthly end use breakdown for the baseline

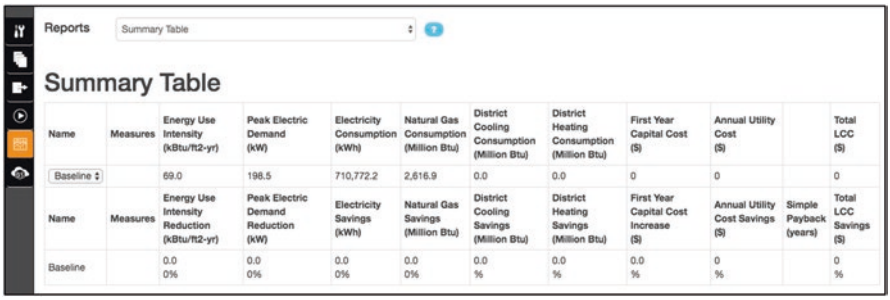


Fig. 6.45 PAT comparison summary containing only the baseline

To add additional Measures and Design Alternatives, first return to the Analysis ( ) Tab and click the + Add Alternative Button next to the OpenStudio Measures section of the window. Let's first begin by downloading some HVAC system Measures from the BCL. Check the search boxes as shown in Fig. 6.46 to limit our search to whole system HVAC OpenStudio Measures available on the BCL.

Click the Button next to the "AedgK12HvacDualDuctDoas" Measure to download it to our Local Measures Library. Using the current filter settings, that Measure appears to vanish. Never fear! Adding the Local Library to our filter reveals that it was downloaded and is available to add to the project using the Button (Fig. 6.47).

Download the "AedgK12HvacFanCoilDoas" and "AedgK12HvacGshpDoas" Measures and add all three to your project (Fig. 6.48).

Dismiss the Measure Library browser and expand the AedgK12HvaDualDuctDoas Measure (Fig. 6.49). Add a Measure Option as shown in Fig. 6.50. Be sure to give it a meaningful name. Also note that this particular Measure has three arguments. We will set the total cost argument to be $150,000 for the purpose of this exercise. The other arguments should be left to their default values.

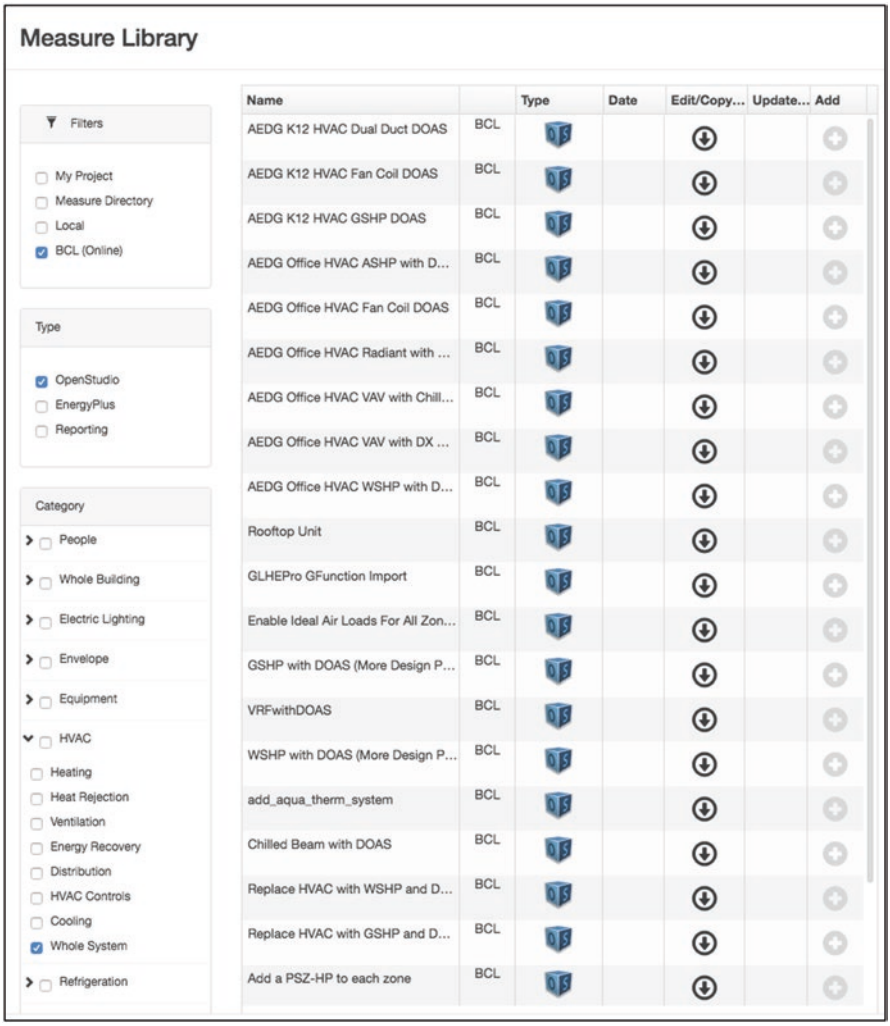


Fig. 6.46 Finding EE Measures for the project

Create Measure Options for the other two HVAC Measures as shown in Figs. 6.51 and 6.52. Be sure to provide appropriate Option names and costs for each system.

