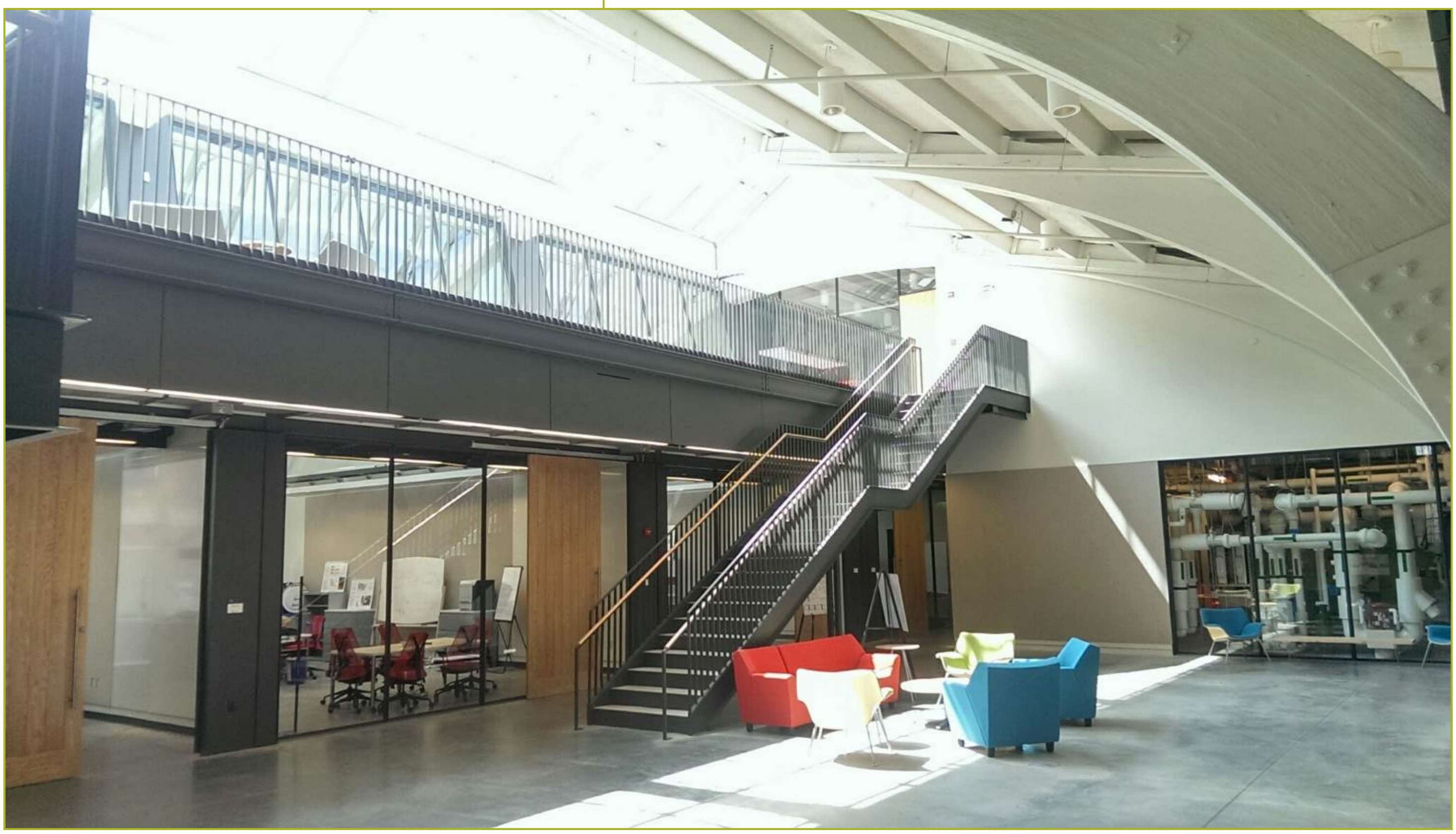
CONSORTIUM for BUILDING ENERGY INNOVATION

# REPORT

**Title: Demonstration of a rapid and reliable advanced energy retrofit decision support tool**

**Report Date: January 2013**

**Report Author(s): Khee Poh Lam**



*CBEI was referred to as the Energy Efficiency Buildings HUB at the time this report was developed.*

# REPORT

## Report Abstract

CBEI developed a web-based integrated design decision support tool which utilizes energy performance data generated through coupling of whole building energy simulation models with systematic search procedures and advanced data analysis techniques. This coupling process was extended with the introduction of a simulation-based numerical optimization framework for the minimization of life cycle costs for building enclosure materials and operational energy consumption for office retrofit cases. This integrated optimization program is highly automated (thereby saving user effort) and utilizes non-commercial, open-source and readily extensible existing toolkits.

## Contact Information for Lead Researcher

**Name:** Khee Poh Lam
**Institution:** Carnegie Mellon University
**Email address:** kplam@cmu.edu

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## Disclaimer

REPORT

# Budget Period 2
# Subtask 4.4 Annual Report

**1 February 2012 – 31 January 2013**

**Principal Investigator: Prof. Khee Poh Lam, Carnegie Mellon University**

**Sub-task 4.4: Integrated Technologies and Decision Support Systems**
**Deliverable #20: Demonstration of a rapid and reliable AER decision support tool**

**1. Summary:** *Short summary of BP2 activities (1 to 2 paragraphs)*

The R&D work of this sub-task is driven by a primary mission to create a ubiquitous Dynamic Life-cycle Building Energy Information Modeling infrastructure for building industry products and processes to address the technical complexities of delivering energy efficient and high performance retrofit (and new) buildings efficiently in the industry.

The research team of Carnegie Mellon University (CMU) developed a web-based integrated design decision support tool which utilizes energy performance data generated through coupling of whole building energy simulation models with systematic search procedures and advanced data analysis techniques. This coupling process was extended with the introduction of a simulation-based numerical optimization framework for the minimization of life cycle costs for building enclosure materials and operational energy consumption for office retrofit cases. This integrated optimization program is highly automated (thereby saving user effort) and utilizes non-commercial, open-source and readily extensible existing toolkits. A web-based designer oriented data visualization and knowledge extraction platform was also developed as an extension of the decision support tool for integrated design of advanced energy retrofit projects. This tool was extended to provide decision tree-based design support for high performance and integrated building systems recommendations to the users. The web-based integrated decision support tool was also equipped with functionality for the visualization of building model, detailed energy and IEQ simulation results as well as comparison functions with measured performance data where available. In parallel with the decision support tool, an XML-based schema with a web-based graphical user interface was generated so as to automate actual manufacturer's product data acquisition and data processing (dedicated to the generation of EnergyPlus input blocks to be integrated into the simulation models). This industry product (material/component/system) data acquisition tool (IPDAT) was instantiated for opaque and transparent material and construction assembly definitions with building enclosure data obtained through collaboration with Bayer and PPG Industries. Current industry product database has more than 4100 glass products from International Glazing Database (IGDB) and 500 other enclosure products. The CMU team also developed an EnergyPlus model of the Philadelphia Navy Yard Building 661 retrofit project case in parallel with project consultant Atelier Ten's eQUEST model to conduct detailed comparisons of the tools by systematically analyzing their respective input parameters and representations and their impact on the simulation results.

