Do We Really Know How Much It Costs to Construct High Performance Buildings?

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ABSTRACT

Understanding the cost of energy efficient construction is critical to decision makers in building design, code development, policy making and energy analysis. How much does it cost to upgrade from R-13 to R-19 in a building wall? How much do low-e windows really cost? Can we put a dollar figure on commissioning? Answers to these questions have a fuzzy nature, based on educated guesses and industry lore. The response depends on location, perspective, bulk buying, and hand waving.

This paper explores the development of a web tool intended to serve as a publicly available repository of building component costs. In 2011 the U.S. Department of Energy (DOE) funded the launch of a web tool called the Building Component Cost Community (BC3), dedicated to publishing building component costs from documented sources, actively gathering verifiable cost data from the users, and collecting feedback from a wide range of participants on the quality of the posted cost data. The updated BC3 database, available at http://bc3.pnnl.gov, went live on April 30, 2012. BC3 serves as the ultimate source of the energy-related component costs for DOE's residential code development activities, including cost-effectiveness analyses.

The paper discusses BC3 objectives, structure, functionality and the current content of the database. It aims to facilitate a dialog about the lack of verifiable transparent cost data, as well as introduce a web tool that helps to address the problem. The questions posed above will also be addressed by this paper, but they have to be resolved by the user community by providing feedback and cost data to the BC3 database, thus increasing transparency and removing information asymmetry.

Background

The Building Component Cost Community (BC3) is a collaborative tool designed to assist cost estimators, builders, architects, engineers and policy makers by providing cost data for energy efficient components. This paper describes the existing prototype software and its functionality, outlines the database structure for the web tool, and discusses the current content of the database; it also addresses possible use cases for different stakeholder groups and the way the tool may be leveraged within the DOE software community.

The BC3 tool was first developed by the U.S. DOE in the fall of 2011 as a method to capture and organize cost data for primary building components. It was designed to:

- provide cost data for the development of new energy code requirements
- allow comparison of construction costs under different energy codes
- support the use of high performance components by providing publicly available cost data for economic analysis.

Accurate and transparent cost data was necessary to support cost-effectiveness analysis for the development of new energy code requirements and standards. The lack of accurate cost data for energy efficiency measures and components in buildings is recognized as a core information gap, which significantly impedes market penetration of energy efficient components. This wiki-based website will allow engineers, analysts, and managers to access the cost data, provide feedback and add their own costs to the mix in the future. This feature will enhance the accuracy and transparency of cost data for estimating purposes for both individual project and policy analyses.

BC3 currently contains 2949 cost entries, with data from Faithful+Gould (F+G) cost estimates, ASHRAE's 2009 Economic Database in Support of ASHRAE 90.2, and California Public Utilities Commission 2008 Database for Energy Efficiency Resources (DEER) cost study. Faithful+Gould, a North America-based project management consultancy and cost estimator, was contracted by the Building Energy Codes Program (BECP), managed by the Pacific Northwest National Laboratory (PNNL) on behalf of the US DOE Office of Energy Efficiency and Renewable Energy, to provide independent cost estimation services for the residential and commercial construction components in this database. This cost data will be used by DOE, PNNL and others to compare costs of construction under various residential and commercial energy code requirements.

The BC3 web tool, developed and hosted by PNNL for BECP, is a publicly available repository of building component costs. BC3 serves as the ultimate source of the energy-related component costs for DOE's residential code development activities, including ongoing national and state-by-state cost-effectiveness analysis. The residential cost-effectiveness methodology explicitly requires use of incremental costs of energy-related components and assemblies to evaluate and compare the induced long-term cost and energy savings resulting from proposed changes in energy code requirements. To comply with this prerequisite, the national and state-by-state cost-effectiveness analysis examines the resultant life-cycle cost, payback and cash flow. Data inputs for establishing incremental costs to compute these economic metrics are based predominantly on the F+G independent cost estimates contained in the BC3 database.

BC3 is not a dataset in a traditional econometric sense. It is rather a public price list with citable sources and documented assumptions to enable transparent cost comparison across different levels of energy code requirements or energy-saving measures. For example, the current conditions in construction component markets make it problematic for non-contractors who are not designing or building a real building to obtain price quotes for fenestrations or wall assemblies. Similar issues exist for other residential and commercial building components; HVAC/furnaces and elevators are the most closed markets in this aspect. BC3 is designed to fill the data gap and eliminate information asymmetry.

