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Review of Existing Energy Retrofit Tools

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1 Introduction

1.1 Objective of the Review

This document presents information resulting from research performed for the California Energy Commission (CEC), as part of the "Small and Medium Building Efficiency Toolkit and Demonstration Program," (SMB Toolkit), CEC agreement number PIR-12-031. This report is the second deliverable for Task 2, Stakeholder and Partner Workshop.

The goal of this work is to review the currently available retrofit tools for small and medium commercial buildings. Researchers investigated retrofit tools both in the public domain as well as in the private sector to better understand the diverse approaches currently in use to evaluate retrofit options: in particular calculation methods, retrofit measures, interoperability, and also target buildings, target audiences, and interface type and accessibility.

This chapter introduces the *Existing Tools Summary*, outlines the scope of this review, and identifies the retrofit tools to be evaluated. Chapter 2 reviews public sector, utility sector, and private sector retrofit tools. Chapter 3 compares the energy calculation methods, and the final chapter closes with a summary of findings.

1.2 Scope of the Review

This review focuses on tools which can identify potential retrofit opportunities and measures for small and medium commercial buildings, and provide energy savings and investment cost analysis. This report summarizes existing retrofit tools, and identifies features and gaps. Many tools can calculate estimated building energy usage, utilizing diverse calculation methods ranging from simple algorithm to dynamic simulation methods. These tools aim to predict energy use 1) for buildings in the design phase, and 2) for energy audits in the operational phase. Although the tools may also be used in retrofit selection to estimate energy savings for different measures, it is not easy for users to identify available retrofit technologies or obtain information for candidate retrofit measures. This review does not include public domain simulation engines such as EnergyPlus and DOE-2 which lack an accessible user interface for retrofit selection analysis. We have also omitted tools that do not provide a retrofit-oriented analysis such as Simergy and OpenStudio, which are built upon EnergyPlus. Finally, since this review is focused on retrofit tools applicable to small and medium size office and retail buildings, we do not include tools targeting residential buildings such as Home Energy Saver by LBNL, TREAT Energy Audit by Performance Systems Development, or National Energy Audit (NEAT) by Oak Ridge National Laboratory.

1.3 Search for Existing Tools

Recent focus on energy efficiency in buildings has generated a wide array of energy assessment tools developed by public, private, and utility sectors that can be used for energy retrofit analysis.

In the past, the California Energy Commission Public Interest Energy Research (PIER) Program sponsored public research to develop new energy efficient technologies and retrofit tools, including EnergyIQ and Retrofit Energy Savings Estimation Method for California (RESEM-CA). EnergyIQ is a benchmarking tool for nonresidential buildings to help refine retrofit action plans based on benchmarking results, and provide decision support information (LBNL 2013). RESEM was developed in 1991 for retrofit energy saving estimation (Hitchcock et al. 1991), and it was updated for California-customized retrofit analysis tool as RESEM-CA (Carroll 2004). There is also a tool developed for California building energy code compliance for commercial/nonresidential buildings (CBECC-Com) that performs energy simulations to evaluate code compliance using the whole-building performance approach.

Department of Energy (DOE)'s Energy Efficiency & Renewable Energy (EERE) office web site provides a list of building energy software. Currently, there are 89 tools under the category of "Retrofit Analysis" within "Whole Building Analysis" (DOE 2013a). Most of them are not applicable for the SMB building energy retrofit analysis for the following reasons:

- Not applicable to SMB building types (22)
- Does not address whole building performance nor considering interactions between various energy and service systems in buildings (30)
- Not publically available (commercial tools) (77)

Only one tool, EnergyPlus, is a publically available tool that can be used by SMB owners for the retrofit analysis of a whole building. EnergyPlus is an energy simulation engine, however, it does not have a user-friendly interface, and it requires a substantial background in energy modeling and building systems (DOE 2013c). Therefore, EnergyPlus is not an appropriate retrofit tool for wide adoption, in particular for small and medium business owners who are likely to lack resources and/or expertise.

In 2013, Pacific Northwest National Laboratory (PNNL) reviewed nine existing tools that can be used for the evaluation of commercial building energy efficiency measures (Wang 2013). Four of these tools were selected for further review in this report -- DOE Commercial Asset Scoring Tool, EnergyIQ, EnCompass, and FirstFuel.

The project team also conducted a wide search of existing tools from other sources and selected nine tools for review to understand current approaches to retrofit analysis of commercial buildings. The selected tools include free, publically available tools, as well as commercially available tools developed by private companies.

1.4 Selected Retrofit Tools

This document reviews a total of 16 tools based on their potential use for energy retrofit; the tools are categorized as follows:

- Tools in the public sector developed by US research laboratories and academic institutions and sponsored by public agencies within the US:
    - DOE Commercial Building Energy Asset Scoring Tool, Simuwatt Energy Audit, CBECC-Com, EEB Hub Tool, Building Performance Database (BPD), EnergyIQ, EnCompass, Evaluator, COMBAT, Chicago Loop Energy Retrofit Tool (pilot study), RESEM-CA
- Tool administered by utility companies:
    - Customized Calculation Tool (CCT)
- Tools developed in the private sector:

- C3 Commercial, Retroficiency, Agilis Energy, FirstFuel

2 Review of Existing Tools

This section examines 16 selected tools. Table 1 outlines the diverse features of the 16 tools, including developer, target buildings, user groups, and interface type, calculation methods, and gaps. This chapter also includes a detailed review of each tool, summarizing main features such as energy use calculation methods, energy conservation measures (ECMs), and gaps.

Table 1 Summary of existing tools for review

Tools	Developer / Sponsor		Latest Update	Target Buildings	Target Audience	Type of Tool	Public Accessibility	Calculation Engine	Features	Gaps
DOE Commercial Building Energy Asset Scoring Tool[*]	Public Sector	PNNL / DOE	2014	US commercial buildings	Building owner, energy manager	Web based	Yes (currently being tested)	OpenStudio / EnergyPlus and FEDS	- Scores buildings by use type on predefined scales and evaluate buildings systems - Creates building geometry using online tool - Identifies ECMs by FEDS based on life cycle cost analysis	Considers a limited number of operational parameters in ECM options
Simuwatt Energy Audit[*]	Public Sector	Simuwatt , Concept3D, NREL / DOD	2014	US commercial buildings	Energy auditor	Web based	To be determined	OpenStudio / EnergyPlus	- Uses online building component library BCL, a repository of energy data for ECMs - Automates modeling from geometry capture technology during walk-though	Not accessible by public
CBECC-Com	Public Sector	Architectural Energy Corporation / California Energy Commission	2014	California commercial buildings	Architect, engineer for code compliance	Stand-alone API	Yes	OpenStudio / EnergyPlus	- Demonstrates compliance with Title 24 2013 - Uses SketchUp for geometry creation - Applies to 16 CA climate zones	Developed for compliance and code check-rather than retrofit analyses
EEB Hub Tool	Public Sector	EEB Hub / DOE	2014	US buildings	Building owner, architect, auditor, analyst	Web based	Yes	Inverse Modeling, simplified simulation, OpenStudio / EnergyPlus	Assesses energy performance using four different platforms: (1) Lite: Energy benchmark from monthly utility data, (2) Partial: Simplified simulation, (3) Substantial: Energy audit, and (4) Comprehensive: Detailed simulation	Uses different methods in each level, and may yield inconsistent energy performance assessment and retrofit recommendations
Buildings Performance Database (BPD)	Public Sector	LBNL, PNNL / DOE	2014	US buildings	Building owner, energy manager	Web based	Yes	Real measured data, retrofit projects	- Conducts statistical analysis using anonymous actual building energy data - Performs retrofit analysis based on real projects	Limited samples of peer building size and availability of estimate of retrofit savings
EnergyIQ	Public Sector	LBNL / California Energy Commission	2014	US commercial buildings	Building owner, energy manager	Web based	Yes	CEC Commercial End-Use Survey CEUS) survey data, eQUEST pre-simulation data	- Benchmarks building energy and system features - Uses CEUS data for CA and Commercial Buildings Energy Consumption Survey (CBECS) for US - Recommends retrofits and analyzes energy savings based on eQUEST pre-simulation	- Lacks building-specific retrofit recommendations - Uses limited measure list from CEUS database - Lacks retrofit measure cost data

EnCompass		Energy Impact Illinois	2014	Chicago, IL large commercial offices	Building owner, energy manager	Web based	Yes	EnergyPlus pre-simulated data	-Uses 275,000 energy models stored in the database -Selects best-fit model from inputs -Benchmarks energy from CBECS 2003 and ENERGY STAR Target Finder -Develops retrofit analysis with local incentive information	Only applicable to Chicago -- large commercial buildings with gross area greater than 800,000 ft^2
Evaluator (beta version)		Energy & Environmental Modeling and Solutions LLC	2014	US commercial buildings	Building owner, facility manager	Web based	No	EnergyPlus, simplified algorithm for HVAC simulation	-Creates an EnergyPlus model from building profile input -Uses EnergyPlus for heating and cooling load -Uses simplified algorithm to simulate HVAC -Addresses five building types (office, hospital, education, retail, technical building)	Lacks retrofit measure cost data
COMBAT		LBNL / China Energy Group	2012	Chinese hotels and shopping malls	Building owner, energy manager	Stand-alone	Yes	Pre-simulated database using EnergyPlus	-Simplified inputs -Pre-simulated data uses EnergyPlus to generate before vs. after retrofit comparison -Embedded cost data for ECMs allows custom inputs -Provides basic economic analysis	Only applicable for retail and hotels in China
Chicago Loop Energy Retrofit Tool (pilot study)		ANL / DOE	2011	Chicago, IL downtown commercial buildings	Building owner, energy manager, policy maker	Stand-alone	No	Normative calculation method	-Uses the normative calculation method based on CEN / ISO Standards -Tests retrofit scenarios from ECM pallets -Benchmarks energy against reference buildings -Supports uncertainty-embedded retrofit decision	-Only applicable to large commercial buildings in downtown Chicago, IL -Does not capture dynamic behavior and control -Not accessible by public
RESEM-CA		LBNL / California Energy Commission PIER	2004	California commercial buildings	Building manager, energy retrofit engineer	Stand-alone	No (not currently supported)	RESegy bin-method	-Simulates and calculates LCC for pre and post retrofit -Covers CA 16 climate zone	-Uses outdated energy simulation engine (RESegy) -No longer supported
Customized Calculation Tool (CCT)	Administered by utility companies	PG&E, SDG&E, SCE	2013	California utility customers	Building owner, energy manager	Stand-alone: PG&E, SDG&E; Web based: SCE	Yes	Engage (a modified version of eQUEST)	-Uses prototype buildings and ECMs in the CEC Database for Energy Efficient Resources (DEER) -Includes 16 CA climate zones -Estimates peak demand and energy savings using DOE-2.2 -Calculates incentives	Limited to measures for HVAC, lighting, auxiliary systems based on DEER