**2. Support of HUB Goal.** *Provide narrative of how this task and subtask deliverable support the Hub's goal of "… reduce annual energy use in the commercial buildings sector in Greater Philadelphia by 20 percent by 2020."*
The simulation-based optimization feature as well as the multi-variate parametric search techniques implemented by the CMU team within LBNL's GenOpt 3.1 computational platform in Subtask 4.4 can be effectively integrated into the building design processes so as to derive optimal solutions to meet the 20% energy reduction goal while minimizing life cycle costs. Current studies already identified design solutions with more than 30% annual energy use

reduction for mid-size commercial office buildings under the climatic conditions of Philadelphia. The team also provided means for integrating these search techniques into design processes with the introduction of a web-based design decision tree structure that draws energy performance data generated by coupled simulation and parametric analysis. The same tool offers a decision tree-based design support (fed by simulated performance data) for the choice of building technologies that will best suit to a given design condition with the aim of reducing annual energy use. Quantitative design decision support are further enhanced with relevant data visualization techniques (for both simulated and measured data) which can consequently ease the process of identifying design alternative which can provide the desired energy use reductions. Current state of the tool provides quantitative feedback for possible design decisions for the case of Building 661, Navy Yard, Philadelphia. State-of-the-art high performance building material/component/system definitions extracted from product manufacturers can be readily converted to EnergyPlus model definitions through the use of XML-based data acquisition and processing tool. The functionality of whole-building simulation using input specifications of actual building products (instead of generic and/or hypothetical specifications) will ensure that the predicted reductions in annual energy use of buildings are indeed **realistic** and **achievable**. The other effort toward this end was to create an EnergyPlus model of the proposed Building 661 advanced retrofit design case based on the eQUEST model of Atelier Ten to compare the modeling assumptions in terms of geometric representation, thermal zoning configurations, materials/components/systems input specifications and their respective impact on the energy reduction predictions.

**3. Support of the Hub's Five Year Plan Objectives.** *Provide narrative of how this subtask supports the five objectives in the Five Year Plan. Insert N/A if the subtask does not support an objective.*

- **Objective 1:** Develop and deploy to the building industry state-of-the-art modeling tools to support integrated energy efficient design, construction, commissioning, and operation.

  The CMU team developed an integrated simulation-based optimization and parametric search platform which comprises the state-of-the-art DOE endorsed EnergyPlus whole-building energy simulation tool and an open-source extensible generic optimization tool of GenOpt (from LBNL). Results of this platform are fully embedded into a web-based design support application that can identify the decision making process for integrated energy efficient retrofits through optimization of building performance so as to enhance design efficiency. The same web-based application has the functionality of identifying energy saving construction materials based on simulated data. Furthermore, simulated building geometry and the related energy performance can be visualized concurrently and in comparison with on-site data that is acquired during commissioning and operational phase of the building life cycle.

- **Objective 2:** Demonstrate the market viability of integrating energy saving technologies for whole building system solutions at the Navy Yard and elsewhere in the region.

The CMU team integrated a database of digitized technology cards which identify and describe energy saving building technologies and linked this database with the web-based design support tool which provides instant whole-building energy performance data about related technologies as energy efficient solutions to advanced retrofit projects. This functionality is exemplified by a number of enclosure technologies as obtained through collaboration with Bayer and PPG Industries. The XML-based product data acquisition tool proposed by the CMU team can link the pertinent data from manufacturers to automatically populate energy model inputs for whole-building simulation, significantly reducing model preparation time (>30%) and enhancing data integrity derived from real-world products. The XML-based data structure can facilitate extension of the national BIM standard so as to serve all stakeholders in the building delivery process. Furthermore, the detailed energy model comparison (Atelier Ten's eQUEST model vs. EnergyPlus) for Building 661 in the Navy Yard and subsequent feedback to the professional design team can have impacts on the industry practice transformation for a better representation of energy saving technologies for whole building system solutions in terms increased fidelity in simulated energy performance.

- **Objective 3:** Identify policies that accelerate market adoption of energy efficient retrofits of commercial buildings and support policy makers in the development of such policies in the Greater Philadelphia region.
**N/A**

- **Objective 4:** Inform, train, and educate people about proven energy saving strategies and technologies whether they design, own, construct, maintain, or occupy buildings.

  The web-based tool can be used for cross-disciplinary education and training of a building design team (architects, engineers, etc.) on how to successfully implement integrated energy efficient design. A proposal has been submitted to GreenBuild 2013 to publicly introduce this tool to the industry and offer a live "hands-on" demonstration of its use.

- **Objective 5:** Help launch business ventures that will exploit market opportunities for providing whole-building energy saving solutions.
**N/A**

**4. BP2 Accomplishments.** *Narrative of what was accomplished during BP2 including major activities, scope of work, significant results, major findings or conclusions, key outcomes or other achievements (e.g., 5 to 10 pages with appropriate graphs, tables, etc.)*

*Provide narrative of issues that facilitated or impeded subtask performance. Provide narrative of potential changes to Five Year Plan objectives and metrics in BP3 and beyond.*

**[1] Development of a simulation-based numerical optimization framework for the minimization of life cycle costs associated with building enclosure materials and operational energy consumption of AER projects**

The CMU team developed an integrated simulation-based numerical optimization framework for the minimization of life cycle costs for building materials and operational energy consumption. The DOE EnergyPlus v6.0 whole-building energy simulation program is coupled with GenOpt v3.0 (Lawrence Berkeley Lab) generic optimization tool to automatically compute the optimal values of thermal insulation thicknesses for external walls and roofs as well as glazing unit types for vertical fenestration. A life cycle cost (LCC) model is implemented within the GenOpt program for the objective function evaluation using simulation outputs pertaining to energy consumption and associated utility costs. A stochastic population-based and multi-dimensional optimization technique of Particle Swarm Optimization (PSO) is utilized for searching the parameter space. This specific algorithm was chosen due to its proven strengths in handling optimization problems with non-linear, non-differentiable objective functions with discrete variables (as in the investigated design case). The effectiveness and accuracy of the PSO algorithm in finding the global optimum design was evaluated through comparisons with a full enumeration technique (Mesh algorithm from GenOpt parametric functions library). It resulted in a 36.2% reduction in the computational effort to converge to the global minimum point with a very high degree of accuracy compared to the full enumeration technique.

This development offers a new approach of extending the source code of GenOpt platform with a standard and well-known life cycle costing model. The updated GenOpt tool can be linked to any simulation engine (having a text-based input-output structure) and applicable to a wide-range of building design optimization problems as opposed to methods that are functional only within a specific setting. The proposed framework can be executed using the existing user interface of GenOpt requiring no additional scripting to automate the iterative simulations.

The application of this optimization framework is exemplified with a reference medium-sized commercial office building model (provided by the U.S. DOE's Building Technologies Program) simulated under the climatic conditions of ASHRAE Climate Zone 5A. Three main categories of building envelope retrofit measures are taken into consideration as discrete independent variables to be investigated, namely, external wall thermal insulation thickness (from zero to 15.24cm with 2.54cm increments), roof thermal insulation thickness (from 2.54cm to 15.24cm with 2.54cm increments) and glazing types (from single clear to double, with/without low-e with different overall thickness).

So as to reduce the time dimension of the computational effort to execute optimization models, parallel processing functionality of GenOpt program is used with necessary code modifications on EnergyPlus program calling functions. The parallel processing allowed running multiple EnergyPlus models simultaneously on a single PC with number of simultaneous iterations equal to the number of CPU threads. The objective function is defined as the life cycle costs (LCC) of the building case which is the present value of material investments and operational energy costs of HVAC and other building systems over a specified life span of 25 years. This model excludes the material replacement costs due to relatively shorter life span for this LCC analysis. Unit bare costs of thermal insulation materials and glazing types are obtained from the U.S. RS Means Cost Database without labor and overhead items.