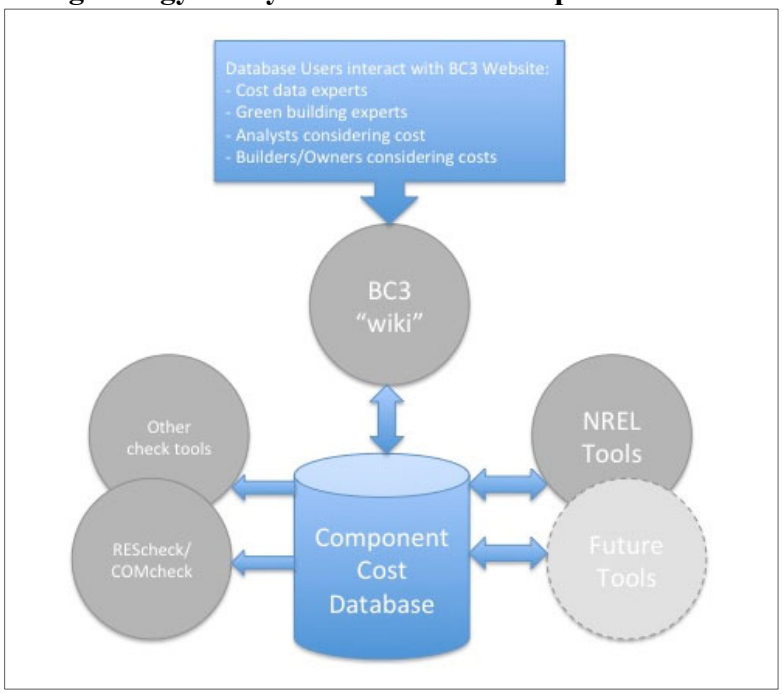
There are other sources of building component costs, for example, RSMeans cost data (Reed Construction Data, Inc. 2011), construction economics publications by Engineering News-Record (ENR), and Green Building Costbook to name a few, but their data are proprietary, which prevents public dissemination and open dialogue about underlying assumptions and cost magnitudes, or user feedback and user cost data input.

BC3 is designed to provide primarily new-construction cost data for residential, multifamily, and commercial buildings, but some retrofit costs are also included. With its main focus on new construction, the BC3 webtool complements the National Residential Efficiency Measures Database supported by National Renewable Energy Laboratory (NREL), which contains more detailed retrofit cost information.

Figure 1 presents an overview of the different users and other software tools that may interact with the BC3 tool. The BC3 website "wiki" is the focus of the functionality discussion here, but other tools may interact directly with the database core in many ways. Specific examples include the National Residential Efficiency Measures Database and BEopt™, REScheck™ and COMcheck™ tools, and EnergyPlus based optimization tools.

For example, BEopt provides optimization based on cost, so BC3 could be used to augment the cost data in the NREL BEopt software. If BEopt were to give users the opportunity to customize the user experience by allowing them to provide feedback on specific energy-efficiency measure (EEM) costs, that user-provided data could be added to the BC3 database. The status of BC3 as a public repository of the building component cost would then allow it to openly share that user-provided documented cost data with the rest of the optimization tools.

Figure 1. Building Energy Analysis Tools That Incorporate Cost-Benefit Analysis



Data Summary

The structure of the BC3 tool includes the database and the website interface. As of April 2012, the updated database contains 2,949 data points for individual components. The database format was developed by reviewing common nomenclature lists from other building-science activities. This included existing DOE tools developed by NREL, existing PNNL software tools like REScheck and COMcheck, existing building cost schemas, and external sources like gbXML (green building markup language) (Green Building 2012).

Data Sources

The final database structure organizes the data at the component level. Prior to the development of this tool, existing data sources were reviewed. A partial list of existing data sources is given below:

- American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Development Data. The envelope committees for both residential and commercial energy efficiency standard development have determined a basic set of cost data (ASHRAE 2009; ASHRAE 2011).
- Database for Energy Efficiency Resources (DEER), California's component-level database of energy costs to support the development of the Title 24 codes (DEER 2008). The DEER database has an emphasis on high performance components for energy efficiency. A portion of this database was converted to the BC3 format and included in the database.
- Cost data collected by F+G for specific components of interest for energy code comparisons and energy code development.

