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HIGHLIGHTS

- Commercial Building Energy Saver is a powerful toolkit for energy retrofit analysis.
- CBES provides benchmarking, load shape analysis, and model-based retrofit assessment.
- CBES covers 7 building types, 6 vintages, 16 climates, and 100 energy measures.
- CBES includes a web app, API, and a database of energy efficiency performance.
- CBES API can be extended and integrated with third party energy software tools.

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ABSTRACT

Small commercial buildings in the United States consume 47% of the total primary energy of the buildings sector. Retrofitting small and medium commercial buildings poses a huge challenge for owners because they usually lack the expertise and resources to identify and evaluate cost-effective energy retrofit strategies. This paper presents the Commercial Building Energy Saver (CBES), an energy retrofit analysis toolkit, which calculates the energy use of a building, identifies and evaluates retrofit measures in terms of energy savings, energy cost savings and payback. The CBES Toolkit includes a web app (APP) for end users and the CBES Application Programming Interface (API) for integrating CBES with other energy software tools. The toolkit provides a rich set of features including: (1) Energy Benchmarking providing an Energy Star score, (2) Load Shape Analysis to identify potential building operation improvements, (3) Preliminary Retrofit Analysis which uses a custom developed pre-simulated database and, (4) Detailed Retrofit Analysis which utilizes real-time EnergyPlus simulations. CBES includes 100 configurable energy conservation measures (ECMs) that encompass IAQ, technical performance and cost data, for assessing 7 different prototype buildings in 16 climate zones in California and 6 vintages. A case study of a small office building demonstrates the use of the toolkit for retrofit analysis. The development of CBES provides a new contribution to the field by providing a straightforward and uncomplicated decision making process for small and medium business owners, leveraging different levels of assessment dependent upon user background, preference and data availability.

1. Introduction

In 2014, 41% of the total U.S. energy consumption was consumed in residential and commercial buildings [1]. 95% of small and medium-sized commercial buildings (less than 50,000 ft^2 or 4645 m^2), occupied 51% of the total floor space of all buildings, and represented 47% of the primary energy in the building sector [2]. With new-building replacement rates at an all-time low (1.0–3.0% per annum) [3,4], energy retrofits on existing buildings provide a viable solution to reduce building energy consumption. Over half (55%) of the energy consumption in small and medium buildings comes from HVAC equipment, with HVAC, lighting and plug loads accounting for almost 90% of the total consumption [5]. Alajmi [6] suggested that 6.5% of the building's annual energy consumption can be saved by low or no cost capital investments, whereas almost half (49.3%) of the annual energy consumption can be saved through extensive investment in retrofit projects. Despite the established benefits of energy retrofit solutions, energy upgrades for commercial buildings occur at very low rates (2.2% per year) [7]. Retrofitting small and medium commercial buildings, poses a huge challenge for small and medium business owners

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(SMBs). Small businesses are hard to reach because they lack the monetary, personnel, and technological resources of large organizations. Small business owners and energy professionals do not have easy and low-cost access to tools that can be used to identify cost-effective energy efficient retrofits. Transaction costs are also a barrier in small buildings, even when owned by large corporations. Therefore, there is a strong need for the development of easy-to-use, low cost tools that can identify cost-effective energy efficient retrofit solutions and specifically target SMB owners.

The objective of energy retrofits is to improve the building energy efficiency by implementing a mixture of energy saving technologies and system upgrades, at an equitable cost [8]. Gliedt and Hoicka [9] and Cagno et al. [10] assessed the barriers of energy performance improvements, suggesting among other factors (e.g. installation costs, difficulty securing financing, payback periods etc.) that incorrect perceptions of the building efficiency and difficulty in accessing affordable and credible external expertise, were key barriers limiting upgrades. Although a broad range of technologies are available and major efforts have occurred in the public and utility sectors to promote and accelerate retrofit activities, the main challenge remains in identifying the most effective retrofit strategies that meet investment criteria [11]. In today's technological world, web-based apps with a user interface and underlying engineering algorithms bring retrofit solutions to building owners [12,13].

Data-driven methods, such as benchmarking and load shape analysis that rely on real measured data, smart meter data and pre-defined databases, provide a simply method to gauge building energy performance [14]. Benchmarking, conducted during the outset of building energy retrofitting, outlines the energy use profile to easily identify subpar performing buildings [15]. Measurement-based benchmarking compares observed energy from an individual building against benchmarks derived from monitored or measured data [16]. At its simplest form, energy-efficiency indicators for commercial buildings such as the energy consumption and floor area are used to calculate the Energy Use Intensity (EUI) and tabulated into a table or database [17]. Filippín [18] calculated the EUI for benchmarking school buildings in central Argentina. FirstFuel used time series data to benchmark and provide building energy estimations. Alternatively, calculation-based benchmarking compares observed energy use with theoretical (simulated) energy use [19,20]. Henze et al. [21] developed an energy signal tool to provide owners and operators of commercial buildings with a likely range of expected energy consumption.

The advent of more benchmarking tools has increased the number of databases hosting actual building energy data. Notably, Lab 21 [22] collects benchmarking data for US laboratories and Portfolio Manager collects energy benchmarking data to assign an ENERGY STRAR score for different building types. The Building Performance Database (BPD) allows users to compare building energy use with peer buildings. The coupling of high performance computing (HPC) with energy efficiency performance parameters derived from building simulations has allowed for the development of extensive databases of large sets of packaged simulations further enabling retrofit analysis solutions [23]. EnCompass uses pre-simulated EnergyPlus simulations stored in a database to be used as reference buildings in benchmarking. Despite the emergence of different databases, due in part to benchmarking, there still exists the need for the creation and development of comprehensive building energy databases [24].

Extending beyond benchmarking and database creation, more complex retrofit toolkits are powered by their calculation type, using empirical data-driven methods, normative methods and physic-based energy models [25]. Normative calculation methods use a set of normative statements containing the physical building parameters and building systems to perform a first order model based on quasi-steady-state heat balance equations [26]. HELiOS Building Efficiency, uses Bayesian calibration methods as part of its web-based platform, allowing non-experts to conduct rapid retrofit analysis. The most complex, highest fidelity, of the calculation types, physics-based energy modeling, utilizes simulation engines such as DOE 2.2 and Energy Plus [27]. Some common web-based tools which use physics-based energy models include: (i) the Customized Calculation Tool (CCT) that focus on the California utility market and use a modified version of eQuest and DOE 2.2 to provide outputs such as peak demand, energy savings from a baseline, and estimated total incentives and (ii) the Consortium for Building Energy Innovation (CBEI Tools) that uses EnergyPlus simulations through the OpenStudio platform and the Retrofit Manager Tool to conduct energy audits and retrofit recommendations to energy managers and consultants.

