The Building Component Library: An Online Repository to Facilitate Building Energy Model Creation

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ABSTRACT

Powerful and affordable computing has made detailed whole-building energy simulations a reality. These simulations require complicated energy models that comprise thousands of inputs ranging from weather data to system component performances. The accuracy and integrity of these data are critical to the accuracy of the predicted performance. Although detailed information is paramount to ensure valid models, recreating the information for each new building model is an arduous task. A vehicle that facilitates input data reuse is vital to minimizing the effort required to adequately model buildings.

This paper describes the Building Component Library, the U.S. Department of Energy's comprehensive online searchable library of energy modeling building blocks and descriptive metadata. Novice users and seasoned practitioners can use the freely available and uniquely identifiable components to create energy models and cite the sources of input data, which will increase the credibility and reproducibility of their simulations.

Introduction

Whole-building energy modeling (BEM) is a complex domain requiring hundreds to thousands of inputs to fully articulate a model for simulation. After simulation, hundreds to thousands of output results are available. Energy modeling is performed to help designers determine the potential energy savings of various designs without needing to construct an actual building. Understanding potential impacts of design decisions helps owners choose technologies to deploy to make their buildings more efficient. Locating data for these technologies can be challenging, however, and model quality is dependent on the quality of these input data.

The Rocky Mountain Institute hosted a Building Energy Modeling Innovation Summit in 2011 (RMI 2011), where experts discussed the challenges and next steps needed for BEM to become widely adopted. The Summit identified many challenges, including lack of credibility that results from: (1) low quality; (2) lack of reproducibility; (3) misguided expectations; and (4) difficulty in assessing the skills of the practitioners. If low quality and nonreproducibility are preventing adoption, datasets used for energy modeling need to be more available, citable, and better vetted. The BCL aims to address these issues.

Background

Google, Autodesk, SMARTBIM, and others have worked to define specific components for building information modeling (BIM) (Autodesk 2012, Google 2012, Long et al. 2011, SMARTBIM 2012). Data required by BEM differ from BIM data in that BIM provides a comprehensive description of the building geometry that could be translated to an energy model, but lacks any description of the heating, ventilation, and air conditioning (HVAC) and operation characteristics. The component models derived from BIM are useful, but there is still a need for data-driven generic building component models for whole-building simulation.

Use Cases

The Building Component Library (BCL) was created to address several issues in BEM workflows. Descriptions of some of these issues follow.

Lack of Credibility. To address RMI's findings about lack of credibility, the BCL can add transparency to the building modeling world. It makes components widely available by serving as a central repository for building modeling data and provides a unique URL for ease of citation and source verification.

Rapid Application of Energy Conservation Measures (ECMs). ECMs are changes made to a building that potentially reduce energy consumption, and are important for BEM. Opt-E-Plus (Long et al. 2010) is an optimization platform that applies different ECMs to determine the most energy- and cost-effective building designs. The BCL can make generic ECMs available to such software so they can be reliably and rapidly applied to building models.

Lonely Modeler Problem. In the current modeling workflow, modelers have a local cache of input snippets that they may reuse in their own models. These snippets could be componentized and contributed via the BCL to ensure consistency and error validation across the modeling community. Measures, especially those containing software algorithms, could even inform modelers about how to best modify their models. Moving data from local caches to the Web will provide greater accessibility and potential for BEM's success.

Codes and Standards. Data required for codes and standards work include generic schedules, weather files, and constructions, which are used to generate baseline models. In the building design process, these models can then be perturbed to maximize energy and cost efficiency. Organizations such as the Commercial Energy Services Network (COMNET 2010), the California Energy Commission (CEC 2012a), and others have guidelines for the creation of baseline models. For example, the Alternative Calculation Method (ACM) manual (CEC 2012b) provides a standards translation to the DOE-2 building energy analysis package (DOE-2 2012). The ACM is unique to DOE-2 and is being updated for alignment with COMNET; however, these standards require that datasets (such as schedules, constructions, loads, and weather characteristics) be generated that are neither easily integrated into energy modeling, nor shared by the community. Furthermore, basic building model transformations need to be applied to baseline models. An example transformation would be to remove all punched windows and replace them with banded windows based on window-to-wall ratio. These generic transformations are not reproducible and must be performed manually on individual models.

