Enabling Detailed Energy Analyses via the Technology Performance Exchange

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ABSTRACT

A key tenet to increasing adoption of energy efficiency solutions in the built environment is improving confidence in energy performance. Industry currently uses predictive modeling, often via detailed hourly or sub-hourly energy simulation programs, to account for site-specific parameters (e.g., climate zone, hours of operation, and space type) and arrive at a performance estimate. Such methods are highly precise; however, they invariably provide less than ideal accuracy because high-quality, foundational energy performance input data are lacking.

The Technology Performance Exchange™—a free, publically accessible Web-based portal—was constructed to allow the transparent sharing of foundational, product-specific energy performance data. It leverages significant external engineering efforts and a modular architecture to agnostically identify and codify the minimum information necessary to accurately predict product energy performance and represents a novel solution to the problem mentioned above. Additionally, by translating contributed foundational data into energy modeling syntax, the Technology Performance Exchange provides an actionable and concrete resource, allowing energy modelers to improve model accuracy, drive energy efficiency decisions, and reduce development time and cost.

This paper (1) presents a high-level overview of the project drivers and the structure of the Technology Performance Exchange; (2) offers a detailed examination of how technologies are incorporated and translated into energy modeling syntax; and (3) examines several ways that this workflow translates energy performance data into actionable energy savings.

Introduction

When building energy modelers investigate products and technologies that claim to increase energy efficiency, they often find that they lack access to what are perceived as credible energy performance data. Even if they move forward with an analysis, the assumptions they must make about product performance (above and beyond those that detail how a product will be used; e.g., a representative operating schedule) reduce the accuracy of the prediction. Therefore, even if modelers determine that a product would *likely* provide an acceptable increase in efficiency, they often have difficulty convincing their clients to move forward with a project because they cannot support the development of a quality business case. This holds true even if measured data for previous applications of a product are available. The use of case-study data to

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predict performance in an alternative building is difficult because such data are usually intertwined with nonapplicable site- and operation-specific parameters.

This is not to say that energy performance data are not available. Generally, product manufacturers provide some level of energy performance data for their products. Sometimes these data are sufficient to support detailed building- and use-case-specific energy performance analyses. But for many technologies, this is not the case.

To facilitate improved identification, storage, and sharing of foundational energy performance data, the U.S. Department of Energy's (DOE) Building Technologies Office and Federal Energy Management Program, and the Bonneville Power Administration (BPA) funded the National Renewable Energy Laboratory (NREL) to develop the Technology Performance Exchange™ (TPEx™; NREL 2014c). The TPEx is a free, publically accessible Web-based portal that serves as a centralized repository for users to share and find product-specific energy performance data. Additionally, within certain technology categories, contributed foundational TPEx data are automatically translated into EnergyPlus (DOE 2013) input objects and stored on the Building Component Library (BCL; NREL 2014a) where they are immediately accessible to users of a variety of public and private sector tools.

This paper provides a brief overview of the TPEx, including a discussion of how data verification challenges were overcome and the workflows implemented to provide open and transparent data exchange. This introduction is followed by a detailed description of how foundational TPEx data are translated into EnergyPlus input objects and stored on the BCL. Finally, a discussion is presented that highlights the benefits of this workflow.

The Technology Performance Exchange

Because the building technology landscape is dynamic, with new technologies and products being brought regularly to market, it is important to ensure that DOE, BPA, NREL, and external stakeholders can easily add new technologies and products into the TPEx. To allow new technologies to be added over time, the TPEx consists of two pieces:

- The core infrastructure. This Web-accessible software nucleus acts as a foundation, providing the services that any user would expect from an information portal, including data indexing, user-driven queries, user registration/account access, and data upload/download pathways.
- Data entry forms (DEFs). The core infrastructure was built to accept the overlay of any number of technology categories via the development of DEFs, which identify "the minimum product-specific energy performance characteristics and other critical properties necessary to evaluate a product's energy performance" (Studer and Lee 2013). Adding a technology category to the TPEx enables product-specific energy performance data to be uploaded and shared. DEFs are similar in aim to the annexes being developed to the as-yet unpublished Standard 205 within ASHRAE Standard Project Committee 205 – Standard Representation of Performance Simulation Data for HVAC&R and Other Facility Equipment (ASHRAE 2013). Current plans call for applicable TPEx DEFs to align with the ASHRAE Standard 205 annexes, as they are published.

This combination enables the TPEx to function as an expandable—but agnostic—data clearinghouse. With a robust foundation on which to build, new technologies can be added as the appropriate energy performance characteristics are identified.

Data Provenance

Of paramount importance during the project was ensuring the credibility of the data housed in the TPEx. The idea of vetting uploaded performance data was dismissed because (1) it would not be practical or sustainable for any entity to validate all uploaded data; and (2) barring conflict with the laws of thermodynamics, there is no reasonably defensible ground for any entity to claim that any other user's data are invalid or otherwise incorrect.

With no practical method to ensure data validity, an alternative was sought. The implemented solution deals with the issue via a less traditional approach, using a combination of constrained workflows and metadata to ensure that TPEx end users can decide *for themselves* whether to trust the uploaded data. These will be discussed below.

