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ZNE for All! Enabling Zero Net Energy Retrofits for Small Commercial Offices

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ABSTRACT

The small commercial office market experiences a number of unique barriers to achieving substantial energy reductions. Those barriers include: 1) a lack of awareness of and access to centralized, comprehensive, cost-evaluative information about how to achieve energy targets, and 2) affordable access to energy reduction services such as engineering and auditing services. Energy efficiency tools and services currently involve higher costs on a per-square-foot or kilowatt-hour (kWh)-saved basis. Small commercial buildings are consequently underserved by the energy services market and disadvantaged in accessing the same detailed retrofit information that larger buildings realize. Meeting national and state energy goals requires whole-building integrated solutions that enable this sector to realize deep energy savings successfully and affordably.

This project developed cost-effective retrofit packages of commercial, whole-building integrated systems to achieve zero net energy (ZNE) performance for California multi-story small commercial offices. The energy efficiency measure (EEM) packages target 50% energy savings over existing energy use, with costs within 10% of conventional-performance construction costs, and internal rates of return (IRR) of 5% or more. The developed packages of EEMs are validated for energy performance, as well as visual and thermal comfort, under both controlled laboratory test conditions for emerging technologies and demonstrated in an occupied small commercial building. Validated EEMs were built into an online public software platform that enables small commercial facilities to conduct whole-building retrofit assessments, relevant to their building, providing cost-evaluative feedback on EEMs and packages of measures.

Background

Small commercial offices in California represent 650 million square feet (ft^2) of real estate, and consumed more than 3,500 gigawatt-hours (GWh) of electricity in 2012 (CEC 2015), about 4% of the state's building electricity use. Efforts to achieve the state's goals for greenhouse gas (GHG) emission reductions must address the barriers to transitioning 50% of California's commercial building stock to ZNE use by 2030 (Greenblatt, 2013). Achieving ZNE designs requires saving 50% or more energy compared to baseline energy use, as demonstrated through case studies (Regnier 2015a; Regnier 2015b; International Living Future 2020). This depth of savings requires whole-building solutions and cannot be achieved by incremental equipment upgrades alone (Regnier, 2018). To date, very few buildings have achieved ZNE, and most of those were new construction. In order to enable the existing small commercial market to transition to ZNE, strategies to enable deeper savings cost-effectively for the small commercial market must be developed, along with accessible means to replicate these strategies.

The small commercial office market experiences a number of barriers to achieving substantial energy reductions. Those barriers include: 1) a lack of awareness of and access to centralized, comprehensive, cost-evaluative information about how to achieve energy targets, and 2) affordable access to energy reduction services, such as engineering and auditing services. Energy efficiency tools and services, such as whole building energy modeling and evaluation currently involve high costs on a per-square-foot or kWh-saved basis for small buildings. Meeting the state's energy goals will require whole-building integrated solutions that enable this sector to realize deep energy savings successfully and affordably.

One approach to accelerating deep, energy saving retrofits is to pre-package sets of technologies and controls that can achieve ZNE performance for multi-story small commercial office retrofits. By coupling this with an accessible online tool that enables EEM evaluations, a substantial barrier to accessing this technology in the small commercial market is lowered. In this study, EEM packages using commercially-available technologies were selected and evaluated for a Northern and a Southern California climate. The EEM packages were targeted to achieve: 1) 50% energy savings and greater over existing energy use; 2) 10% IRR over 5 years; and 3) achieve 30% or greater energy savings over California Title 24-2016. To further lower risks related to constructability, performance and occupant comfort, a subset of the technologies and packages of EEMs were analyzed at LBNL's FLEXLAB® (FLEXLAB.LBL.GOV), an advanced high-accuracy, high-resolution facility for testing whole-building integrated systems to develop and validate solutions under varied climate and use conditions. The simulation models for the EEMs were also validated through results from FLEXLAB testing and a whole-building demonstration pilot located at the City of Berkeley's Mental Health Services facility.

Validated EEMs were then packaged into the Commercial Building Energy Saver (CBES) platform (CBES.LBL.GOV), an online public resource that enables small commercial facilities to conduct whole-building retrofit assessments, providing cost-evaluative feedback on EEMs and packages of measures. Data on energy, occupant comfort, and occupant behavior also will be analyzed and packaged into best practices.