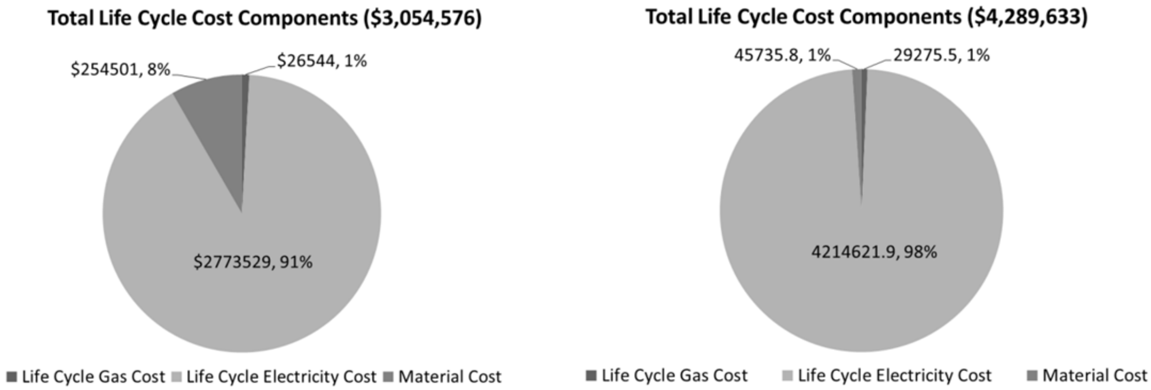
Results of this optimization study indicates the design option having 15.24cm (6”) of external wall insulation, 12.70cm (5”) of roof insulation and equipped with 25mm thick Double LowE IGU as the optimum design (best iterate) in terms minimum life cycle cost. On the other hand, the design option reflecting the initial case model with external walls with R-0 thermal insulation, 2.54cm (1”) of R-0.8 roof insulation and windows with single clear glazing units was found as the worst performing iterate as would be expected.

**Table 1** Comparison of annual site energy consumption (by end-use breakdowns)

| End-Use Category | $x^*$ (Minimum Point ) (Best Iterate) | $x_{max}$ (Maximum Point) (Worst Iterate) | Percent Deviation (Worst to Best Iterate) |
|---|---|---|---|
| | Energy Use Intensity (kWh/m$^2$) | | (%) |
| Space Heating | 22.0 | 89.1 | -75.3 |
| Space Cooling | 18.3 | 24.8 | -26.2 |
| Fans & Pumps | 4.61 | 7.41 | -37.8 |
| Lights & Equipment | 46.8 | 46.8 | 0.0 |
| Service Water Heating | 2.0 | 2.0 | 0.0 |
| TOTAL BUILDING | 153.1 | 229.6 | -33.3 |

As seen in Table 1, the optimized design solution shows 75.3% energy use reduction for space heating and 26.2% for space cooling with respect to the maximum point. An energy reduction up to 33.3% can be achieved with optimized design at total building level due to the fact that building envelope measures only affect space heating, cooling and fan energy consumptions while all other end-uses remain constant between different design alternatives. Main findings of this study can be listed as:

- Design option with 15.24cm (6”) and 12.7cm (5”) of wall and roof insulation and 25mm thick Double Low-E IGU is found to be the optimum design solution for the medium-sized commercial reference office building in the ASHRAE Climate Zone 5A.
- The optimum design solution can yield a 28.7% life cycle cost reduction ($1,235,057 reduction) over a 25 years life span. Simple pay-back time for the investment differential imposed by the optimum solution is 4.2 years (Figure 1).




Optimum Case Maximum Case

**Figure 1** LCC components of the best (optimum) vs. worst (maximum) design options

- The PSO algorithm implemented in the parametric setup shows satisfactory performance in terms of accuracy and efficiency. It can result in a 36.2% reduction in the computational effort to converge to the global minimum point with a very high degree of accuracy compared to the full enumeration technique.
- The optimal design solution suggested by the implemented approach indicates that choosing the "best" specification from all design options does not necessarily provide the best overall design solution in terms of life cycle costs over a long run. This implies the possible potentials of simulation-based optimization as a design decision support method in terms of detecting the global optimum design choices which are otherwise ignored or unrecognized due to inefficient and conventional methods of simple heuristics or even certain "expert" judgments.

This integrated simulation-based optimization framework can potentially be applied to any type and size of building case for new construction and advanced energy retrofit (AER) projects. The tools utilized in this framework are open-source and non-commercial products. The modular and open-source programming architecture can be extended and/or updated to calculate customized objective functions values in order to serve different aspects of building design decision making.

**[2] Development of a web-based decision support application**

As a continuation of the R&D effort from BP1 to formulate an integrated design decision support based on a decision-tree framework, CMU, PPG and Bayer reviewed the previous technology cards associated with this tree and identified focus areas. The team selected enclosure technologies as a focus in BP2 to address roofs and facades and increase collaborative opportunities with Subtask 5.4.

The findings of parametric simulation studies (one-at-a-time and combinatorial parametric) conducted on thermal insulation measures of the roof assemblies (previously analyzed on Building 661 case) were discussed with Bayer and shared with other Hub members. Physical and thermo-physical properties of thermal insulation materials as required by the EnergyPlus program for energy simulation analysis were profiled, and Bayer provided the necessary input information about polyurethane rigid foams and poly-iso products for inclusion into a database.

A product data schema mapping tool for early design decision support has been developed and implemented as a web-based assistant tool to facilitate the transfer of industrial products information (which may be incomplete, disorganized, and with different units of measurements) to systematic xml-based databases in order to generate ready-to-use simulation input file sections, which are essential for the whole building performance simulation and the decision-making support in the early building design phase (see Section [3] below).

Research findings for high performance integrated roof retrofits (Sub-task 5.4 Roof) and integrated design process for interior blinds, glazing, sensor networks and occupant comfort assessments (Task 5.4 Façade) were incorporated into the decision trees.

A technology card example can be seen at Figure 2.

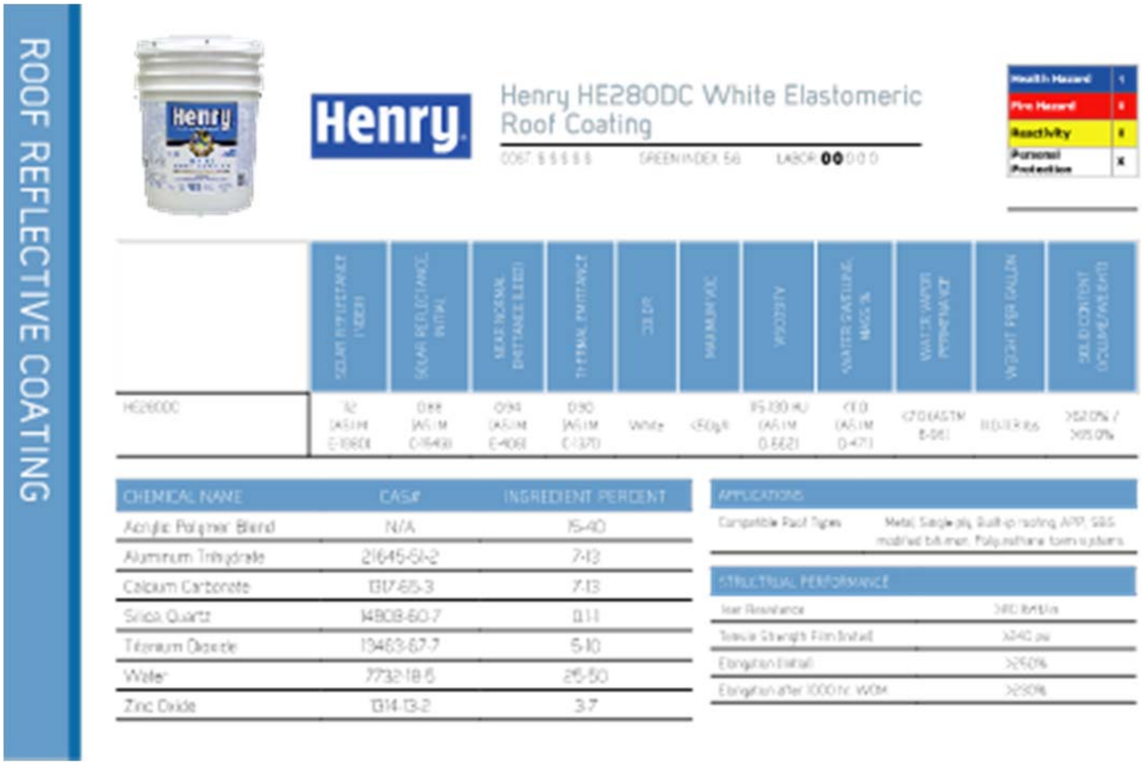



**Figure 2 a, b** A technology card example for roof assemblies.

720 parametric simulations were conducted for every combination of the building envelop specification. A web-based user interface was developed to enable the user specified parameter combination (Figure 3) to be selected, and the analysis results based on the simulated case will then be shown (Figure 4).