C3 Commercial	Private sector	C3 Energy	2014	Small and medium-size business customers	Building owner, energy manager	Web based	Yes	Smart meter data, statistical model based on white paper, DEER	-Uses national, state, and utility building stock data for benchmarks -Compares energy benchmark to functionally equivalent average and high performing buildings -Metered data drives statistical model based on the inverse modeling method	-Uses proprietary algorithm -Not for public use
Retroficiency		Retroficiency	2014	US commercial and industrial portfolio	Building owner, energy manager	Web based	No	Smart meter data, statistical model, normative model	Conducts two levels of analysis based on measured data driven analysis and normative energy calculation method	-Uses proprietary algorithm - Not for public use
Agilis Energy		Agilis	2014	US commercial and industrial buildings	Building owner, energy manager	Web Service	No	Smart meter data, statistical model	-Analyzes smart meter data -Uses 3D graph pattern recognition technology -Analyzes energy savings using statistical mathematics	-Uses proprietary algorithm - Not for public use
FirstFuel		FirstFuel	2014	US commercial	Building owner, energy manager	Web Service	No	Smart meter data, statistical model	-Conducts smart meter data pattern analysis -Analyzes energy savings from statistical model	-Uses proprietary algorithm - Not for public use

[*] Tools are under development, review, and test, and not available to the public at the moment.

2.1 Tools Developed by the Public Sector

2.1.1 DOE Commercial Building Energy Asset Scoring Tool

The Commercial Building Energy Asset Score is a web-based tool and voluntary energy rating system, which can evaluate the physical characteristics of an existing building (as built) and its overall energy efficiency independent of occupancy and operational conditions (DOE 2014). The tool generates asset scores by evaluating the building envelope and mechanical and electrical systems. The tool also identifies cost-effective upgrade opportunities and helps users gain insight into their energy efficiency potential. Figure 1 shows screen captures of DOE Commercial Building Energy Asset Scoring Tool.

Features:

An asset scoring system provides an energy performance evaluation of the as-built physical characteristics of a building and assesses its overall energy efficiency from the standard operation per building type. The physical characteristics include building envelope, HVAC systems, lighting systems, domestic hot water systems, and other major energy-using equipment commonly found in commercial buildings. The core of energy model is based on two tools: (1) Facility Energy Decision System (FEDS) and (2) OpenStudio. FEDS has been developed by Pacific Northwest National Laboratory (PNNL) to assess cost–effective retrofits from a database of hundreds of proven building technologies (PNNL 2013). The tool uses EnergyPlus as an underlying simulation engine and OpenStudio to support energy modeling for EnergyPlus. The tool generates outputs, including a score for a building as-is and with an upgrade; provides evaluations of building systems; and identifies retrofit opportunities.

Gaps:

The main purpose of the tool is to score building physical assets. The tool provides an energy score considering only the building's physical characteristics. The operational parameters that include plug loads, operation schedule, and occupant behaviors are not part of the retrofit recommendations. To include operational parameters, the tool uses the pre-determined assumption per building type based on ASHRAE Standard 90.1. Using the derived asset score, the tool provides cost effective retrofit recommendations along with payback information identified by FEDS. The FEDS database is not publically available for review. Although the tool provides the potential score from retrofit recommendations, it currently does not allow users to evaluate improved asset scores for user-defined retrofit measures. It will allow users to customize measures in the future.

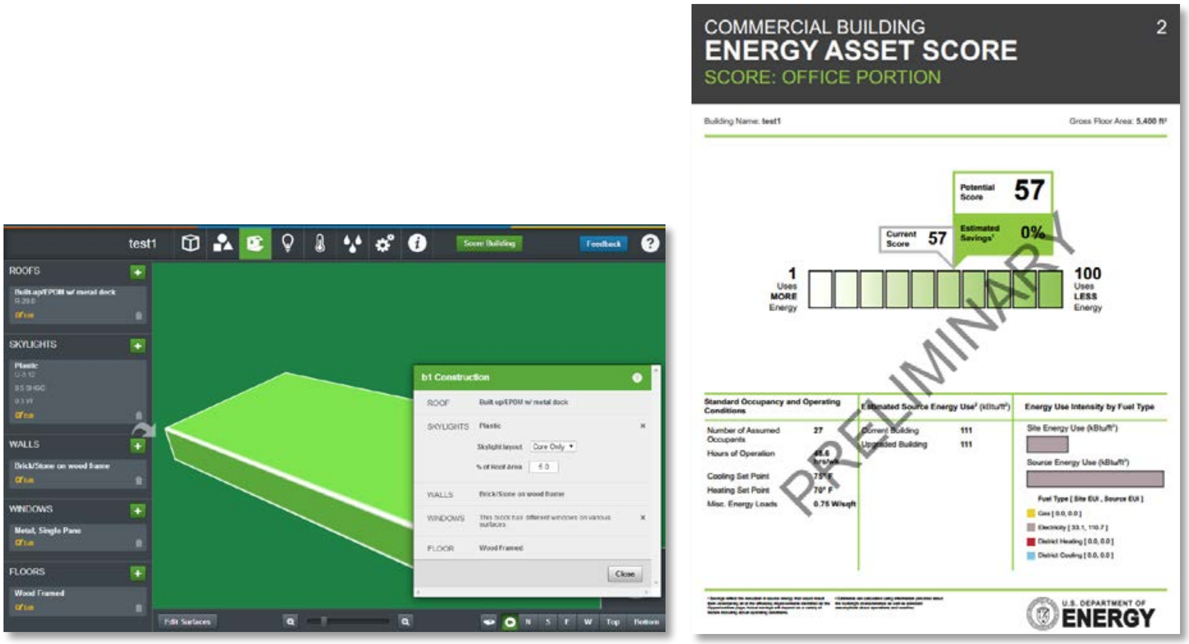


Figure 1 Screen capture of inputs and output report from the DOE Commercial Building Energy Asset Scoring Tool

2.1.2 Simuwatt Energy Audit

The Simuwatt Energy Audit (Simuwatt 2013) is a web-based building energy auditing tool which allows facility managers to conduct energy audits of US federal office buildings with standardized data collection and processes. Currently, the tool is under development and planned for demonstration at Department of Defense (DOD) facilities. Simuwatt is based on energy auditing methodology, OpenStudio platform, building component library (BCL) by National Renewable Energy Laboratory (NREL), and geometry capture technology by concept3D software company (NREL 2013). The tool targets a quick building energy audit and cost savings through a standardized audit process offering benefits over traditional methods. Figure 2 shows screen captures of the Simuwatt Energy Audit.

Features:

The Simuwatt Energy Audit combines a virtual audit and an onsite assessment, and aims to reduce cost of walk-through audits and increase the information input to enable rapid energy modeling. NREL's energy modeling framework and building energy audit processes are embedded within a tool that is tablet-based and provides walk-through onsite assessment. Information is collected to create a whole building energy model, supported by the geometry capture technology combined with real-time connections to large sets of BCL data. NREL's BCL is equipped with an online repository of data on building components. The use of BCL helps identify ECMs from building energy models created by OpenStudio, then disaggregates the separate components that represent parts of a building.

Gaps:

The tool is intended for full building energy audits of federal office buildings. Simuwatt can help streamline the auditing process by automating energy model creation with links to the BCL database.

However, Simuwatt Energy Audit still requires auditors to have experience and knowledge of building systems, operations, and indoor environments to capture dynamics of a building in order to create a valid energy model of the building. Automating model creation and using standardized data may represent a breakthrough for current energy audit practices; nonetheless Simuwatt needs one more layer that can embed experienced know-how and thus prioritize retrofit recommendations.

The OpenStudio platform uses EnergyPlus as its core calculation engine. Users may need to optimize the input details when using the automated 3D geometry capture technology to create a model. Too much detail results in long analysis time and too little detail sacrifices modeling accuracy and may prevent comprehensive analysis of the implications of alternative energy efficiency measures. After completion, Simuwatt Energy Audit may not be publically available in the future since major developers are private sector software companies.

Figure 2 Screen captures of the Simuwatt Energy Audit on a tablet (Source: NREL 2013)

2.1.3 California Building Energy Code Compliance for Commercial (CBECC-Com)

The California Energy Commission has been sponsoring the development of building energy analysis tools to assess code compliance. CBECC-Com is a tool that can be used by architects, engineers, and energy consultants to demonstrate compliance with energy codes (Architectural Energy Corporation 2013).