Workflow Restrictions

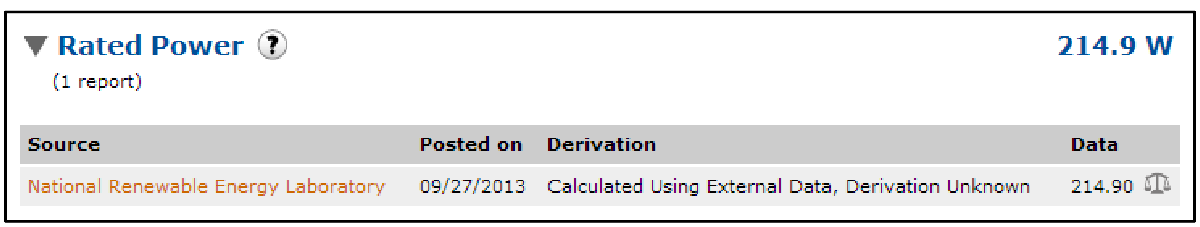
Before TPEx users can upload performance data, they must first register using one of three registration options: *Manufacturer/Brand Owner*, *Third-Party Test Laboratory*, or *Contributing Evaluator*. Registration requires association with an organization; all new organizations are reviewed and must be approved by an administrator for a user to contribute content to the TPEx.

Each registration option has a unique set of allowed behaviors or workflows. The use of numerous registration types (1) helps to prevent intentional misrepresentation (either through over- or understatements) of product performance; and (2) provides background information that TPEx users can refer to when deciding whether to use posted data.

Metadata

To empower all TPEx users to make informed decisions about which, if any, performance data to use in product or technology energy analyses, the TPEx displays a host of additional information related to product performance data provenance (see Figure 1). Referred to as *metadata*, the following information is displayed alongside each piece of performance data:

1. The name of the organization that uploaded the data.
2. The date the performance data were uploaded.
3. The data derivation method. Options are chosen from an enumerated list and associated with each data parameter (not just a dataset).
4. The registration type of the contributing organization, denoted as a graphical icon.


▼ Rated Power (?) 214.9 W
(1 report)

Source	Posted on	Derivation	Data
National Renewable Energy Laboratory	09/27/2013	Calculated Using External Data, Derivation Unknown	214.90

Figure 1. This TPEx screenshot shows metadata displayed in conjunction with product performance data. The scale icon (right) indicates that NREL is registered as a Contributing Evaluator. *Source:* Daniel Studer, NREL.

When TPEx users download performance data from the site, the metadata are downloaded as well (whether the data are accessed through the user interface [UI] or through the application programming interface [API]). This ensures that TPEx users can make informed decisions about the information they choose to use in analyses, even if those data are not obtained directly from the TPEx (e.g., forwarded from a TPEx user to another individual, or accessed via a third-party data portal that references TPEx data).

Data Accessibility

Because the TPEx is meant to be a mechanism through which data are actively shared, two mechanisms were created to facilitate easier data access: a Web interface (the UI) and an API. Figure 2 provides a graphical representation of how users interact with the TPEx.

