The BayREN Integrated Commercial Retrofits (BRICR) Project: An Introduction and Preliminary Results

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ABSTRACT

BayREN Integrated Commercial Retrofits (BRICR) is a DOE-funded project which aims to enhance the capacity of energy efficiency programs to recruit participants, develop retrofits, and measure outcomes in small and medium-sized commercial buildings, a sector notoriously hard to reach and expensive to serve, that accounts for ⅔ of US commercial floor space. To address these barriers, BRICR leverages existing incentives, financing, data, and open source software to facilitate two paths for comprehensive improvements: a deep energy retrofit, or serial upgrades integrated into capital improvement and maintenance cycles. BRICR is developing an integrated workflow for iterative energy modeling of commercial buildings for city energy program managers and auditors - starting with mass building-scale simulation based on public records and proceeding through audit, retrofit, and measurement and verification stages. BRICR builds on existing tools including LBNL's CBES, NREL's OpenStudio, PNNL's Audit Template, and DOE's BuildingSync and SEED Platform™. At each stage, BRICR uses available information to inform simulations (starting with public records but iteratively augmented with observations from energy program staff) to improve the quality of the models that inform decision making.

This paper presents initial results from energy models of 1699 office and retail buildings in San Francisco. Building stock data from public records were translated to create a BuildingSync file for each building which was stored in SEED. Each BuildingSync file was then translated to multiple OpenStudio Workflow files for EnergyPlus simulation to estimate energy savings of energy conservation measures (ECM). Energy savings predictions for each ECM were written back to an updated BuildingSync file for each building and re-uploaded to SEED. The distribution of baseline energy simulations was calibrated against the publicly disclosed distribution of energy benchmarking data to increase confidence in results.

Introduction

The nine counties that comprise the San Francisco Bay Area collaborate in the Bay Area Regional Energy Network (BayREN) to develop and deliver targeted, integrated, regional-scale energy, water, and resiliency programs. BayREN's Integrated Commercial Retrofits (BRICR) project aims to enhance the capacity of energy efficiency programs to facilitate and measure substantial energy efficiency improvement in small and medium commercial buildings by reducing the cost of energy retrofit targeting, design, and project development. To do so, BRICR performed region-wide energy modeling for Bay Area commercial facilities smaller than 70,000 square feet, and is developing software and workflow for San Francisco Energy Watch (SF Environment 2017) energy efficiency programs to direct building owners along two paths for comprehensive improvements: (1) deep energy retrofits, and (2) serial upgrades within capital improvement cycles. The San Francisco Energy Watch program offers energy efficiency services and financial incentives to qualifying commercial customers and multifamily building owners.

BRICR builds upon US Department of Energy (DOE) open source software to construct an extensible database of Bay Area small and medium-sized commercial buildings, and provides a public template for data collection and energy modeling workflow for retrofit analysis. The project utilizes the Standard Energy Efficiency Data Platform^{TM} (SEED Platform) (DOE 2017a); in addition to its established use for managing energy consumption data, SEED is extended to collect and manage building information and audit data. Building information is stored in BuildingSync - a schema for the exchange of commercial building energy audit data consistent with the Building Energy Data Exchange Specification (BEDES) (DOE 2017b). The energy performance evaluation and retrofit analyses adopt features from LBNL's Commercial Building Energy Saver (CBES) (Hong et al. 2015) and NREL's OpenStudio-based simulation platform (Heidarinejad et al. 2017; NREL 2016).

BRICR's regional database of energy efficiency potential and project outcomes are comprised of energy models for individual buildings. For each given building, development of the energy model is broken into:

- Phase 0: Simplified models for analyzing regional energy efficiency potential and prioritizing leads. Phase 0 models are informed by public records, prototypes corresponding to building use and vintage, and (if available) retrofit history. Phase 0 modeling happens for all buildings in the region automatically.
- Phase 1: Information from informal site visits and interviews of building management inform more detailed models supporting the development of project concepts, incentive eligibility, and potential financing. Phase 1 modeling occurs when a potential customer expresses interest in the identification of energy retrofit options.
- Phase 2: Most detailed models supported by BRICR, corresponds to an ASHRAE level 2 audit (ASHRAE 2011), supporting project finance application, incentive calculations, and ECM installation. Phase 2 modeling occurs when customer interest/commitment is high enough to justify investment in an ASHRAE level 2 audit.

This paper introduces the project, focusing on Phase 0 scope and preliminary results for buildings in San Francisco. The project team is currently developing Phase 1 functionality.

Overview of BRICR Software Tools and Workflow

Figure 1 shows the BRICR workflow used by energy program staff. Figure 2 shows the software tools used to support the BRICR workflow at each stage. The workflow starts by processing building stock public records, which include building footprints, land use, assessor record, and building energy disclosure into individual BuildingSync (NREL 2017a) XML (BuildingSync) files. This is a one-time batch operation for each city. The BuildingSync format offers a standardized representation of commercial building energy audit data. The BRICR team refers to BuildingSync derived solely from public records as Phase 0 BuildingSync. After generation, all Phase 0 BuildingSync files are uploaded to an instance of the SEED data platform. Once uploaded to SEED, Phase 0 BuildingSync files are processed by the BRICR software, a newly developed open source software (https://github.com/nrel/bricr), to calculate potential energy and energy cost savings of various energy efficiency conservation measures (ECMs). Energy program staff can use these initial estimates during the process of lead generation to identify potential projects through a variety of channels.