The last Measure we will add to our HVAC system comparison is a utility tariff or rate. Along with each system's capital cost, which we entered above, the utility rate will be used to calculate the relative cost of each Design Alternative in addition to energy savings. Utility rates are implemented as EnergyPlus Measures, so be sure to click the + Add Alternative Button next to the correct Measure category. Download and add the "XcelEDATariffSelectionandModelSetup" Measure to the Project (Fig. 6.53). This Measure adds energy rates charged by Xcel Energy, the utility that will serve our school in the Denver Colorado area.

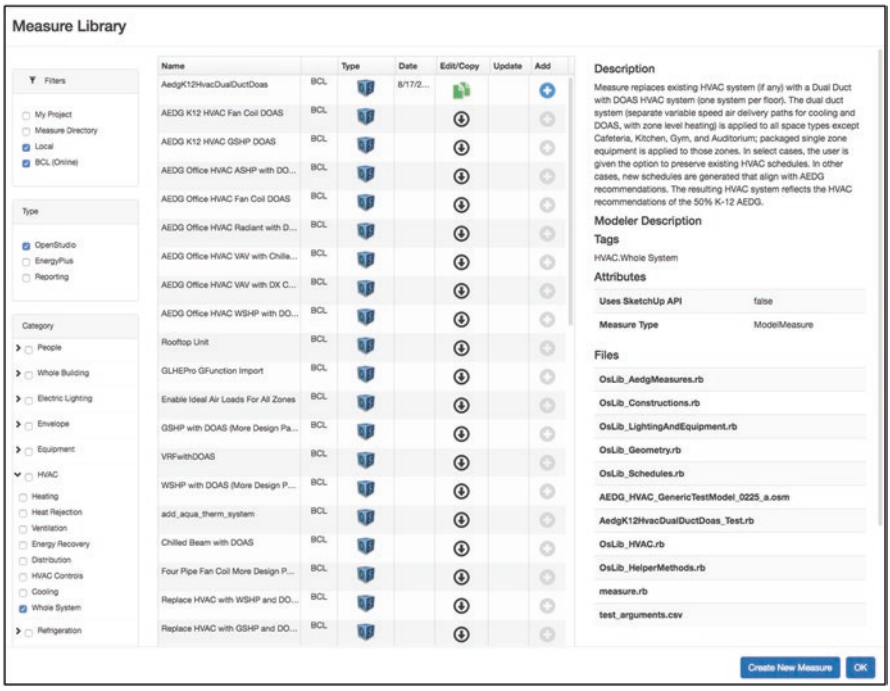


Fig. 6.47 Downloading the AEDGK12HVACDualDuctDoas Measure

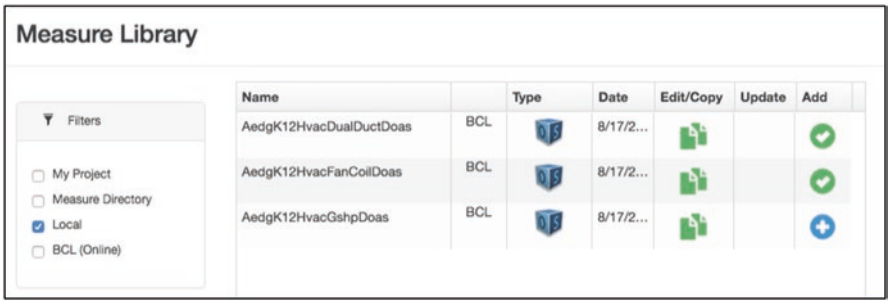


Fig. 6.48 Adding three AEDG K-12 HVAC Measures to the project

Finally, create a Measure Option for the utility rate as shown in Fig. 6.54. Note that this Measure contains two input arguments. Each is a list of choices for the electricity and gas tariffs appropriate for our building. Select "Commercial" and "Small CG" for the electricity and gas rates respectively.

Defining the additional Design Alternatives is performed on the Design Alternatives ( ) Tab. Add three additional alternatives as shown in Fig. 6.55. It's worth taking the time to type in proper names for each alternative so that the comparison report will be more meaningful. Relying on PAT's automatic naming scheme