Cost Effective ZNE Retrofit Packages

Three main types of retrofit approaches were investigated using energy simulations to evaluate which combinations of these retrofit approaches provide the highest potential for a cost-effective retrofit to achieve ZNE. These retrofit packages were applied to baseline building energy models created in OpenStudio for Northern California (Oakland) and Southern California (Burbank). The models represent 2-story 50,000 ft^2 office buildings whose baseline energy usage was calibrated to benchmarking data from the 2006 California Commercial End-Use Survey (CEUS). Another baseline energy model was created in the California Building Energy Code Compliance for commercial/nonresidential buildings (CBECC-COM) for benchmarking with respect to a minimally code compliant building with respect to California Title 24 2016.

The three areas of focus for retrofit were selected for initial evaluations representing three types of feasible retrofit conditions for a site. These included a site that was already conducting envelope improvements for other reasons (e.g. roof replacement), and thus had an opportunity to improve efficiency there (Package 1); an approach that focused on improving lighting and daylighting strategies (Package 2); and an approach that leveraged deeper heating, ventilation, and air-conditioning (HVAC) retrofit opportunities, perhaps taking advantage of an end of life equipment replacement (Package 3). Each of these packages were chosen as they were expected to provide significant energy savings for small multistory offices, at varying degrees of first cost. Added to each of these focus areas were basic retrofit improvements to the other systems in the building that were previously deemed to be cost-effective, which include replacing the domestic hot water heating system with electric instantaneous heaters and changing to low flow fixtures, replacing exterior lighting to 50 watt (W) bulbs, and reducing plug loads energy use by 30% through a combination of selective equipment replacement and controls strategies. The three packages and their EEMs are presented in the table below.

Table 1. List of new EEMs in each retrofit package

Package 1: Building envelope improvements	Package 2: Lighting and daylighting focus	Package 3: HVAC retrofit
Add top floor ceiling insulation – Apply 6.5” (R-40) polyisocyanurate insulation over top of roof sheathing	Replace interior lighting to reduce lighting power density to 0.4 W/ft^2 (light-emitting diodes (LED) typically)	Install a dedicated outside air system (DOAS) with energy recovery ventilator (enthalpy wheel) and variable air volume (VAV) fan
Add wall insulation – Apply 4.5” (R-20) rigid mineral wool board continuous insulation. Use thermally broken z-girts to support new cladding	Install wall-mounted occupancy sensors	Install variable refrigerant flow (VRF) heat pump with refrigerant heat recovery
Add window exterior shading – Two opaque surfaces: top of window and 2.5ft from top of window, 1ft depth	Add Tubular Daylighting Devices (TDD), skylight products to provide lighting to interior spaces	Add demand-controlled ventilation carbon dioxide (CO_2) sensors to reduce outside air rate when appropriate
Seal envelope leaks – Target 30% reduction in exfiltration	Install daylighting sensors	Implement unoccupied room temperature setbacks
Replace windows – Thermally broken aluminum frame	-	Widen zone temp. dead bands: +2ºF for cooling/ -2ºF for heating
-	-	Reduce HVAC equipment runtime via scheduling for unoccupied hours

The building envelope (Package 1) and lighting improvement (Package 2) focused retrofits also included replacing the HVAC system with a VAV single packaged heat pump system. The building envelope (Package 1) and HVAC (Package 3) focused retrofits also included upgrading the interior lighting to achieve 0.8 W/ft^2 connected lighting load. These three retrofit packages were evaluated first individually to determine whether ZNE use could be achieved on an annual basis, and the resulting successful EEMs were then made available in the online tool for customizable retrofits for specific small commercial projects.

The energy reduction, first cost and financial payback of the retrofit packages was also compared to two “business as usual” retrofit packages to determine the relative cost-effectiveness of the retrofits. Standard package 1 consists of an LED lighting and an HVAC upgrade to single-zone packaged rooftop units with DX cooling and natural gas heating. Standard package 2 consists of an LED lighting upgrade and an HVAC upgrade to package rooftop units with direct expansion (DX) cooling and multi-zone VAV boxes with hot water reheat coils, served by a natural gas boiler.