Features:

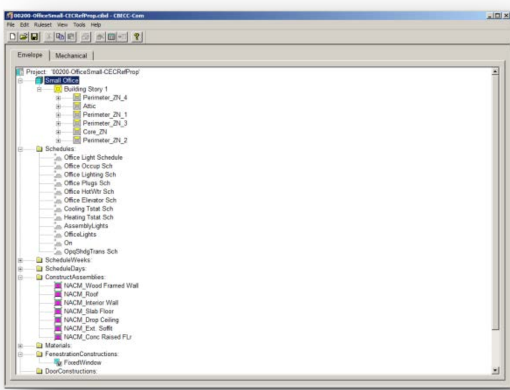
CBECC-Com is stand-alone software and is publically available. It targets newly constructed nonresidential buildings for code compliance in all 16 California climate zones. The tool uses EnergyPlus as its core simulation engine. The OpenStudio plug-in for Trimble SketchUp is used for the building geometry and zone assignment. The geometry is exported to an XML file for input into the CBECC-Com interface. The other inputs such as internal heat gains, schedules, and HVAC systems are obtained from the CBECC-Com user interface. Figure 3 shows screen captures of the user inputs and outputs for CBECC-Com. The tool generates two compliance models from the user's building model:

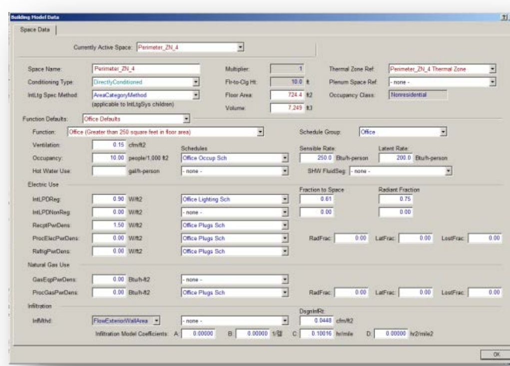
- the proposed design model, and
- the standard (baseline) design model meeting the prescriptive requirements of Title 24-2013.

Each model is translated to an EnergyPlus input data file (IDF) and is simulated using the EnergyPlus engine. CBECC-Com performs three automated simulations: (1) the proposed design annual simulation, (2) the standard design sizing simulation to determine HVAC system sizes, and (3) the standard design annual simulation. The tool generates a compliance report that summarizes building's compliance-related characteristics and forms that can be used for building permit submission. The tool provides an open Application Programming Interface (API) to allow third party software developers to utilize the functionality of the CBECC-Com compliance checking module.

Gaps:

The main purpose of the CBECC-Com development is to check and demonstrate compliance with Title 24 energy code for newly constructed nonresidential buildings. CBECC-Com tests the energy performance of design options in user's proposed building against Title 24 baseline. However the user interface of the tool is not retrofit–oriented, as it does not identify economics analysis. Thus, it is not easy for inexperienced users to find cost-effective ECMs. Also, the tool is designed for evaluation of new buildings using Title 24-specific operating assumptions, which can be quite different from actual operating conditions.





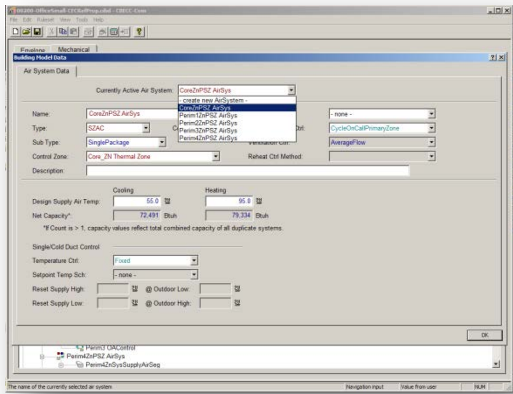
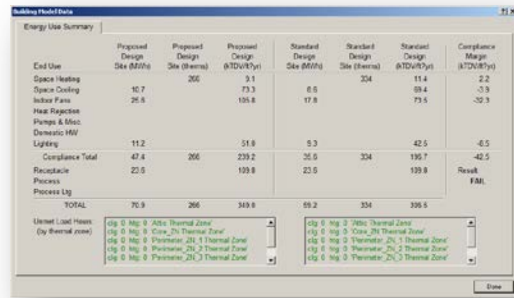
 

Figure 3 Screen captures of the CBECC-Com, top left for building design user input, top right for zone detailed input, bottom left for HVAC system input, and bottom right for compliance report

2.1.4 Energy Efficient Buildings Hub Tools

The Energy Efficient Buildings (EEB) Hub has been developing a web-based simulation platform that integrates four different levels (Lite, Partial, Substantial, and Comprehensive) of energy modeling and simulation (Energy Efficient Buildings Hub 2013). Table 2 summarizes the target audience and building stock, calculation engines, and features of the simulation tool. The four platforms have different levels of complexity in energy modeling, calculation, and output analysis. Figure 4 shows screen captures of the EEB Hub tool.

Table 2 Summary of EEB Hub simulation tools

Platform	Target Audience	Target Building Stock	Developers / Calculation Engine	Features	Notes
Lite	Building owners	Commercial and special use	ASHRAE Inverse modeling toolkit and IBM inverse modeling toolkit that uses representative cities' TMY3 climate data for ASHRAE's climate zones	-Computes the building performance indicators for overall, heating, and cooling based on the inverse modeling with limited set of inputs: building location, type, size, and height associated monthly utility data. -The geographic information system based visualization and benchmarking tool allows comparison of the energy performance of buildings in a portfolio and provides the ability to screen a set of candidate buildings for retrofits	IBM inverse modeling toolkit could potentially result in different outcomes when compared to ASHRAE inverse modeling toolkit -
Partial	Building designers	Commercial and special use	Massachusetts Institute of Technology (MIT)'s Design Advisor Tool (DAT)	-The simplified simulation algorithm for conceptual building designs. -The uncertainty quantification feature informs parameters sensitive to the energy performance and identifies risk that the energy savings does not perform as designed.	Applicable to a simple building geometry

Substantial	Building auditors	SMB commercial with potential large savings opportunities	United Technology Research Center (UTRC) and Penn State University's Energy Audit Tool, University of Pennsylvania (UPenn)'s Parametric Analysis Toolkit	- The platform calibrates the calculated energy consumption based on the measured energy data and climate. - It uses the calibrated model for energy audit for retrofit recommendations. - The audit enables capturing operational problems such as occupancy schedule, equipment capacity, and controls. - Parametric analysis enables the evaluation of the impact of system control parameters on energy performance.	Applicable to a simple building geometry
Comprehensive	Building analysts	Medium commercial buildings with potential for major savings opportunities, or facilities with a dedicated facility manager that can manage a strategic retrofit plan	Penn State University's modeling shell using OpenStudio / EnergyPlus and University of Maryland's Retrofit Manager Tool	- The platform creates an OpenStudio model for EnergyPlus simulation from web-interface Inputs - The platform supports daylighting simulation with the use of LBNL's RADIANCE-based DAYSIM, and airflow simulation with CONTAM.	Limited ECMs are available, as the platform is under development.

Gaps:

The EEB simulation platform is under development, and holds promise for various user groups. The first level (Lite) relies on monthly utility and average temperature data, and analyzes temperature-related energy consumption using regression analysis. Interval data from smart meters will enhance the operational energy performance based on the load shape analysis from both occupied and unoccupied periods. The second level (Partial) is only applicable to conceptual building designs, and may not reflect real building design with diverse systems. The third level (Substantial) targets energy audits of existing buildings with the calibration capability. However, emerging technologies may not be accurately evaluated due to the limitations of the calculation engine. The fourth level (Comprehensive) uses OpenStudio for energy modeling and EnergyPlus as the calculation engine. At the moment, the tool is under development and is not available for testing.

The simulation platform has four integrated tools. For the energy modeling across the four levels, the amount of input information is about the same. However, each level uses different energy calculation engines developed by different institutions. They are more or less based on similar approaches, using the simulation method with different fidelities. Also, the different levels of EEB may produce inconsistent results for the same building.

Figure 4 Screen captures of the EEB Hub tools, top left for energy benchmarking from the “Lite” tool, top right for results from the “Partial” tool, bottom left for results from the “Substantial” tool, and bottom right for retrofit analysis from the “Comprehensive” tool

2.1.5 Buildings Performance Database (BPD)

The DOE Buildings Performance Database (BPD) is a web-based tool that explores building energy use data and enables energy benchmarking and retrofit analysis (DOE 2013b). The BPD provides access to empirical data on the actual energy performance and physical and operational characteristics of commercial and residential buildings. Figure 5 shows screen captures of the benchmarking and retrofit analysis using the BPD tool.

Features:

The BPD is driven by actual energy data, as opposed to a tool based on a simulation model. BPD aggregates data from many other tools such as ENERGY STAR Portfolio Manager, DOE’s Commercial Asset Scoring Tool, the 2003 Commercial Building Energy Consumption Survey (CBECS) database, the California Commercial End-Use Survey (CEUS) database and other sources. The data fields include the building's energy usage, location, climate zone, building type, and floor area. Additional information such as age, operational characteristics, and building system can also be entered.

Currently, the tool allows users to analyze the energy saving percentage from a specific energy efficiency measure and uses statistical analysis to estimate the probability of achieving different levels of energy savings. There are 73 retrofit measures available under six categories -- air flow control, cooling, heating, lighting, window glazing layers, and glazing type. In the future, an API will be developed so that external software can conduct analysis using BPD data.

Gaps:

The value of the BPD depends upon the amount and quality of aggregated data. Basic building information and monthly energy consumption data can be used to compare similar buildings and identify high and low performers. The total number of buildings is 181,177 as of March 2014. However, there are only 3,026 small and medium (floor area smaller than 50,000 ft^2) nonresidential buildings in California. With this filtered peer building group, only limited lighting and glazing system measures are applicable for retrofit analysis. The retrofit analysis does not allow for interactive effects between technologies. As the data in BPD becomes richer and more robust, users will be able to conduct more relevant retrofit analysis.