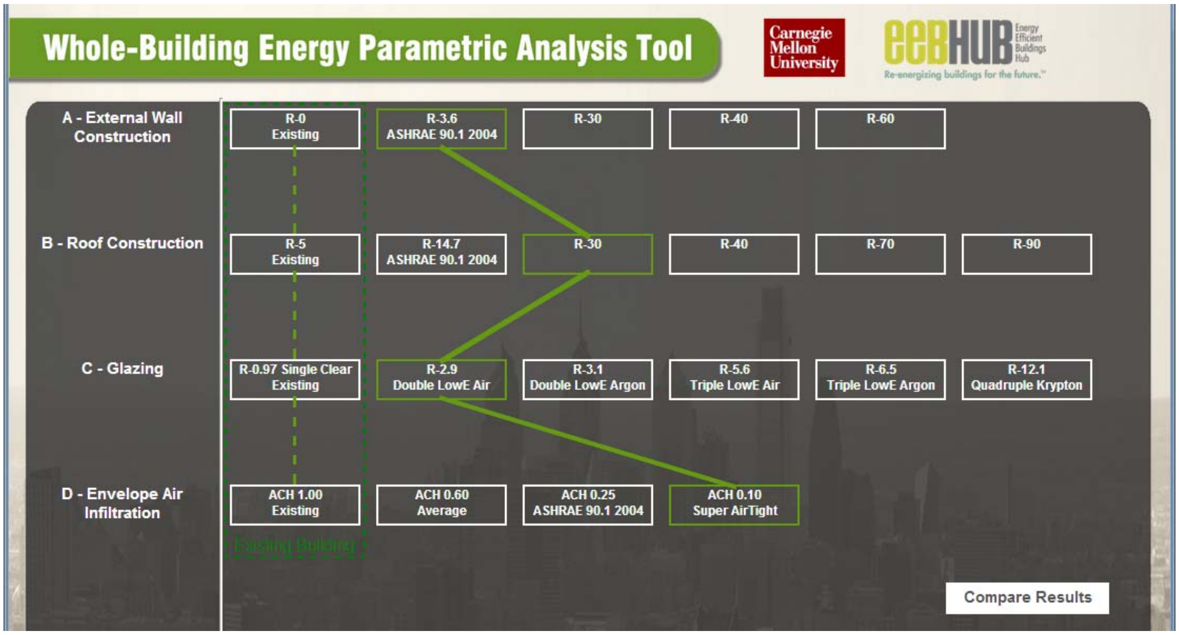
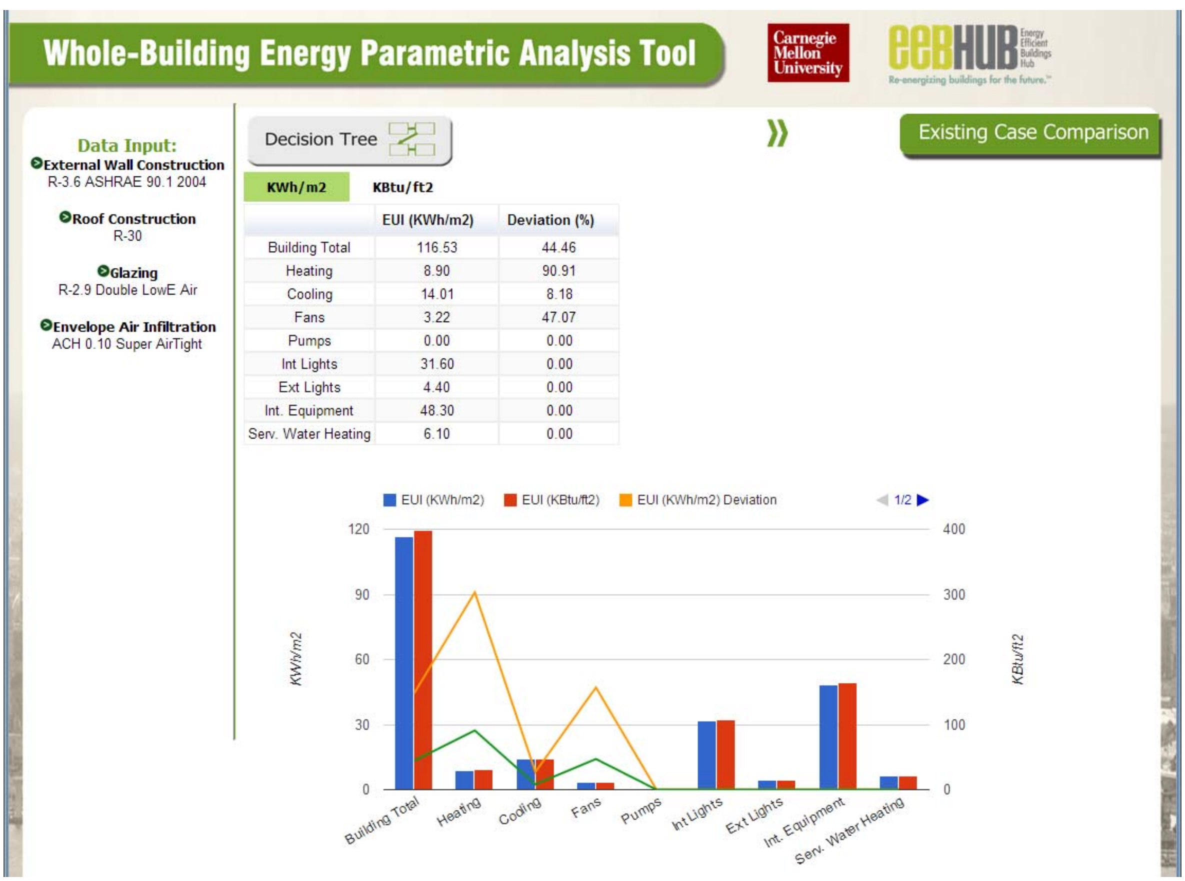