Figure 1 shows a typical baseline building's roof R-value standard definition. When modeling an R-20 roof for a nonresidential building in Climate Zone 5, the standard specifics a maximum assembly U-value of 0.048 $Btu/h{\cdot}ft^2{\cdot}°F$.

Figure 1. ASHRAE 90.1-2001 Roof R-Value Standard Definition

Applicable Standard	Space Category	Climate Zone	Standard Design Minimum Insulation	Maximum Assembly
90.1 – 2007	Nonresidential	1	R-15 c.i.	U-0.063
		2-8	R-20 c.i.	U-0.048
	Residential	1-8	R-20 c.i.	U-0.048
	Semi-Heated	1, 2	R-3.8 c.i.	U-0.218
		3, 4	R-5.0 c.i.	U-0.173
		5	R-7.6 c.i	U-0.119
		6,7	R-10.0 c.i.	U-0.093
		8	R-15.0 c.i.	U-0.063

Credit: COMNET 2010

Guidelines, ACMs, and various user manuals minimize the ambiguity of the standard by further specifying individual construction layers (Figure 2). Here the construction is fully enumerated layer by layer with matching R-values, and the total matches the standard in Figure 1. However, this enumeration is not directly translatable to a model, as interior and exterior films are handled automatically in various building analysis programs. The BCL will contain components that comply with guidelines and standards, but that can be directly applied to energy models.

Figure 2. ACM Example

Construction	Layer	Thickness (inch)	Conductivity (Btu/h ft F)	Density (lb/ft²)	Specific Heat (Btu/lb F)	R-value (ft²·°F·h/Btu)	U-factor (Btu/h-ft²-F)
Roof R-20 c.i.	Exterior air film	-	-	-	-	0.17	-
	Roofing membrane	-	-	-	-	0.00	-
	R-20 continuous insulation	4.8	0.02	1.8	0.29	20.00	-
	Steel deck	0.06	26	480	0.10	0.00	-
	Interior air film	-	-	-	-	0.61	-
	Total for assembly	-	-	-	-	20.78	0.048

Credit: COMNET 2010

Building Component Library Structure

The BCL contains various entities that are used in BEM. The main entity type is called a component, and represents the physical or operational elements that make up a building model. Measures are the other entity type and are used to replace one component with another. Details about each entity type are provided in the following sections.

The BCL provides a powerful search mechanism to sift through the many entities currently in the BCL as well as the hundreds of thousands of additional entities we expect will soon be added. An application programming interface (API) has also been developed so the data can be accessed programmatically.

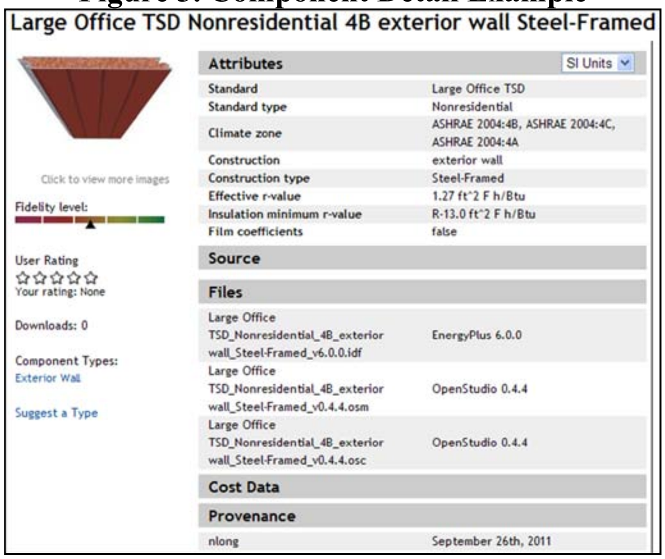
Components

Components are the building blocks of an energy model. They can represent physical characteristics of the building such as roofs, walls, and windows, or can refer to related operational information such as occupancy and equipment schedules and weather information. Components are classified into hierarchical categories, although the taxonomy has been kept relatively flat for flexibility. The topmost component categories are Construction Assemblies, Location-Dependent Components, Schedules, Lighting, HVAC System, and Miscellaneous Electrical Loads (MELs). These categories expand to two other levels of subcategories. The

MELs category is the most extensive, and includes various types of plug loads from computers and printers to coffee makers and dishwashers.