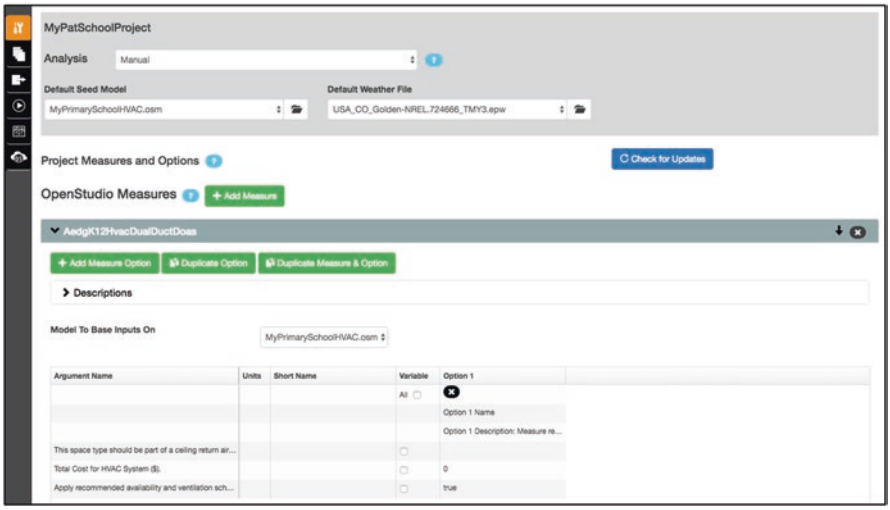


Fig. 6.49 Defaults for a new dual duct DOAS option

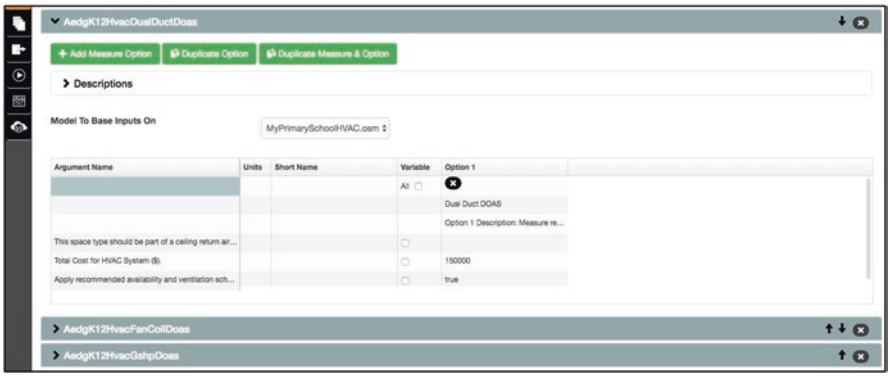


Fig. 6.50 Defining the dual duct DOAS option and entering system cost

of Alternative 1, Alternative 2, etc. may be fast, but it's not always so easy to remember what was included in Alternative 13 after you've run a bunch of simulations!

Also, don't forget to assign the Utility Tariff and Report Options to each Design Alternative. One way to quickly do this is to check the Baseline Alternative and then use the Duplicate Alternative Button to make copies. This preserves all of the Options from the copied data point, allowing you to simply change different Options in subsequent points.

Once the Alternatives have been defined, save your Project. It's time to kick off our simulations in the Run Simulations ( ) Tab. You can save a bit of time by checking just the new data points and clicking Run Selected, or you can click Run Entire Workflow to run everything. Figure 6.56 shows the Run Simulations ( ) Tab with simulations in progress.

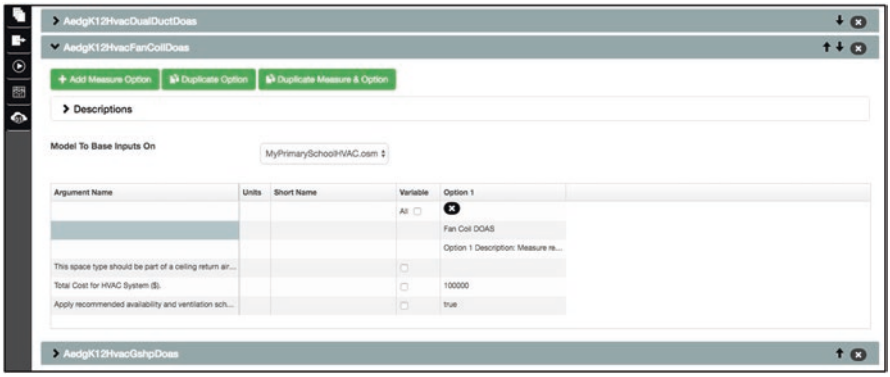


Fig. 6.51 Creating a fan coil DOAS Measure option

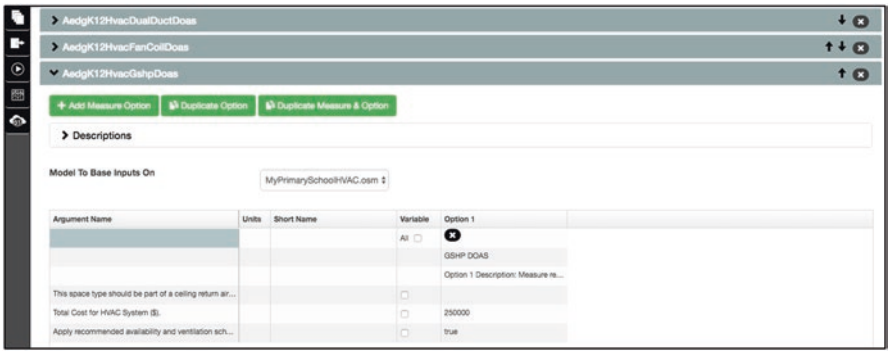


Fig. 6.52 Creating a GSHP DOAS Measure option

While simulations are running, it's worth taking a moment to look at the structure of a typical PAT Project directory (Fig. 6.57). As data points run and complete, subdirectories with rather cryptic names appear. Each of these directories corresponds to one of our data points, and includes the data point's OSM, results, etc. The data_point.zip also includes the detailed EnergyPlus files related to the data point.

Compare Fig. 6.57 with Fig. 6.58 and note that one of the data point IDs shown in PAT matches one of these directories. If you should ever need access to specific files associated with a given Design Alternative – be it a Model, results, or EnergyPlus files for troubleshooting; start by finding the data point ID, then going to the appropriate subdirectory in the PAT Project's *localResults* directory.

While we have that data point "open," take a moment to look at the diagnostic messages from each Measure in the data point's workflow. Note that both the dual duct DOAS and fan coil DOAS Measures were "skipped," but that the GSHP DOAS Measure removed the old HVAC system from the Model and replaced it with the new system. The utility tariff was also applied to the Model. As stated earlier in the chapter, these messages can be incredibly valuable in verifying that a workflow was executed as expected and troubleshooting problems when things don't go as planned.