Once a specific building has been identified for the program, the program staff retrieves BuildingSync for that building from SEED and uploads it to the PNNL's Audit Template (AT) tool (PNNL 2018). Energy program staff leverages the AT user interface to edit and expand information about the building and potential ECMs. After making these modifications, energy program staff can export a modified BuildingSync file from AT and re-upload this file to SEED where it is processed by the BRICR software to update energy and energy cost savings estimates. The BuildingSync team refers to BuildingSync which includes input from energy program staff as Phase 1 BuildingSync. At this stage, the energy program staff may use the AT to generate report content to share with building owners and other decision makers.

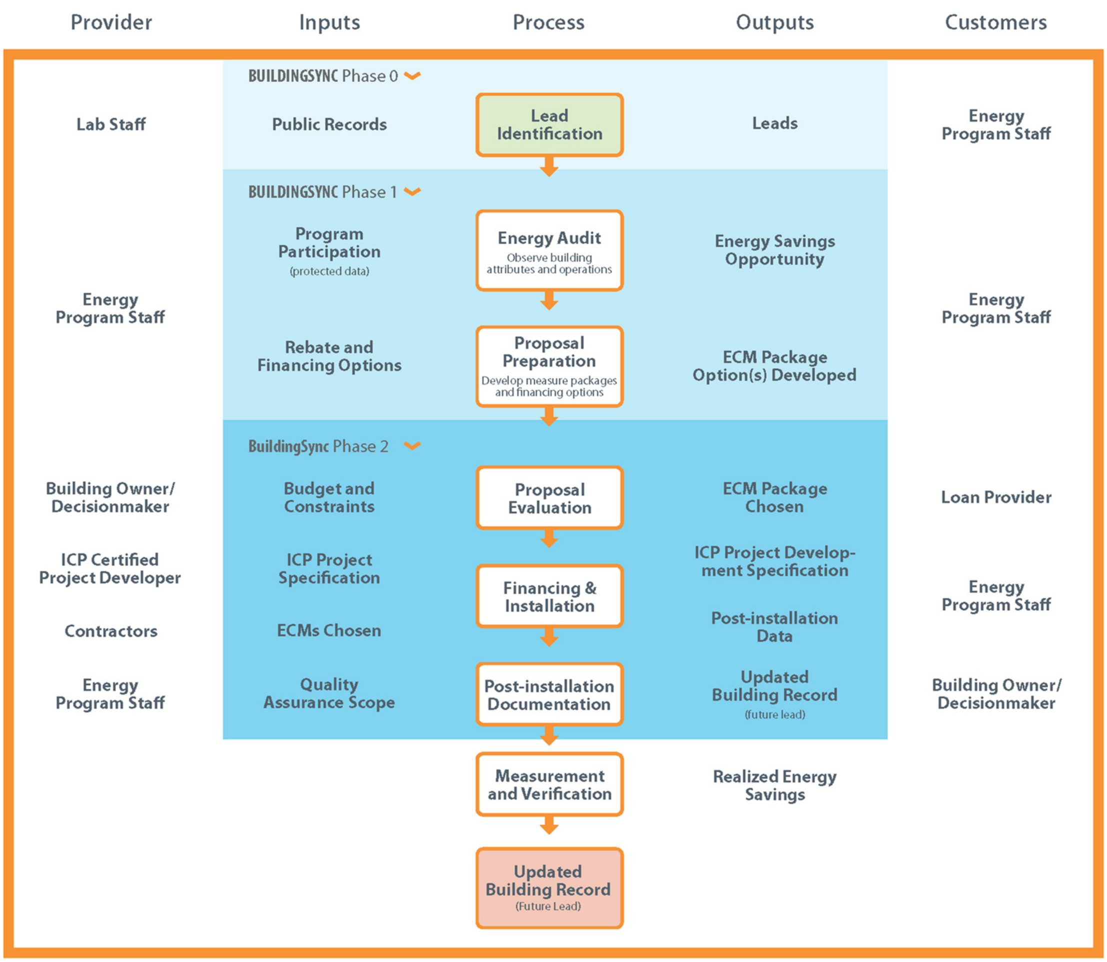

Figure 1. BRICR Energy Program Process

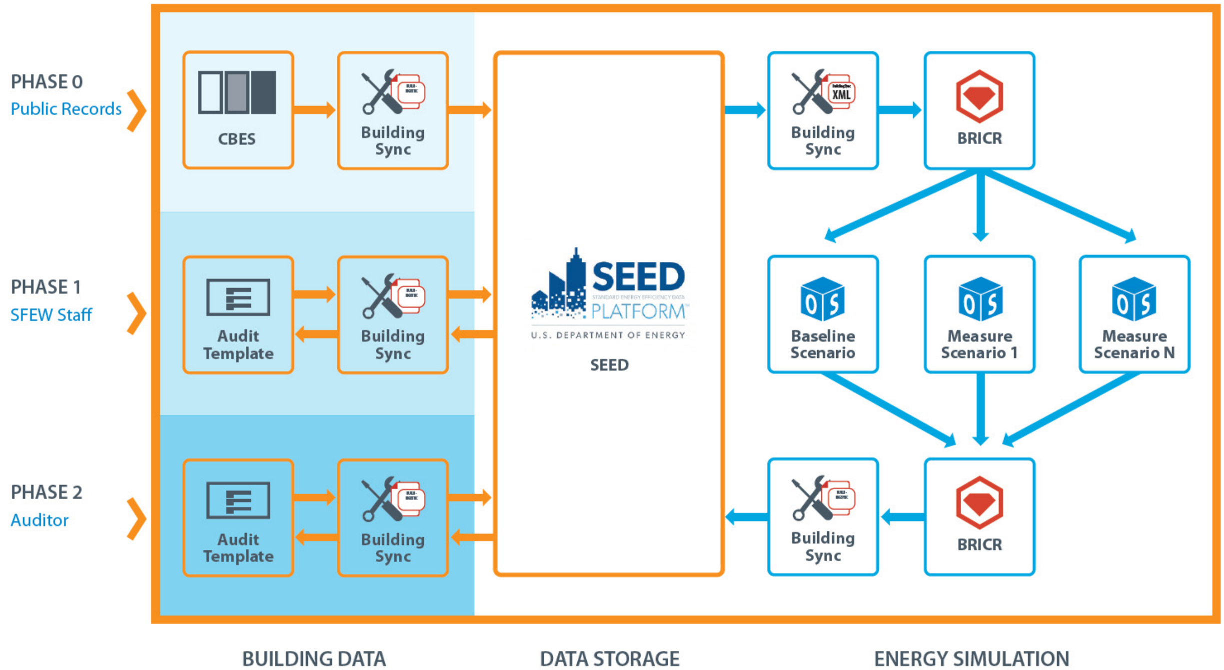

Figure 2. BRICR Software Tools and Data Flows

If a decision is made to proceed with a given project, then a complete audit is likely ordered. Data collected during this audit can be added to the building's BuildingSync using the AT – yielding BuildingSync Phase 2 level of detail. The BuildingSync is then re-uploaded to SEED where it is re-processed by the BRICR software to provide final energy and energy cost savings estimates. BRICR provides financial metrics for ECM options, and recommends the most compelling ECMs or a package of ECMs. BRICR uses the SEED platform to maintain the audit data and track energy savings from retrofit analysis for comparison with measurement and verification of savings. Once a project is complete, the