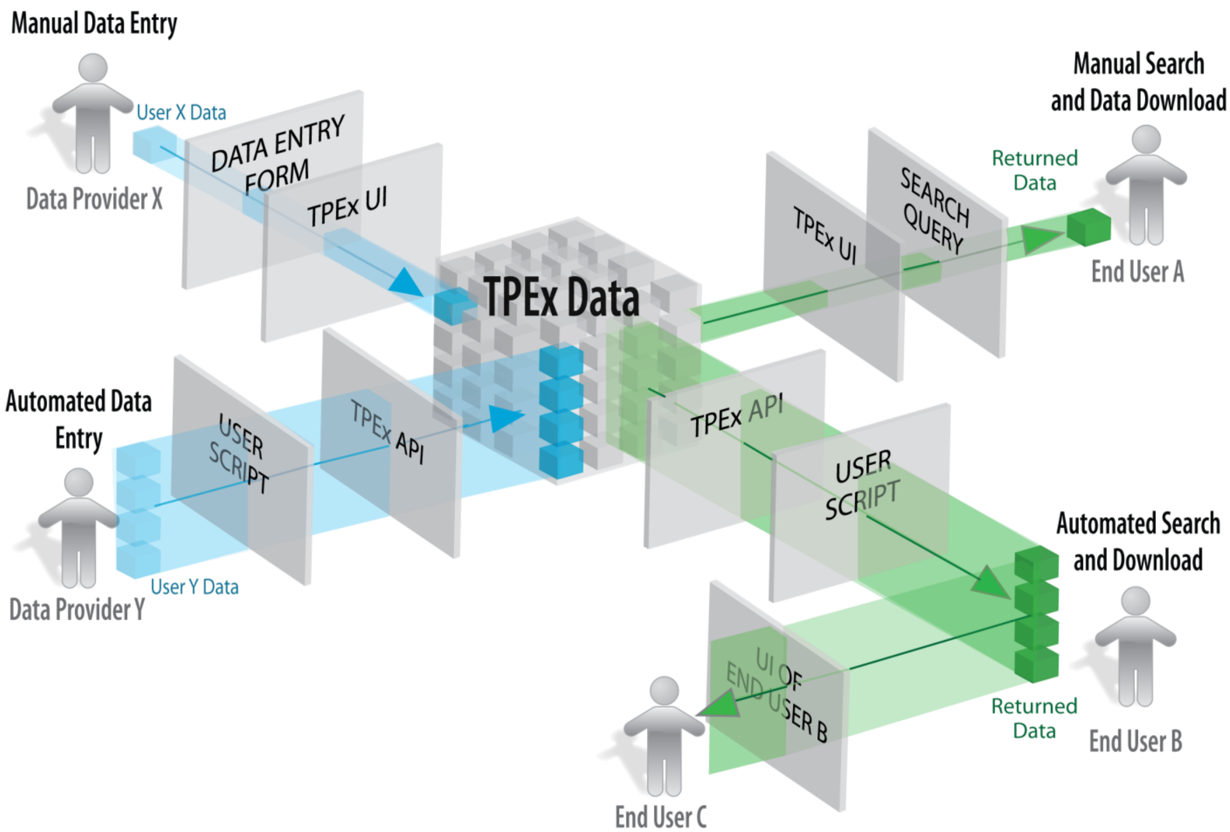


Figure 2. This diagram provides an overview of how TPEx end users contribute and access performance data: (a) directly via the UI, or (b) by accessing the TPEx API via user-created scripts. Note that the integration of TPEx data into third-party applications and databases (bottom right) is encouraged. *Source:* Marjorie Schott, NREL.

Application Programming Interface

The TPEx API enables users to automate interaction with TPEx data. Users can automatically query the TPEx database via the TPEx API *search*, *download*, and *fields* resources and download any or all performance and metadata for products of interest. TPEx users can also automate the upload of product and performance data (contingent on their registration type).

Web Interface

The TPEx UI, shown in Figure 3, provides similar, though manual, capabilities to the TPEx API. Users can browse technology categories, search for products, and download energy performance and metadata via the UI. However, two main features available through the TPEx Web interface are not available through the API: (1) users can easily track and maintain (edit, update, or delete) their product or performance data submissions as part of their account pages; and (2) users can compare up to four products in any technology category side-by-side. This comparison feature is helpful if a user is investigating only a handful of products and desires an easy way to compare performance.

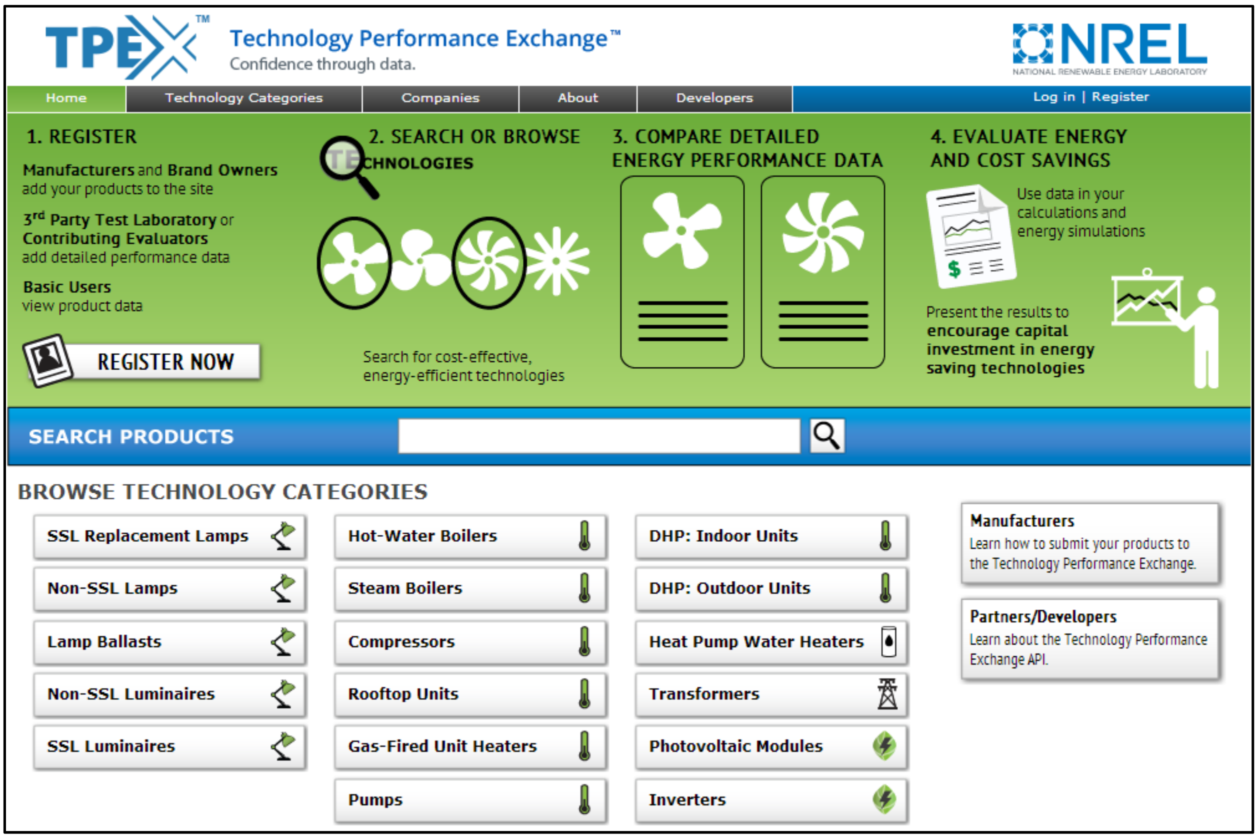


Figure 3. Screenshot showing the TPEx UI. *Source:* Daniel Studer, NREL.