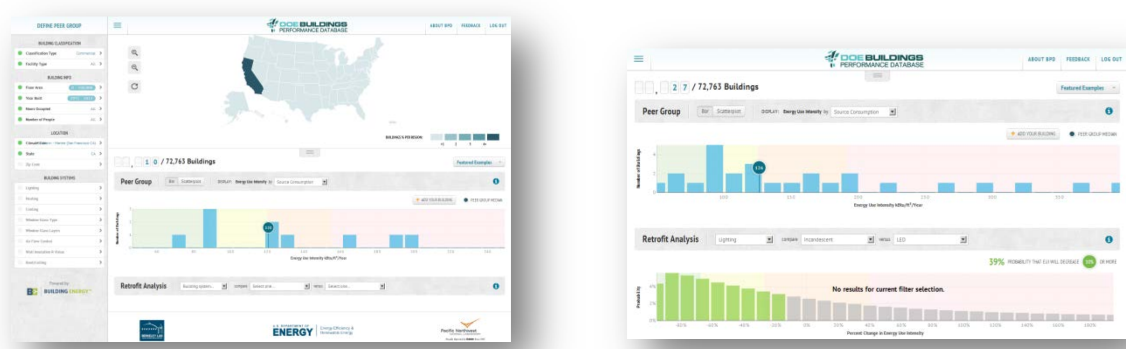


Figure 5 Screen captures of the DOE Buildings Performance Database. Left: energy benchmarking, right: retrofit analysis

2.1.6 EnergyIQ

EnergyIQ is a web-based tool for building energy benchmarking of nonresidential buildings developed by LBNL with sponsorship from the California Energy Commission's PIER program (LBNL 2013). It is an action-oriented tool that provides a benchmark assessment against peer group buildings, as well as decision support information to help refine action plans. EnergyIQ is built on the CalArch tool (developed by LBNL) that is widely used for benchmarking. EnergyIQ provides a detailed benchmarking of energy use, costs, and emissions for 62 building types based on the energy use characteristics of 2800 buildings in the CEUS database. The tool also allows benchmarking of the energy performance on a national scale by using the 2003 CBECS database. The tool compares the building performance against a filtered peer-building group, and allows users to specify the benchmarking group for different benchmarking targets. A wide array of energy metrics are available for benchmarking, such as energy type, system specific end use, and peak demand as well as a variety of building system features. Figure 6 shows screen captures of the EnergyIQ.

Features:

EnergyIQ provides comprehensive benchmarking of commercial buildings. Users can tailor benchmarks to small and medium sized buildings (floor area smaller than 25,000 ft^2) at various vintages and California climates, which will return relevant energy performance benchmarks for SMBs in California.

The tool is intended for action-oriented benchmarking, providing analysis for upgrades and tracking. Based on a user's input, EnergyIQ provides a list of retrofit recommendations and associated energy savings. The analysis is based on over 65,000 eQUEST pre-simulated data that represent retrofit measure-building combinations integrating 50 ECMs in the subset of the CEUS buildings.

Gaps:

The tool provides various energy metrics and building system features for benchmarking. When a peer group is defined by size, vintage, location, and energy use type, the query may result in a small sample size, which limits the coverage of the benchmarking.

The retrofit recommendations are limited to those that were prepared for the CEUS measure database (Mills & Mathew 2012). Although the CEUS data include a large number of commercial buildings, limited combinations of measures cannot produce a complete representation of retrofit opportunities. The pre-simulated data need to be periodically updated in order to capture new market available measures as well as to provide a more comprehensive data set for energy benchmarking.

The major limitation is that the tool recommends general energy saving opportunities based on user's energy consumption data published in CEUS. It needs more engineering-based energy estimation, which can better identify the most effective energy retrofit measures for a specific building.

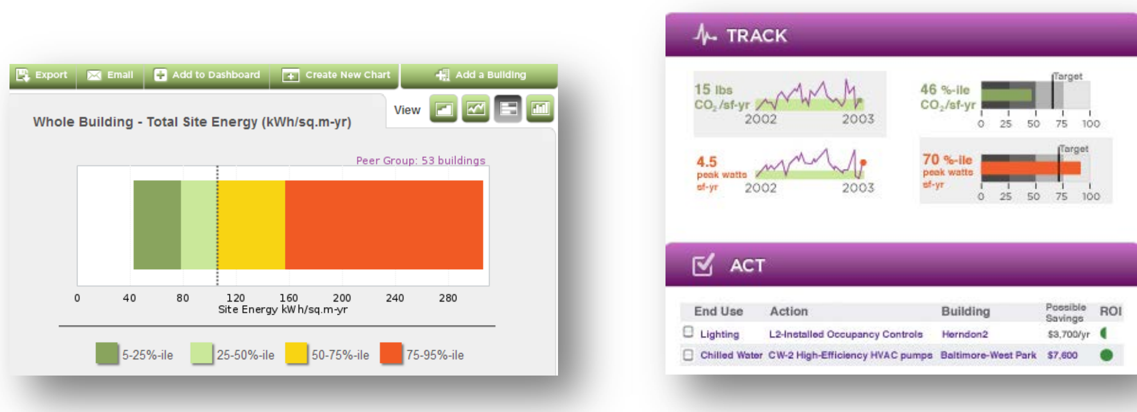


Figure 6 Screen captures of the EnergyIQ, left for energy benchmarking and right for the energy performance target and retrofit recommendations

2.1.7 EnCompass

EnCompass is a web-based tool to evaluate the building energy performance and potential energy savings from retrofits for large office buildings in the Chicago area (Energy Impact Illinois 2013). Figure 7 shows screen captures of the EnCompass for energy benchmarking and retrofit recommendations.

Features:

EnCompass relies on pre-simulated (EnergyPlus) energy data for large office buildings in Chicago. The database stores more than 275,000 energy models. The user inputs building information, and the tool selects a best-fit baseline energy model from the database and presents the pre-simulated results. The pre-simulated results are based on the DOE commercial reference buildings (modified from medium and large offices) with building characteristics defined from multiple resources, including the 2003 CBECS, ASHRAE Standard 90.1, and the Building Owners and Managers Association (BOMA) Experience Exchange Report.

The best-fit energy baseline model represents a candidate building, and is compared against the industry average energy use intensity in the Midwest region defined in the 2003 CBECS and the data from the ENERGY STAR Target Finder. Users receive their benchmarking results and a set of recommended ECMs with associated energy and cost savings. To encourage users to take the next step in improving their building efficiency, the tool also provides information on local and federal incentives, utility programs, and service providers who can fund or implement the selected ECMs.

Gaps:

Although the tool streamlines an easy energy efficiency evaluation by providing benchmarking, it is restricted to large commercial buildings in the Chicago area, limited to buildings greater than 800,000 ft^2 in the downtown area and 165,000 ft^2 in the greater suburban area. The pre-simulated database will need expansions and updates in the future.

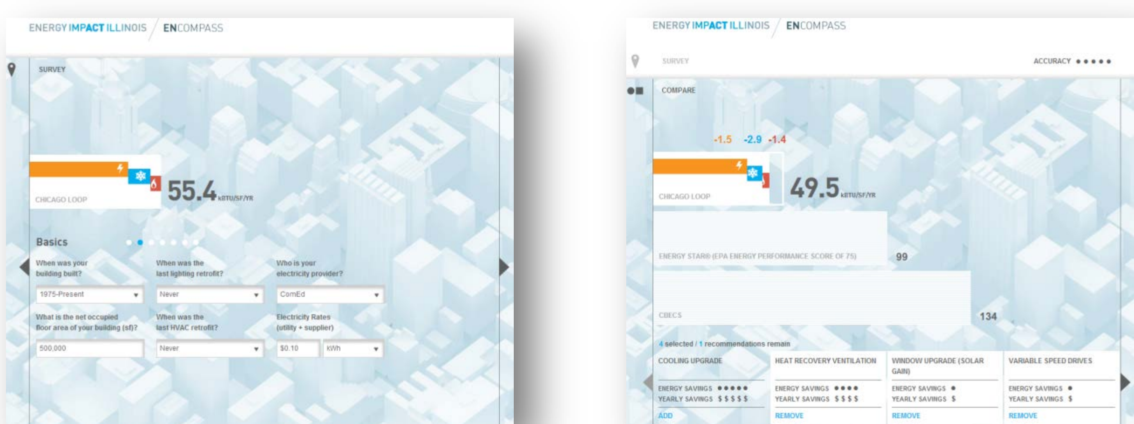


Figure 7 Screen captures of the EnCompass, left for simplified building profile inputs and right for energy benchmarking and retrofit recommendations

2.1.8 Evaluator for NYSERDA

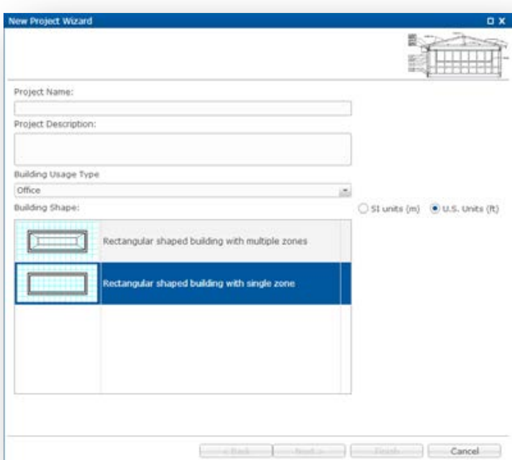
The Evaluator (currently in beta version) is a web-based tool for quick analysis and screening of potential energy saving projects for commercial buildings. Energy & Environmental Modeling and Solutions LLC (EEMS) is developing the tool for the New York State Energy Research & Development Authority (NYSERDA) (EEMS 2013). Evaluator considers the technical, financial, and environmental operation of the existing building equipment and suggests potential equipment replacement and schedule changes for more efficient energy use and to reduce greenhouse gas (GHG) emissions. The Evaluator also benchmarks the energy performance via the ENERGY STAR Building Program; it enables peak demand analysis and advises on selection of peak load reduction programs available in the State of New York (EEMS 2012). Figure 8 shows screen captures of the Evaluator with an example office building in New York State.