Pre-simulated approaches have some limitations such as using prototypes which do not match the actual geometry or features of the building being modeled. Alternatively, real-time energy simulation toolkits which used EnergyPlus or eQUEST suffer from complexity, longer data input and simulation run time [28]. Different tools offer different prediction uncertainties, with the high fidelity physics-based methods leading to more accurate results, but suffering from intricacies whereas simpler benchmarking or database methods suffer from accuracy [25]. Additionally, with building performance influenced by the physical building characteristics (structural design, climates, sub-component systems) and the stochastic interaction of occupants with sub-level components (i.e. lighting, HVAC systems etc.), energy modeling is challenging to predict [13]. Errors associated with data input, the user's skill, project scope and timeline all influence the simulation speed, and output quality [29]. Wang [30] evaluated 14 existing commercial building tools, standards, and rating systems, reviling large gaps between calculated (modeled) and measured building energy use. Understanding the need for new features and capabilities of energy analysis tools is extremely important to identify robust and low cost techniques to reduce the energy use in buildings.

Retrofit techniques utilize energy conservation measures (ECMs) that are technological upgrades for electric lighting, building envelope, equipment (i.e. plug loads), heating, ventilation, and air conditioning (HVAC), service hot water and occupancy or schedules. Some specific examples of ECMs used in CBES include installing daylighting sensors for interior lighting control, replacing wall and ceiling, or roof insulation, upgrading an HVAC rooftop unit with a high efficiency unit, adding an economizer, or upgrading to LED lights [31]. Hong et al. [32] identified a package of measures resulting in an estimated 20% improvement of the whole building electricity consumption. Li et al. [33] showed the three most commonly installed energy-efficient technologies in high performance buildings (HPBs) are daylighting (76.5%), high efficiency HVAC systems (64.7%), and improved building envelope (62.7%). However, the effectiveness of the widespread deployment of these technologies depended on the specific building characteristics, such as location, size, operation building envelope, electrical, heating, cooling and ventilation system properties [33] and the integrated effects (i.e. the sum of individual ECMs does not equate to a package ECMs) [34].

This paper details the development and primary aspects of the Commercial Building Energy Saver (CBES) (cbes.lbl.gov), an energy retrofit toolkit. CBES, developed by Lawrence Berkeley National Laboratory, provides an easy, yet powerful, tool for building owners, facility managers and energy consultants to conduct a quick retrofit analysis of small commercial buildings. The development of CBES provides a new contribution to the field of building energy retrofit toolkits and energy efficiency assessment. Its formulation addresses four main aspects:

(1) Provides a straightforward and uncomplicated decision making process for SMB owners leveraging different levels of assessment dependent upon user preference and background.
(2) Contains energy benchmarking, load shape analysis, preliminary retrofit analysis and detailed retrofit analysis features providing results for simple data input to complex real-time EnergyPlus simulation analysis.
(3) Provides an application program interface (API) which can be easily integrated and adopted by third party tools.
(4) Includes one of the most extensive ECM lists that encompass IAQ, technical performance and cost data.

This paper provides an explanation of the key elements that went into the development of the CBES toolkit, including the (1) software architecture, (2) energy benchmarking, (3) load shape analysis, (4) energy conservation measures, (5) preliminary retrofit analysis (6) detailed retrofit analysis, (7) prototype building, (8) energy model calibration, (9) the impact of retrofit measures on IEQ, and (10) EnergyPlus and OpenStudio. In addition, a case study is presented to demonstrate the tool's operational function. The capabilities and limitations of the CBES provide valuable insights into the role web-based toolkits have in reducing building energy consumption.

2. Synopsis of CBES Toolkit features

The CBES Toolkit helps users analyze the energy performance of buildings for pre- and post-retrofit to identify optimal energy retrofit measures and evaluate their energy savings and economic payback. CBES targets a broad audience including building owners, facility managers, energy managers, building operators, energy auditors, designers, engineers and consultants.

The features of CBES provide energy benchmarking and three levels of retrofit analysis depending upon the user's experience and the degree of the input data (Fig. 1). An overview of the features includes: (1) Benchmarking using the EnergyIQ [35] and Energy Star Portfolio Manager [36], (2) Load Shape Analysis (Level 1) to identify potential building operation problems or unexpected changes in energy use patterns using statistical analysis of the building's 15-min interval electric load data, (3) Preliminary Retrofit Analysis (Level 2) provides a quick look-up table style assessment of retrofit measures with their energy and cost benefits using a database of energy efficiency performance metrics [37], and (4) Detailed Retrofit Analysis (Level 3) performs on-demand energy simulation using EnergyPlus to calculate the energy performance of the building with user configurable ECMs and a detailed description of the building and its operation characteristics. The CBES Toolkit considers the impact of ECMs on indoor environmental quality (IEQ) during the retrofit of a building.

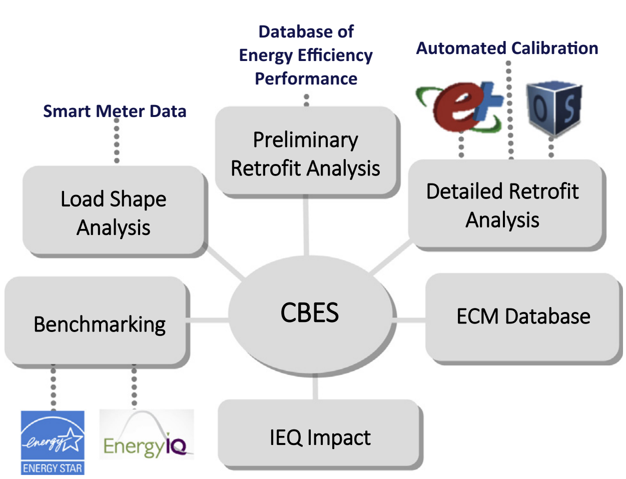


Fig. 1. Key components of the CBES Toolkit.

The CBES Detailed Retrofit Analysis employs advanced automated calibration algorithms to attune inputs prior to simulating the energy savings of ECMs. For the detailed retrofit analysis, on-demand energy simulations using OpenStudio SDK and EnergyPlus calculate the energy performance of the building with user configurable ECMs. CBES is flexible enough that the user can use any feature (i.e. the benchmarking, no- or low-cost improvement, or preliminary retrofit evaluation), after the common inputs are provided. To extend geographically beyond California, a U.S. national version based on the same API called the Whole Building Retrofit Tool is available at the 2030 Districts web portal [37].

The CBES Toolkit has two main components, the CBES App and the CBES API. The CBES API guides the programming interface to command the full features of the CBES retrofit analysis. The CBES App is a web-based prototype app aimed at demonstrating the main features and provides a sample user interface that calls the CBES API. A snapshot of the CBES App shows the main layout menus (Introduction, Common Inputs, Benchmarking, No- or Low-Cost Improvement, Preliminary Retrofit Analysis, Detailed Retrofit Analysis, Contacts) and the sub menus required for the detailed retrofit analysis (Fig. 2).