The Building Component Library

As mentioned earlier, certain TPEx technology categories are automatically translated into EnergyPlus input objects and stored in the BCL, an online, searchable repository of building energy model inputs that (1) encourages the sharing and reuse of energy modeling code; and (2) increases the transparency and reproducibility of energy simulation results. The BCL is currently being leveraged by many public and private sector tools, including DOE's modeling platform, OpenStudio (NREL 2014b), DOE's Asset Score (DOE 2014), and simuwatt (concept3D 2014).

The BCL primarily stores data termed *components*, which represent the primary building blocks necessary to construct an energy model. Examples include representations of physical components (either generic instances or specific products such as windows, walls, and HVAC subsystems) as well as ancillary information needed to complete an energy modeling simulation, such as weather data and operating schedules. BCL components are categorized using a specific BCL taxonomy term, or *type*. Components also include descriptive attributes that further identify the components and serve as facets to efficiently filter results when searching for a particular component on the site. A component includes associated payload files that are representations of the component in terms of one or more specific modeling software packages; payload files can be added directly to an energy model. Although payload files of any type can be stored in the BCL, most components currently contain either EnergyPlus (.idf) or OpenStudio (.osm) payloads.

The BCL can also store energy conservation *measures*. Measures represent a change that can be applied to a current building energy model, either by modifying a component or characteristic of the model, or by adding and removing components. As with components, BCL measures are categorized according to the BCL measure taxonomy, contain associated payload files, and use attributes to describe the measure and enhance search functionality. BCL measures consist of Ruby scripts that perform operations on an OpenStudio building energy model along with related spreadsheets that contain reference information.

BCL users who are registered as members of an approved organization can contribute content to the BCL. Similar to TPEx, content that users upload is associated with their respective organizations, although uploaded BCL data are accessible by group members only, until a group moderator decides to publish it. In addition to its Web interface, the BCL also provides an API that can be used to upload and update content, as well as to search for and download components and measures.

For more information about the BCL, please see NREL (2014a), Fleming, Long, and Swindler (2012), and Long, Fleming, and Brackney (2011).

Data Translation

TPEx and BCL API users can automate data queries, data aggregation/synthesis, and energy modeling based analyses. This last approach is currently being pursued by BPA, which sponsored the work to automate the translation of products within specific TPEx technology categories into publically accessible EnergyPlus input objects (Studer and Lee 2013).

This section describes in detail the process employed to facilitate this translation, including the decisions implemented to handle multiple or malformed datasets to generate a single, usable EnergyPlus product representation.

Discussion of Product Representation

The performance of a single "real-life" product can be represented in many ways. In the TPEx to EnergyPlus translation process, the TPEx representation is initially composed of energy performance parameter values (possibly containing duplicate entries) and performance maps that specify the performance of the product over a variety of conditions. The translator's purpose is to convert this tool-agnostic representation into a form that is ready for inclusion in the BCL, and ultimately in a specific simulation tool (in this case EnergyPlus).

In some modeling applications, it may be sufficient to include only rated conditions in a simulation model formulation. This approach may be useful when detailed performance data are very difficult to obtain, or when the model formulation is required to be highly simplified. In such cases, provisions may be included to handle off-design conditions.

When using detailed simulation programs such as EnergyPlus, detailed component performance data over a variety of conditions are necessary to provide an accurate result. This minimum information criterion is strongly considered when determining whether a product's TPEx representation is sufficient for translation.

From Foundational Data to EnergyPlus Object

The TPEx data to EnergyPlus object translation process is composed of several steps, illustrated at a high level in Figure 4. The translator is composed of a set of scripts that perform database and mathematical operations. The translator is extensible to allow easy implementation of new product categories. Currently, the translator can convert heat pump water heater (HPWH) and ductless heat pump (DHP) system TPEx data (including variable refrigerant flow systems), into EnergyPlus objects.

Figure 4. Overview of the process used to convert product-specific foundational energy performance data from the TPEx to EnergyPlus syntax. *Source:* Marjorie Schott, NREL.

The data the translator initially retrieves consist of all the product and performance data available on TPEx for that particular product. This can include multiple values for any given performance parameter as well as multiple performance maps. The translator attempts to aggregate the entirety of the data into a single EnergyPlus representation of the product. The resulting EnergyPlus files are then pushed to the BCL; this last step is detailed in a later section.

The translation process consists of four high-level tasks:

1. The translator retrieves the TPEx dataset for a single product (all product and performance data, including performance maps) and unpacks it into a directory hierarchy. This structure is immediately validated to ensure the process can continue.
2. Performance parameter data are aggregated (if applicable) from the raw-text summary file that is generated as part of Step 1. Additional validation checks are run to ensure that critical performance parameter data are present.
3. When present, performance map files are individually transformed into a new format. If a product has multiple maps, the files are merged to create a single representative dataset. This dataset is then examined to ensure enough data are available to proceed.
4. If the translation to this point has been successful (no errors), the translator completes the process by writing the aggregated performance data and performance map data as a single EnergyPlus object.