Fig. 6.53 Adding the Xcel Energy utility rate tariff to the project

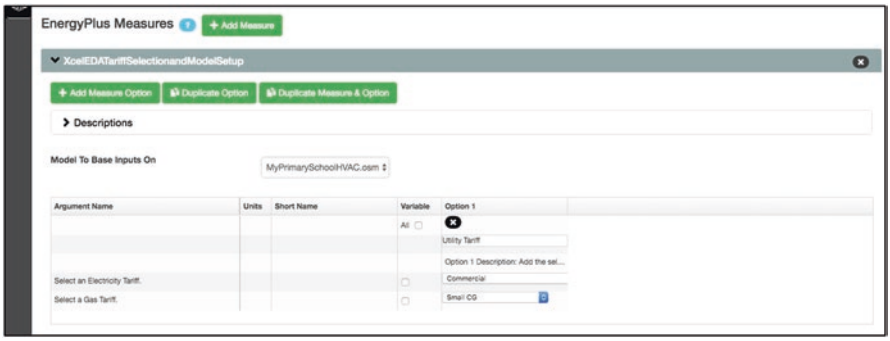


Fig. 6.54 Creating a utility rate Measure option

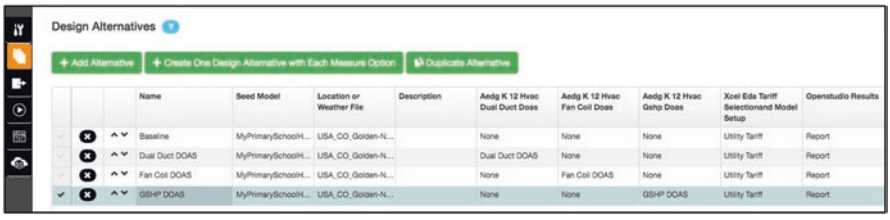


Fig. 6.55 Adding three additional Design Alternatives to the project

Now that we have multiple Design Alternatives, the Compare Results ( ) Tab is more meaningful. Selected the Baseline data point as the basis for comparison and you should see a performance summary similar to Fig. 6.59. Because we have added capital and utility costs to our data points, PAT is able to compare not only energy performance, but also the simple payback and total life cycle cost of the proposed HVAC alternatives.

Note that the Ground Source Heat Pump alternative contains data in both the district heating and cooling columns while the other alternatives do not. Does this make sense? What is the best system choice? Is there a clear winner?

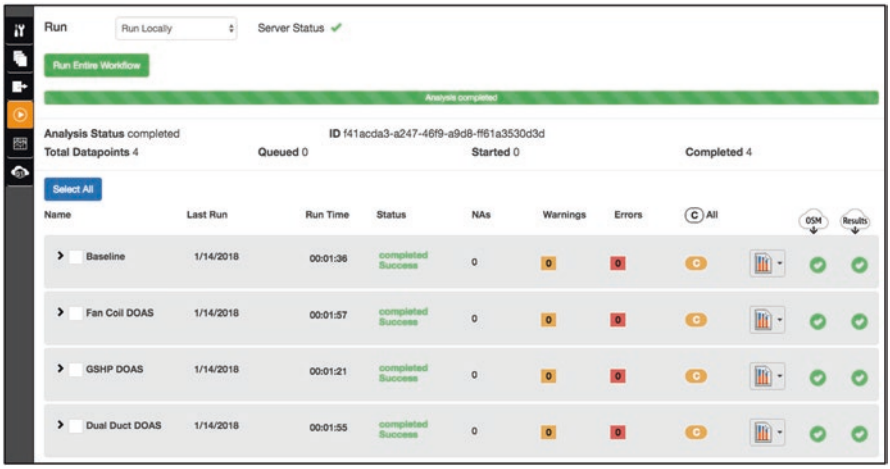


Fig. 6.56 Simulating the four Design Alternatives

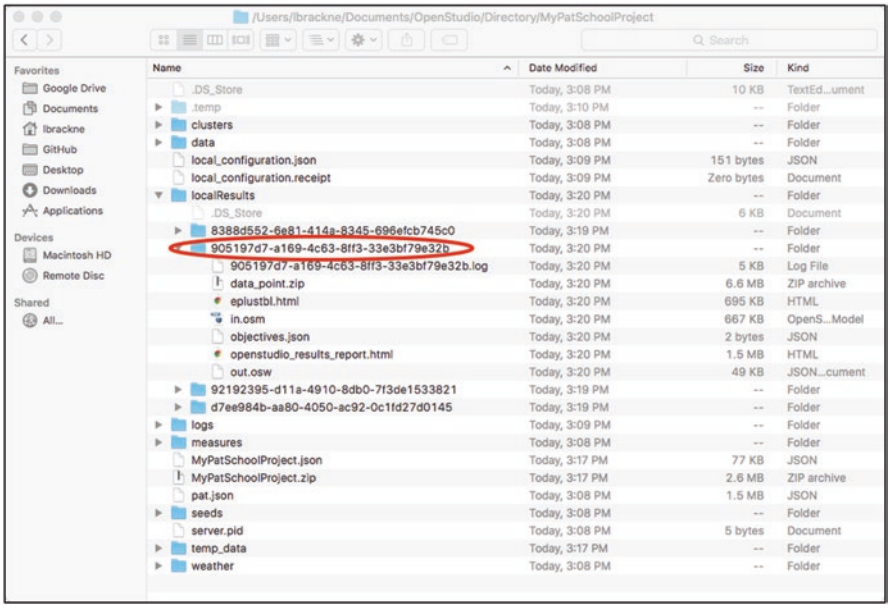


Fig. 6.57 PAT Project directory structure

Next, let's add a few more EE Measures into the mix. Return to the Analysis ( ) Tab and add the Measures shown in Fig. 6.60. You will need to locate and download these from the BCL.