2.1. Software architecture

The CBES API is the core of the toolkit. It utilizes three external APIs and four databases, including the pre-simulated Database of Energy Efficiency Performance [38], a prototype buildings database, an ECM and cost database, and a zipcode database. Each database was uniquely created or tailored specifically for CBES. The software architecture has three layers: (1) the CBES API, the core; (2) the External APIs, the bottom layer, and (3) the top application layer with third party applications/GUIs and CBES Web App. A schematic diagram of the CBES Toolkit software architecture is shown in Fig. 3. The object oriented software architecture of CBES enables its expansion for more features, e.g. additional building types, more climates, and new retrofit measures, as well as its integration with other energy software via the CBES API.

2.2. Energy benchmarking

Energy benchmarking is usually the first step in a retrofit analysis. Benchmarking compares a building's actual energy use with peer buildings and the potential for retrofit energy savings. If the building consumes more energy (in EUI) than most peer buildings, significant energy savings may be attained by retrofitting the building using the latest technologies and operational improvements. The data needed for benchmarking include the building information (e.g. type/use, vintage, location and floor area), and 12 months of utility usage data. Following the data input, CBES calls EnergyIQ [35] and Energy Star Portfolio Manager [36] APIs to perform the benchmarking analysis. The benchmarking results include an Energy Star score of the building and the ranking of the building, in terms of EUI, compared with the peer buildings in California. The U.S. Environmental Protection Agency's Energy Star program developed an energy performance rating system, using a scale of 1–100, to provide a means for benchmarking the energy efficiency of specific buildings to evaluate their energy performance. For assessing the Energy Star score, a minimum score of 75 is required for Energy Star certification [39].

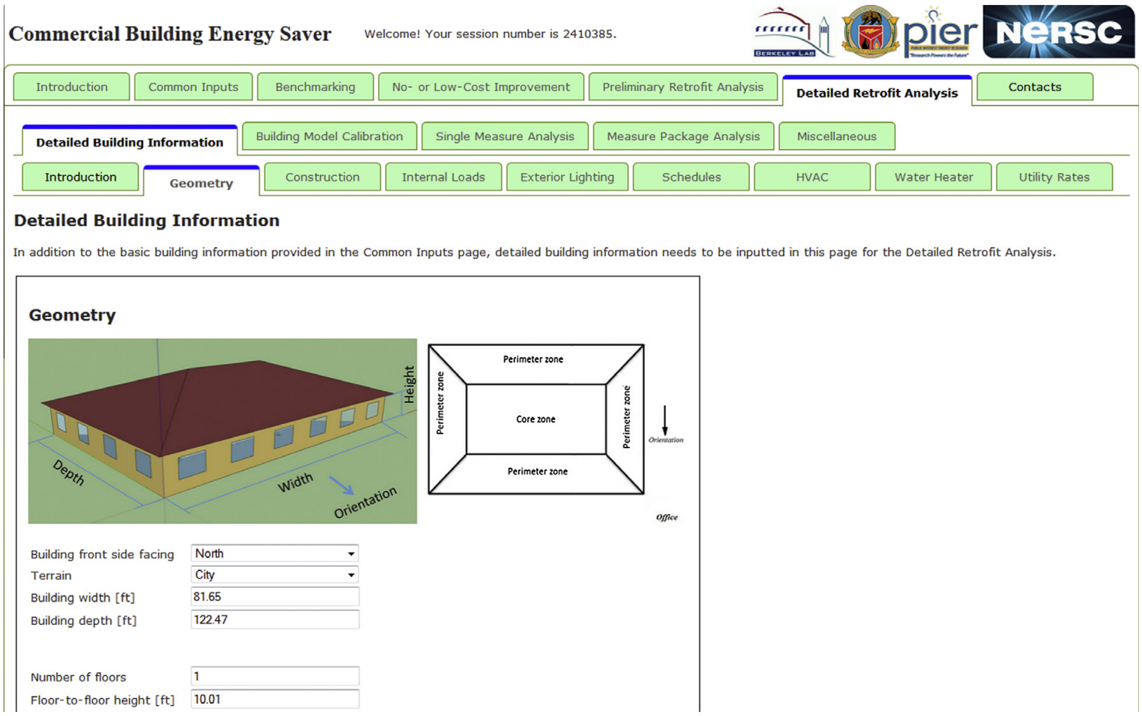


Fig. 2. The CBES App, cbes.lbl.gov.

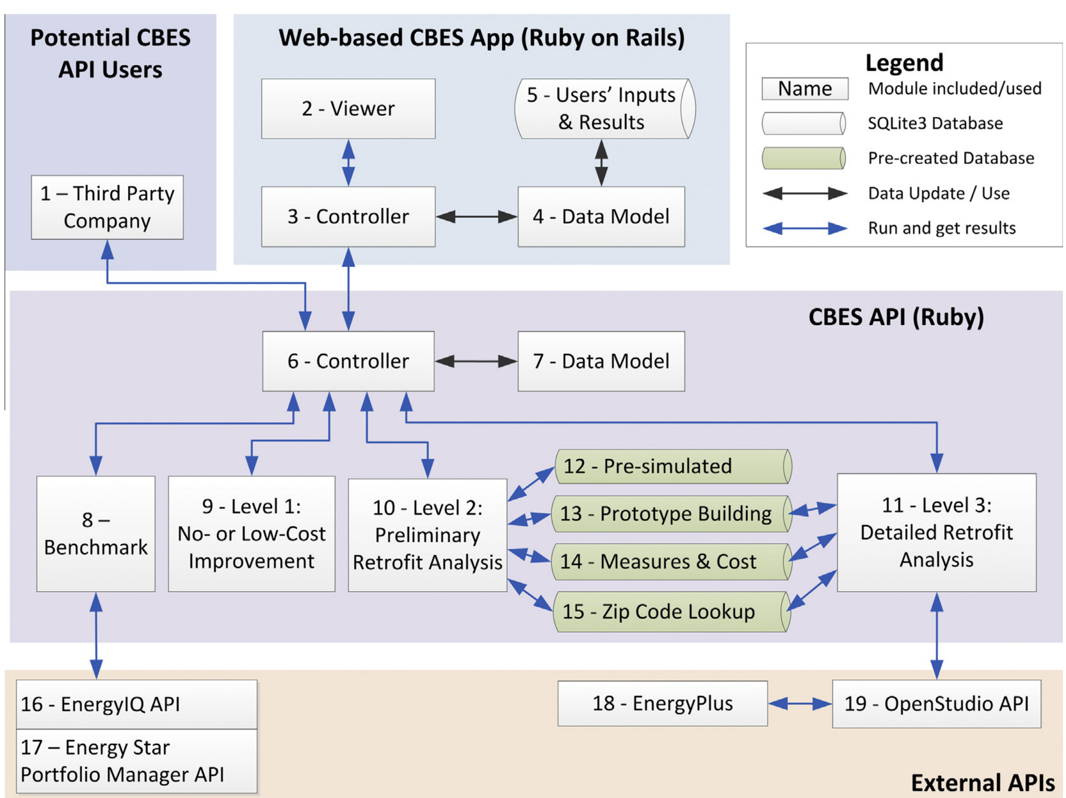


Fig. 3. The software architecture of the CBES Toolkit.