Figures 1a and 1b provide a summary of results from this study, of various simulations of the energy efficiency retrofit . The building envelope retrofit (Package 1) performs very well in reducing energy usage, but at a relatively high cost, far greater than the mandated upper cost limit of 10% above the cost of a standard retrofit project. Packages 2 (lighting) and 3 (HVAC) also reduced building energy usage intensity significantly while meeting the financial requirements. In fact, the HVAC retrofit was estimated to be cheaper than a standard retrofit due to downsizing of ductwork that is characteristic of a DOAS installation compared to a standard packaged HVAC unit. This study also looked at combinations of the three packages for optimizing energy use intensity (EUI) (e.g. Package 1-2 is a combination of Packages 1 and 2). All three packages combined led to the lowest energy usage, though the high cost of envelope improvements made this project have a relatively high first cost. The annual energy use was also compared to the available annual solar energy production using photovoltaic (PV) installed in a portion of available roof area.

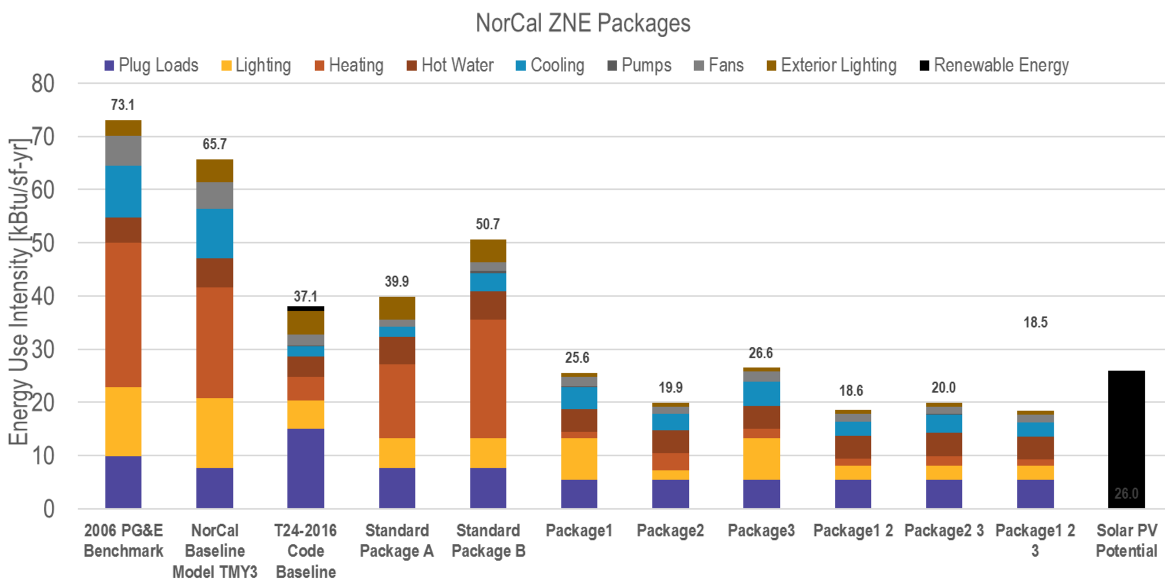

Figure 1a. Northern California ZNE Package Annual Energy Intensity Compared to Onsite PV Production, Existing Building Baselines and Title 24-2016 Minimum Energy Code Compliance