The data currently in the BC3 web tool were subjected to internal review, as well as external peer review by organizations with expertise on the subject matter. The reviewers were asked to provide feedback on the underlying technical reports, assumptions used to develop cost estimates, the estimate boundaries for the assemblies, and the actual component costs. The reviewers were also invited to submit any additional documented cost estimates to the database using the BC3 web tool.

The updated BC3 web tool went live on April 30, 2012 at http://bc3.pnnl.gov. At the time of release no user-contributed data was incorporated in the database because of the early state of the peer review. Now that the updated database is public, all users are welcome to provide feedback on the posted data and submit additional cost data with accompanying documentation. This is one feature that distinguishes BC3 from the majority of existing cost databases and sources: users can give feedback and contribute to the BC3 database by providing cost data. A screening process is in place to verify user submitted data; once reviewed and approved, the data will be added to the database.

Data Structure

The underlying database structure is based heavily on the Uniformat II, Standard Classification for Building Elements and Related Sitework (ASTM E1557). The BC3 layout is posted at http://bc3.pnnl.gov/wiki/index.php/Site_Map. The advantage of using Uniformat II rather than a preference-based taxonomy is that Uniformat II is an accepted industry standard in estimating and construction project management. The limitation of adopting Uniformat II for a public cost data repository is that it classifies categories as Major Group Elements, Group Elements and Individual Elements, which are nondescriptive for the general public.

In addition to the Uniformat II structure, category names and descriptions were added to each piece of data to simplify user interaction with the BC3 and capture additional information that identifies parameters, performance characteristics and other relevant descriptors. Searchable tags and notes were used to catalog energy data that did not easily fit into an existing format. Numeric data [including u-factors, solar heat gain coefficient (SHGC), visible transmittance (VT), cavity R-value, continuous R-value, annual fuel utilization efficiency (AFUE), etc.] were tracked as a numeric field if present for a component.

A sample of how the data is arranged in the database is shown in Figure 2. This figure does not incorporate Uniformat II coding fields. The full dataset with the appropriate coding is available at http://bc3.pnnl.gov/wiki/index.php/Downloads.