The TPEx API uses software scripts that enable this translation to be automated. Currently, the process is repeated nightly for all products in the HPWH and DHP technology categories. The translator processes only files that have been updated since the last processing period.

Aggregating Multiple TPEx Datasets

As mentioned above, TPEx data for a particular product may include performance parameter data and performance maps, although in some instances only one or the other may be present. Additionally, multiple values for one or many parameters, or multiple performance maps may be present for a particular product. Because the TPEx to EnergyPlus translator seeks to create a single representation for each product, and not a representation for each TPEx dataset, the translator can aggregate the data.

In keeping with the TPEx's data validation philosophy, the translator does not attempt to determine whether any given data value is correct. Instead, a weighted-average approach is employed to create a single representative value when multiple parameter values are found (Step 2). When any given parameter has multiple data values, the following equation is used to calculate a weighted average:

$$\tilde{x} = \frac{\sum_i \beta_i x_i}{\sum_i \beta_i}$$

Where: x = A numeric performance parameter value
β = Weighting factor for this parameter

By assigning each performance parameter value, x, a weight, β, according to its data source type, a single weighted average for that parameter is obtained. Values entered by Manufacturers/Brand Owners and Contributing Evaluators are assigned weights of 1.0. Third-Party Test Laboratory-entered data are assigned weighting factors of 1.2. Because of the equation used, only the relative values of the weighting factors (not their absolute values) are important.

Performance map data are treated similarly (Step 3). When a particular product has multiple performance maps, data that are blatantly invalid (non-numeric, for example) are first pruned. Then, for each performance map point, values are aggregated using the same weighting factors used to aggregate performance parameter values. TPEx users may enter partially completed performance maps. This means that the final, aggregated performance map may contain voids and averaged data values.

Data Validation

Data are validated in multiple stages during the entire TPEx to EnergyPlus translation process. Although not explicitly labeled in Figure 4, data are validated in each step. Figure 5 lists the validation checks that are run during Steps 2 and 3 of the translation process; decision points illustrate the reasons that a product passes or fails validation. Because energy performance parameters are validated against a set of basic rules (i.e., some inputs are required to be numeric) when they are first entered in the TPEx, the translator does not repeat this. Performance map data, however, are not validated on TPEx, so the translator validates these data.

During Steps 2 and 3, after the performance parameter or performance map dataset for a given product has been aggregated into a single representation (if necessary) and been verified as sufficient, the translator validates the quality of the data. This is not a thermodynamic evaluation, but rather a step to ensure a useful translation can occur. The translator checks to see whether sufficient performance parameter or performance map data are available to proceed with translation to an EnergyPlus object.

For each TPEx technology category, certain performance parameters are identified as critical. If the aggregated product representation does not include a value for any of these, the translator cannot provide a useful EnergyPlus object, so the process is terminated for that product.[2]