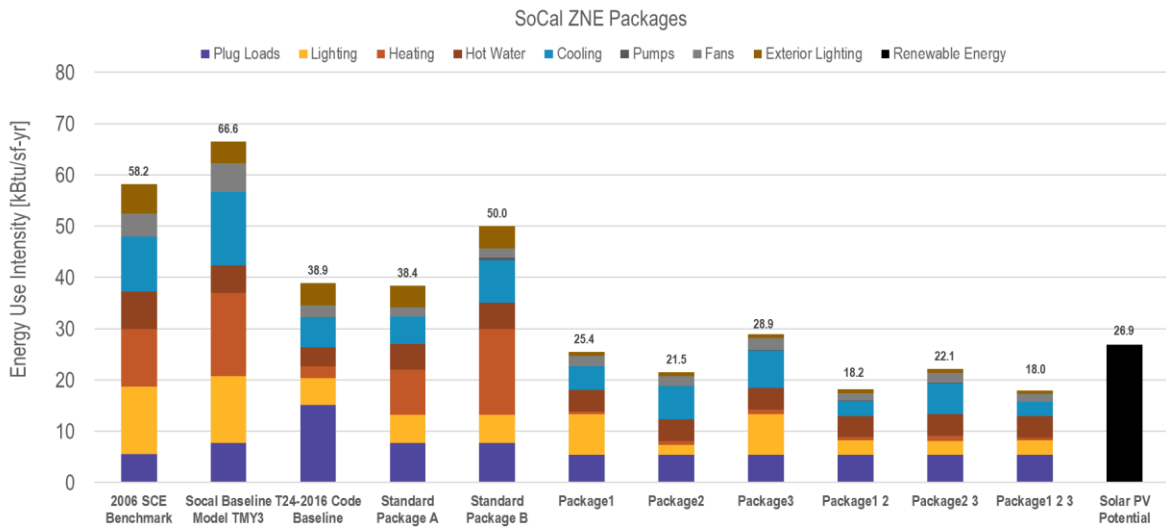

Figure 1b. Southern California ZNE Package Annual Energy Intensity Compared to Onsite PV Production, Existing Building Baselines and Title 24-2016 Minimum Energy Code Compliance

The Commercial Building Energy Saver (CBES)

CBES (cbes.lbl.gov) is an energy retrofit analysis toolkit developed using the energy efficiency measures from the simulation study to support small commercial retrofits. CBES 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 (Figure 2) including: (1) Energy Benchmarking providing an ENERGY STAR® score, (2) Load Shape Analysis to identify building operation improvements, (3) Preliminary Retrofit Analysis using a custom developed pre-simulated database and, (4) Detailed Retrofit Analysis which utilizes real-time EnergyPlus simulations. CBES includes 100 configurable EEMs with cost data, for assessing 7 different prototype buildings in 16 climate zones in California and 6 vintages. The development of CBES provides a simplified decision-making process for small and medium business owners, leveraging different levels of assessment dependent upon user background, preference and data availability. Relevant to the small commercial market, an energy assessment could be made with as little as seven inputs, without requiring deep technical expertise. However, it can also support more advanced users.

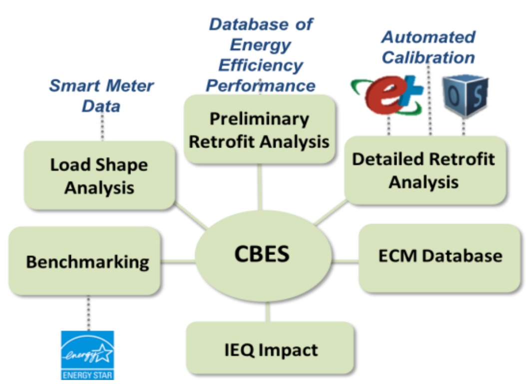

Figure 2. CBES Functional Architecture

To enable the evaluation of ZNE potentials, CBES tool has been updated with: (1) 12 new EEMs, listed below in Table 2 (Appendix); (2) Photovoltaics (illustrated in Figure 3, Appendix) and electric batteries, and (3) Time Dependent Valuation (TDV) metrics to enable the ZNE calculation specifically in California. We used the measured data from the FLEXLAB experiments to validate the simulation accuracy of the CBES tool. More details are described in the next section.

Technology Testing and Validation Under Controlled Setting (FLEXLAB®)

In order to evaluate the ZNE packages under a controlled setting, tests were conducted at LBNL's FLEXLAB® facility located in Berkeley California (Figure 4). FLEXLAB (FLEXLAB.lbl.gov) is a completely customizable and configurable whole-building integrated systems test facility that was designed to study, develop and validate systems level solutions, tools and processes for the commercial building market. Launched in 2014, FLEXLAB has four testbeds each consisting of two identical test cells calibrated to a high standard and level of accuracy between test cells, enabling detailed evaluations under controlled conditions. FLEXLAB provides energy monitoring at the device level, as well as high accuracy instrumentation and sensors to capture numerous other performance conditions. The tests described in this paper were performed in FLEXLAB's rotating testbed in order to evaluate technologies for more than one facade orientation.