Use Table 6.1 for Option names and arguments as you set up your Measure Options.

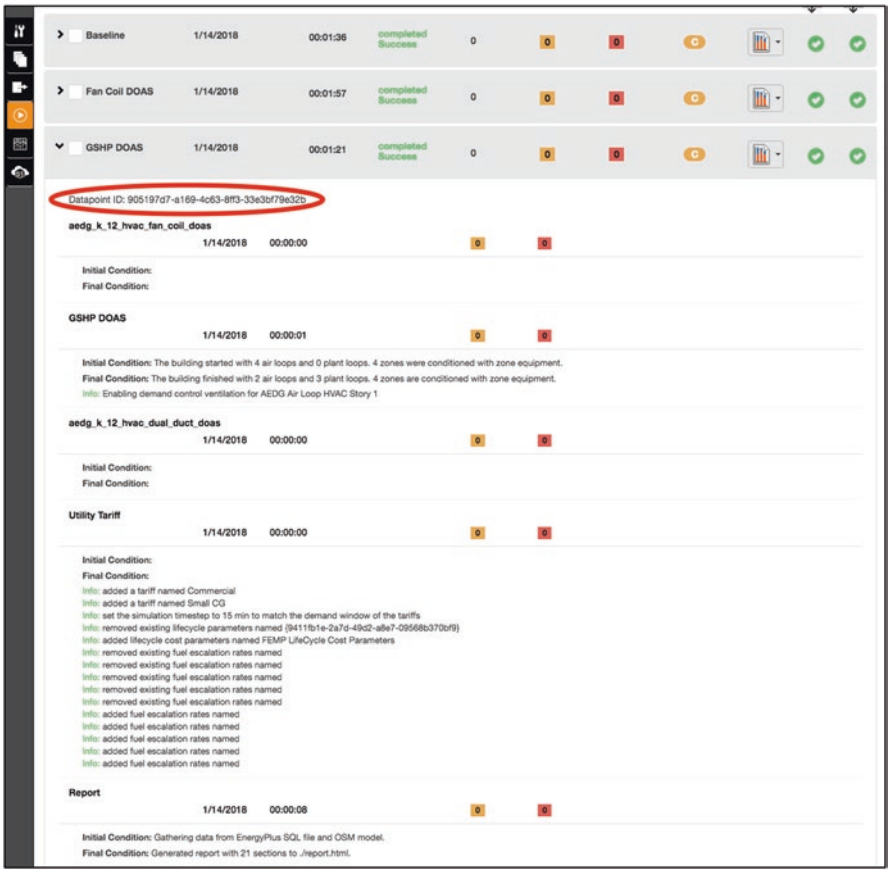


Fig. 6.58 Reviewing the Measure actions that produced the GSHP DOAS data point

Summary Table

Name	Measures	Energy Use Intensity (kBtu/ft2-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 ($)
Baseline		69.0	198.9	710,599.7	2,613.8	0.0	0.0	0	89,965		1,578,071
Name	**Measures**	**Energy Use Intensity Reduction (kBtu/ft2-yr)**	**Peak Electric Demand Reduction (kW)**	**Electricity Savings (kWh)**	**Natural Gas Savings (Million Btu)**	**District Cooling Savings (Million Btu)**	**District Heating Savings (Million Btu)**	**First Year Capital Cost Increase ($)**	**Annual Utility Cost Savings ($)**	**Simple Payback (years)**	**Total LCC Savings ($)**
GSHP DOAS	• GSHP DOAS	24.9 36%	-10.7 -5%	35,305.4 5%	2,276.7 87%	-344.9 -∞%	-232.6 -∞%	250,000.0 ∞%	19,984 22%	12.5	115,291 7%
Fan Coil DOAS	• Fan Coil DOAS	29.7 43%	-7.7 -4%	57,376.6 8%	1,975.2 76%	0.0 %	0.0 %	100,000.0 ∞%	19,913 22%	5.0	258,345 16%
Dual Duct DOAS	• Dual Duct DOAS	12.4 18%	-24.0 -12%	-93,159.2 -13%	1,225.5 47%	0.0 %	0.0 %	150,000.0 ∞%	-443 0%	-338.4	-147,956 -9%