Figure 2. Example of Cost Data Entries

Component ID	Building Type	Category	Description	Component	Tags	Energy Measures	Cost Unit
460	Commercial	Envelope	Windows	Metal Frame Quad Pane Glass	0.46 VT;Air Filled; HSG	0.23 U Factor; 0.28 SHGC	$/ft2
461	Commercial	Envelope	Windows	Wood Frame Quad Pane Glass	0.46 VT;Air Filled; HSG	0.22 U Factor; 0.27 SHGC	$/ft2
462	Commercial	Envelope	Windows	Wood Frame Quad Pane Glass	0.46 VT;Air Filled; HSG	0.18 U Factor; 0.27 SHGC	$/ft2
463	Commercial	Envelope	Windows	Vinyl Frame Quad Pane Glass	0.46 VT;Air Filled; HSG	0.19 U Factor; 0.27 SHGC	$/ft2
464	Commercial	Envelope	Windows	Vinyl Frame Quad Pane Glass	0.46 VT;Air Filled; HSG	0.16 U Factor; 0.27 SHGC	$/ft2
465	Commercial	Envelope	Windows	Metal Frame Quad Pane Glass	0.46 VT;Argon Filled; HSG	0.58 U Factor; 0.34 SHGC	$/ft2
466	Commercial	Envelope	Windows	Metal Frame Quad Pane Glass	0.46 VT;Argon Filled; HSG	0.54 U Factor; 0.34 SHGC	$/ft2
467	Commercial	Envelope	Windows	Metal Frame Quad Pane Glass	0.46 VT;Argon Filled; HSG	0.39 U Factor; 0.31 SHGC	$/ft2
468	Commercial	Envelope	Windows	Metal Frame Quad Pane Glass	0.46 VT;Argon Filled; HSG	0.34 U Factor; 0.3 SHGC	$/ft2
469	Commercial	Envelope	Windows	Metal Frame Quad Pane Glass	0.46 VT;Argon Filled; HSG	0.22 U Factor; 0.28 SHGC	$/ft2
470	Commercial	Envelope	Windows	Metal Frame Quad Pane Glass	0.46 VT;Argon Filled; HSG	0.21 U Factor; 0.28 SHGC	$/ft2
471	Commercial	Envelope	Windows	Wood Frame Quad Pane Glass	0.46 VT;Argon Filled; HSG	0.2 U Factor; 0.27 SHGC	$/ft2
472	Commercial	Envelope	Windows	Wood Frame Quad Pane Glass	0.46 VT;Argon Filled; HSG	0.16 U Factor; 0.27 SHGC	$/ft2
473	Commercial	Envelope	Windows	Vinyl Frame Quad Pane Glass	0.46 VT;Argon Filled; HSG	0.18 U Factor; 0.27 SHGC	$/ft2
474	Commercial	Envelope	Windows	Vinyl Frame Quad Pane Glass	0.46 VT;Argon Filled; HSG	0.14 U Factor; 0.27 SHGC	$/ft2
475	Residential	Envelope	Roof	Cathedral Celing	24 inch on center;	R-19 Batt	$/ft2
476	Residential	Envelope	Walls Above Grade	Wood Frame AG Wall	1 inch EPS; 16 inch on center; 2x4	R-11 Batt; R-4 Cont. Rigid	$/ft2
477	Residential	Envelope	Walls Above Grade	Wood Frame AG Wall	2 inch EPS; 16 inch on center; 2x4	R-13 Batt; R-4 Cont. Rigid	$/ft2
478	Residential	Envelope	Walls Above Grade	Wood Frame AG Wall	3 inch EPS; 16 inch on center; 2x4	R-15 Batt; R-4 Cont. Rigid	$/ft2
479	Residential	Envelope	Walls Above Grade	Wood Frame AG Wall	4 inch EPS; 16 inch on center; 2x4	R-19 Batt; R-4 Cont. Rigid	$/ft2
480	Residential	Envelope	Walls Above Grade	Wood Frame AG Wall	5 inch EPS; 16 inch on center; 2x4	R-21 Batt; R-4 Cont. Rigid	$/ft2
481	Residential	Envelope	Walls Above Grade	Wood Frame AG Wall	1 inch EPS; 24 inch on center; 2x4	R-11 Batt; R-4 Cont. Rigid	$/ft2
482	Residential	Envelope	Walls Above Grade	Wood Frame AG Wall	2 inch EPS; 24 inch on center; 2x4	R-13 Batt; R-4 Cont. Rigid	$/ft2

The building type is the highest level category for the components and includes commercial, commercial retrofit, residential, residential retrofit and multi-family. At this time costs for more residential components have been published than for other building types because of cost collection priorities. Commercial data collection for envelope, mechanical and lighting is currently underway and will be included in future updates to the web tool.

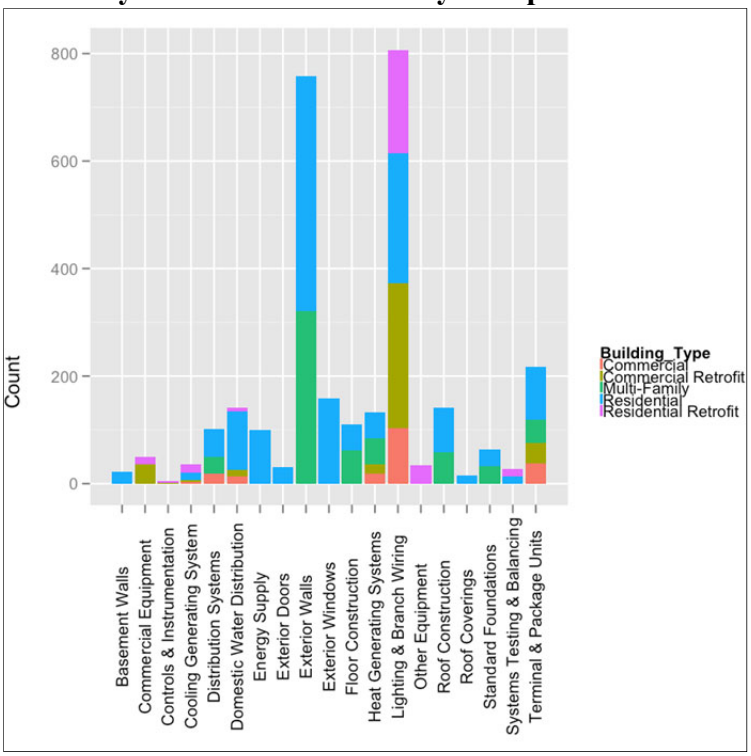
Although some of the residential retrofit data are included, the BC3 primary focus is new construction. The BC3 webtool complements the National Residential Efficiency Measures Database, which is more focused on retrofit cost information.