proposed measures are changed to implemented measures in the BuildingSync. Open Energy Efficiency Meter will be applied after project implementation to perform pre- and post-retrofit measurement of realized energy savings and to validate savings predictions made by the BRICR software. Further details about Phase 1, Phase 2, and energy savings measurement will be presented in future papers.

City Dataset Integration

The first step for the city-scale retrofit analysis is to create a dataset for the city building stock. A separate project funded by DOE integrated building datasets from multiple agencies of the City of San Francisco. Figure 3 shows the workflow to create the dataset. The city datasets (land use, assessor records, and energy disclosure) use the assessor's parcel number as an identifier for building data. Parcel-related data were merged and mapped with the building footprint data to create a master building dataset with 182 attribute fields for each building. Next, the master dataset was simplified and standardized (using the BEDES) to create 3D city models for all SF buildings in CityGML, GeoJSON, and FileGDB formats. The simplified dataset has 106 attribute fields for each building, including 45 fields containing building characteristics and 61 fields from City of San Francisco's Existing Commercial Buildings Ordinance, which requires annual disclosure of energy consumption for buildings over 50,000 square feet. GeoJSON is a data format based on JSON for encoding a variety of geographic data structures (GeoJSON 2018). The final building dataset in GeoJSON format was used in this project to generate the Phase 0 BuildingSync files.