Fig. 6.59 Comparing the three Design Alternatives against the baseline

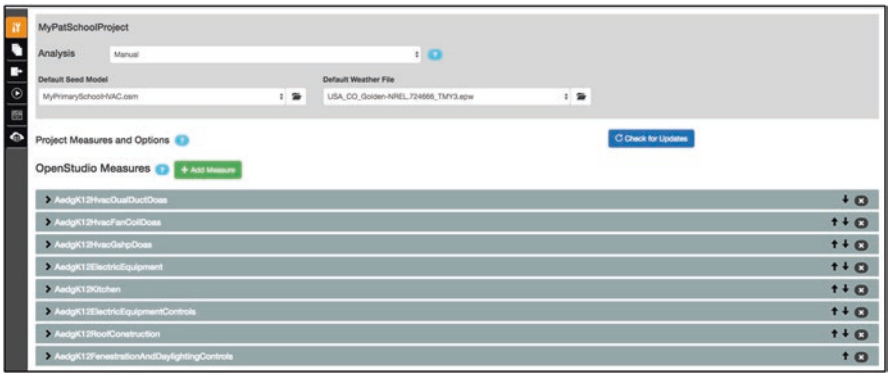


Fig. 6.60 Adding additional Measures to the project

Table 6.1 EE Measure Option names and arguments

Measure name	Option name	Arguments
AedgK12ElectricEquipment	Improve electric equipment efficiency	$2 per equipment
AedgK12Kitchen	Improve kitchen efficiency	$40,000
		200 students
AedgK12ElectricEquipmentControls	Improve electric equipment controls	$1500
AedgK12RoofConstructions	Improved roof construction	$1 per ft^2 insulated
		$0 per ft^2 solar
AedgK12FenestrationAndDaylightingControls	Fenestration and daylight controls	$1 per ft^2 daylight
		$1 per ft^2 view
		$2 per ft^2 skylight
		$0.5 per ft^2 shading
		$2 per ft^2 light shelf

On the Design Alternatives ( ) Tab, add a new Option that combines the GSHP system with all of the new EE Measures we just added. Again, don't forget to make sure that this new alternative includes the utility tariff and standard report as shown in Fig. 6.61.

Run the additional Design Alternative on the Run Simulations ( ) Tab and use the Compare Results ( ) Tab to compare the results with the previous Alternatives. Figures 6.62 and 6.63 compare the additional data point with the previous HVAC alternatives. Do these results make sense?

To conclude this exercise, recall that none of the Measures we have added to our school project included more than one Option. Let's get a bit of practice in with multiple Options by adding the "Reduce Lighting Loads by Percentage" Measure to our Project as shown in Fig. 6.64.

		Name	Seed Model	Location or Weather File	Description	Aedg K 12 Hvac Dual Duct Doas	Aedg K 12 Hvac Fan Coil Doas	Aedg K 12 Hvac Gshp Doas	Aedg K 12 Electric Equipment	Aedg K 12 Kitchen	Aedg K 12 Electric Equipment Controls	Aedg K 12 Roof Construction	Aedg K 12 Fenestration And Daylighting Controls	Xcel Eda Tariff Selectionand Model Setup	Openstudio Results
✖	^ v	Baseline	MyPrimarySch...	USA_CO_Gold...		None	None	None	None	None	None	None	None	Utility Tariff	Report
✖	^ v	Dual Duct DOAS	MyPrimarySch...	USA_CO_Gold...		Dual Duct DO...	None	None	None	None	None	None	None	Utility Tariff	Report
✖	^ v	Fan Coil DOAS	MyPrimarySch...	USA_CO_Gold...		None	Fan Coil DOAS	None	None	None	None	None	None	Utility Tariff	Report
✖	^ v	GSHP DOAS	MyPrimarySch...	USA_CO_Gold...		None	None	GSHP DOAS	None	None	None	None	None	Utility Tariff	Report
✖	^ v	GSHP with Additional M...	MyPrimarySch...	USA_CO_Gold...		None	None	GSHP DOAS	Improve Electr...	Improve Kitch...	Improve Electr...	Improved Roo...	Fenestration a...	Utility Tariff	Report

Fig. 6.61 Defining a Design Alternative with GSHP and additional EE Measures

Name	Measures	Energy Use Intensity (kBtu/ft2-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 ($)
Baseline		69.0	198.9	710,599.7	2,613.8	0.0	0.0	0	89,965		1,578,071
Name	**Measures**	**Energy Use Intensity Reduction (kBtu/ft2-yr)**	**Peak Electric Demand Reduction (kW)**	**Electricity Savings (kWh)**	**Natural Gas Savings (Million Btu)**	**District Cooling Savings (Million Btu)**	**District Heating Savings (Million Btu)**	**First Year Capital Cost Increase ($)**	**Annual Utility Cost Savings ($)**	**Simple Payback (years)**	**Total LCC Savings ($)**
GSHP with Additional Measures	• GSHP DOAS • Improve Electric Equipment Efficiency • Improve Kitchen Efficiency • Improve Electric Equipment Controls • Improved Roof Construction • Fenestration and Daylight Controls	30.9 45%	-0.6 0%	146,779.3 21%	2,392.6 92%	-312.0 -∞%	-320.8 -∞%	377,701.9 ∞%	31,807 35%	11.9	197,687 13%
GSHP DOAS	• GSHP DOAS	24.9 36%	-10.7 -5%	35,305.4 5%	2,276.7 87%	-344.9 -∞%	-232.6 -∞%	250,000.0 ∞%	19,984 22%	12.5	115,291 7%
Fan Coil DOAS	• Fan Coil DOAS	29.7 43%	-7.7 -4%	57,376.6 8%	1,975.2 76%	0.0 %	0.0 %	100,000.0 ∞%	19,913 22%	5.0	258,345 16%
Dual Duct DOAS	• Dual Duct DOAS	12.4 18%	-24.0 -12%	-93,159.2 -13%	1,225.5 47%	0.0 %	0.0 %	150,000.0 ∞%	-443 0%	-338.4	-147,956 -9%