**Figure 3** Whole Building Energy Parametric Analysis Tool graphical user interface.



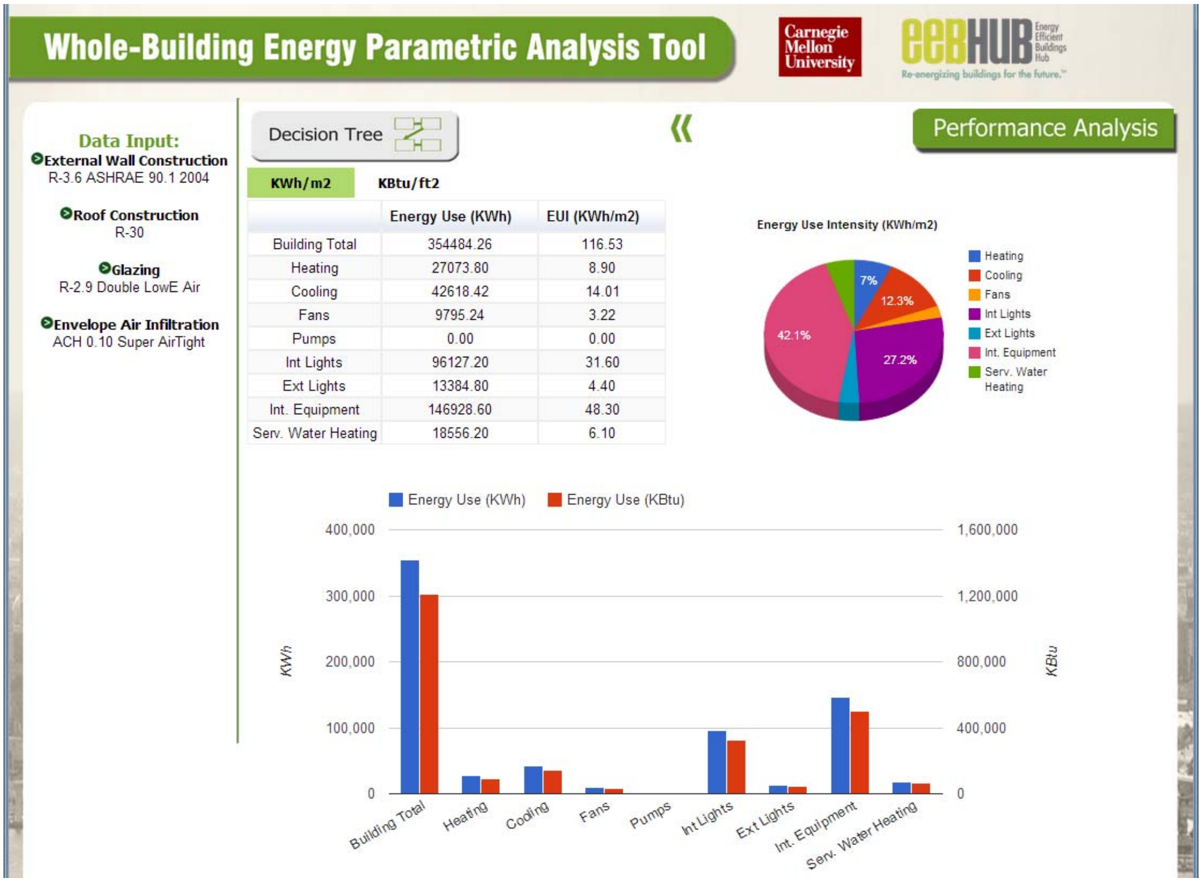



**Figure 4a, b** Parametric analysis results visualization

A new Energy & Environment Awareness Hub (eeAHUB) has been developed as an extended feature of the web-based integrated decision support tool that provide visualization of the building model, detailed energy and IEQ simulation results as well as comparison function with measured performance data when available
(see http://128.2.109.122/WBEPATool/DashBoard.html).

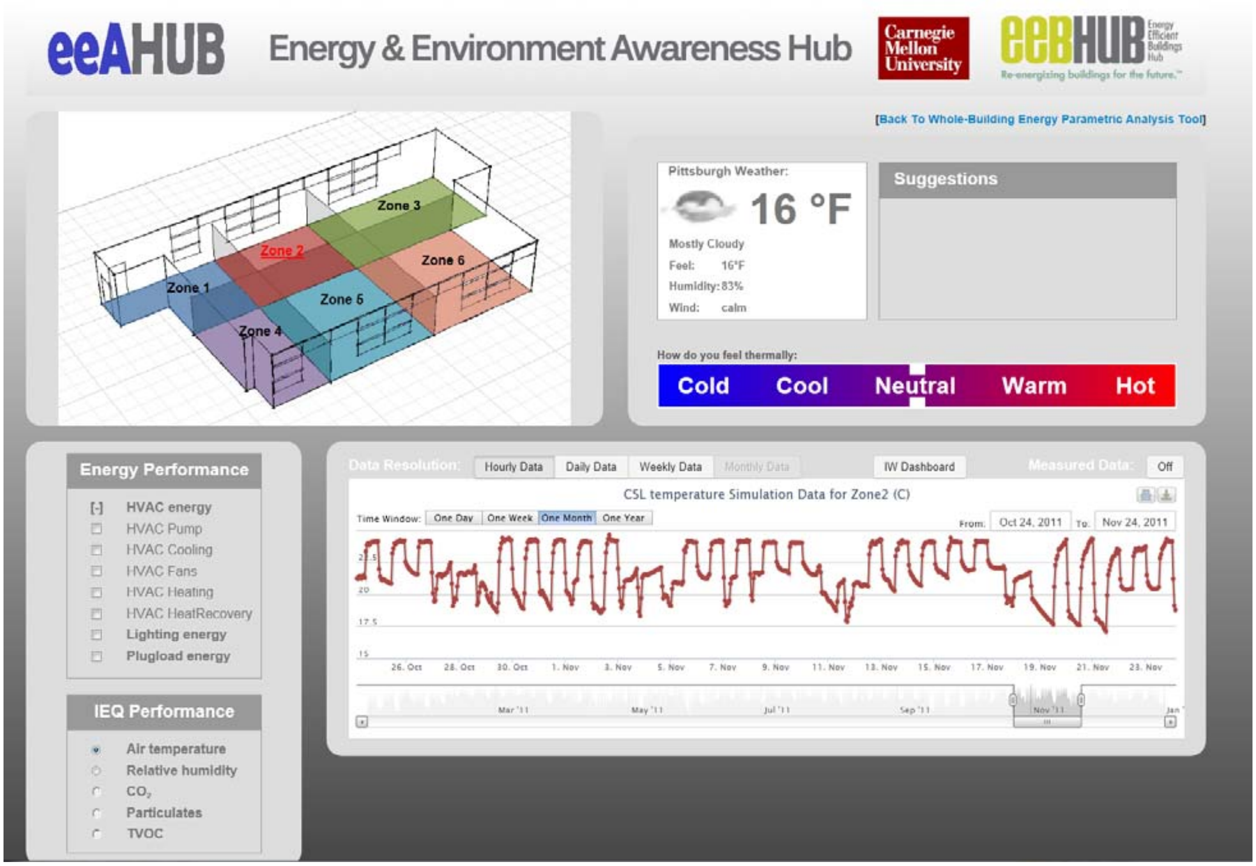



**Figure 5** Energy and Environmental Awareness Hub graphical user interface

**[3] Development of A Web-Based Industry Products Data Acquisition and Schema Mapping Assistant Tool**

A web-based industry products data acquisition and schema mapping assistant tool (IPDAT) has been developed with the purpose of facilitating the transfer of real-world industrial material/component/system products to systematic XML-based databases.