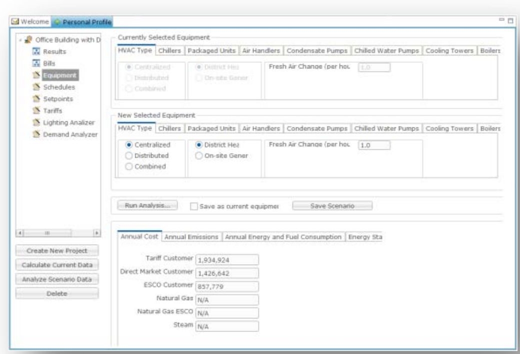
Features:

The user enters basic building profile information through a simplified web input interface for EnergyPlus model creation. The Evaluator creates an EnergyPlus model to calculate a building thermal load profile enabled by a fast simulation process. The tool then uses separate simplified algorithms (not EnergyPlus) to conduct HVAC equipment simulations.

Gaps:

The tool contains several modules for evaluation of separate or combined measures in lighting, HVAC, and auxiliary systems, but ECMs are limited to building systems that do not include the building envelope or operational changes. EnergyPlus is used only to calculate the heating and cooling load profile of a building. The HVAC systems calculation is performed outside the EnergyPlus engine, using algorithms provided in the ASHRAE Handbook. The approach may reduce simulation time for large and complex buildings, but the real benefit of EnergyPlus simulations is not realized -- capturing the dynamics of HVAC systems under different operational conditions.





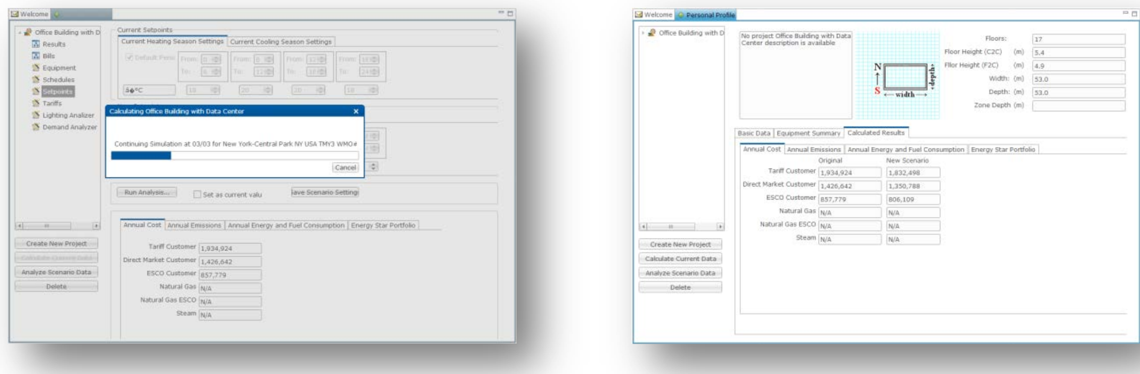


Figure 8 Screen captures of the Evaluator, top left for model creation, top right for specifying HVAC systems for the retrofit case, bottom left for simulation run, and bottom right for retrofit analysis from applied ECMs.

2.1.9 COMBAT

The Commercial Building Analysis Tool (COMBAT) is a stand-alone energy efficiency assessment and retrofit tool designed to identify cost-effective ECMs for commercial buildings in China (China Energy Group LBNL 2013). The LBNL China Energy Group developed this tool to enable policy makers, facility managers, and building retrofit practitioners to estimate energy and cost savings, as well as payback period for the retrofit investment (Pan et al. 2012). Figure 9 shows screen captures of COMBAT inputs and energy saving estimates from various retrofit opportunities.

Features:

The target audience for COMBAT includes facility managers, building owners, and policy makers who do not have detailed energy modeling knowledge. COMBAT is designed to be easy to use, and to provide quick retrofit analysis. The tool generates retrofit analysis with life cycle cost analysis and estimates payback period on the investment based on the user's financial input information.

COMBAT uses prototype buildings for different commercial building types in China. Since research to develop prototype buildings in China has not yet been performed, a set of commercial building prototype characteristics was developed based on a series of investigations, on-site surveys in the Shanghai area, and China's commercial building code requirement for ventilation. The prototype building was modeled in EnergyPlus. The prototype model was applied to a large number of ECMs in major Chinese cities, creating a pre-simulated database. The pre-simulated results account for interactions among retrofit measures (in a simplified way) as well as user-defined building information. The use of the pre-simulated database allows users to avoid time-consuming input of detailed descriptions of ECMs, and simulation processing times.

Users can add measured energy usage data to COMBAT, and calibrate the simulated energy consumption. The tool provides predetermined ECMs for retrofit analysis, including envelope, lighting, appliances, simplified HVAC systems, and combinations of interacting measures. The tool also includes China-specific cost data for each ECM.

Gaps:

The tool is developed for energy-efficiency retrofits of the Chinese commercial building sector, specifically for shopping malls and hotels. The development of the pre-simulated database results in a convenient and easy-to-use tool. However, building-specific retrofit assessment may be limited and emerging technologies may not be included in the current pre-defined set of ECMs. COMBAT is a stand-alone tool, and does not allow user customization or further third-party development.

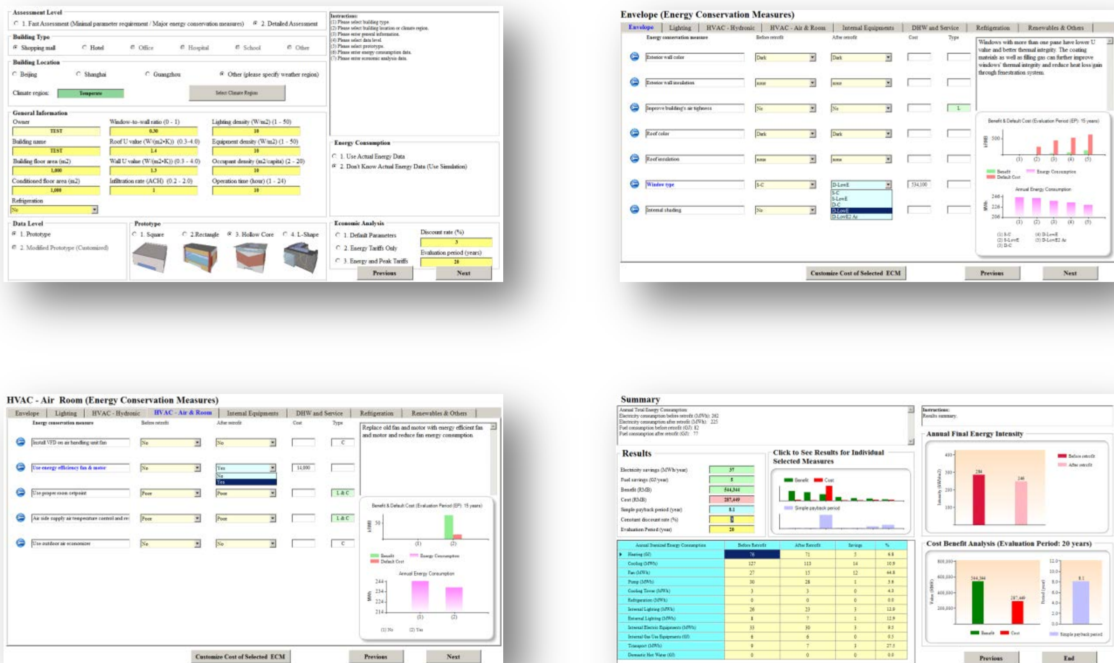


Figure 9 Screen captures of the COMBAT, top left for building data input, top right for envelope ECMs, bottom left for HVAC ECMs, and bottom right for reporting.

2.1.10 Chicago Loop Energy Retrofit Tool (pilot study)

Argonne National Laboratory (ANL) developed a stand-alone pilot tool to study the Chicago Loop building retrofit decision-making environment. The purpose of the Chicago Loop Energy Retrofit Tool was to enable retrofit analysis at the aggregate level as well as at the individual building level. The aggregate level analysis inspects different energy improvement scenarios for any collection of buildings in the Chicago Loop (the central business district of Chicago) area. The tool helps determine a level of intervention in the energy performance of certain buildings in order to reach an overall energy improvement target in Chicago Loop commercial buildings. At the individual level, the tool enables the selection of the right mix of ECM options for optimal energy improvement of the selected building (Heo et al. 2012). Figure 10 shows screen captures of the mockup tool for the pilot study.

Features:

The energy retrofit analysis is based on a building energy model that uses actual building information. The pilot tool uses the normative calculation method as its energy calculation engine, which is suitable for scalable and transparent assessment and benchmarking. The normative method is based on various calculation standards developed by the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO). The standards define the calculation methods to a meet set of normative statements of functional building category, physical building parameters, building systems, etc. Based on the normative method, the tool calculates the energy performance at different levels of thermal energy demand, delivered energy per carrier, primary energy, and emissions.

A large variety of ECMs can be considered for energy retrofit of existing commercial buildings. The tool enables testing of different ECMs and allows the user to group them into a retrofit scenario. Once retrofit ECMs are selected, affected input parameters feed to the energy model, and the building and aggregate energy performance is updated.

Gaps:

The energy model is based on the normative method, which is suitable for building energy rating, and can be used to estimate the energy performance during energy efficient building design. The energy model is based on the monthly balance of heat gains and heat losses determined in quasi-steady-state conditions in a single zone, and does not consider dynamic conditions between internal zones. Consequently, the tool cannot capture dynamic behaviors and controls of HVAC systems.