The component category ties the component to a specific function area in the building. At this time most of the data represents exterior enclosures and HVAC equipment. Figure 3 shows a breakdown of the cost entries in the database by component and building type.

The cost data has been organized with several sets of inputs in a method consistent with cost estimating industry standards:

- Cost Unit: a clear identification of the cost basis, for example "$/ft^2."
- Material and Additional Cost: the cost of the materials if available separately from the total cost.
- Labor Cost: the cost of labor if available separately from the total cost.
- Equipment Cost: the cost of utilized equipment if available separately from the total cost.
- Total Cost: the summation of the other cost categories if available.

Figure 3. Summary of Database Entries by Component and Building Type



To analyze all data in common dollars, the National Construction Index, published quarterly by Rider Levett Bucknall (RLB 2011) was used to inflate both the ASHRAE 90.2 and DEER data. Original costs, including materials, labor, installation and total costs were indexed and presented in 2011 dollars.

The database includes a large amount of additional information about each component. Summary tables list the date of the data collection, which as the data set grows, will be valuable for analysis of cost changes over time. Cost data location is identified for each estimate as well.

To aid region-specific analysis, BC3 contains a list of location factors by city, state, and climate zone. Faithful+Gould (F+G) developed a labor index, a material index and a composite index based on material and labor cost data for 122 cities to enable location-specific adjustment. The F+G composite index was compared with published sources, including 2011 RSMeans, 2010 Compass International and the Architects, Contractors, Engineers Guide to Construction Costs (A.C.E. Guide). These location factors were specifically developed by F+G for BECP. They are publicly available as part of the BC3 webtool and are currently used in the national and state-by-state cost-effectiveness analysis conducted by BECP.

Website Structure

The website interface structure is based on a collection of open-source software that has been adapted by PNNL for semantic media activities in other research areas. The umbrella software is the Knowledge Encapsulation Framework (KEF), a suite of tools to enable subject-matter experts to discover, gather, and arrange evidence and other material in support of modeling and simulation projects, as well as other domains that require collaborative workspaces for knowledge-work (Cowell et al. 2009).

The KEF has been used in other research projects to provide the following features:

- Capture and investigate data, such as material provided by the users (journal articles, government reports, etc.).
- Automatically discover new data (harvested from web sources, covering both traditional and social media).
- Enable collaboration and discussions through traditional wiki interaction mechanisms such as discussion tabs, synchronous chat, and social profiles.
- Automatically generate semantic annotations and relationships.