Each component is identified through a set of attributes that are specific to its type. Examples include R-value, glazing type, and frame material for windows or building type and schedule type for schedule components. Figure 3 shows the attribute names and values of a particular exterior wall construction.

Figure 3. Component Detail Example



Credit: Building Component Library / NREL (http://bcl.nrel.gov)

Other metadata are also associated with components. When applicable, the *Source* section contains information about the manufacturer, model number, and year the represented component was built. The *Provenance* section captures information about the user who uploaded the component and the way the data were compiled. The *Cost Data* section includes any generic pricing information related to the component, such as operations and maintenance, salvage, materials, and installation costs. Lastly, the *Files* section includes information about each associated file; these files can have various formats and are associated with various energy simulation software packages.

All component metadata are stored in Extensible Markup Language (XML) format. The component type classifications are stored as tag elements (see Figure 4). When a component is downloaded from the site, the payload includes the XML schema and any associated files and any images, videos, and SketchUp models. The schema definition is available from the website at http://bcl.nrel.gov/api-documentation.

Energy Conservation Measures

An ECM describes a change to a building and its associated model. For the BCL, this description attempts to define a measure for reproducible application in BEM, either to compare it to a baseline model, to estimate potential energy savings, or to examine the effects of a particular implementation. There are three possible measure operations: (1) *replacement*—replacing a building component with another; (2) *addition*—adding a component to a building model; and (3) *removal*—removing a component from a building model. The measure structure can be one of three types:

- Handles component replacements and includes two components:
  - A base component that is currently present in the model
  - A replacement component that will replace it.

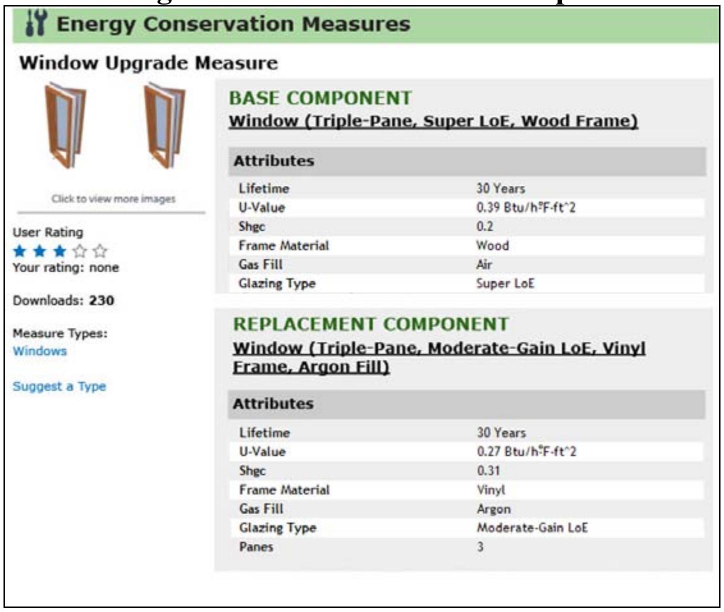
  This type of measure lists relevant attributes of the base and replacement components, as well as links to the individual components if more information is required (Figure 5).
- Includes a component and a software algorithm. The component is to be added to or removed from the building model, but the change is not as straightforward as in the previous case. Therefore, the algorithm provides additional logic necessary to apply the change. Examples include changing all south-facing windows, regardless of window type, and replacing all variable volume fans with an efficiency rating lower than 40%.
- Includes only a software algorithm. No components are added or removed; instead, an operation is performed on the entire building. For example, this type of measure could change the window-to-wall ratio of the building (or of a specific façade) to a new value. In this case, the model is numerically perturbed and no component swapping is required. Software algorithms may accept multiple arguments to operate. Arguments may be optional or required, and may come with default values that may or may not be changed by the algorithm.