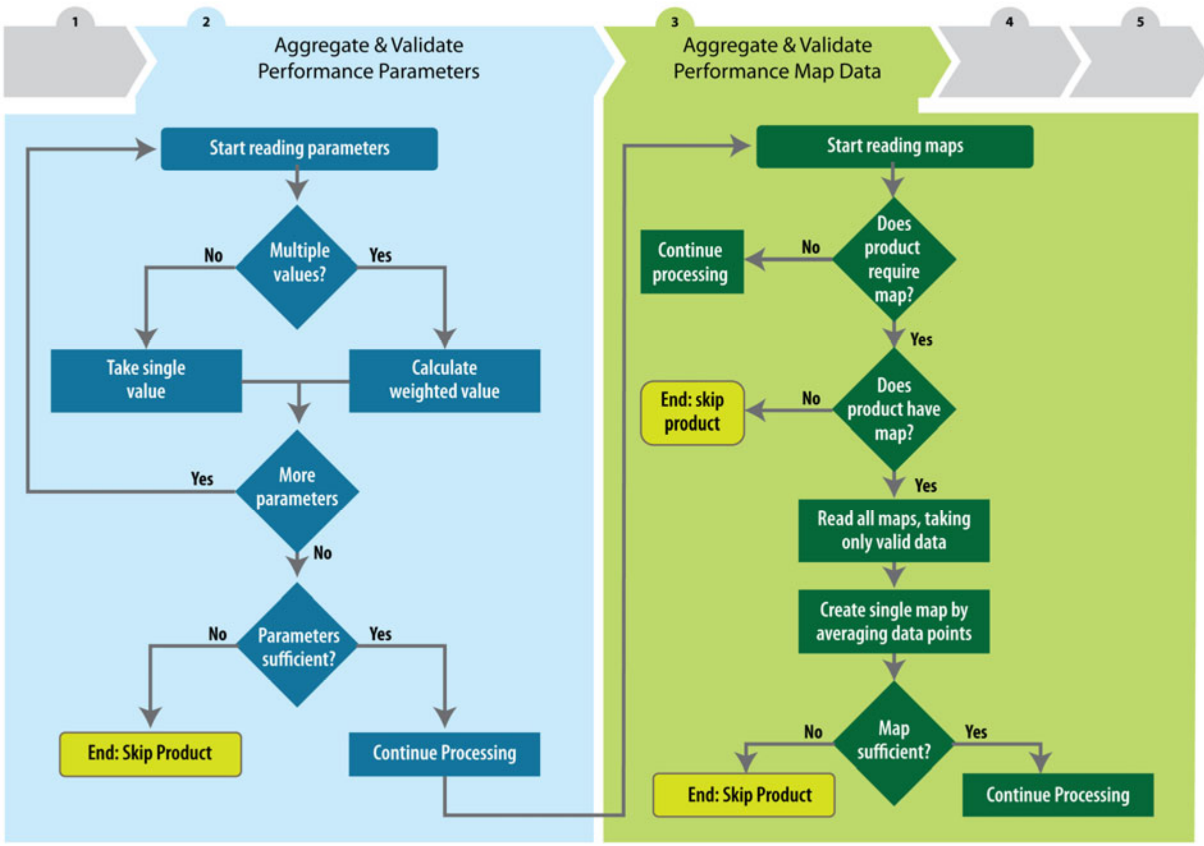


Figure 5. Overview of the data aggregation and validation steps employed in the translation process from TPEx data to EnergyPlus input syntax. *Source:* Marjorie Schott, NREL.

Instead of a single data point, a minimum fraction of the requested performance map data must be present in the aggregated performance map to generate a usable curve or lookup table representation for that product. For an actual dataset A, with a performance map template that defines a possible set B and a minimum tolerance for dataset size ε, the decision for determining whether to continue is described as:

$$Continue = \begin{cases} True, & if: \ \bar{\bar{A}} \geq \bar{\bar{B}}\varepsilon \\ False, & if: \ \bar{\bar{A}} < \bar{\bar{B}}\varepsilon \end{cases}$$

[2] Even though the process stops for this product, a log is always maintained to allow inspection of components that fail the translation process.

Many products on the TPEx may include multidimensional performance maps, where dependent variables are requested for a combination of multiple independent variables. For example, if a product's energy performance is dependent on three independent variables, the performance map is defined to include the performance of the unit in response to many permutations of the independent variables to best capture the performance representation:

$$Z = f(\vec{x})$$

After translation, however, the final EnergyPlus formulation must instead represent the product's performance using individual curves, each of which is dependent on a single element in $\vec{x}$, while holding all other elements constant:

$$Z_i = f(x_i); for\ all\ i$$

As such, when products use multidimensional performance maps as part of the TPEx product representation, the TPEx to EnergyPlus translator examines each dimension to verify that each curve contains sufficient data to be represented in the final form.

Creating Translated Objects

Once the TPEx dataset has been aggregated and validated, the translator writes the product representation in the desired form (Step 4), which in this case is EnergyPlus. The EnergyPlus syntax consists of a comma/semicolon delimited list of input data. Simulationists can use this set of inputs as necessary as a component in their own building and system simulations.

Pushing Content to BCL

Once TPEx performance parameter and performance map data have been aggregated and translated into EnergyPlus product representations, a separate script is used to package the resulting files into BCL components (Step 5).

Each BCL component package includes an xml file that contains descriptive information about the component and about the building energy model file representing the product. The xml file generated using the script contains the name of the component (which matches the TPEx product name), a description of the component, and source information linking the BCL component back to the product's TPEx URL and unique identifier (uuid). Other pieces of identifying information such as the product manufacturer, brand, product line/family name, model number, and a subset of the technology category-specific performance data are also stored as BCL component attributes.

Not all performance parameter data stored on the TPEx are used as BCL attributes; only the information most relevant to the energy model representation of the product. These attributes are used to describe the component and to filter search results on the BCL. Each BCL component is associated with a specific component type representing the component's technology category. The BCL's component types and the TPEx's technology categories are derived from the same taxonomy, so the mapping of technology categories to component types is trivial. This information is also stored in the xml file. Lastly, a reference to each payload file associated with the component, along with the file's associated software program and version, is stored in the xml. Although BCL component files can be any building energy model files or other files relevant to the model, the TPEx translated components contain EnergyPlus model files.

All this information is packaged into either a zip or a tar.gz file and uploaded to the BCL via the BCL API. Users must be part of an approved organization to publish content on the BCL, so all TPEx products are uploaded to the NREL TPEx group.

The Process from Start to Finish

The complete TPEx to BCL workflow is described in Figure 6. The TPEx search API resource is first used to retrieve products (in the relevant technology categories) that have been created or updated since the script was last run. The TPEx download API resource is then used to download all performance data and files associated with each returned TPEx product. This information is input into the translation module, which then processes the information to create an EnergyPlus model file representing the product. If the translation module deems the information is insufficient to create an EnergyPlus file, the process is aborted and no BCL component is created. If a file is created, it is then used—along with the downloaded TPEx product data—to create a BCL component package. The product's TPEx uuid is used in the BCL search API resource to determine whether the BCL already has a component matching the TPEx product. If it does, the component package updates that component. Otherwise, the component package creates a new component. This entire procedure is run automatically each night.