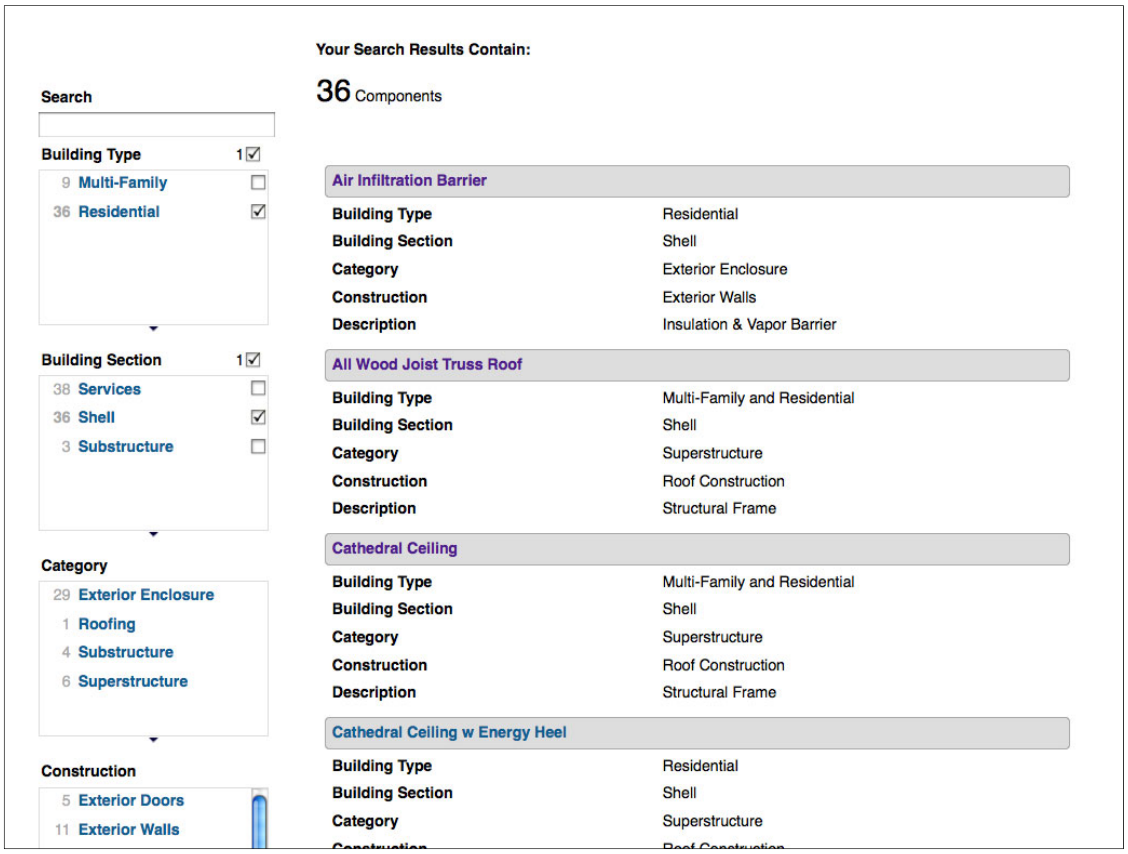
From within a wiki environment, the current KEF implementation provides a simple but powerful collaborative space for participants to review, annotate, discuss, and align data with their specific needs. This approach allows for the combination of automatically tagged and user-vetted resources, which leads to an intuitive user experience with the website (Cowell et al. 2009).

The database provides transparency and a discussion mechanism for participants using this open source KEF. The KEF suite of tools is built on MediaWiki, the same technology that powers Wikipedia. MediaWiki provides a number of "out of the box" capabilities, such as user management; content creation, edits, deletes, and revisions; and an application programming interface (API) that allows developers both at PNNL and in the MediaWiki community to write custom modules that extend the core functionality. KEF is a blending of these publicly available community modules and custom development performed at PNNL.

KEF is further enhanced by semantic technology through the Semantic MediaWiki (SMW) extension. The core wiki allows for text to be entered into "pages." SMW further classifies the text within these pages as having semantic properties (e.g. dates, names, cities, etc.). Thanks to these semantic properties, users of BC3 are able to rapidly sift through data using these properties to view only relevant data. The user is presented with a faceted browser that gives an insight into the categorization of the content. Making selections in the facets will narrow the results of the content and show only the components that match the user's selections. An example would be components that are only used in the "shell" building section of a "residential" building type. Any component that is not in the "shell" building section of "residential" building types would not be displayed. Currently on BC3 this selection limits the search results to 36 out of the original 102 components (Figure 4).

The BC3 Database employs faceted browsing features (menu boxes on the left in Fig. 4) to aid in information retrieval. Faceted browsing is a technique that uses multiple filters to narrow website search results according to assigned categories. The faceted browser interface contains multiple facet boxes from which users select filtering criteria. Inside the facet boxes, a number appears next to each criterion that indicates the number of database items associated with that term. As multiple filters are applied, the number next to each term changes, the total number of results is reduced, and only those items tagged with all of the selected search criteria are displayed. To that end the searchable category definitions for the database are generic in title but have a fixed number of possible inputs.

Figure 4. Sample Selection Results



BC3 can be accessed using any combination of the following:

- using the search function by typing a key search term in the search box
- selecting terms in one or more facet boxes to refine search results
- scrolling through the results using the arrows at the bottom of the page
- using the Site Map index to select any of the items from the list.