Figure 4. LBNL's FLEXLAB, A Commercial Integrated Systems Test Facility

High accuracy thermal and power measurements were used throughout the test period. Power measurements for example had an accuracy of +/- 1% typically, and +/- 2% for low loads. In addition, a calibration run was conducted with both test cells in the same configuration to document the combined level of thermal accuracy between the two cells.

Between February 2018 and January 2019, two different configurations were tested to validate performance and also provide a dataset to compare and validate the CBES tool. One ZNE package was tested, as well as one specific EEM to ensure it was well represented in CBES:

1. ZNE package: This configuration was aimed at evaluating the overall performance of a package of the cost-effective developed EEMs, including

HVAC, lighting, and plug loads. It is a combination of Packages 2 and 3 shown in Table 1.

2. TDD: This configuration was aimed at evaluating the daylight delivery and glare performance of TDDs.

The ZNE package was tested for two facade orientations: south and west. The TDD configuration was tested with twelve different combinations of TDD manufacturer, tube diameter, exterior dome and interior diffuser. Testbed configuration for the ZNE package tests is shown in Table 3 and Figure 5. The testbed configuration for the TDD tests is shown in Figure 6.

Table 3. Testbed configuration for the ZNE package tests.

Cell B – Test Case	Cell A - Baseline

• Orientations: South, West
• HVAC: VRF 3 pipe split system, DOAS, wide deadband, unocc. setbacks/shutoff
• Façade:
  ■ Window-wall ratio (WWR) 0.25
  ■ Single-pane window w/ thermally broken (single break) aluminum frame
  ■ metal stud wall w/ R-19 batt cavity insulation
• Lighting: 0.4 W/ft^2, LED, occ. sensing, daylight harvesting
• Plug loads: 0.539 W/ft^2 connected load, 90% diversity, 0.485 W/ ft^2 max oper. load
	• Orientations: South, West
	• HVAC: VAV with hydronic coils, to be translated to Gas Furnace energy in post processing
	• Façade:
	  ■ WWR 0.25
	  ■ Single-pane window w/ thermally broken (single break) aluminum frame
	  ■ metal stud wall w/ R-19 batt cavity insulation
	• Lighting: 1.19 W/ft^2, T8, no automated controls
	• Plug loads: 0.77 W/ ft^2 connected load, 90% diversity, 0.70 W/ ft^2 max oper. load

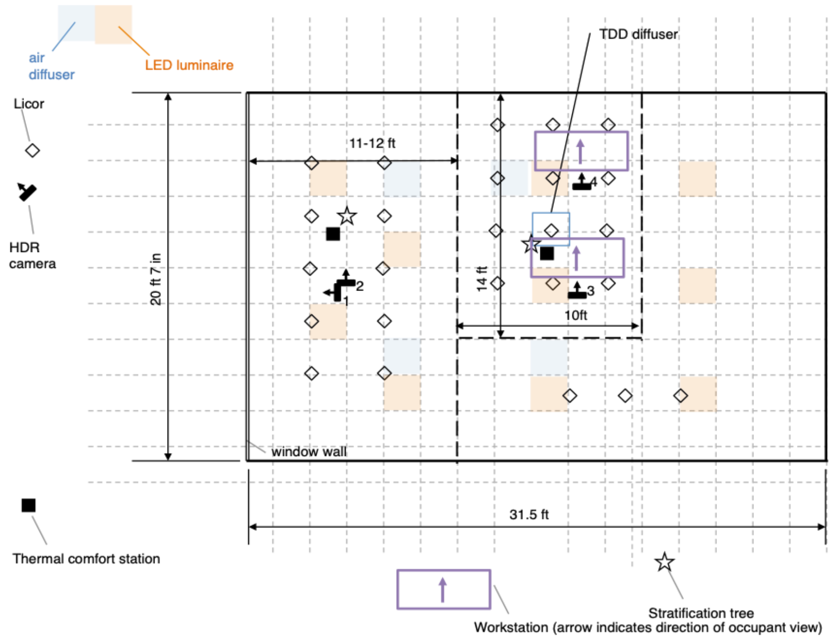

Figure 5. Test cell configuration for the ZNE package tests. Test cell (Cell B) is shown. Baseline cell (Cell A) configuration was similar except a) the size and location of luminaires was different (nine 2 x 4 ft fluorescent troffers instead of ten 2 x 2 ft LED luminaires) and b) the cell was symmetrical along the horizontal axis of this figure.