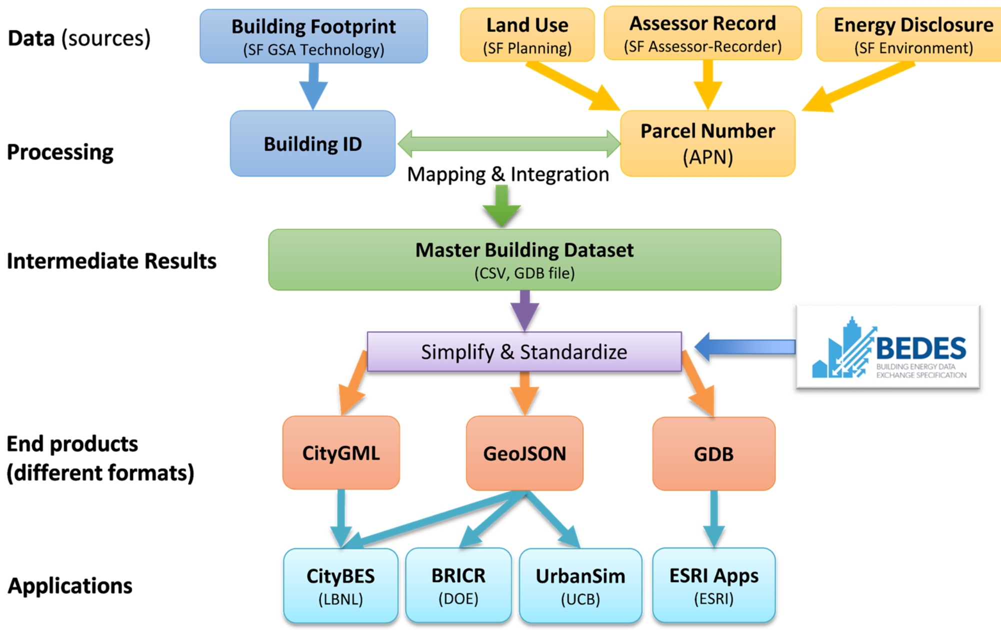

Figure 3. Data and workflow used to create the city building dataset for San Francisco (Chen et al. 2017)

A total of 3,866 small and medium-sized commercial buildings with a gross floor area less than 70,000 ft^2 were found from the San Francisco building stock data. Among them, 1,699 buildings that are predominantly office and retail use were selected as the targeted buildings for retrofit analysis under the BRICR project. Office and retail buildings are selected as first targets as these two categories comprise the largest fraction of floor area among small and medium commercial building stock in San Francisco and the Bay Area. Table 1 shows the composition of the targeted buildings by vintage. The vintages correspond to major revisions of the California Title 24 building energy efficiency standards.

Table 1. Number of small and medium office and retail buildings in San Francisco

Vintage	Small office <20,000 ft^2	Medium office 20,000 to 70,000 ft^2	Retail	Total
Before 1978	82	10	285	377
1978-1992	7	2	18	27
1993-2001	93	30	322	445
2002-2005	41	16	111	168
2006-2008	47	23	80	150
After 2009	155	59	318	532
Total	425	140	1134	1699

Upload to SEED

The Standard Energy Efficiency Data Platform™ (SEED Platform) provides public agencies and other organizations with a standardized but flexible, cost-effective, secure, enterprise data platform to manage portfolio scale building performance data from a variety of sources. SEED has been developed to support the city, county, and state governments implementing policies or supporting programs focused on managing building performance data (such as energy benchmarking or audit programs). SEED offers several features to support these types of programs such as data cleansing, validation, matching records, and pairing records between properties and tax lots. This functionality is key to SEED's ability to merge data from multiple sources. Analyzing this data, assessing compliance, and disclosing results per public transparency requirements makes the results of these programs useful to government, public, and private users. The BRICR project has extended SEED to accept the upload of BuildingSync files as a data source which can be merged with other existing data. Once a SEED record has accepted a BuildingSync file, that BuildingSync file can be downloaded for future use.

Retrofit Measures Modeling and Evaluation of Savings

Each BuildingSync contains information about the building as well as potential ECMs. The BRICR software translates each BuildingSync file to multiple OpenStudio Workflow (OSW) files for building energy simulation using EnergyPlus. One simulation is performed for the baseline energy analysis and another simulation is performed for each potential ECM. ECM packages can also be developed for retrofit analysis to take into account interactive energy saving effects from multiple measures. Simulation results for each case are stored back to BuildingSync and pushed back to SEED for use by the San Francisco Energy Watch program.

Prototype Building Energy Models

The BRICR tool adopted three small and medium-sized office and retail prototype energy models from the Commercial Building Energy Saver (CBES). CBES provides seven small and medium commercial prototype models in 16 California climate zones at six vintages, based on the Database for Energy Efficiency Resources (DEER) (CEC 2014), DOE reference models (DOE 2017c), and California Title 24 building energy efficiency standards (CEC 2017). The prototype models contain detailed characteristics of the building and systems, internal loads, and operation schedules. Typical HVAC systems are packaged single zone (PSZ) air conditioning system with furnace heating for small office and retail buildings and packaged variable air volume (PVAV) system with hot water boilers for medium-sized office buildings.

Table 2 shows the small office, medium office, and standalone retail prototype energy models used in the Phase 0 baseline energy models. The BRICR tool creates OpenStudio Models (OSMs) for the small and medium offices and retail buildings for energy simulation to evaluate energy saving potentials of different ECMs. These prototype models were added to OpenStudio Standards modeling environment (DOE 2016). Different levels of energy modeling parameters are required at various phases of BuildingSync for its use within BRICR. Phase 0 models are based on publically available data (e.g., building footprint, land use, and tax assessor's records) and default energy efficiency levels of local building energy code (California Title 24). Phase 1 adds more information from building owner interviews, and Phase 2 adds details from an ASHRAE level 2 audit.