2.3. Load shape analysis – Level 1

The CBES Toolkit provides load shape analysis to identify low- or no- cost improvement opportunities based on statistical analysis. The input data needed to conduct the load shape analysis includes: (1) smart meter data at 15 min intervals of electricity use, (2) the building floor area, and (3) the outdoor air temperature. The load shape analysis results show the operational and non-operational hours of the building, as well as the average load during those hours. These findings may indicate high energy consumption during the non-operational hours because some lighting, HVAC and plug equipment are unnecessarily operating. The results also provide the sensitivity of building energy use vs outdoor air temperature, which can be an indicator of the building's overall envelope insulation performance or the amount of outdoor air used for ventilation or cooling.

2.4. Energy conservation measures

The CBES Toolkit includes a rich set of ECMs, each to be considered as a potential retrofit measure. The measures were compiled from extensive literature review and included the following sources: the Database for Energy Efficiency Resources (DEER) [31], the Advanced Energy Retrofit Guide for Office Buildings [40], Advanced Energy Retrofit Guide for Retail Buildings [41], Advanced Energy Design Guide for Small to Medium Office Buildings [42], Small HVAC System Design Guide [43] and RSMeans (rsmeans.com). From this, an ECM database of over 100 ECMs, was compiled. The database includes detailed descriptions of the technical specifications, modeling methods and investment costs for each ECM. In general typical and emerging building technologies of the building envelope, HVAC, indoor lighting, plug-loads, service water heating, outdoor lighting, and building operation and maintenance were specified. A sample list of 9 out of the 100 ECMs is shown in Table 1.

2.5. Preliminary retrofit analysis – Level 2

The Preliminary Retrofit Analysis aims to provide a quick assessment and screening of the ECMs and identifies which are the most applicable to the building. This analysis is intended to be performed at the early stage of a retrofit project and is not as extensive as the detailed retrofit analysis. The minimal data needed to conduct the preliminary retrofit analysis includes the building information (type/use, floor area, vintage, and location), and the investment criteria (e.g. maximizing energy savings, cost savings, CO_2 reduction, or economic payback). The preliminary retrofit analysis uses the SQL based database, called DEEP [37,44] that was created from pre-simulated results of about 10 million EnergyPlus simulations, run on clusters, in the U.S. Department of Energy's National Energy Research Scientific Computing Center (NERSC). Each simulation calculated the energy performance of the ECM in conjunction with the 7 different prototype buildings, 16 climates and 6 vintages. To provide perspective, running so many EnergyPlus simulations would take about 40 years on current desktop computers. The results provide the user with the measures which best fit the investment criteria and provide some analysis of the energy and cost savings. Additionally, the measures identified from the Level 2 preliminary retrofit analysis, will be stored for use in the Level 3 detailed analysis.

2.6. Detailed retrofit analysis – Level 3

The detailed retrofit analysis enables building owners and energy managers to make retrofit decisions by quantifying the energy and cost performance of the retrofit measures. This level of analysis requires energy professionals to enter extensive details about the building, in an effort to further customize the prototype building to match the actual building. The required user input data includes the following general categories: geometry, construction, internal loads, exterior lighting, schedules, HVAC, water heater, and utility rates. For guidance, default input parameters based on the zipcode, building type and the built year, are provided. The default values are extracted primarily from California's building energy efficiency standards Title 24 [45] and ASHRAE standard

Table 1
A sample list of energy conservation measures in the CBES Toolkit.

Category	Component	Name	Description
Lighting	Interior lighting equipment retrofit	Replace existing lighting with LED upgrade (6.5 W/m^2)	Replace existing lighting to LEDs with 6.5 W/m^2 [2.38 Btu/h/ft^2]. LEDs consume less power and last longer than fluorescent lamps. A retrofit kit is recommended for converting ballasts. Replacement may improve lighting quality
Plug Loads	Equipment control	Use plug load controller (30% efficient from baseline)	Connect plug loads to a smart plug strip with some or all of the following functions: Occupancy sensing, load sensing, timers, remote control
Envelope – exterior wall	Exterior wall	Apply wall insulation (R21)	Apply blown-fiberglass insulation (R21) to wall cavity will help maintain the thermal comfort. Insulation provides resistance to heat flow, taking less energy to heat/cool the space
Envelope – roof	Roof	Reroof and roof with insulation	Demolish existing roof, install insulation (R24.83) and reroof to reduced unwanted heat gain/loss. This measure is most applicable to older roofs
Envelope - window	Window	Replace fixed-window to U-factor (0.25) and SHGC (0.18)	Replace existing window glass and frame with high performance windows by changing the U-factor and SHGC of the window material. The U-factor is a measure of thermal transmittance and SHGC stands for Solar Heat Gain Coefficient, values taken as 1.42 W/(K m^2) [0.25 Btu/(h ft^2 °F)], SHGC: 0.18. The SHGC and U-factor are 30% below Title 24 values
Service hot water	Storage tank	Efficiency upgrade of the gas storage water heater	Replace the existing service hot water heater with more efficient gas storage unit, with better insulation, heat traps and more efficient burners to increase overall efficiency of (0.93)
HVAC – cooling	Cooling system	Packaged rooftop VAV unit efficiency upgrade (SEER 14)	Replace RTU with higher-efficiency unit with reheat, SEER 14. Cooling only; include standard controls, curb, and economizer
HVAC – economizer	Ventilation	Add economizer	Install economizer for existing HVAC system (includes temperature sensors, damper motors, motor controls, and dampers). Typically an economizer is a heat exchanger used for preheating
Envelope – infiltration	Infiltration	Add air sealing to seal leaks	Air sealing can reduce cold drafts and help improve thermal comfort in buildings. Air sealing is a weatherization strategy which will change the air exchange rate and IAQ

90.1 [46]. User customization is possible, where each default parameter can be changed by the user.