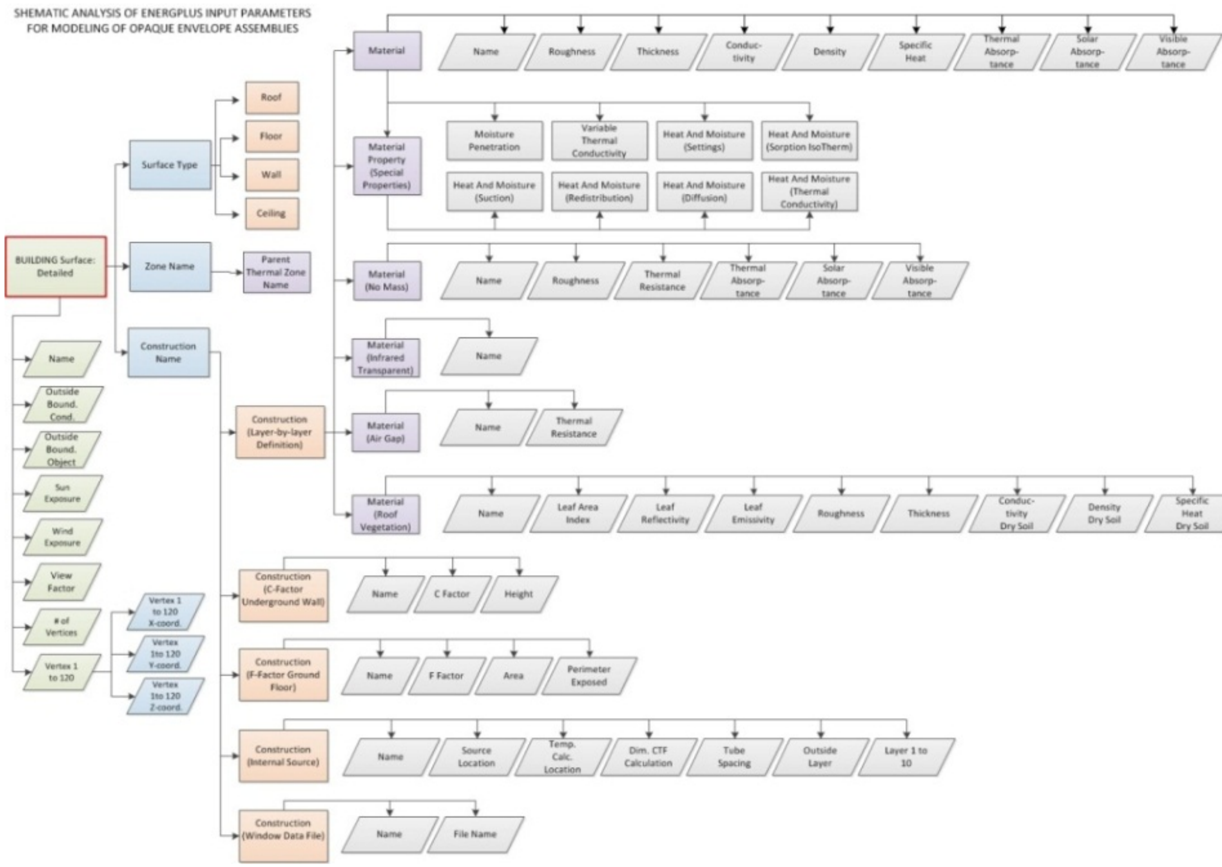



**Figure 6** Schematic Description of EnergyPlus Modeling Structure for Opaque Envelope Definitions

The databases can be further extended to support the generation of ready-to-use simulation input file components in order to conduct whole building performance simulations, which are essential for the evaluation of the industry products and decision-making support in the early building design phase. As an implemented example, the EnergyPlus input structures for both the opaque and transparent envelope material and construction assembly definitions as illustrated in Figure 6 are extracted. An XML-based material/component/system product database schema compatible with the EnergyPlus input structure is then created to support the development of the tool (shown in Figure 7).

As an extensible language, XML allows the user to define new property fields (markup tags) and thereby create their own customized markup schema for exchanging information within and between their respective domains of interest. This adaptable feature enables the implemented database schema to be easily extended to work with various simulation programs with different input structure requirements. The implemented XML based data infrastructure also provides outstanding data serialization and interoperability potentials to the developed platform, which allows the tool to easily support and integrate with the whole-building energy parametric analysis and integrated design decision support (DDS) application (another platform developed by CMU in the EEB Hub project).


```
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- <Material xsi:noNamespaceSchemaLocation="" xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance">
  - <General>
    - <Material id="General_Cotton Batt">
        <Name required="true">Cotton Batt</Name>
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        <Conductivity required="true" inputtype="input_range" unit="Btu-in/h-ft2-F">0.033,0.125</Conductivity>
        <Density required="true" inputtype="input_range" unit="lb/ft3">1.000,1.375</Density>
        <SpecificHeat required="true" inputtype="input_unknow" unit="Btu/lb-F"/>
        <ThermalAbsorptance inputtype="input_unknow"/>
        <SolarAbsorptance inputtype="input_unknow"/>
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      </Material>
    - <Material id="General_Spray Foam EPS Expanded Polystyrene">
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        <SpecificHeat required="true" inputtype="input_unknow" unit="J/kg-K"/>
        <ThermalAbsorptance inputtype="input_unknow"/>
        <SolarAbsorptance inputtype="input_unknow"/>
```


**Figure 7** Illustration of the XML-Based System/Component/Material Product Database Schema

A web-based graphical user interface (GUI) for the designed schema has been developed to facilitate the data acquisition and data processing (Figure 8). With the help this tool, more than 4100 glass products from the International Glazing Database (IGDB) and about 500 other enclosure products were added to the database to instantiate the XML schema developed. The GUI can be accessed via http://128.2.109.122/ProductData/Acquisition.html. A manual is available online which provides detailed explanation and instructions on the use of the data acquisition tool.

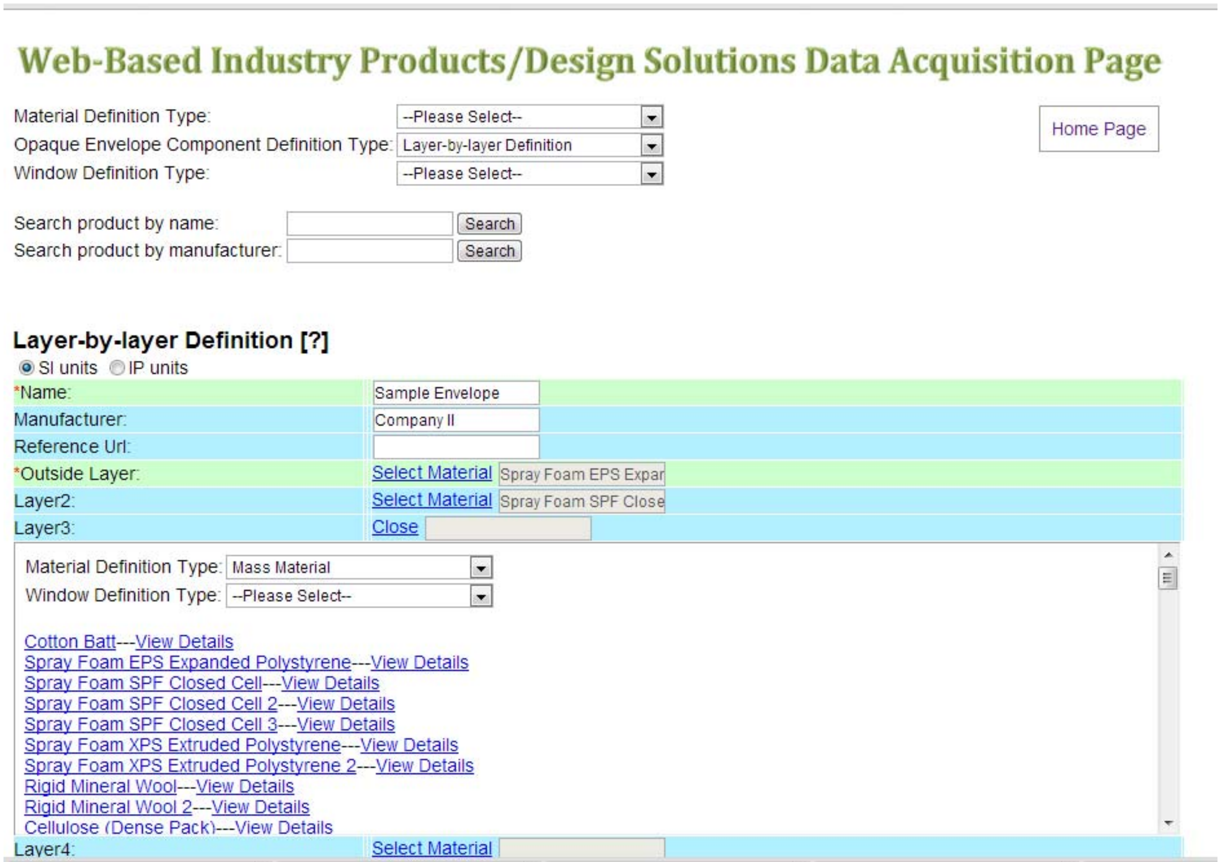


**Figure 8** Graphical User Interface (GUI) of the web-based industry product (material/component/system) data acquisition tool (IPDAT)