Table 2. Prototype Energy Models (based on California Title 24 Standards) added to OpenStudio Standards

Building Types	Vintages	Climate Zones / Reference City
1. Small office 2. Medium office 3. Stand-alone retail	1. Pre-1978 2. 1978-1991 3. 1992-2000 4. 2001-2004 5. 2005-2007 6. 2008 and after	CZ1, Arcata; CZ2, Santa Rosa CZ3, Oakland; CZ4, San Jose CZ5, Santa Maria; CZ6, Torrance CZ7, San Diego-Lindbergh; CZ8, Fullerton CZ9, Burbank-Glendale; CZ10, Riverside CZ11, Red Bluff; CZ12, Sacramento CZ13, Fresno; CZ14, Palmdale CZ15, Palm Spring-Intl; CZ16, Blue Canyon

Baseline Model Creation Measures

The BRICR tool uses OpenStudio measures from NREL's Building Component Library (NREL 2017b) to create energy models from the building data in BuildingSync. The model creation measures assign prototypical geometry, constructions, HVAC systems, and efficiency values for target buildings as specified in the BuildingSync files.

Report Measure

To track energy savings from retrofits, the tool uses the OpenStudio results measure to extract the simulated results of annual electricity and natural gas savings and energy cost savings for different measures. The BRICR tool then records the savings results back into the BuildingSync file so that the outcome of the retrofit analysis can be pushed to SEED. The project uses the extended SEED platform, and it is important to store and update building information, audit data, energy and energy cost saving estimates in SEED.

Utility Rate Measure

BRICR uses Pacific Gas and Electric Company's time of use (TOU) rates for small commercial buildings: electric rate A-1 and natural gas rate G-NR1 (PG&E 2018) The OpenStudio tariff_selection_generic measure is used to deal with complex TOU rates, which allows creating EnergyPlus models with current utility rate structures.

Verification of the Baseline Simulation Results

DOE's Building Performance Database (BPD) (DOE 2017d) was used for benchmarking as a verification of the BRICR baseline simulation results. BPD (bpd.lbl.gov) is United States' largest dataset of information about the energy-related characteristics of commercial and residential buildings. The BPD combines, cleanses and anonymizes data collected by Federal, State and local governments, utilities, energy efficiency programs, building owners and private companies, and makes it available to the public. Currently, BPD has asset and annual energy use information for more than 1 million buildings. There are 819 offices and 126 retail buildings found from BPD with the gross floor area less than 70,000 ft2 and ASHRAE climate zone 3C which includes the San Francisco Bay Area. The baseline energy models based on the prototypes were calibrated at the portfolio level, serving to correct and verify major assumptions (e.g., LPD) used in the prototype models. Figure 4 shows the benchmarked mean site EUI from BPD for the small and medium offices is 53 kBtu/ft2/year, which is 9% greater than the average EUI, 48 kBtu/ft2/year from the baseline simulation results for the small and medium offices, and shows the distribution of the Phase 0 simulated site energy for 565 office buildings.

The BRICR Phase 0 baseline models show a good match of site EUI distribution with the benchmarked BPD buildings. It is observed that BPD shows a wider range of the energy consumption distribution, reflecting diverse building operations and system types. BPD also includes many buildings that had recent retrofits, which reflect the buildings with low energy consumption compared to the typical buildings. However, the Phase 0 baseline models do not include energy efficiency measures in place, which will be addressed in Phase 1 and Phase 2.

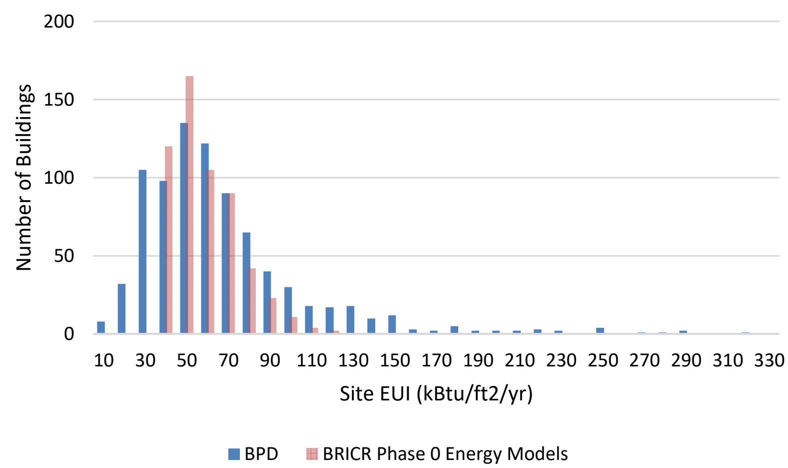

Figure 4. Energy distribution of office buildings from BPD and the BRICR Phase 0 Baseline Simulation Results

Figure 5 shows the EUI distribution of the retail buildings. The median retail site EUI is 72 kBtu/ft2/year, 27% less than the median Phase 0 BRICR retail baseline simulation result for 1134 retail buildings.