The detailed retrofit analysis provides a streamlined process to create and run real-time detailed EnergyPlus models based on the user's input information. Prior to evaluating the ECMs, an automatic model calibration procedure is recommended to bring the predicated energy consumption close to the utility bills of the baseline building. Based on the detailed baseline energy model (either calibrated or not), single retrofit measures as well as user defined packages of measures can be evaluated for potential energy and cost savings. Unlike many existing retrofits packages, the detailed retrofit analysis allows the use of actual weather data and utility bills to calibrate energy models and does consider the integrative effects of multiple measures. These capabilities enable a more accurate assessment when determining appropriate retrofit measures. The outputs generated include the annual site energy and CO_2 emissions, the annual economic analysis and annual energy cost savings percentage. For this level, knowledge of the building systems and energy modeling is required to gain effective and correct results.

2.7. Prototype buildings

The CBES Toolkit uses prototype building models for the Level 2 and the Level 3 Retrofit Analyses. The prototype buildings were developed based on the Database for Energy Efficiency Resources (DEER) [47], the USDOE reference buildings [48], and California Title 24 building energy standards [44]. The prototype building models represent seven small and medium-sized office and retail building types in all 16 climate zones in California at six vintages (year built) (Table 2). The six vintages are: Before 1978, 1978–1992, 1993–2001, 2002–2005, 2006–2008, 2009–2013, each representing a specific version of Title 24 [44]. The prototype models contain detailed characteristics of the building and systems, internal loads, and operation schedules.

2.8. Energy model calibration

The CBES Toolkit Level 3 Detailed Retrofit Analysis uses a new pattern-based, automated calibration approach, to calibrate the building model with monthly electricity and natural gas consumption data. A model is considered calibrated if the differences between the simulated and measured monthly electricity and natural gas data are small enough to meet the criteria defined in ASHRAE Guideline 14 [49] (i.e. the Normalized Mean Bias Error (NMBE) is less than 5%, and the Coefficient of Variation of the Root Mean Square Error (CVRMSE) is less than 15%).

The pattern-based calibration approach first compares the monthly measured and simulated energy use of the building to determine the bias. This bias can be a consistent year-round trend, such that the simulated energy use is always higher or lower than the actual consumption, or a seasonal trend such that the simulated energy use is only higher or lower than the actual consumption during summer, spring, fall or winter seasons. Different patterns indicate different symptoms of the energy model deviating from the actual building, and different sets of model parameters will be adjusted during the automatic calibration. A list of 16 model parameters, shown in Table 3, are the main drivers of the various patterns based on a sensitivity analysis of the prototype models. CBES adjusts one parameter at a time, runs the EnergyPlus simulation, then compares the simulated energy use with the actual energy use to determine whether the calibration criteria are met. If not, it determines a new deviation pattern and then moves on to adjust the next parameter. The calibration procedure stops when the calibration criteria have been met or when the number of simulations reaches a pre-set maximum.

Table 2
The prototype buildings in the CBES Toolkit.

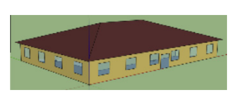
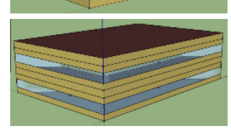
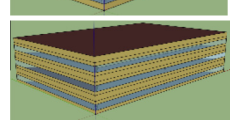
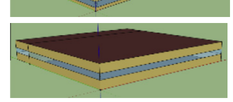
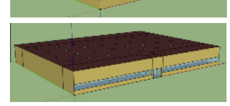
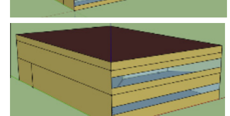
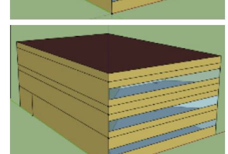
Building types		Gross floor area (m^2/ft^2)	Forms	Climate zones	Vintages
Prototype buildings					
Office	Small 1-story	511/5500		CZ 1: Arcata CZ 2: Santa Rosa CZ 3: Oakland CZ 4: Sunnyvale CZ 5: Santa Maria CZ 6: Los Angeles CZ 7: San Diego CZ 8: El Toro CZ 9: Pasadena CZ10: Riverside CZ11: Red Bluff CZ12: Sacramento CZ13: Fresno CZ14: China Lake CZ15: El Centro CZ16: Mount Shasta	Before 1978 1978–1992 1993–2001 2002–2005 2006–2008 2009–2013
	Medium 2-stories	929/10,000			
	Medium 3-stories	4982/53,628			
Retail	Small	743/8000			
	Medium	2294/24,962			
Mixed-use	Retail at the 1st floor, office at the 2nd Floor (929/9996)				
	Retail at the 1st floor, office at the 2nd and 3rd Floors (1394/14,494)				

Table 3
A list of parameters to adjust in model calibration.

Category	Influencing factors
Internal loads	Occupant density Lighting power density Electric equipment power density Outdoor air flow rate Infiltration rate
HVAC system	Cooling efficiency Heating efficiency Fan efficiency Cooling temperature setpoint Heating temperature setpoint With or without Economizer
Construction	Window U-value Window SHGC
Schedules	HVAC operation schedule Lighting schedule Electric equipment schedule

The pattern-based calibration approach is fully automatic without any need of manual intervention. The approach employs predefined rules, determined by characteristics of bias patterns, to adjust the model parameters. This method is very different from the traditional optimization-based automatic calibration approach which searches a parameter space according to a specific optimization algorithm to minimize the difference between the simulated and measured energy use of the building.

The procedure provides detailed results of the adjusted parameter, the simulated energy use, and the NMBE and CVRMSE for each step in the calibration process. More details of the automated calibration approach will be described in a separate paper. CBES does provide an alternate, Customized Calibration, to the automated calibration which allows users to choose a list of parameters to tune and input their ranges for the calibration. The calibration is the longest phase of the process (several minutes to an hour depending on the building complexity and the deviations between user inputs and true values).

2.9. Impact of retrofit measures on IEQ

Energy efficiency retrofits will affect the indoor environmental quality positively or negatively. In particular, increased insulation will impact the thermal comfort conditions, weatherization or the sealing of cracks can reduce the air exchange rate potentially leading to an increase in the level of indoor pollutants, a decreased productivity and sick-building syndrome [50–52]. Lee et al. [25], following a review of 19 retrofit toolkits, showed that only 25% of the tools mentioned IEQ, suggesting ample opportunity for toolkits to evaluate a wider range of environmental parameters. The CBES Toolkit provides 23 IEQ recommendations in conjunction with 48 retrofit measures. The goal is to equip decision makers with basic information about some of the potential IEQ effects associated with the retrofit measures.

2.10. EnergyPlus

EnergyPlus, was selected based on its extensive features, notoriety and code validation, as the simulation engine used in the CBES Toolkit. Simulating the performance of a building with EnergyPlus enables building professionals, scientists and engineers to optimize the building design and operations, to use less energy and water. Each release of EnergyPlus is continually tested extensively using more than four hundred example files and the test cases defined in the ASHRAE Standard 140 [53]. EnergyPlus, an open source code that runs on the Windows, Macintosh, and Linux platforms and models heating, ventilation, cooling, lighting, water use, renewable energy generation and other building energy flows. EnergyPlus includes many innovative simulation capabilities including time-steps less than an hour, modular systems and plant integrated with heat balance-based zone simulation, multi-zone air flow, thermal comfort, water use, natural ventilation, renewable energy systems, and user customizable energy management system. These features make EnergyPlus ideal for the CBES toolkit.