Figure 4. Component XML Schema Example


```xml
<component>
  <name>Large Office TSD_Nonresidential_4B_exterior wall_Steel-Framed</name>
  <uid>db27e700-ca7e-012e-0706-00ff10a04904</uid>
  <description>Constructions based on building codes and standards. R-13.0</description>
  <provenances>
    <provenance>
      <author>nlong</author>
      <datetime>2011-09-26T15:05:12Z</datetime>
    </provenance>
  </provenances>
  <tags>
    <tag>Exterior Wall</tag>
  </tags>
  <attributes>
    <attribute>
      <name>construction</name>
      <value>exterior wall</value>
    </attribute>
    <attribute>
      <name>effective r-value</name>
      <value>1.27</value>
      <units>ft^2 F h/Btu</units>
    </attribute>
  </attributes>
  <files>
    <file>
      <version>
        <software_program>OpenStudio</software_program>
        <identifier>0.4.4</identifier>
      </version>
      <filename>Large Office 4B_exterior wall_Steel-Framed_v0.4.4.osm</filename>
      <filetype>osm</filetype>
    </file>
  </files>
</component>
```


Credit: Katherine Fleming / NREL

Figure 5. Measure Detail Example



Credit: Building Component Library / NREL (http://bcl.nrel.gov)

The schema used to describe measures is similar to that of components. If the measure contains a base or a replacement component, this information will be found in the attributes section, along with the unique identifier. As with components, measures contain type classifications (tags), attributes, provenance, and cost data. Figure 6 shows an example schema for a replacement measure containing a base component and a replacement component.

Measures can also have a *files* section, which contains a bit more information than its component equivalent. Because the concept of a script has been introduced for measures, this type of file necessitates a few more descriptors. An example *files* section with argument definition is also shown in Figure 6. The specific argument has a name and value, is of type double, and has no units. It is required by the particular script and is not "settable," which means that the user cannot overwrite the value.

Figure 6. Measure XML Schema with Script Arguments Example

```
<measure>
  <name>Replace Windows...</name>
  <uid>db27e700...</uid>
  <description>Window Replacement</description>
  <provenances>
    <provenance>
      <author>nlong</author>
      <datetime>2011-09-27T15:05:12Z</datetime>
    </provenance>
  </provenances>
  <tags>
    <tag>Window</tag>
  </tags>
  <attributes>
    <attribute>
      <name>baseComponent</name>
      <nid>41669</nid>
    </attribute>
    <attribute>
      <name>replacementComponent</name>
      <nid>41657</nid>
    </attribute>
  </attributes>
</measure>
```

```
<files>
  <file>
    <version>
      <software_program>OpenStudio</software_program>
      <identifier>0.4.4</identifier>
    </version>
    <filename>Alter Window to Wall Ratio</filename>
    <filetype>rb</filetype>
    <argument>
      <name>WindowWallRatio</name>
      <value>0.40</value>
      <datatype>Double</datatype>
      <required>1</required>
      <setable>0</setable>
    </argument>
    <argument>
      <name>Facade</name>
      <value>South</value>
      <datatype>String</datatype>
      <required>0</required>
      <setable>1</setable>
    </argument>
  </file>
</files>
```