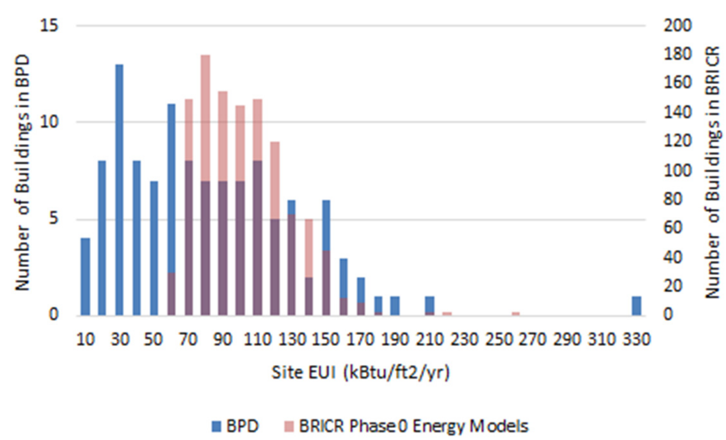

Figure 5. Energy distribution of retail buildings from the BPD and the BRICR Phase 0 Baseline Simulation Results

Energy Conservation Measures

After the baseline energy models are created based on the data from BuildingSync files, the BRICR tool creates additional OpenStudio Models including ECMs to estimate energy saving potentials. The ECMs included in BuildingSync were taken from those used in the DOE's Compliance Tracking System (NREL 2015). Currently, 27 system categories, 21 technology categories, and approximately 175 measure descriptions are listed in the BuildingSync 2.0 schema. Table 3 shows a total of 29 ECMs applied to the baseline energy models to evaluate energy saving potentials. The 29 ECMs cover major building energy systems including lighting, space cooling, space heating, ventilation, envelope, plug-loads, DHW and water use. The 29 ECMs are selected based on their common use in retrofit of small- and medium-sized office and retail buildings, as well as based on retrofit measures implemented in San Francisco's Energy Watch projects. Energy modeling and simulation using the BRICR platform offer flexibility to analyze energy savings from measures integration and provide a life cycle cost analysis for Energy Watch program. These ECMs are planned according to the phases, considering later phases will have more data on the targeted buildings from site visit or energy audit.

Table 3. ECMs for different phases of BRICR energy modeling

BuildingSync Measures			Applicable to BRICR		
SystemCategory	TechnologyCategory	MeasureName	Phase0	Phase1	Phase2
Lighting	LightingImprovements	Retrofit with light emitting diode technologies	Y	Y	Y
		Add daylight controls		Y	Y
		Add occupancy sensors		Y	Y
Plug Load	PlugLoadReductions	Replace with ENERGY STAR rated	Y	Y	Y
		Install plug load controls		Y	Y
		Replace ice/refrigeration equipment with high efficiency units			Y
Wall	BuildingEnvelopeModifications	Air seal envelope	Y	Y	Y
		Increase wall insulation		Y	Y
		Insulate thermal bypasses		Y	Y
Roof / Ceiling	BuildingEnvelopeModifications	Increase roof insulation		Y	Y
		Increase ceiling insulation		Y	Y
Fenestration	BuildingEnvelopeModifications	Replace windows			Y
	BuildingEnvelopeModifications	Add window films		Y	Y
Heating System	OtherHVAC	Replace burner	Y	Y	Y
	BoilerPlantImprovements	Replace boiler			Y
Cooling System	OtherHVAC	Replace package units	Y	Y	Y
Other HVAC	OtherHVAC	Replace AC and heating units with ground coupled heat pump systems			Y
		Replace HVAC system type to VRF			Y
		Replace HVAC system type to PZHP			Y
General Controls and Operations	OtherHVAC	Upgrade operating protocols, calibration, and_or sequencing		Y	Y
Fan	ElectricMotorsAndDrives	Replace with higher efficiency			Y
Air Distribution	OtherHVAC	Improve ventilation fans			Y
		Enable Demand Controlled Ventilation			Y
		Add or repair economizer			Y
Heat Recovery	OtherHVAC	Add energy recovery			Y
Domestic Hot Water	ChilledWaterHotWaterAndSteamDistributionSystems	Replace or upgrade water heater		Y	Y
		Add pipe insulation			Y
		Add recirculating pumps			Y
Water Use	WaterAndSewerConservationSystems	Install low-flow faucets and showerheads			Y
Total numbers			5	15	29

Results

Energy simulations were conducted for the targeted 1699 small and medium-sized offices and retail buildings in San Francisco using the BRICR automated simulation workflow. Baseline energy models were created based on the building type, gross floor area, and default values determined based on the vintage, aspect ratio, number of floors as gleaned from the public building stock data. The default efficiency levels are based on California Title 24 requirements. Twenty-nine ECMs were then applied to the Phase 0 baseline models to evaluate energy saving potentials. Table 4 shows the simulation results of energy saving (total site energy, electricity, and natural gas) percentages for the selected individual ECMs compared to the Phase 0 baseline energy consumption. The saving percentages are the average of all targeted buildings across different vintages. The energy saving for individual buildings might be different depending on the building conditions and prior retrofits.