2.11. OpenStudio

The CBES API builds upon the open source OpenStudio SDK platform. OpenStudio is a collection of software tools that support whole building energy modeling using EnergyPlus and has advanced daylight analysis using Radiance [54]. The implementation of ECM measures causes the modification of the model component connections, which can be time-consuming and challenging, but the CBES API, based on OpenStudio, is able to easily handle this process. OpenStudio allows building researchers and software developers to quickly get started through its multiple entry levels, including access through C++, Ruby, and C#. All of these reasons were taken into consideration when choosing to use OpenStudio for the CBES toolkit.

3. Case study

This section provides an example of how to use the CBES toolkit. A hypothetical building owner has a one-story small office located in San Francisco, California. The building has a packaged DX cooling system with gas furnace for heating. The utility rate of electricity is \$0.17/kWh and \$2.52/kW, and for natural gas \$0.99/therm (1 therm = 100 kBTU). The owner wants to benchmark the building energy consumption with other peer buildings and then, if needed conduct a retrofit analysis. He has a total of \$15,000 to invest in the retrofit project, he wants the simple payback period to be less than three years and his primary goal is to save energy cost. Table 4 summarizes his available data for the CBES common inputs section and Table 5 shows the monthly electricity and natural gas consumption of his buildings in 2014.

Table 4
Input data for the CBES Toolkit common inputs.

Input variable	Description
Building type	1-story office building
Zip code	94127
Year built	1977
Gross floor area	7500 ft^2 (697 m^2)

Table 5
Monthly electricity and natural gas usage.

Month	Electricity (kWh)	Natural gas (kBTU)
January	10,223	13,621
February	9156	8528
March	10,568	7204
April	9501	6149
May	10,162	3330
June	10,178	2608
July	10,118	1908
August	10,881	2103
September	10,362	2094
October	10,213	3903
November	9825	8055
December	10,043	12,578

3.1. Energy benchmarking

The benchmarking results show that the building has an Energy Star score of 17 and the building's annual total primary energy use is 65 kBTU/ft^2·a (204 kWh/m^2 a). The EnergyIQ benchmarking result shows that the site energy consumed for a typical building, similar to this building is 31.9 kBTU/ft^2·a (101 kWh/m^2 a) (median), with a range of 22.4–91.6 kBTU/ft^2·a (71–289 kWh/m^2 a) (5th to 95th percentiles). Therefore, the building consumes more energy than 88% of its peers. The results suggest that the energy performance of the building is poor and therefore there is a significant energy savings potential with retrofitting the building. Fig. 4 shows the CBES benchmarking results.

3.2. Load shape analysis – Level 1

The Load Shape Analysis of CBES provides operational improvement recommendations from the result of the interval data analysis. CBES provides four seasonal sets of graphical results, with Fig. 5 showing a snippet for the months of June, July, and August, 2014, with the black line indicating the electric load for a typical (average) week and the grey lines indicating individual weeks.

The results show that the energy consumption during the daytime period on the weekends is higher, relative to non-operating hours. This trend may indicate that the HVAC system and other electrical equipment are operating despite occupant absence during the weekends. Fig. 6 shows the average power as a function of the weekly operating and non-operating hours of the building for June, July and August. The results indicate that the building has half the average rate of energy use during non-operating hours (2 kW) than during operational hours (4 kW). This non-operational energy consumption is non-trivial and could indicate lighting and/or equipment maybe unnecessarily operating.

Fig. 7 shows a sensitivity analysis of the whole building electricity use as a function of outdoor air temperature divided by different times of the day. The results indicate that the electricity use is slightly sensitive to the outdoor air temperature during the daytime hours, and less so during the nights. However, this building is located in San Francisco, California and a greater contrast could be achieved from buildings located extreme climates. In addition, this building has small cooling loads and space heating is handled by a furnace using natural gas instead of electricity, leading to the minimal differences in the load as a function of outdoor air temperature.

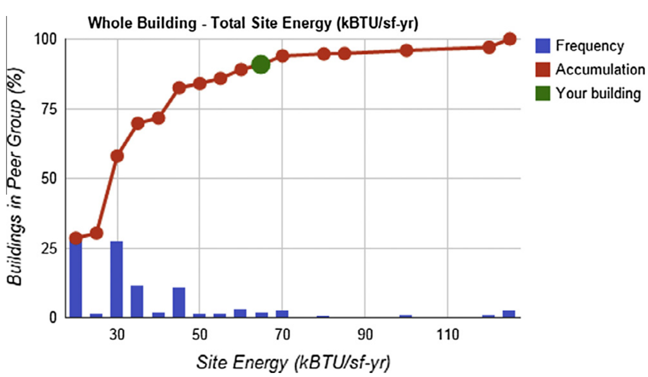


Fig. 4. Example benchmarking results from the CBES Toolkit.

3.3. Preliminary retrofit analysis – Level 2

With these initial results, the building owner want to conduct a quick retrofit analysis to see what retrofit options are available. For the preliminary retrofit analysis, the owner is able to provide some additional input parameters about his building. For example, he had previously upgraded the lighting system of the building to reduce the lighting power from 2.0 to 1.1 W/ft^2 (21.5–11.8 W/m^2). This information was included in the CBES data input.

For the preliminary retrofit analysis, the input information along with querying the DEEP [37,44] database will unearth the recommended ECMs that meet the owner's investment criteria. The ECM results, ranked by the investment criteria, are shown in Table 6. The three selected ECMs are ECM 1 (upgrade current lighting with T8), ECM 12 (add HVAC air economizer) and ECM 15 (use plug loads controls). The process of generating these results took 3–5 min.