Users will be able to provide feedback regarding data quality by submitting comments on line. Users can submit their own data to be added to the repository after it is validated by the BC3 technical lead. The user input form, available at http://bc3.pnnl.gov/wiki/index.php/Form, allows direct submission of the data to the BC3 administrator. This form includes some basic fields, such as building type, component type, product description, performance characteristics, cost units, total cost or materials/labor/equipment cost (if available), the year when the estimate was collected and cost location data. Users are required to upload accompanying documentation in which the cost and product description are explicitly stated. The documentation can be an invoice, a shipping bill, a cost study or a report with an exact cost reference or any other document that specifically shows what the product and the estimates are. Once reviewed and approved for publication, user-submitted cost data will be added to the BC3 on-line database during the next scheduled update. The user will be notified when the data is accepted.

Accepting feedback from the user community on posted data and on underlying technical assumptions provides an additional layer of peer review for the original BECP-published data, as well as for user-provided estimates.

Current and Future Applications

The main objective of the BC3 webtool is to provide a public repository of documented cost data for energy-related components in buildings. It is the ultimate source of the energy-related component costs for national and state-by-state cost-effectiveness analysis conducted as part of the DOE's residential code development activities.

The BC3 website also contains the F+G cost-study "Residential Energy Efficiency Measures: Prototype Estimate and Cost Data" that estimates the incremental costs of 2006, 2009 and 2012 IECC code requirements for a prototype single family home defined in Appendix B of the report. The report also includes cost estimates for the components and assemblies that support "above code" construction practices. The component and assembly cost estimates by F+G when developing these incremental costs will be used by BECP in cost-effectiveness analysis of the published versions of the IECC as well as when developing future proposed changes to that code.

Encouraging external peer review by the organizations with expertise on the subject matter, as well as soliciting feedback from the user community regarding the posted data, allows for an open, transparent, documented data source that could be used for analysis of various economic metrics. Publicly available location factors for materials and labor costs allow for not only national analysis, but also regional cost scaling to states and climate zones.

The capability to directly interact with other databases or cost-based optimization tools such as BEopt allows for an integrated analytical framework for selecting the optimal composition of energy measures or improvement packages based on regionality, available constraints, simulated performance and projected cost-effectiveness.

Possible additional use cases for the BC3 web tool can include:

- Informing the builder or architect during the design phase of the structure. They may be trying to justify the cost of a more energy efficient component to the project team or customer. For example, the lighting designer might believe that high performance parking lot lighting would dramatically reduce cost of operation over the life of the product but might not have unbiased data for the difference in installation costs. Although the database might not be the primary source to inform decision-making in private industry, having a transparent set of estimates documented in multiple sources, or a quick tool for cost-effectiveness analysis tailored to the specific location and/or building configuration, could help increase the penetration of energy efficient solutions into the market.

- A team on a successful new building that has been constructed as part of the DOE Commercial Building Partnerships (CBP) or Building America process. This might include architects or engineers from a Leadership in Energy and Environmental Design (LEED) project. This type of user represents one of the most accurate possible data sources in the BC3 system and the team might input specific data into the database.

While cost estimates vary depending on the location, performance characteristics and size of the project, to understand the variability or to conduct, for example, hedonic price analysis, it is first necessary to have a cohesive dataset that captures the variability and associated characteristics to support this analysis. The BC3 can be useful as a data collection tool with its established validation and quality control mechanism in place.

- Staff working on code development or CBP and Building America teams. For example, if a user is interested in justifying the incremental change from R-13 to R-19 in wood-framed walls in a specific climate zone, the BC3 database would provide data to inform the decision.

- Often-overlooked private remodels and construction by energy efficiency enthusiasts and energy-conscious homeowners can provide first-hand performance testimonials, along with understanding of the market-traction and performance issues hampering market penetration. While the BC3 tool is not intended to collect this type of information, making the transparent cost data available to the active web communities such as the Dwell blog, The Daily Green or Green Building Advisor will help to better inform the consumer by delivering "how-to" jointly with "how-much."