Credit: Katherine Fleming / NREL

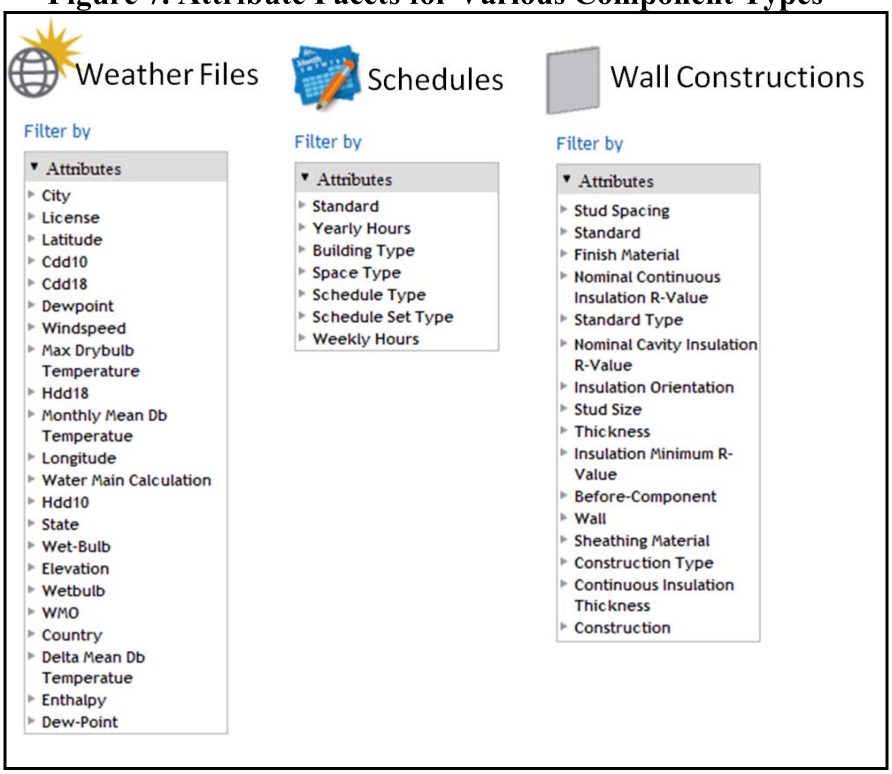
Search

The BCL currently contains more than 30,000 components and measures; we expect this number to increase significantly. The tool must therefore have a powerful search engine that gives users the controls to locate information. A faceted search mechanism has been implemented on the BCL site using Apache Solr (ApacheSolr 2012). This allows users to filter through the search results (either within a component or measure type or by matching a keyword) using various facets. Facet categories include component and measure types, data source, and energy modeling software type. All attributes of a component or measure can also be used to filter the results, which is very important in narrowing down to the desired result set. Figure 7 shows a list of facets available for three component types; the facets differ from one component type to the next, as they are derived from the attributes.

There are three types of facets (1) text, such as those for *city* and *state*, are unrestricted text inputs; (2) range, which are used for numerical attributes and allow users to specify a range of values (the total range of the stored data is displayed in Figure 9); and (3) selection, which provide a list of values to choose from. Figure 8 gives examples of each facet type.

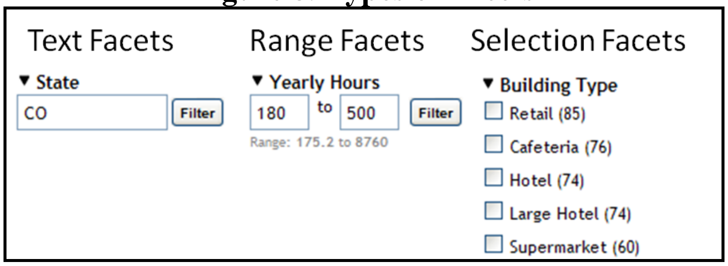
Facets are essential in narrowing down search results. For example, a search for the keyword "wall" returns 1144 components. Limiting the *construction type* to "steel-framed" and the *effective R-value* to 2.6 filters the search to a manageable 47 entries, as shown in Figure 9. The search can be further narrowed with the remaining applicable facets.

Figure 7. Attribute Facets for Various Component Types



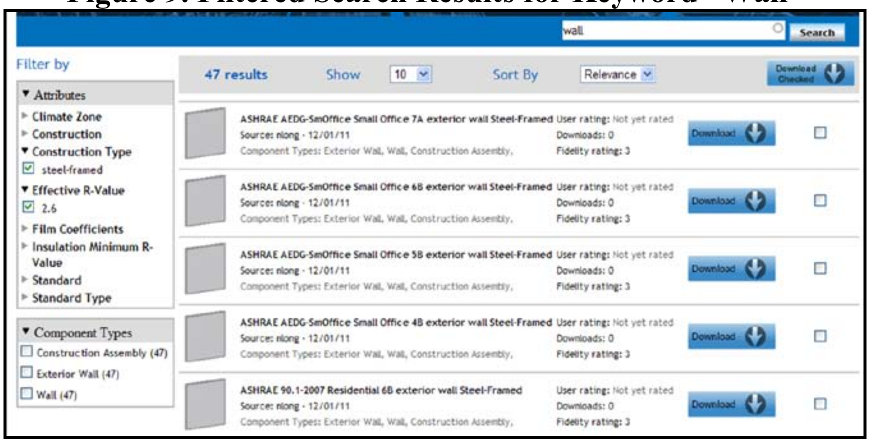
Credit: Building Component Library / NREL (http://bcl.nrel.gov)