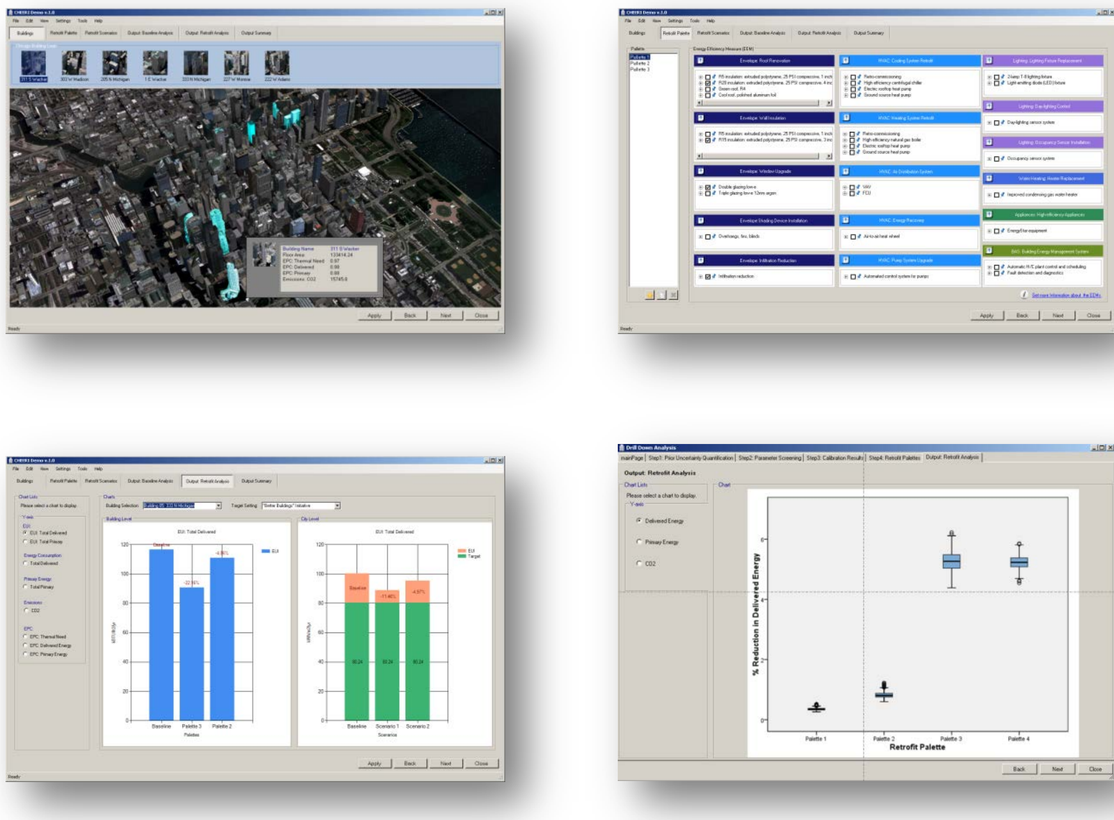


Figure 10 Screen captures of the Chicago Loop Energy Retrofit Pilot Tool, top left for selecting a target building, top right for ECM pallet management, bottom left for retrofit analysis, and bottom right for retrofit analysis with uncertainty.

2.1.11 Retrofit Energy Savings Estimation Method for California (RESEM –CA)

In 2004 LBNL created RESEM-CA, which was developed from the 1991 RESEM tool (Hitchcock et al. 1991). RESEM-CA is a stand-alone tool sponsored by CEC to enable California-customized retrofit analysis. The tool is no longer publically available.

Features:

RESEM-CA performs an economic analysis of building retrofits, providing decision support during the retrofit selection process. RESEM-CA calculates life-cycle cost and payback based on energy savings for pre- and post-retrofit derived from the simulation and other inputs for operation, maintenance, and financing.

RESEM-CA uses the RESegy energy simulation engine for the energy assessment of a specific building in a particular climate. This engine was developed for the original federal RESEM project, and enhanced during the update in 2004. The simulation is based on a bin-method approach, which represents a reasonable tradeoff between speed and accuracy that is designed to be fast and flexible, and supports the component-based approach to building specification (Carroll 2004).

Gaps:

The energy calculation method of the RESegy is not used in current energy simulation tools. No screenshots are available since the tool is no longer supported.

2.2 Tool Administered by the Utility Sector

2.2.1 Customized Calculation Tool (CCT)

The California statewide Customized Calculation Tool (CCT) was developed by California utility companies, Pacific Gas and Electric (PG&E), San Diego Gas & Electricity (SDG&E), and Southern California Edison (SCE) to estimate energy savings for a variety of ECMs. PG&E and SDG&E use a stand-alone version of the tool, while SCE uses a web-based version. CCT is designed to estimate energy savings and incentives, simplify and facilitate completion of the required forms, and prepare the retrofit project application package for statewide utility customers in California. (Pacific Gas and Electric et al. 2013). Figure 11 shows screen captures of the CCT for energy upgrade projects and calculated incentives.

Features:

The CCT energy saving calculation uses prototype buildings that reference the 2004 – 2005 Database for Energy Efficiency Resources (DEER). Prototype buildings include 23 commercial and three residential building types. Users select a building type that most closely matches their building. Upon choosing the selected building type, the tool asks for detailed input of the building, and CCT estimates the energy savings and peak demand reduction for 40 ECM categories including air conditioning and refrigeration, gas, lighting, and other systems. The energy savings are calculated from Engage, a modified version of eQUEST, which uses DOE2.2 as the simulation engine, and is based on normalized annual weather data for the 16 California climates. From the simulation, the tool generates outputs including peak demand and estimated energy savings for the base and proposed buildings, and then calculates total incentives.

Gaps:

The available ECMs for retrofit analysis are based on building systems that tie to the DEER energy efficiency technologies and energy cost data. The tool only allows evaluation of one technology for the incentive calculation tied to the utility program. The energy saving calculation is not based on the user's physical building profile, but instead is based on the prototype profile that includes assumptions and stipulations. To fully understand available ECMs, CCT provides further references explaining how the technology is applicable to a particular building. The tool is based on the energy calculation using Engage (version v1-20 prepared in 2007), a modified version of eQUEST. As a result, the retrofit analysis of emerging technologies cannot be supported, such as variable refrigerant systems (VRF) and natural ventilation strategies.

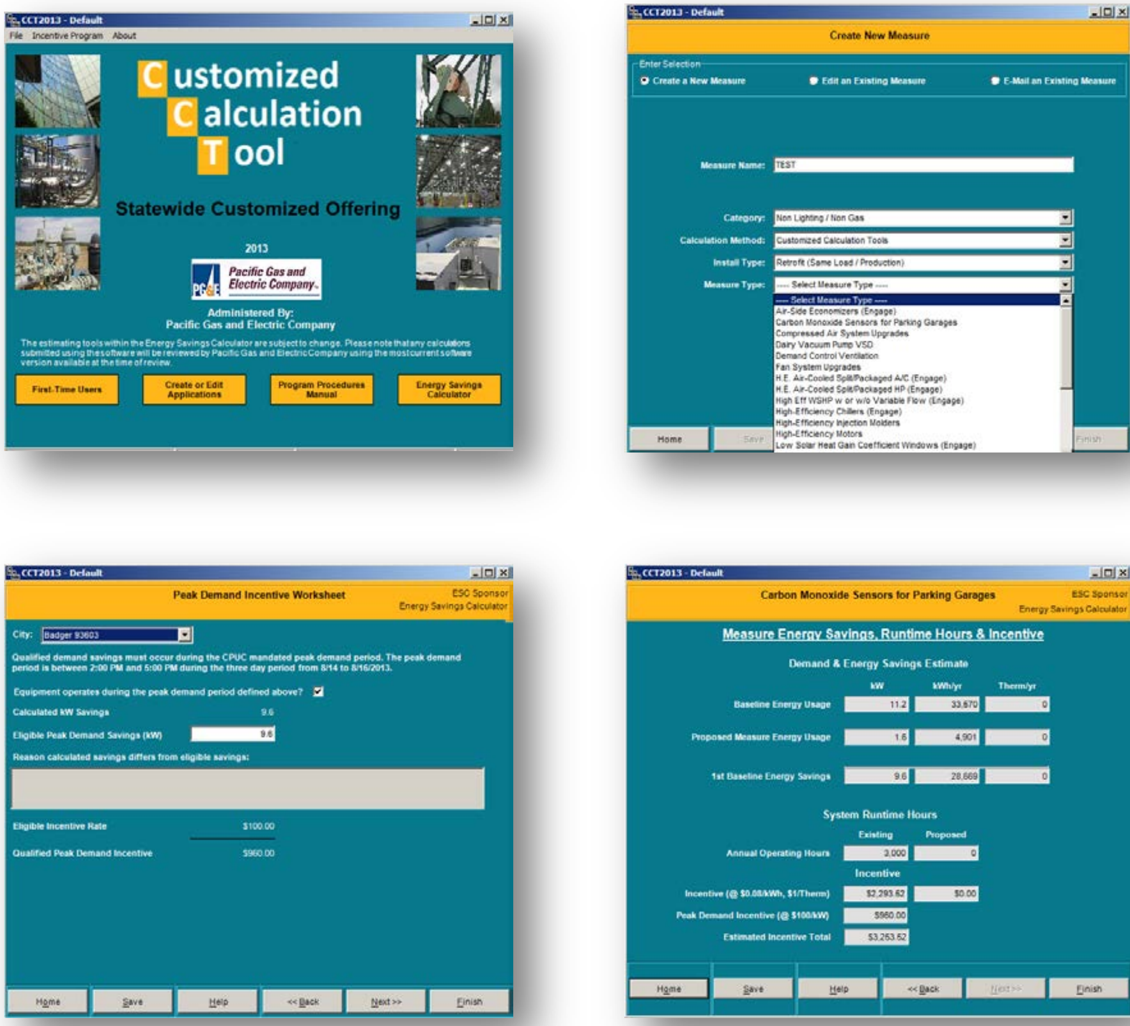


Figure 11 Screen captures of the stand-alone CCT, top left for creating a retrofit project, top right for selecting type of retrofit, bottom left for specifying retrofit project, and bottom right for retrofit analysis and incentive calculation results.