As illustrated in Table 4, five individual ECMs can yield site energy savings of more than 10%. Specifically, replacing the existing HVAC with GSHP systems can achieve 23.6% savings (although payback can be long); retrofit with LED lighting can save 16.2% site energy; and adding daylight controls can save 12.5% site energy. The next four individual ECMs, including retrofit with double pane low-e windows, use EnergyStar rated appliances, improved BAS programming, and use demand-controlled ventilation, can achieve more than 5% site energy savings. Figure 6 shows the energy consumption distribution boxplot showing 5%, 25%, 50%, 75%, and 95 percentile of individual measures for Phase 0 buildings. The table provides potential energy savings from selected measures for prototype models. Throughout the process of developing an energy retrofit, the auditor can tailor the package of measures to the building owner's interest and receive an updated estimate of potential energy savings. Note that cost-effectiveness calculations are not included in Phase 0 analyses.

Table 4. Simulated energy saving potentials for the selected ECMs

Measure Name		Average Energy Saving %		
		Total Energy	Electricity	Natural Gas
M1	Replace AC and heating units with ground coupled heat pump systems	23.6%	19.9%	24.4%
M2	Retrofit with light emitting diode technologies	16.2%	27.9%	-15.3%
M3	Replace HVAC system type to PZHP	14.6%	7.3%	37.5%
M4	Add daylight controls	12.5%	19.2%	-5.3%
M5	Replace HVAC system type to VRF	11.5%	3.9%	22.7%
M6	Replace windows	9.0%	11.6%	3.0%
M7	Replace with ENERGY STAR appliances	8.7%	13.3%	-6.2%
M8	Upgrade operating protocols, calibration, and_or sequencing	5.9%	2.7%	15.4%
M9	Enable Demand Controlled Ventilation	5.0%	-2.2%	22.3%
M10	Replace with higher efficiency fan motor	4.6%	9.2%	-8.0%
M11	Increase wall insulation	4.2%	1.6%	11.5%
M12	Install plug load controls	4.0%	6.4%	-3.0%
M13	Add or repair economizer	3.6%	6.5%	-4.6%
M14	Replace burner	3.3%	0.0%	11.7%
M15	Replace package units	3.2%	4.4%	0.0%

M16	Air seal envelope	3.0%	0.2%	10.5%
M17	Replace boiler	3.0%	0.0%	13.1%
M18	Replace or upgrade water heater	2.8%	0.0%	10.6%
M19	Add window films	2.8%	5.6%	-4.9%
M20	Add recirculating pumps	2.7%	0.0%	10.0%
M21	Add pipe insulation	2.6%	0.0%	9.8%
M22	Improve ventilation fans	2.4%	4.8%	-4.1%
M23	Add occupancy sensors	1.4%	2.3%	-1.0%
M24	Increase roof insulation	1.2%	0.3%	4.3%
M25	Insulate thermal bypasses	1.1%	0.4%	3.0%
M26	Replace ice/refrigeration equipment with high efficiency units	1.0%	1.6%	-0.7%
M27	Increase ceiling insulation	0.5%	0.1%	1.9%
M28	Install low-flow faucets and showerheads	0.5%	0.0%	2.2%
M29	Add energy recovery	0.1%	0.3%	-0.5%