Fig. 6.62 Comparing the four Design Alternatives to the baseline

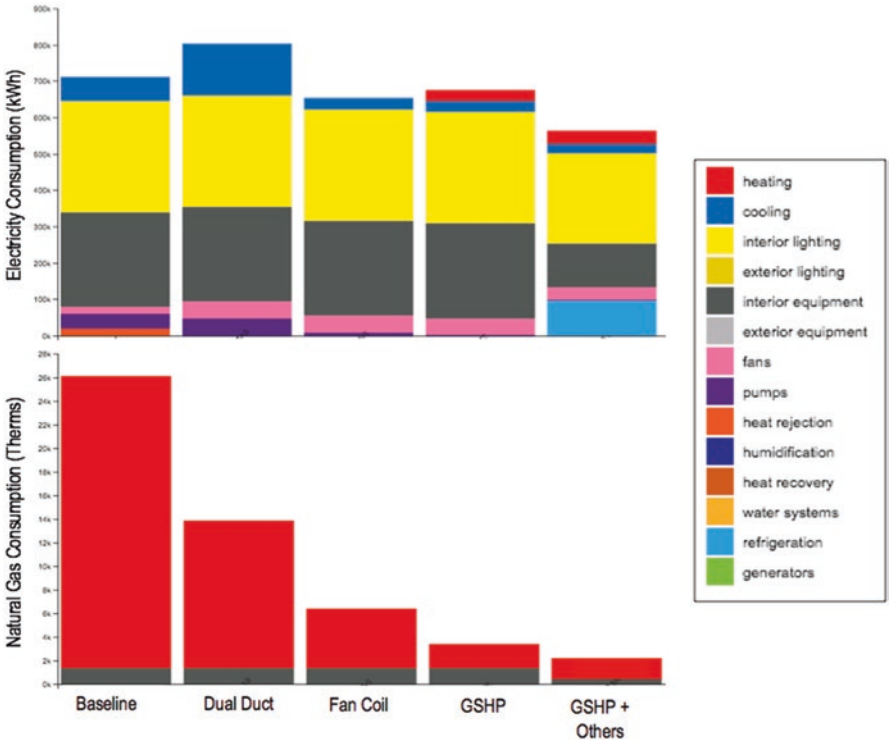


Fig. 6.63 Comparing end use breakdowns for the baseline and Design Alternatives

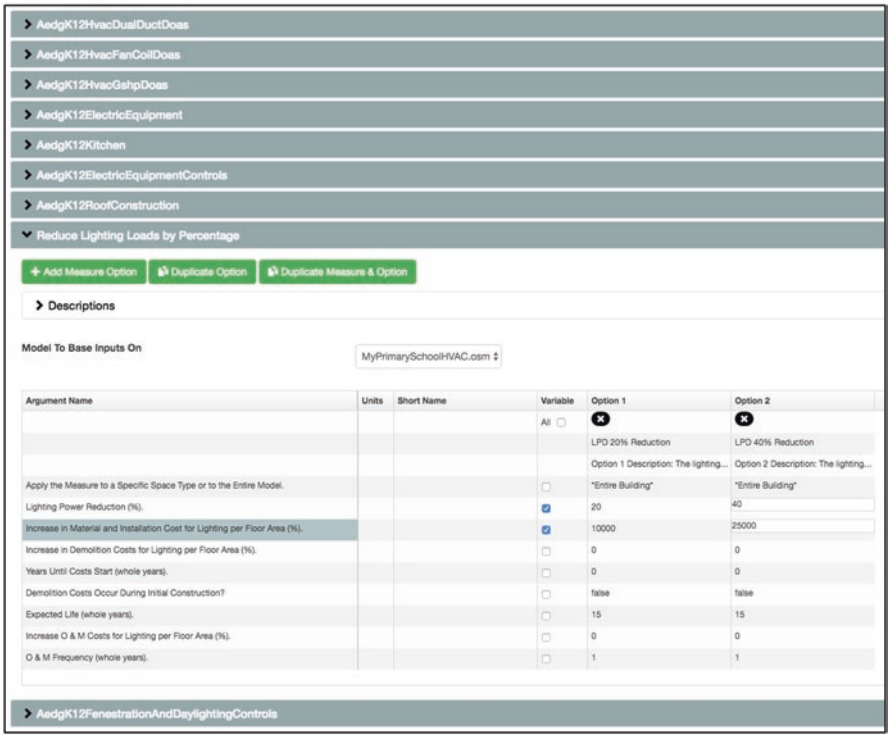


Fig. 6.64 Adding the "Reduce Lighting Loads by Percentage" Measure with two options

Note that arguments we intend to vary across an option must be checked as variables or PAT will not allow us to change their values. It is also important that each Option be given a unique and descriptive name. Lastly, note that we have placed the lighting load reduction Measure ahead of the fenestration and daylighting controls Measure. This ensures that we modify all light fixtures in each Space before daylighting controls are applied.

Create two more Design Alternatives that include the GSHP System, all of the previous EE Measures, and either the 20% or 40% LPD reduction Option. Running those additional points should produce the comparison shown in Figs. 6.65 and 6.66.

Have our changes to LPD had the expected results in the last two Design Alternatives? What other Measures might we consider for our school, and in what combinations? Now that you have a reasonable understanding of how Measures work with PAT and access to additional Measures from the BCL, consider exploring the school's design for additional energy and cost savings.