2.3 Tools Developed by the Private Sector

2.3.1 C3 Commercial

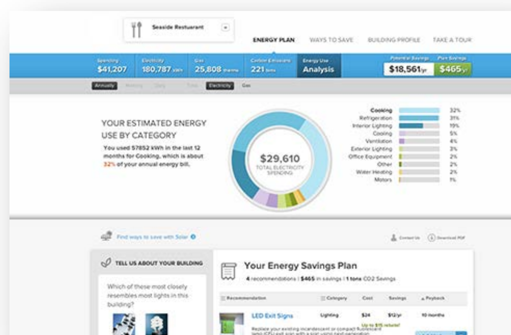
The C3 Commercial is a web-based service offered by C3 Energy, and deployed through utilities. C3 Commercial is a tool to provide energy usage, benchmarking, and retrofit recommendation for SMB customers (C3 Energy 2013). C3 Commercial helps customers understand the energy efficiency of their buildings and promotes energy retrofit efforts from the ECM recommendations. Figure 12 shows screen captures of the C3 Commercial tool for an example building.

Features:

The tool uses the interval data from smart meters extracted from a utility company. The energy consumption is compared to average buildings as well as energy efficient buildings that are functionally equivalent -- the same type and floor area as the candidate building. The benchmark is based on the CEUS. As part of the retrofit analysis, the tool collects building profile information from the input platform, identifies a list of energy saving ideas tailored specifically to the building, recommends energy savings actions, and provides retrofit costs and energy savings.

Gaps:

The analysis is based on a data-driven inverse energy modeling method. The tool is limited when capturing the dynamics of heat gains from internal sources and heat transfer between internal and external environmental conditions. For example, in addition to providing lighting energy savings, a lighting fixture retrofit also reduces the cooling load, thus reducing HVAC system energy consumption. The C3 tool is effective at evaluating a single retrofit measure without considering the interactive effects from multiple measures. The C3 tool is not based on an energy modeling method. Instead, all energy savings from a particular retrofit technology are calculated by statistical analysis built from an existing ECM list using the DEER database. The algorithm used by the tool is not open to public. The C3 Commercial tool only supports buildings in the service areas of utility customers. C3 Energy does not make its API open to public, which limits its use for user customization or further development for various purposes.



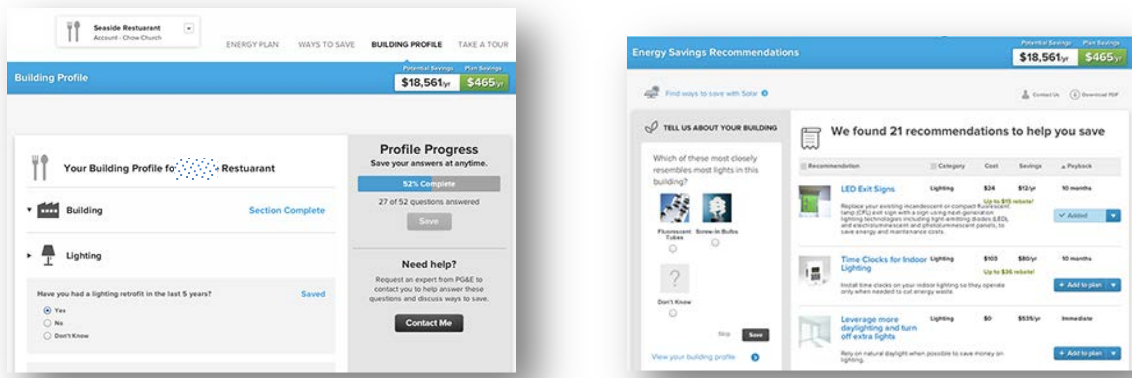


Figure 12 Screen captures of the C3 Commercial tool, top left for energy benchmarking against typical buildings and energy efficient buildings, top right for extrapolated energy end uses, bottom left for building profile input, and bottom right for retrofit analysis recommendations and saving opportunities (C3 Energy, 2013)

2.3.2 Retroficiency

Retroficiency is a private company providing a web-based service that evaluates building energy performance and provides an energy retrofit analysis report for commercial building owners and portfolio energy managers (Retroficiency 2013). Figure 13 shows screen captures provided by Retroficiency.

Features:

The Retroficiency tool has a building energy performance evaluation platform with two layers of service: Virtual Energy Assessment (VEA) and Automated Energy Audit (AEA). The VEA analyzes interval energy data from smart meters to understand how a building responds to weather, occupants' usage, and systems operation, and provides retrofit recommendations. Based on the user's input, the AEA evaluates energy performance using a simplified normative calculation method, and generates life cycle cost analysis and payback period for a selected retrofit ECM.

Gaps:

The tool targets large commercial buildings and portfolios for virtual energy management. The underlying calculation engine performs pattern recognition and develops a statistical model for VEA and a simplified physics-based calculation method for AEA.

The tool is dependent on a reduced-order energy model, which limits detailed analysis when considering dynamic conditions of HVAC system operations and controls. The tool is not in the public domain, thus APIs are not open to the public for further development by a third party.

Figure 13 Screen captures of the Retroficiency tool, top left for interval data analysis, top right for extrapolated monthly energy consumption per energy consumer, bottom left for building profile input, and bottom right for retrofit analysis (Retroficiency, 2013)

2.3.3 Agilis Energy

The web-based Agilis tool uses utility data to perform load shape analysis and evaluate building energy performance (Agilis Energy Analytics & Solutions 2013). Using 3-D graphs, the tool identifies operational energy usage patterns. Agilis illustrates the electrical power from day to day over the course of weeks or months, which can reflect intraday temperatures, demand, occupancy, or even energy system operations. Figure 14 shows screen captures of the Agilis Energy tool for various analyses of the example interval energy data.

Features:

The tool focuses on the operational energy performance based on smart meter interval data and climate data. The system measures the energy performance across similar days and conditions and creates best-fit trend lines to quantify energy and cost savings. The trend lines monitor energy consumption in real time to track and alert the user if savings have been achieved.

Gaps:

The tool conducts energy analysis using a statistical model depending on the smart meter data. It has limitations on detailed retrofit analysis for measures that have energy efficient systems and designs. The tool is not in the public domain, thus APIs are not open to allow further development by a third party.

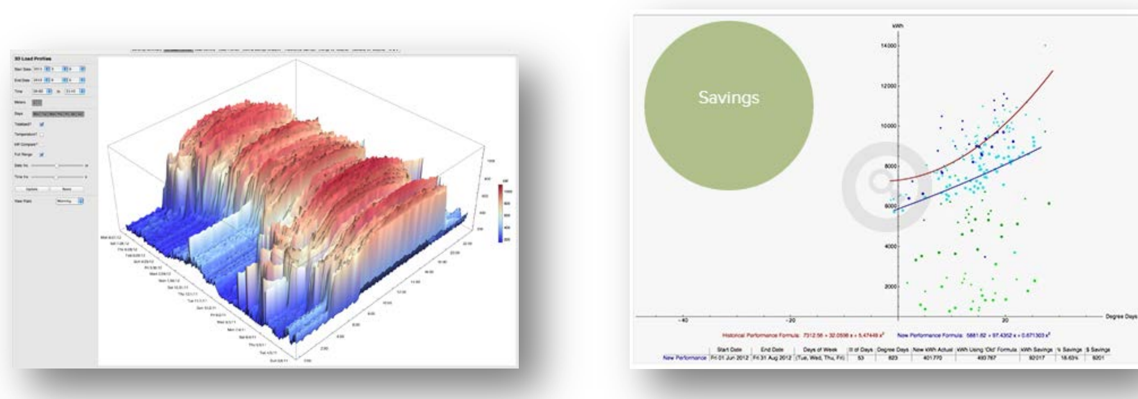


Figure 14 Screen captures of the Agilis tool. Left: 3D graph of interval data, right: energy consumption trend lines (Agilis Energy Analytics & Solutions, 2013)

2.3.4 FirstFuel

The FirstFuel tool is a web-based tool using time series data analysis for building energy estimation and retrofit recommendations (FirstFuel Software 2013). Figure 15 shows screen captures of the FirstFuel tool for energy analysis and benchmarking.

Features:

The tool combines one year of hourly electricity consumption data from the utility, hourly local weather data, and high level building data from geographic information systems. The tool delivers a remote building energy assessment for customers, which benchmarks the building end-use energy performance, customizes operational and retrofit recommendations, and verifies energy savings from actions over time. It is an effective energy performance and building operation tracking tool for facility managers who may not have adequate technical knowledge to analyze a large amount of building energy data.

Gaps:

The analysis is based on a smart meter data-driven statistical model, and may support only limited detailed retrofit analysis. The tool is not in the public domain, thus APIs are not open to the public.

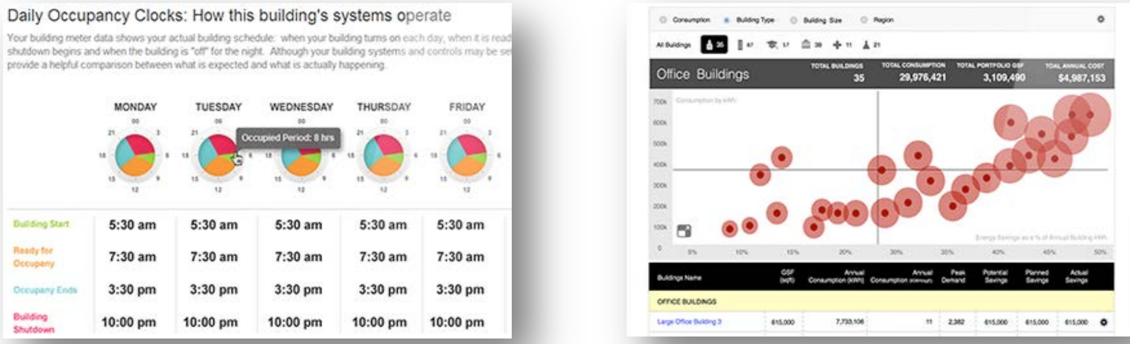


Figure 15 Screen captures of the FirstFuel tool, left for energy consumption analysis, right for energy benchmarking (FirstFuel Software, 2013)

3 Review of Energy Calculation Methods

Retrofit tools can be categorized by three types of calculation methods: (1) empirical data-driven statistical methods, (2) pre-simulated database of retrofit measures, and (3) energy modeling – detailed dynamic simulation or simple algorithms. Table 3 maps the selected tools to the three methods.