A description of the measure, the potential IEQ impact during retrofit for each measure, the investment cost, energy use and cost, as well as the energy use savings and energy cost savings compared with the baseline results of the building before retrofit are

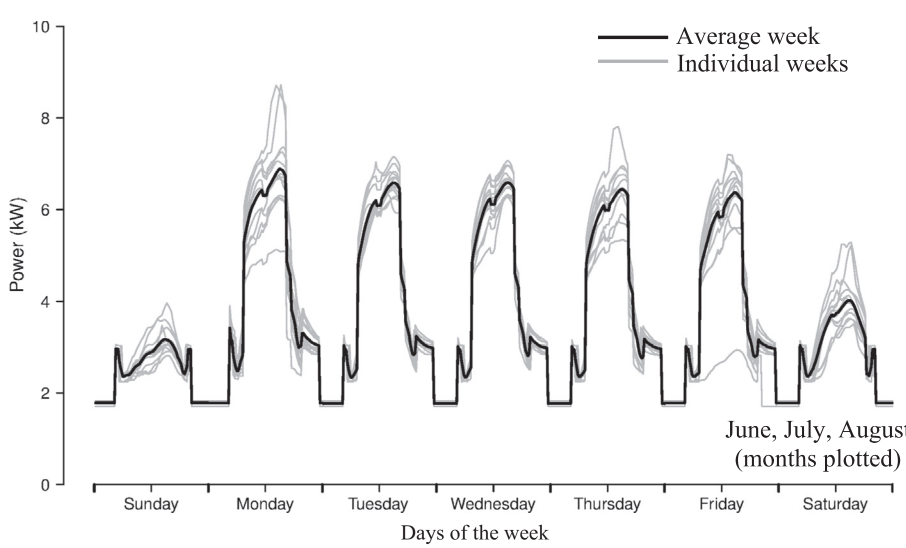


Fig. 5. Weekly electric load shape.

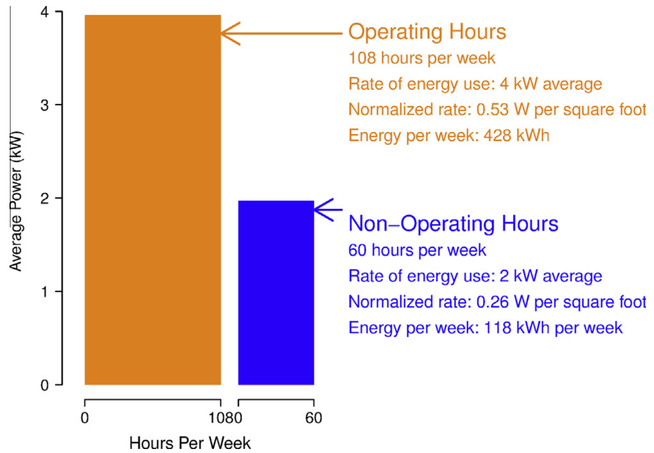


Fig. 6. The average power as a function of the weekly operating and non-operating hours for the months of June, July and August.

provided (Table 6). The combination of adding an economizer (ECM 12) and reducing the plug loads (ECM 15) results in the maximum annual energy cost savings of $2956 with a payback of 2.9 years and a total investment of $8697. ECM 1 does not show significant lighting energy savings because the lighting system of the building had already been upgraded once before.

3.4. Detailed retrofit analysis – Level 3

Following the preliminary analysis, the owner sees an attractive retrofit potential and now wants to more accurately assess his building. He customizes the building by changing the default prototype geometry and the appliance power density from 1.36 to 1.2 W/ft^2. He changes the program default orientation from north to the actual building orientation which is facing south. He also changes the window-to-wall ratio from the default setting value to 0.4, to more closely match that of the building. These changes show that the default parameters can be changed to more closely match that of the actual building. The remaining input parameters are unchanged.

The CBES Toolkit automatically calibrates the energy model to match the owner's building, based on his building input, utility data and weather data. The calibration results are: NMBE for electricity −4.2%, NMBE for natural gas −4.9%, CVRMSE for electricity 8.6%, CVRMSE for natural gas 12.6%. The toolkit provides step-by-step calibration results with each changed parameter and its value. Now, the owner uses the calibrated model for detailed retrofit analysis.

He wants to further look at the measures recommended from Level 2. He customizes the lighting measure with power density of 0.85 W/ft^2 (9.1 W/m^2) and cost data. Also, he is interested in the combination of measures that include the lighting measure. Table 7 shows the results based on this customization. It turned out that the lighting measure is more effective than what was indicated in the preliminary analysis. The payback was reduced from 2.8 years to 1.8 years. The combination of the three measures provide the building owner with a maximum annual energy cost savings of $5924 with an investment cost of $12,060 and a payback of two years. Since the building is in San Francisco which has good outdoor air quality, the indoor air quality is improved because the HVAC retrofit measure adds an air economizer, allowing the use of more outdoor air for cooling and ventilation. The lighting upgrade has potential to improve visual comfort, while the plug load measure is neutral to the IEQ impact (Table 6).

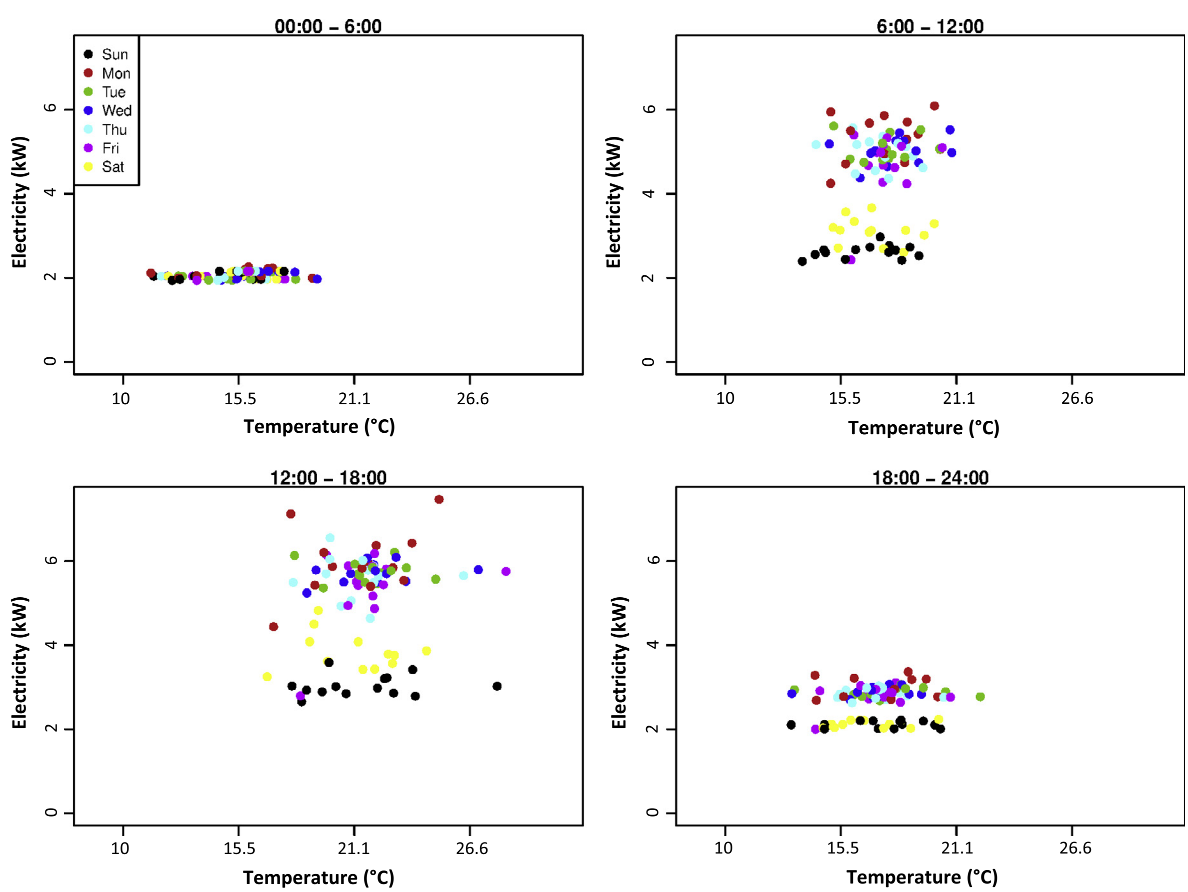


Fig. 7. The electricity use as a function of outdoor air temperature during summer.