Figure 8. Types of Facets



Credit: Building Component Library / NREL (http://bcl.nrel.gov)

Figure 9. Filtered Search Results for Keyword "Wall"



Credit: Building Component Library / NREL (http://bcl.nrel.gov)

Social Engagement

Currently, only vetted users can upload components to the site. The intention is to open this functionality up to the public, as crowd-sourcing could greatly increase the amount of data to millions of measures and components. This expansion will, however, make quality control more difficult to enforce. Content uploaded from a U.S. Department of Energy (DOE) national laboratory or other trusted organization will be differentiated from publically uploaded content to address variations in fidelity and reliability.

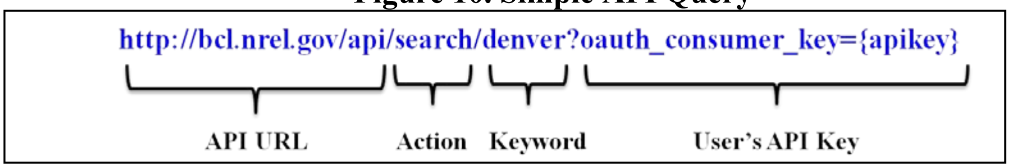
To further classify content qualitatively, users are encouraged to provide feedback. User ratings also differentiate high-quality components from less desirable ones. Search results will allow sorting by rating to give priority to highly rated data. Users can also leave comments on the component's or measure's detail page to reinforce a rating or issue a warning.

Application Programming Interface

The BCL can be used to create other applications through its API, which allows access to BCL's search engine. It can be used to query the library and return components by using the *filters* parameter to specify the component type as well as attributes such as manufacturer, location, and other component-specific attributes. A full list of search filters is available on the site at http://bcl.nrel.gov/apifields. Once components have been identified, the component details and the actual component payload can be retrieved. Query results are returned in XML format by default, but JSON and YAML formats are also available. Components are downloaded in compressed file format (zip). A maximum of 10 records are returned at a time, but this number can be specified in the query through the *show_rows* parameter. A *page* parameter is also available to iterate through a larger result set. The API can be accessed from novel applications that are encouraged to use the API.

The API is available to all registered users provided they have created an API key. Figure 10 shows an example query in three parts: (1) the API URL, which will be the same for all API functionality; (2) the action to be taken by the API, in this case a search (two other actions are available—*component*, which will display the metadata associated with a particular component, and *component/download*, which will download all metadata and files related to a component or measure specified by its node id); and (3) a keyword on which to center the search. Here we wish to retrieve all entities matching the keyword "denver." The final part of the query specifies the user's unique API key.