Table 3 Energy calculation methods used in the selected retrofit tools

	Energy Modeling				Pre-Simulated Database	Measured data / Statistical Methods
	Dynamic Simulation Use of EnergyPlus		Other Simulations	Simplified Normative Calculation Method		
	OpenStudio SDK (built upon EnergyPlus)	Direct use of EnergyPlus				
Public Sector	Commercial Building Energy Asset Score; simuwatt (a cOncept3D product); EEB HUB simulation platform	Evaluator; CBECC-Com	RESEM-CA; EnergyIQ; EEB HUB simulation platform	Chicago Loop Energy Retrofit Tool	ENCOMPASS; EnergyIQ; COMBAT	EEB HUB simulation platform; DOE Buildings Performance Database
Utility Sector			Customized Calculation Tool			C3 Energy C3 Commercial™
Private Sector				Retroficiency		Retroficiency; Agilis / Energy; FirstFuel

3.1 Dynamic Simulation

Many building energy simulation programs have been developed in recent decades, and in 2008 (Crawley et al. 2008) provided a comprehensive review of the dynamic simulation tools. DOE-2.2, eQUEST, and EnergyPlus are the most frequently used simulation tools in the U.S. DOE-2.2 can simulate the energy use for all types of buildings based on an hourly simulation of the building. eQUEST uses DOE-2.2 as the calculation engine and can be used by energy modelers and engineers from early building design stages to the final stage (James J. Hirsch & Associates 2013).

EnergyPlus is a whole building energy simulation tool mostly targeting engineers and researchers which calculates energy use and environmental performance in buildings (DOE 2013c). EnergyPlus has capabilities that enable the analysis of more innovative and complex mechanical systems than other simulation tools. For example, neither eQuest nor DOE-2.2 can model a variable refrigerant system, radiant cooling and heating system, or natural ventilation. Although EnergyPlus helps energy modeling professionals assess building energy performance in detail, it is a simulation engine without a graphical user interface (GUI). Use of EnergyPlus without a GUI requires a significant background in energy modeling and building systems in order to represent a building correctly. SMB owners typically do not have energy modeling experience, and consequently will not be able to use EnergyPlus for their energy retrofit analysis. To address this issue, graphical user interfaces have been created which use EnergyPlus as their simulation engine. Among them, OpenStudio developed by NREL is publically accessible. More importantly, use of OpenStudio's API enables using EnergyPlus as a calculation engine for third-party energy assessment tool development. Another graphical interface, Simergy, was recently released by LBNL. Simergy can be used by various types of users during the building design process. Simergy is a stand-alone program that needs to be installed on a personal computer running Microsoft Windows.

3.2 Normative Calculation Method

An energy model can be derived from a normative calculation method, which is a first order model based on quasi-steady-state algorithms. The normative method uses dynamic parameters introducing utilization factors for heating and cooling demand calculation, resulting in normatively defined parameters for different locations (ISO 2008). The method is based on a set of calculation standards developed by the European Committee for Standardization (CEN) and the International Organization for Standardization (ISO). It is widely used for energy performance standardization. The standards define the calculation method based on a set of normative statements of functional building category, physical building parameters, and building systems, etc. The method calculates the energy use at different levels of thermal energy demand, delivered energy per carrier, primary energy, and emissions.

The correlation between the normative method outcome and detailed dynamic simulated energy consumption has been studied, and results prove that the approach is adequate to ensure the calculated energy performance as an objective indicator of performance (González et al. 2011; Augenbroe & Park 2005; Beerepoot & Beerepoot 2007).

Through its simplicity and unified modeling assumptions, the method forms the basis for assessing building energy performance in a standardized and transparent way. The method has been mainly used for energy performance rating with standard operating conditions (Poel et al. 2007; Roulet & Anderson 2006). Recently there have been efforts to use this method beyond energy rating, for example to assess large scale energy use at the campus scale and building energy stock (Lee et al. 2013). This method was also tested to perform an energy retrofit analysis for an aggregate of commercial buildings (Heo et al. 2012).

3.3 Statistical Method

Energy consumption can be inferred by extrapolating the energy data of a city or region with a known energy profile and weather information. This can be stated as:

$$PI_i = f(\boldsymbol{X}_{design,i}, \boldsymbol{X}_{operation,i}, \boldsymbol{X}_{climate,i}) + \varepsilon_i$$

where PI_i is an energy performance indicator of observation i, for instance, annual delivered electricity or annual primary energy consumption; $\boldsymbol{X}_{desin,i}$, $\boldsymbol{X}_{operation,i}$, and $\boldsymbol{X}_{climate,i}$ are vectors of design, operation, and climate parameters of observation i, respectively. f is a statistical function identical for all buildings in the data set. ε_i is the error term. A statistical model can be used to estimate a building's energy use based on a large energy consumption data set, which is further applied to infer input parameters of a building energy model; for example, inferring an HVAC system efficiency that would replicate the building stock energy distribution data.

The regression model is based on a statistical method that can be used to solve an inverse problem. By using the inverse model, a building design or operational parameter can then be inferred when energy consumption data is available. Different from a conventional energy modeling process, the inverse statistical model derives inputs from known outputs (Zhao 2012).

The statistical energy performance assessment methods can be used by energy policy makers and utilities to evaluate incentives for energy retrofit and economics of demand-response programs (Swan & Ugursal 2009). The regression analysis and inverse problem solving techniques can also be used by engineers to quickly estimate energy consumption of individual buildings with a few parameters, and can be used by researchers to derive more information from city-wide energy consumption data.

4 Summary

This review explores a wide range of existing tools that could be applied to evaluating energy performance and possible energy efficiency retrofits for small and medium-sized buildings. The sixteen tools described in this report were developed by three sectors, including 1) the public sector (including research institutions and governments), 2) the utilities sector, and 3) the private sector. This review explores and summarizes diverse features of the tools, such as target buildings and audiences, interface type, accessibility, and the calculation methods of each tool. The objective of this document is to help stakeholders understand the status quo of current analysis methods used in the existing retrofit tools.

The existing energy retrofit tools use three major calculation methods: statistical analysis, pre-simulated database, and energy modeling:

- Statistical analysis uses empirical data to extrapolate the energy consumption from a limited set of building information.

- Pre-simulated database creates a database that contains energy savings data for different measures using energy simulations. The database can be used for a quick assessment of energy retrofit.
- Energy modeling uses an engineering method accounting to estimate energy consumption based on the dynamic simulation or simplified normative calculation method.

EnergyPlus is a principal calculation engine for the latest tool development that uses the energy modeling method by most of research institutions and governments. As a simulation engine only, EnergyPlus is difficult to use. Built upon EnergyPlus, OpenStudio provides APIs that can be used by other tools. This enables a much wider use of EnergyPlus for various building energy retrofit projects. The private sector leads the development of tools that are based on statistical methods. The trend is based on the boom in energy benchmarking and energy auditing in commercial buildings. Statistical methods enable private companies to provide a remote energy benchmarking and auditing service with limited building information and utility data. Statistics-based tools can do quick analyses, but they have obvious limitations in capturing dynamics of HVAC system operations and controls under actual building conditions. Consequently, the analysis may not be as accurate as using the energy modeling method.

This document reviewed existing tools, and identified gaps in existing tools for retrofit analysis of small and medium-sized office and retail buildings for California-specific conditions. Furthermore, most tools are not publically available, which can discourage retrofit attempts because SMB owners typically do not have enough resources to conduct an energy performance assessment. Major gaps include the following:

- Due to its complexity, EnergyPlus can be used by technically sophisticated users. However the OpenStudio Software Development Kit (SDK) that is built upon EnergyPlus makes this model more accessible to a wider group of users.
- The current tool used by California utility companies for incentive calculations, the Customized Calculation Tool, is based on eQUEST/DOE-2.2, and lacks the capability to model new technologies such as VRF, natural ventilation, and radiant cooling/heating systems.
- Most tools evaluate retrofit measures individually, without considering or over-simplifying the interactions between measures due to lack of real-time simulations.

An easy-to-use, readily accessible retrofit assessment tool is needed to help SMB owners make wise decisions by providing information about energy savings and economic benefits from the investment in energy efficiency retrofits. This review helps pinpoint a unique desirable approach to address the project objectives. The SMB toolkit project will develop a prototype web-based retrofit application and provide APIs that enable a third party to develop applications using web services. The retrofit toolkit will be free and publically available. It will provide energy benchmarking and various levels of retrofit analysis depending on the degree of input data available and the user’s experience in building systems, operations, and energy efficiency. Energy benchmarking will use external energy benchmarking software APIs including EnergyIQ and ENERGY STAR Portfolio Manager. At the first level, the tool will identify no- or low-cost operational improvements from load shape analysis using electricity and gas data. This level only relies on energy data and outdoor air temperature data. The second level will provide preliminary retrofit analysis based on a database that compiles the pre-simulated energy performance of prototype buildings with retrofit measures, and associated cost data for measures. The database will cover energy performance of offices (small -one story; medium – two stories; and medium – three stories), retail stores (small and medium), and mixed-use (two stories with retail at first floor and office at second floor; and three stories with retail at first floor and office at second and third floors) for 16 California climate zones and various vintages. Levels one and two can be used by all types of users, including those who do not have knowledge of energy performance assessment. The third level will provide a detailed retrofit analysis using real-time EnergyPlus simulations to calculate the energy performance of the building with user-configurable retrofit measure(s). The target audient for this level is facility managers, engineers, and experienced building owners. Required inputs include actual building characteristics, user-defined retrofit measures, and potentially time–of-use energy rate for energy cost saving analysis for peak hours. Level three will allow energy modeling of measures that include emerging technologies and consider synergistic interactions between multiple efficiency measures. The toolkit will also provide indoor environmental quality (IEQ) analysis and address IEQ related implications associated with retrofits such as benefits to occupant comfort and health.

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