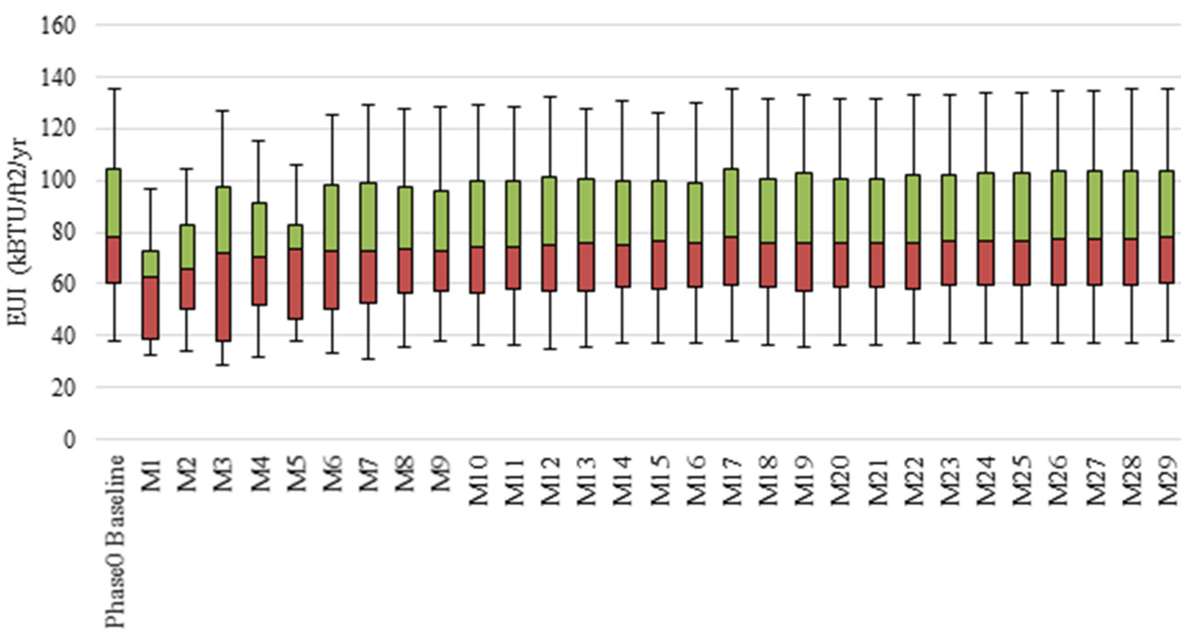

Figure 6. Site EUI ranges of the baseline building models and ECMs

Conclusions

The BRICR project aims to develop a framework of data, tools, and workflows to streamline the building energy retrofit modeling and analysis to achieve large-scale energy savings and GHG reductions. The BRICR project is designed in three phases considering the data availability and model complexity. This paper introduces the overall project and preliminary simulated results of 1699 targeted commercial buildings in San Francisco.

Future work will test incorporation of Phase 1 building data collected by San Francisco Energy Watch staff and incorporation of Phase 2 information collected by energy auditors. Detailed retrofit modeling and analysis (Phase 1 and Phase 2) will be done for a small set of selected buildings to further identify and evaluate individual and packages of ECM savings. The goal of the BRICR project is to implement the recommended cost-effective ECMs in a dozen buildings and follow up with M&V to verify the actual energy savings. With these initial results, the workflow will be scaled up to apply across the San Francisco Bay Area region, and freely available for use by others.

References

ASHRAE. 2011. Procedures for Commercial Building Energy Audits, Second Edtion. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

CEC. 2014. "DEER - Database for Energy Efficient Resources." *Http://www.energy.ca.gov/deer/*. http://www.energy.ca.gov/deer/.

CEC. 2017. "Building Energy Efficiency Program." http://www.energy.ca.gov/title24/.

Chen, Yixing, Tianzhen Hong, and Mary Ann Piette. 2017. "Automatic Generation and Simulation of Urban Building Energy Models Based on City Datasets for City-Scale Building Retrofit Analysis." *Applied Energy* 205 (August). Elsevier: 323–335. doi:10.1016/j.apenergy.2017.07.128.

DOE. 2016. "New OpenStudio-Standards Gem Delivers One Two Punch." https://energy.gov/eere/buildings/articles/new-openstudio-standards-gem-delivers-one-two-punch.

DOE. 2017a. "Standard Energy Efficiency Data Platform." https://energy.gov/eere/buildings/standard-energy-efficiency-data-platform.

DOE. 2017b. "Building Energy Data Exchange Specification (BEDES)." https://energy.gov/eere/buildings/building-energy-data-exchange-specification-bedes.

DOE. 2017c. "Commercial Reference Buildings." https://energy.gov/eere/buildings/commercial-reference-buildings.

DOE. 2017d. "DOE Buildings Performance Database." https://bpd.lbl.gov/.

GeoJSON. 2018. "GeoJSON." http://geojson.org/.

Heidarinejad, Mohammad, Nicholas Mattise, Matthew Dahlhausen, Krishang Sharma, Kyle Benne, Daniel Macumber, Larry Brackney, and Jelena Srebric. 2017. "Demonstration of Reduced-Order Urban Scale Building Energy Models." *Energy & Buildings* 156. Elsevier B.V.: 17–28. doi:10.1016/j.enbuild.2017.08.086.

Hong, Tianzhen, Mary Ann Piette, Yixing Chen, Sang Hoon Lee, Sarah C. Taylor-Lange, Rongpeng Zhang, Kaiyu Sun, and Phillip Price. 2015. "Commercial Building Energy Saver: An Energy Retrofit Analysis Toolkit." *Applied Energy* 159. Elsevier Ltd: 298–309. doi:10.1016/j.apenergy.2015.09.002.

NREL. 2015. *BuildingSync Implementation Guide Version 1.0.0*. https://buildingsync.net/documents/BuildingSync v1.0-legacy Implementation Guide.pdf.

NREL. 2016. *Portfolio-Scale Optimization of Customer Energy Efficiency Incentive and Marketing*.

NREL. 2017a. "BuildingSync." https://buildingsync.net/.

NREL. 2017b. "Building Component Library." https://bcl.nrel.gov/.

PG&E. 2018. "Rate Information." https://www.pge.com/tariffs/rateinfo.shtml.

PNNL. 2018. "Audit Template Tool." https://buildingenergyscore.energy.gov/documents/asset_score_quick_start_guide_audit_template.pdf.

SF Environment. 2017. "SF Energy Watch." https://sfenvironment.org/energy/energy-efficiency/commercial-and-multifamily-properties/sf-energy-watch.