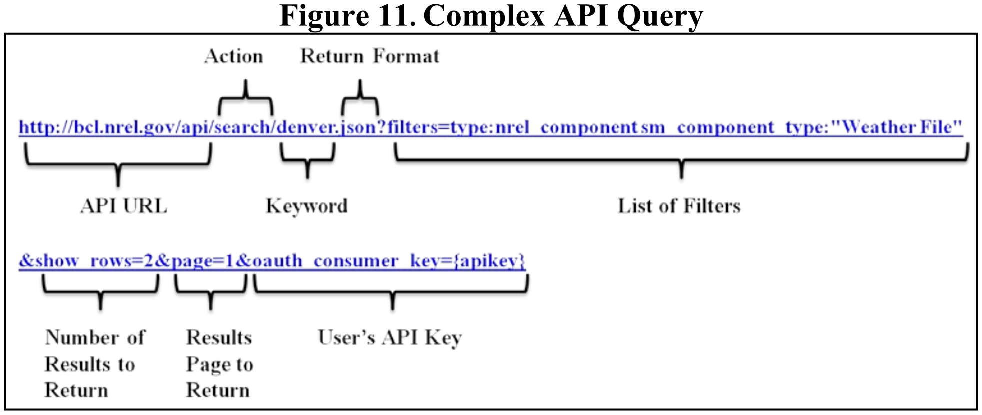
Figure 10. Simple API Query



Credit: Katherine Fleming / NREL

Figure 11 shows a more complicated query. The first three parts are identical to the simple API query. The next part specifies the return format of the data (JSON in this case), followed by the filters to be applied to the query. These filters are name/value pairs separated by a colon (:) and are separated by a space. Again, we are querying for entities that match the keyword "denver," but we wish to retrieve only component entities, and these components must be of type "Weather File." The *show_rows* parameter is used here to limit the results set to two, and the *page* parameter indicates that the first page of the overall results set should be returned.

Figure 11. Complex API Query



Credit: Katherine Fleming / NREL

Building Component Library Workflows

The BCL API can be used to create novel applications or enhance existing ones. The API can be used by any third party provided that a "key" is procured on the BCL website. The following sections contain example applications of the BCL API.

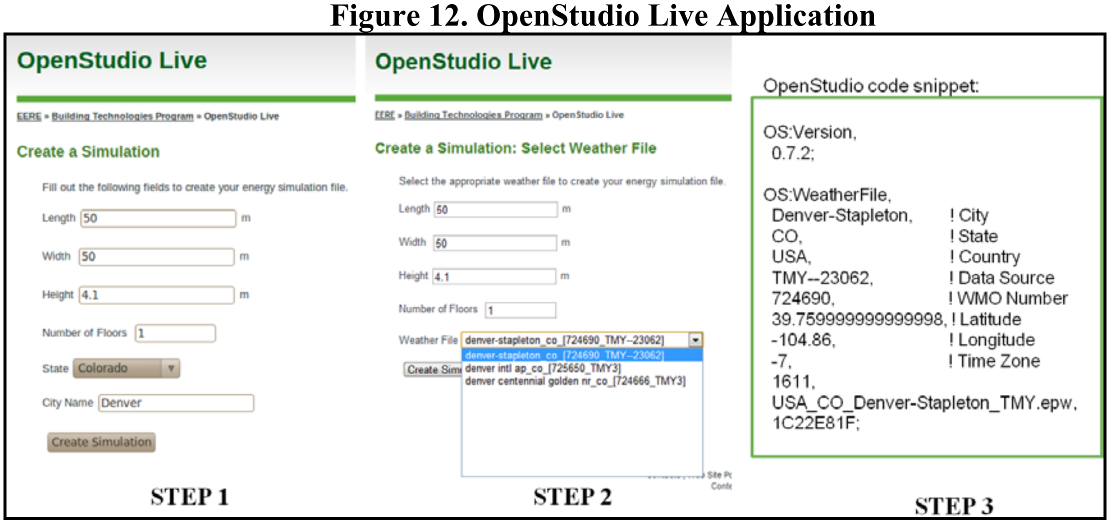
OpenStudio Live

OpenStudio Live is a simple, proof-of-concept application that creates building energy models from a small set of inputs. It was created to demonstrate a simple application of the BCL API, which is used to retrieve weather files based on the location entered in the input form. The application flow is shown in Figure 12. In step 1, the user is prompted to enter a few simple building parameters, including city and state. The application then uses the location information to create a search request through the API. The returned results are then parsed by the application and displayed in a drop-down box, as shown in step 2. The user can then select the appropriate weather file and resubmit the form so the file is downloaded and the appropriate software code snippet is created for use in the simulation, as shown in step 3.

OpenStudio Integration

OpenStudio (NREL 2012) is an open-source cross-platform software product developed by NREL and DOE with the objective of helping building owners, architects, designers, engineers, and others involved in the design process to design energy-efficient buildings. It provides a suite of tools to support EnergyPlus (Crawley et al. 2008) modeling and workflows. It facilitates an iterative workflow of design, simulation, and analysis. This allows for ongoing feedback about the energy impacts of decisions, along with other design factors such as program requirements, costs, and building codes.