Table 6
Results from the CBES Level 2 Preliminary Retrofit Analysis.

Measure ID	Category	Name	IEQ Impact	Cost Unit	Total cost per Unit
Description of measures					
ECM 1	Lighting	Replace existing lighting with T8 upgrade (0.7 W/sf)	Lighting conditions can affect occupant satisfaction and may affect work performance. Lighting upgrades need to provide adequate illumination and accessible control	$/sf	0.63
ECM 12	HVAC – Economizer	Add Economizer	Adding an economizer will increase outside air ventilation and can improve indoor air quality. In office settings, studies found that more outside air can reduce sick building syndrome (SBS) symptoms and improve work performance. Similar benefits may also apply to retail and mixed-use buildings	$/ton	387
ECM 15	Plug Loads	Use Plug Load Controller (30% efficient from Baseline)	NA	$/sf	0.8

	Measure ID (s)	Energy cost savings ($)	Energy savings (kWh)	Electricity cost savings ($)	Electricity savings (kWh)	Natural gas cost savings ($)	Natural gas savings (therm)	Investment cost ($)	Payback (Year)
Annual economic analysis									
1	ECM 12;15	2956	15,923	2873	17,109	−40	−40	8697	2.9
2	ECM 12;1	2882	15,490	2812	16,749	−43	−43	7450	2.6
3	ECM 1	1698	8472	1656	9865	−47	−48	4740	2.8
4	ECM 12	1396	8341	1362	8112	8	8	2612	1.9

Table 7
The Results from the CBES Level 3 Detailed Retrofit Analysis.

	Measure ID(s)	Energy cost savings ($)	Energy savings (kWh)	Electricity cost savings ($)	Electricity savings (kWh)	Natural gas cost savings ($)	Natural gas savings (therm)	Investment cost ($)	Payback (Year)
Annual economic analysis for single measures									
1	ECM 1	2081	8750	2143	10,569	−62	−62	3750	1.8
2	ECM 12	2115	10,235	2116	10,250	−1	−1	2476	1.2
3	ECM 15	2178	9212	2239	11,004	−61	−61	6000	2.8
Annual economic analysis for package of measures									
1	ECM 12;1	3988	17,952	4051	19,791	−62	−63	6155	1.5
3	ECM 1;15	4253	17,640	4387	21,588	−134	−135	9750	2.3
2	ECM 12;15;1	5924	25,670	6058	29,642	−135	−136	12,060	2

4. Discussion

The CBES Toolkit provides a rich set of features to support a wide range of users to conduct a quick and reliable retrofit assessment of commercial buildings. The toolkit was tested and used in several retrofit projects in five California cities. Software companies are interested in licensing the CBES API for integration with their products. Several universities and community colleges are using the toolkit for their education and training programs for HVAC engineers and technician. One main limitation is the use of prototype buildings that may not be able to be customized to exactly match an uncommon building footprint. Another limitation is, despite the customizable pre-selected rich set of ECMs, users cannot add new types of ECMs. Currently CBES does not directly support user input of incentives or rebates for ECMs used to retrofit buildings, instead users have to manually adjust the cost of ECMs by considering the incentives or rebates. Additionally, the implementation and operation of efficiency measures maybe subpar and therefore the planned performance indicated by the toolkit may not be achieved. Nord and Sjøthun [55] demonstrated that more expensive measures often yield higher energy savings due in part to focused engagement during the installation and operation phases. Despite this issue, the CBES toolkit may be able to provide the potential to engage experts early in the design and energy retrofit process allowing for better awareness and measurement persistence. Another area for improvement is to enhance the interoperability of CBES with other energy software, such that CBES can exchange data with the USDOE Building Energy Asset Score Tool, and the USEPA Energy Star Portfolio Manager. This will avoid reentry of the building and utility data by users.

Despite these limitations, the CBES web app provides a platform for evaluating the retrofit alternatives for various audiences, including building owners, building operators, facility managers, engineers, and energy consultants, depending upon their experience and available building data.

Based on the feedback from project partners and participants of the public workshops, future development will focus on the following areas to ensure that the CBES Toolkit can be used to accelerate the retrofit of commercial buildings, this includes: (1) covering more building types, e.g. restaurants, hotels, hospitals, large offices, schools, (2) including incentives and rebates, (3) adding renewable energy systems, (4) considering demand response measures, and (5) further customizing the characteristics of building systems. Additionally, the development of more robust energy cost models to support long term energy planning would be a useful extension [56].

Lastly, the CBES web app is a prototype aiming to demonstrate the main features of CBES Toolkit. However it is not intended to be a full-feature comprehensive GUI, for example it only displays retrofit analysis results in tables, no figures or reports are produced. It is expected that third parties software vendors can adopt and integrate the CBES API with their building energy software or platform and alter the GUI to fit their specific objectives.

5. Conclusions

The development of the CBES application programming interfaces (APIs) delivers SMB retrofit energy savings calculations for a wide range of web-based applications. For example, CBES provides discernable and rapid web-based retrofit analyses, based on load shapes, benchmarking and pre-simulated databases of retrofit measures for energy and cost savings. In addition, for the advanced user, real-time, in-depth energy retrofit analyses conducted using whole building energy simulations, using OpenStudio and EnergyPlus, provide more detailed results. CBES features advance the tool beyond existing technology and include:

(1) Easy and powerful use for various audiences, including building owners, building operators, facility managers, engineers, and energy consultants, depending upon their experience and building data availability.
(2) The CBES Toolkit API can be integrated into third party software and utility portals that provide energy retrofit incentives, energy and cost savings evaluations, considering the integrated effects of ECMs.
(3) Object oriented software architecture of CBES enables its expansion to cover more building types, more climates, and more building technologies, in the future.

The CBES Toolkit can help accelerate the energy retrofit of the small and medium commercial buildings where building owners or tenants have limited resource for detailed on-site energy audits, or have insufficient experience for a comprehensive retrofit analysis on their own.

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