**[4] Whole-building energy simulation model comparison for the proposed retrofit design of Building 661**

A detailed comparison of two whole building energy simulation models for Building 661 in the Navy Yard, Philadelphia – eQUEST by Atelier Ten and EnergyPlus by Carnegie Mellon University – was conducted. The models were systematically analyzed in terms of their respective input parameters and representations and their impact on the simulation results. Features compared include: (1) complex building geometry of the existing building, and (2) HVAC system configurations involving variable refrigerant flow systems, active and passive chilled beams and dedicated outdoor air system. Similarities and differences as well as necessary abstraction of the input representations were observed and reported.

The proposed design of Building 661 has been modeled in EnergyPlus v7.2.0.0.0.6 using Design Builder 3.0.0.105 as the interface. The geometry of the building is modeled according to the REVIT model provided by Kieran Timberlake Architects. The main geometric differences between the eQUEST the EnergyPlus models are highlighted in Figure 9. As can be seen, the eQUEST model has the plenum area across the entire span of the high bay area, which in effect reduced the conditioned volume of the space, as the space above the plenum is designated as non-conditioned. As the proposed HVAC system is a conventional VAV system, this assumption would not be representative of the actual design scenario unless a physical “plenum” separation is indeed constructed. The EnergyPlus model has the plenum area which is only below the mezzanine area – a more realistic thermal zoning configuration, but this increases the conditioned volume significantly as compared to the eQUEST model.

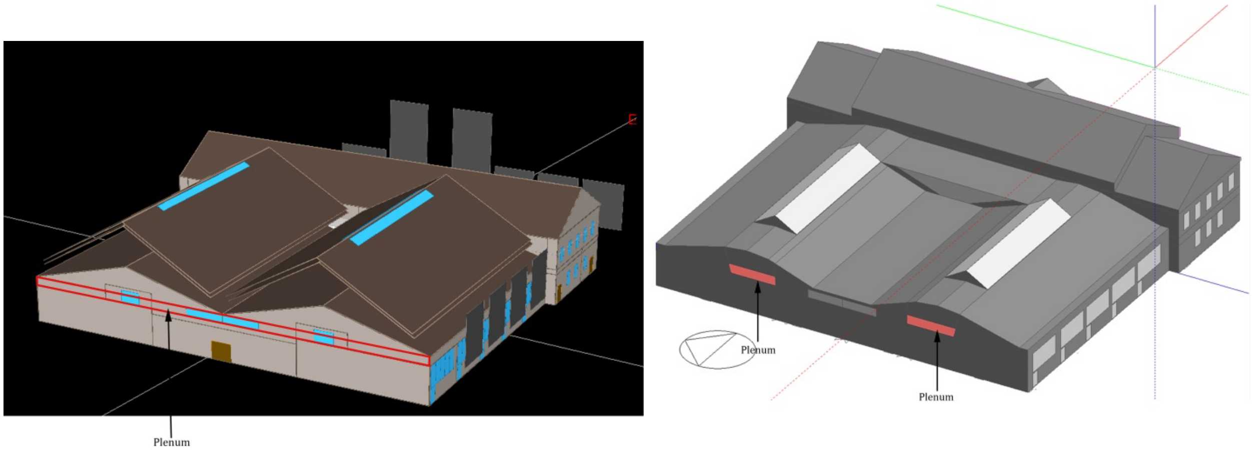


**Figure 9** eQUEST and Design Builder views of Building 661 highlighting the plenum areas.

Other modeling inputs such as operation schedules, lighting/equipment power densities and construction assemblies are in accordance with the eQUEST model provided by Atelier Ten. The mechanical systems modeled in EnergyPlus consist of variable refrigerant flow system, variable air volume system with direct expansion cooling and heating via furnace. Heating to other zones are provided through a water heater module in EnergyPlus with heat recovery from the chiller. Other systems include chilled beams (Active and Passive) with variable dedicated outdoor air system and fan coil units, all connected to a single electric chiller and a single speed cooling tower. The under floor air distribution system has been modeled for the iConLab and the Symposium in the head house with a transition height of 1.8m. A cooling tower has been modeled in EnergyPlus instead of an air cooled chiller (eQUEST model) and a water heater instead of a boiler (eQUEST model). This is because EnergyPlus accepts only the use of heat recovery loop where a condenser water loop is specified and fed to a water heater system. The water heater capacity is kept consistent with the eQUEST model which is 172.62 kW. A detailed description of the differences in the input parameters can be found in the detailed report of this task.

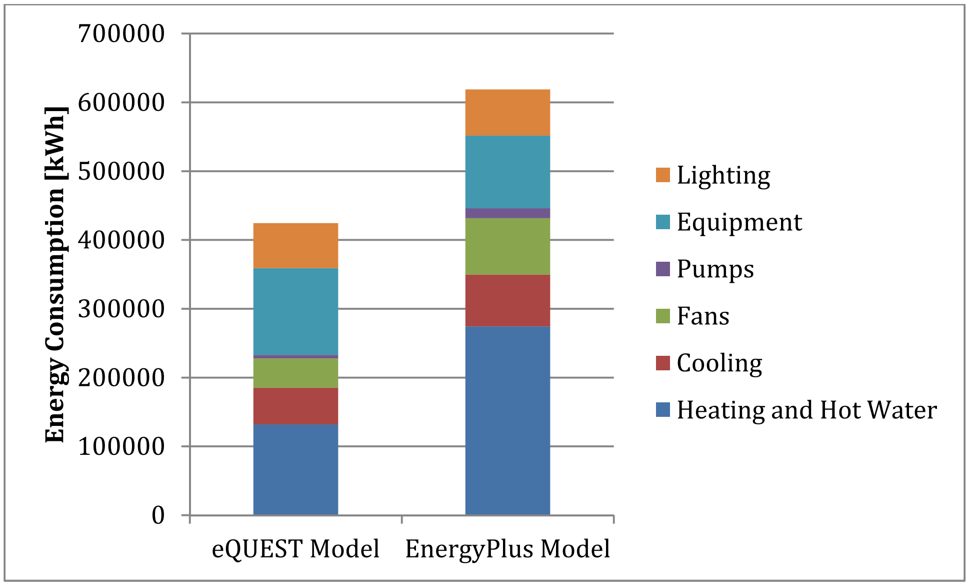


**Figure 10** Breakdown of building energy consumption for eQUEST and EnergyPlus model
Note: Since EnergyPlus does not allow the use of a boiler with a chiller for the heat recovery system as proposed in the design, heating is added together with the hot water consumption because a water heater is used to model the boiler. EnergyPlus therefore reports the consumption from this water heater together with the domestic hot water consumption. Although in eQUEST heating (114986kWh) and hot water consumption (11643kWh) are reported separately, the numbers are added together for the purpose of comparison.

Figure 10 shows the breakdown of energy consumption predicted by both eQUEST and EnergyPlus models. From Table 2, it is observed that the energy use intensity of the eQUEST model is significantly lower than that obtained from the EnergyPlus model. The energy use breakdown indicates that this is due to the significantly higher consumption for heating, pumps, and fan.