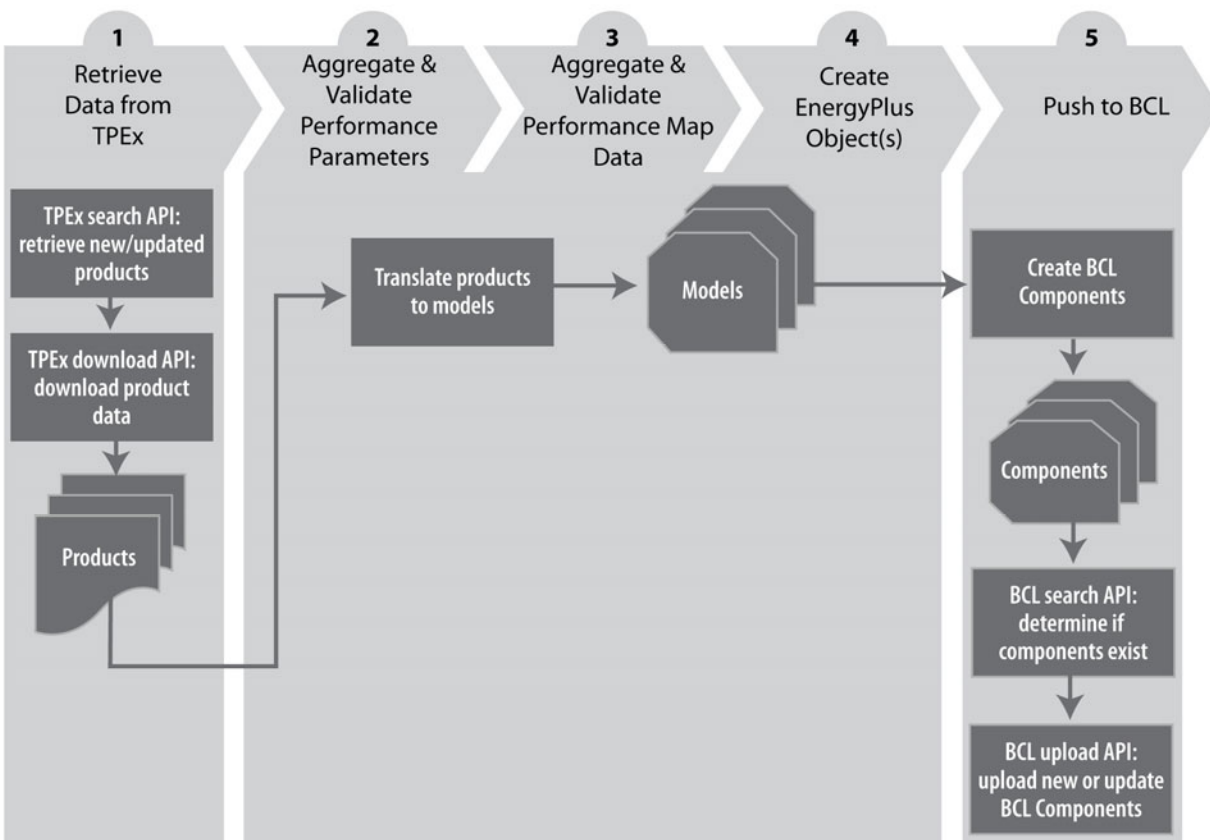


Figure 6. A high-level description of the entire TPEx to BCL workflow. *Source:* Marjorie Schott, NREL.

Workflow Benefits

The TPEx interface mechanisms (the UI and API) and the TPEx to BCL workflow were developed to enable interested parties to use and share large amounts of relevant energy performance data efficiently. Although the translation mechanism was developed specifically to support the energy modeling community (and is the main subject of this paper), the TPEx was designed to support a broad set of users. The following sections detail several possible use cases.

Data Contributors

Product manufacturers sometimes face an uphill battle convincing potential customers that their products provide cost-effective and environmentally friendly solutions to the customer's needs. Because the DEF development process ensures that the parameters the TPEx accepts are systematically identified, manufacturers can help to assuage customers' product performance doubts by providing energy performance data to the TPEx. The TPEx API allows manufacturers to efficiently upload entire product catalogs.

Many electric and gas utilities currently oversee or participate in technology field demonstrations to assess technology energy performance. These programs are used to identify technologies that are likely to provide demand or energy reduction, but common practices make it difficult to share test results in a meaningful way. Although project summary reports and aggregated analyses are published and shared, innate differences between utility service territories (climate, generation mix, demand profiles, prevalence of building type, etc.) often preclude the rote application of demonstration results from one utility to another.

The TPEx's standardized structure to share measured foundational energy performance data (i.e., characterized product performance) provides a mechanism through which multiple utilities can collaborate to avoid duplication of effort and reduce total project time and cost. By co-sponsoring field testing efforts, or by using an alternative round-robin style technology demonstration approach to increase the number of examined technologies, utilities can leverage a common set of measured data and then apply utility-specific characteristics (weather data, region-specific usage patterns, etc.) to the data during the evaluation process.