Figure 12. OpenStudio Live Application



Credit: Katherine Fleming / NREL

The BCL is being integrated with OpenStudio to provide a seamless workflow for leveraging the vast resources of the BCL with local OpenStudio models. The OpenStudio application loads an interface to the online repository into a pane on the right (see Figure 13). This allows users to browse, download, and add components to their models. The interface also contains a local library where each downloaded component is also added so it can be reused.

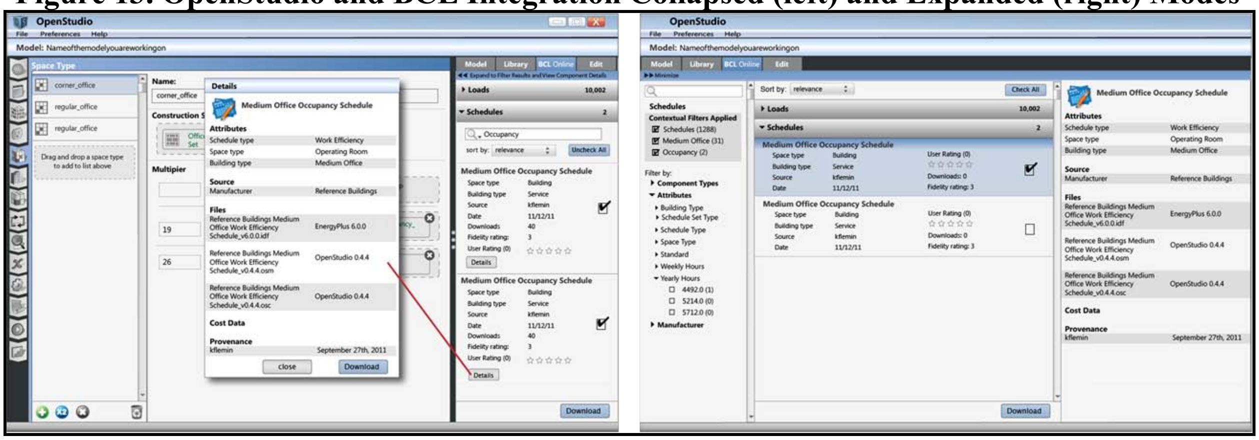
There are many steps to creating a building energy model, such as space and thermal zone generation, construction assignments, internal loads and schedules identification, and

HVAC determination. The BCL pane also presents components that are contextually relevant to the current workflow; for example, if a user is creating construction sets to be used in the model, the library is preloaded with constructions and materials needed to complete this step. Figure 13 shows a view of the BCL library containing only loads and schedules, because the space type context of the building model workflow is enabled.

When the BCL pane is in the collapsed mode (Figure 13), components are listed by contextually relevant component type. A few details are visible and the entire list of metadata can be accessed through the "details" button. A keyword search can be performed and the results can be sorted in a few ways. Screen real estate limitations prevent the faceted search functionality on the Web application from being available in this view.

The expanded mode of the interface (see Figure 13) allows access to BCL's faceted search feature. In addition to the contextual filters, which can be enabled or disabled in this mode, the component-specific attributes, as well as component types and source information, are all available as search filters.

Figure 13. OpenStudio and BCL Integration Collapsed (left) and Expanded (right) Modes



Credit: Marjorie Schott / NREL

Conclusions

The BCL is an online repository of components and measures that can be directly added or applied to building energy models. It aims to add transparency to energy simulation by providing uniquely identified components that can then be cited, validated, and reused by the BEM community.

In addition to the enhancement of modeling workflows by further integrating the BCL with OpenStudio, future work will involve a more detailed implementation of economics. With the creation of measures, costs will be much more important in evaluating ECMs. Components contain absolute costs, but measures necessitate marginal costs, to compare the cost of replacing windows with the increase in energy performance, for example. These cost data will be gathered from various sources including standards committees, cost estimators, and cost databases.

The BCL does not account for life cycle inventory data in its current state. Such data are envisioned to be stored alongside the components. This would allow for life cycle analysis on building energy models to better understand the life cycle impacts of ECM application or design decisions and facilitate the selection of components with low embodied energy.

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