**Table 2** Energy consumption per unit area and volume for eQUEST and EnergyPlus model

| | **eQuest Model** | **EnergyPlus Model** |
|---|---|---|
| Energy Per Total Building Area (non-conditioned and conditioned) [kWh/m²] | 60.18 | 135.78 |
| Energy Per Conditioned Building Area [kWh/m²] | 121.42 | 184.93 |
| Total Building Area [m²] | 7108.72 | 4623.37 |
| Conditioned Building Area [m²] | 3523.26 | 3394.60 |
| Unconditioned Building Area [m²] | 3585.46 | 1228.77 |
| Total Building Volume [m³] | 16516.68 | 18810.68 |
| Total Conditioned Volume [m³] | 12158.21 | 15323.33 |
| Total Unconditioned Volume [m³] | 4358.47 | 3487.35 |

The reason for this increase in energy consumption may be attributed to be the large volume in the high bay area modeled in EnergyPlus wholly as a conditioned space, while this is modeled as an unconditioned space in eQUEST, separated by a plenum zone. This could be due to the limitations in eQUEST for modeling a complex geometry like building 661. Hence, even though the total building area for the eQUEST model is larger due to insertion of the plenum floor (which does not exist in reality), its total conditioned volume is significantly reduced while the unconditioned volume is increased, in comparison with the EnergyPlus model. While the absolute EUI figures may be different, the relative energy savings in both models remain similar at around 30% compared to their respective ASHRAE 90.1 2007 baselines.

This task highlighted clearly the importance of thoroughly understanding the energy simulation modeling assumptions in detail vis-à-vis the results obtained from the model. Besides considering the uncertain occupancy schedule and behavioral impact (which are not addressed in this exercise), the critical points pertaining to the physical design that should be noted for achieving reasonably accurate predicted results when compared to the actual energy performance during operations include:

1. Configuring the geometric **volume** of the thermal zones accurately according to the architectural/spatial configurations;
2. Selecting an energy modeling tool that has a well-defined and validated HVAC system module in its library that technically represents the system in the proposed building design.

**5. Technology Transfer.** *A narrative description of any product produced or technology transfer activity accomplished during BP2 such as:*

1. *Publications. List journal name/volume issue, conference papers or public release of results.*

Aziz A., Cochran E., Lam. K.P., Hartkopf V., Loftness V., Wylie A. (2012). Dissemination of GPIC results and benefits of retrofits and identify potential clients. PA Department of Education. April 2012.

Aziz A., Park J., Cochran E. (2012). Dissemination of EEB Hub results and benefits of retrofits and identify potential clients. Waldorf Charter School. April 2012.

Cochran E. (2012). Dissemination of EEB Hub results and benefits of retrofits and identify potential clients. Green Building Alliance. February, March and April 2012.

Cochran, E. (2012). Dissemination of EEB Hub results and benefits of retrofits and identify potential clients. Erie School District. March and April 2012.

Cochran, E. (2012). Dissemination of EEB Hub results and benefits of retrofits and identify potential clients. Urban League of Pittsburgh Charter School. March and April 2012.

Cochran, E. (2012). Dissemination of EEB Hub results and benefits of retrofits and identify potential clients. Waldorf Charter School. March and April 2012.

Cochran E. (2012). Established Graduate Course: "Redesigning our Built Environment: From Energy Waste to Efficiency". Spring 2012. Carnegie Mellon University.

Cochran E. (2012). Presenter. The Urban League Institute (ULI) and the Aspen Institute's "Global Forum on the Culture of Innovation: Harnessing the Power of Creativity, Policy and Technology". September 5-6, 2012. San Diego, CA.

Cochran, E. (2012). Won best Proposal for Walter Reed Medical Center. DOE Better Buildings Challenge. March 2012. Washington DC.

Karaguzel O.T. (2012). Presenter. Webex: "Strategies for Energy Modeling & Simulation Analysis". August 1-4, 2012. EEB Hub, Philadelphia, PA.

Karaguzel O.T., Zhang R., Lam K.P. (2012). Integrated Simulation Based Optimization of Office Building Envelopes for the Minimization of Life Cycle Costs. In: Proceedings of the Second International Conference on Building Energy and Environment (COBEE 2012). August 1-4, 2012. Boulder, CO.

Karaguzel O.T., Zhang R., Lam K.P. (2013). Coupling of Whole-Building Energy Simulation and Multi-Dimensional Numerical Optimization for Minimizing the Life Cycle Costs of Office Buildings. Journal Article Submitted to The International Journal of Building Simulation.

Lam K.P., Loftness V., Aziz A., Cochran E. (2012). Demonstration of simulation, control, test and lifecycle cost analysis of lighting, heating, cooling, and plug load management. DOE-Siemens-CMU Project Milestone 4 Demonstration. May 4, 2012.

Lam K.P., Hartkopf V., Loftness V. (2012). Chinese Delegation Guangdong Energy Leadership Workshop. Delegation from Guangdong, China. February 2012.

Loftness V. (2012). BOMI International Sustainability Curriculum Workshop. May 10, 2012. Washington DC.

Loftness V. (2012). Canadian Energy Efficiency Products Workshop, Innovative Components and Systems Integration for Energy. March 28, 2012.

Loftness V. (2012). Conference Keynote. Innovative Control and Strategies for Energy Efficiency. Technical University of Munich. May 25, 2012.

Loftness V. (2012). Led workshop on Meaningful Energy Metrics ($M^2$) for High Performance Buildings Magazine. ASHRAE High Performance Buildings Conference. March 12-14 2012. San Diego, CA.

Loftness V. (2012). Presenter. Green Build: "Climate Change Hits Home: Impacts on Buildings and Health". November 12-17, 2012. Washington DC.

Loftness V. (2012). Presenter. U.S. EPA Green Building Symposium, "Applying Green Building Research Today; Session 1: How Smart is Your Building: Implications of a Data Driven Built Environment: Integrate Systems in Sustainable Buildings". July 17, 2012. Philadelphia, PA.

2. *Web site or other internet sites that reflect the results of this subtask effort.*

1. Whole Building Energy Parametric Analysis Tool
   http://128.2.109.122/WBEPATool/login.html.
2. Energy & Environment Awareness Hub
   http://128.2.109.122/WBEPATool/DashBoard.html
3. Web-Based Industry Products Data Acquisition Assistant Tool
   http://128.2.109.122/ProductData/Acquisition.html

3. *Networks or collaborations fostered.*

CMU team collaborated with Subtask 5.4 through simulation-based identification and evaluation of the roof characteristics that have impact on energy use in the Philadelphia region with a demonstration case of Building 661, Navy Yard.

4. *Inventions/Patent Applications.*

N/A

5. *Other products such as data or databases, physical collections, audio or video, software or netware, models, educational aid or curricula, instruments or equipment.*

1. Simulated energy performance data for Building 661 case (from 720 different parametric runs with varying building envelope product specifications as well as infiltration rates) associated with the Whole Building Energy Parametric Analysis Tool

2. Database of local weather information (temperature, dew point temperature, relative humidity, global solar radiation, wind speed, wind direction, gust speed), energy performance data (HVAC (pumps, fans, heating, cooling, heat recovery), lighting, and plug loads), IEQ data (air temperature, relative humidity) associated with the Energy & Environment Awareness Hub.

3. Database of industry products comprising over 4100 glass products from International Glazing Database (IGDB) and 500 other enclosure products associated with the Web-Based Industry Products Data Acquisition Assistant Tool.

**6. Key Personnel.** *Narrative/listing of absence or changes in key personnel or changes in consortium/teaming arrangements*

N/A