Name	Measures	Energy Use Intensity (kBtu/ft2-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 ($)
Baseline		69.0	198.9	710,599.7	2,613.8	0.0	0.0	0	89,965		1,578,071
Name	**Measures**	**Energy Use Intensity Reduction (kBtu/ft2-yr)**	**Peak Electric Demand Reduction (kW)**	**Electricity Savings (kWh)**	**Natural Gas Savings (Million Btu)**	**District Cooling Savings (Million Btu)**	**District Heating Savings (Million Btu)**	**First Year Capital Cost Increase ($)**	**Annual Utility Cost Savings ($)**	**Simple Payback (years)**	**Total LCC Savings ($)**
LPD 40%	• GSHP DOAS • Improve Electric Equipment Efficiency • Improve Kitchen Efficiency • Improve Electric Equipment Controls • Improved Roof Construction • LPD 40% Reduction • Fenestration and Daylight Controls	38.2 55%	22.6 11%	249,384.6 35%	2,372.3 91%	-219.3 -∞%	-212.0 -∞%	377,701.9 ∞%	42,057 47%	9.0	376,077 24%
LPD 20%	• GSHP DOAS • Improve Electric Equipment Efficiency • Improve Kitchen Efficiency • Improve Electric Equipment Controls • Improved Roof Construction • LPD 20% Reduction • Fenestration and Daylight Controls	34.7 50%	10.5 5%	198,537.2 28%	2,382.6 91%	-262.8 -∞%	-261.7 -∞%	377,701.9 ∞%	36,976 41%	10.2	287,660 18%
GSHP with Additional Measures	• GSHP DOAS • Improve Electric Equipment Efficiency • Improve Kitchen Efficiency • Improve Electric Equipment Controls • Improved Roof Construction • Fenestration and Daylight Controls	30.9 45%	-0.6 0%	146,779.3 21%	2,392.6 92%	-312.0 -∞%	-320.8 -∞%	377,701.9 ∞%	31,807 35%	11.9	197,687 13%
GSHP DOAS	• GSHP DOAS	24.9 36%	-10.7 -5%	35,305.4 5%	2,276.7 87%	-344.9 -∞%	-232.6 -∞%	250,000.0 ∞%	19,984 22%	12.5	115,291 7%
Fan Coil DOAS	• Fan Coil DOAS	29.7 43%	-7.7 -4%	57,376.6 8%	1,975.2 76%	0.0 %	0.0 %	100,000.0 ∞%	19,913 22%	5.0	258,345 16%
Dual Duct DOAS	• Dual Duct DOAS	12.4 18%	-24.0 -12%	-93,159.2 -13%	1,225.5 47%	0.0 %	0.0 %	150,000.0 ∞%	-443 0%	-338.4	-147,956 -9%

Fig. 6.65 Comparing the two additional Design Alternatives with the baseline

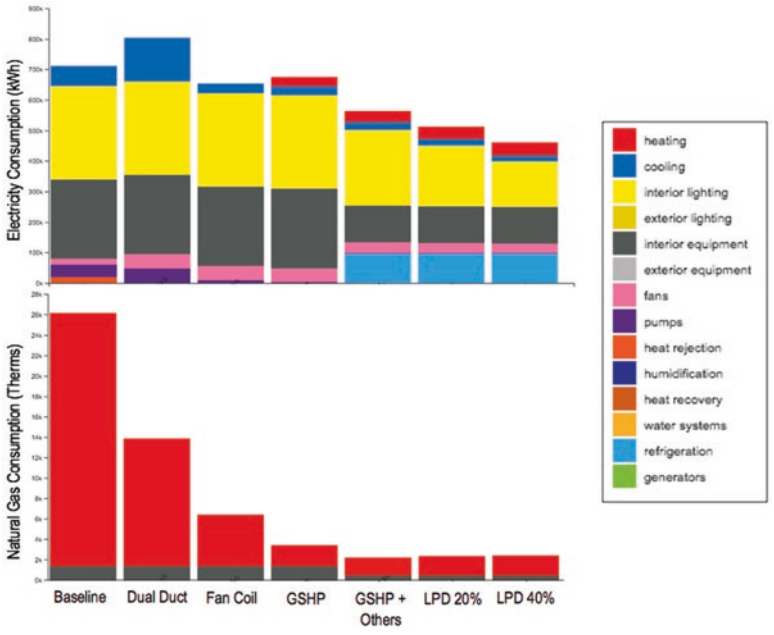


Fig. 6.66 Comparing end user breakdowns for baseline and alternatives

6.6 Additional Exercises

1) Recommended additional exercises involving the Checkpoint Nine Model include application of additional Measures within the PAT. The BCL contains a large number of Measures related to envelope, lighting, loads, systems and more. Spend some time navigating the available Measures and create additional Design Alternatives for further comparison with the Checkpoint Nine results.
2) Assess the relative merits of various efficiency measures on the "Additional Exercises" Model you created in Chap. 4 using PAT. You may consider some of the same Measures used in Checkpoint Nine but are encouraged to explore other Measures available in the BCL.

References

ASHRAE (2011) Advanced energy design guide for K-12 school buildings: 50% energy savings
Fleming K, Long N, Swindler A (2012) Building Component Library: an online repository to facilitate building energy model creation. ACEEE summer study on energy efficient buildings, Pacific Grove, CA, August 12–17
https://bcl.nrel.gov/node/39440
https://bcl.nrel.gov/node/39783
https://bcl.nrel.gov/node/82771
https://bcl.nrel.gov/node/83307
https://bcl.nrel.gov/node/83591
https://bcl.nrel.gov/node/83647
https://github.com/NREL/openstudio-standards
https://www.ruby-lang.org/en/