Data Users

By providing a central, standardized repository for tool-agnostic energy performance data, the TPEx increases the likelihood that *required* input data will be available for any user to leverage in their own analysis. Whether helping energy modelers to reduce their need to use rules of thumb, or simply providing the high-level information a user needs to perform a "back of the envelope" calculation, the TPEx provides the data necessary to drive those calculations.

The true analytical power of the TPEx is most likely to be realized by users who take advantage of the site's integration with the BCL. By automatically generating EnergyPlus input files from the raw performance data, energy modelers (1) don't have to spend the time constructing product representation themselves (or settling for "close-enough" solutions); and (2) are assured that the resulting product representation is based on real, available, and transparent data. Additionally, by storing the resulting EnergyPlus product representations on the BCL, users can more easily take advantage of other tools built on top of DOE's modeling platform, OpenStudio, which provides additional analysis benefits.

Figure 7 illustrates the workflows enabled by TPEx, BCL, EnergyPlus, and OpenStudio integration.

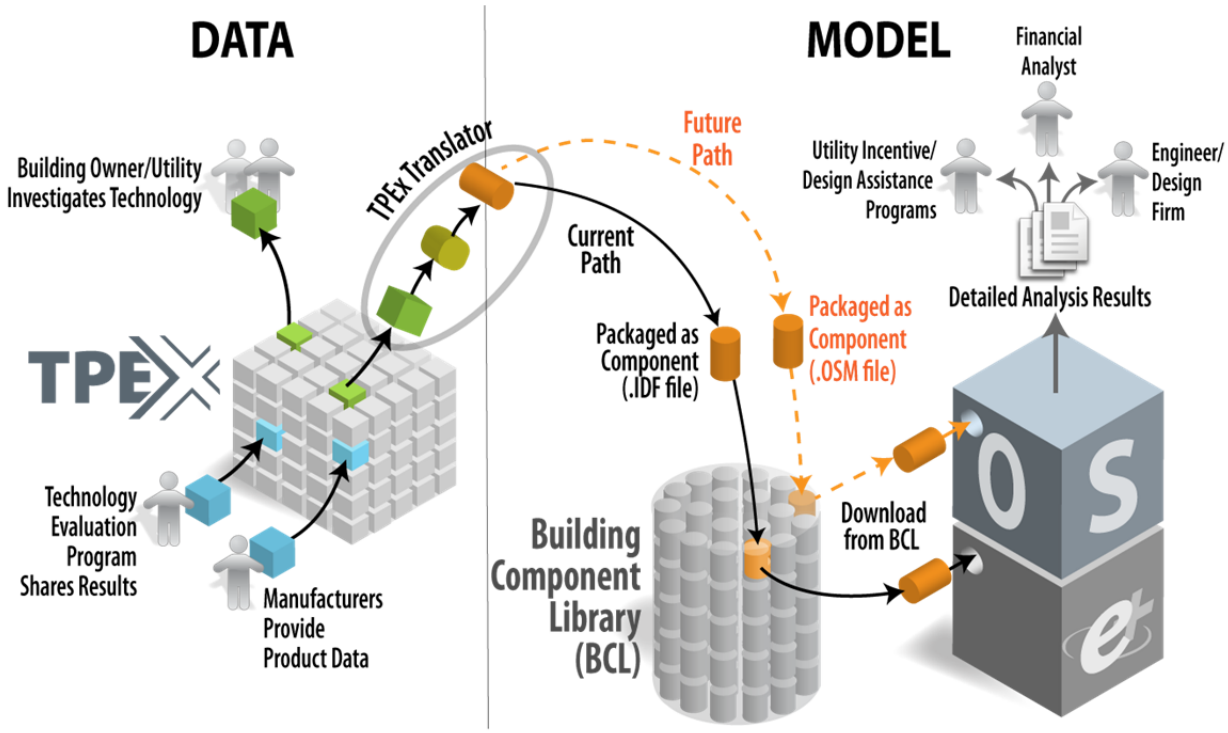


Figure 7. Diagram illustrating the workflows enabled by integrating the TPEx with the BCL, and indirectly with EnergyPlus and OpenStudio. TPEx users are free to leverage the evaluation-tool agnostic data using the TPEx UI or API, or take advantage of translated data that are stored on the BCL. *Source:* Marjorie Schott, NREL.

Conclusion

Many stakeholders are interested in adopting energy efficiency solutions in the built environment, but up to now have lacked the energy performance data to determine whether these solutions are cost effective. With stakeholders unable to identify whether particular products make fiscal sense, and unable to support any conclusions with confidence, many otherwise cost-effective (and energy-efficient) projects remain unimplemented.

The TPEx is designed to provide a mechanism through which data providers and data consumers can interact. It uses a modular structure, a series of carefully constructed user workflows, an open and transparent set of processes, and a robust API to improve the identification, storage, and sharing of foundational energy performance data across a range of building technologies. Translation of TPEx data into EnergyPlus syntax, and storage of these code snippets on the BCL provide significant resource and confidence benefits to the energy modeling community as a whole.

Acting as a freely accessible public repository and clearinghouse for product-specific energy performance data, the TPEx enables stakeholders to find, leverage, and share data in ways not formerly possible, opening new collaboration pathways, and enabling them to conduct more effective financial analyses and make better-informed procurement decisions.

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