- While the building cost information can be more easily available to contractors through different channels, it is ultimately the consumer who has to make the choice to pursue energy-efficient products and solutions. The traditional mechanism in the construction industry is acquiring quotes from several providers. Having cost data readily available to the consumer at the click of a button, along with the basic results for primary economic metrics, removes that additional information barrier and helps the consumer make informed decisions.

There is no universal "true" cost of constructing high-performance buildings. It is highly variable, depending on multiple factors and their interactions such as the size of the project, the qualifications of the building team, timely availability of materials and efficiency of the construction management. Building heterogeneity and the multivariate nature of construction costs make it hard to make any generalizations or cross-comparisons at the overall system level. Sometimes a requirement or measure is focused on an individual component—for example, increasing wall insulation from R-13 to R-19. In other cases, the measures apply to a system or are defined as a package that spans several components – for example, proper daylighting design. There are often multiple ways of meeting the requirement, or multiple configurations of the package that would result in a comparable improvement. Thus, generalizations are often not appropriate because the estimates are design-specific and results are valid only within the narrow context of the particular set of assumptions.

Therefore the natural approach is that of comparative statics for the individual building component. The comparative static analysis requires understanding of the incremental costs for each of the changing requirements or proposed measures. The BC3 webtool aims to facilitate this type of analysis as the documented, transparent, publicly available repository of building-component cost data.

Conclusion

On April 30, 2012, the DOE launched the BC3 webtool. It is dedicated to publishing building component costs from documented sources, actively gathering verifiable cost data from users, and collecting feedback from a wide range of participants on the quality of the posted cost data. BC3 webtool is available at http://bc3.pnnl.gov.

BC3 is the ultimate source of energy-related component costs for DOE's residential code development activities, including ongoing national and state-by-state cost-effectiveness analyses that examines life-cycle cost, payback and cash flow implications for various energy code requirements.

BC3 is not a dataset in a traditional econometric sense. It is rather a public price list with citable sources and documented assumptions to enable transparent cost comparison across different levels of energy code requirements or energy-saving measures. Obtaining any price quotes for fenestrations or wall assemblies by non-contractors who are not designing or building a real building is problematic. BC3 is designed to fill the data gap and eliminate information asymmetry.

Heterogeneity in buildings and the multivariate nature of construction costs make it hard to generalize or cross-compare costs at the overall system level. There are often multiple ways to meet the requirements, or multiple configurations of the package that would result in a comparable energy efficiency improvement, thus necessitating the comparative statics analysis at the individual component level. The BC3 webtool aims to facilitate this type of analysis as the transparent source of documented building component cost data.

In addition, the lack of accurate cost data for energy efficiency measures and components in buildings is recognized as a core information gap, which significantly impedes market penetration of energy-efficient components. BC3 attempts to fill that gap by serving as a publicly available repository of cost data that is open to comment. This openness plus the capability and intent to accept user feedback and user data input on a continuous basis distinguishes BC3 from other cost data sources.

The data currently contained in the BC3 web tool were subjected to internal review, as well as external peer review by organizations with expertise on the subject matter such as The National Association of Home Builders, ASHRAE 90.2 SC and the Building Codes Assistance Project. The reviewers provided feedback on the underlying technical reports, assumptions used to develop cost estimates, the estimate boundaries for the assemblies, and the actual component costs; they were invited to submit any additional documented cost estimates to the database using the BC3 web tool.

BC3 also contains the tools for users to provide feedback and submit documented cost data to be added to the repository after validation. Feedback from the user community on posted data and underlying technical assumptions provides an additional layer of peer review.

The BC3 database contains predominantly new-construction data. It complements the National Residential Efficiency Measures Database, which contains more detailed retrofit cost information. Direct sharing through API is currently under consideration for future scope. BEopt, the REScheck and COMcheck web applications and Energy Plus based optimization tools can interact directly with the database core using the same API mechanism, as well as built-in features of the KEF platform. For example, any tool that performs cost-based optimization can give users the opportunity to customize the user experience by allowing them to provide feedback on specific EEM costs. Then that user-submitted documented cost data could

be added to the BC3 database. The status of BC3 as a public repository of the building component cost would then allow it to openly share that user-provided documented cost data with various optimization tools and databases. Through cooperation and direct interaction with optimization tools, BC3 has the potential to serve as the cohesive, documented, transparent publicly available data source for supporting analytical tools and cost studies beyond DOE's code development activities.

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