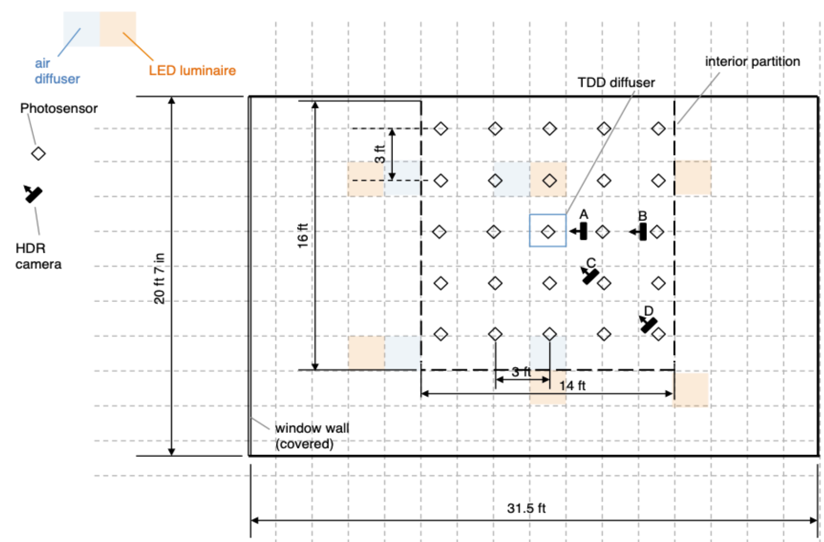

Figure 6. Test cell configuration for the TDD tests. Position of luminaires is shown but luminaires were not powered during these tests.

Overall, the ZNE package (Test case/Cell B) resulted in significant energy savings relative to the reference configuration (Baseline/Cell A), with the exception of HVAC energy use during heating-dominated periods. During cooling-dominated periods, measured HVAC thermal energy savings were 79% for south orientation and 81% for west orientation; the corresponding values for heating-dominated periods are -25% and -49%, respectively. Some of the impacts on heating performance were due to a reduction in internal loads providing heat to the space (lighting and plug loads). The package developed was also carbon neutral – the electric based heat pump would consume more electricity than the base case gas-based HVAC unit. In terms of calculated actual HVAC energy use, for cooling-dominated periods savings were 49% for south orientation and 63% for west orientation; the corresponding values for heating-dominated periods are -41% and -77%, respectively. It should be noted however that on balance the annual energy use of this package saved considerable energy and did result in a ZNE equivalent energy use intensity[1]. The increase of energy use during heating season being substantially compensated for by the large cooling savings, and the climates studied having a limited heating season.

Plug load energy savings was in the 31% regardless of orientation. There were no measured differences in visual comfort between the ZNE package and reference condition. During cooling-dominated periods results showed some variations in thermal comfort between the two configurations, but there was no consistent trend in favor of one or the other than the ZNE configuration showed wider ranges for thermal comfort metrics. During heating-dominated periods, preliminary results suggest the ZNE configuration was slightly cooler and less comfortable than the reference condition, but still within acceptable ranges.

The TDD-only tests showed overall potential lighting energy savings of 23% to 69%, depending on the diameter of the TDD and sky cover. No negative visual comfort impacts were measured during TDD testing. In general, for the same tube diameter, there were no significant differences in performance between TDD dome and diffuser types.

CBES Validation Using FLEXLAB Experiments

We also used the measured data from the FLEXLAB experiments to validate the simulation accuracy of the CBES tool. An equivalent building model was developed using CBES to represent the FLEXLAB chamber, by customizing the SmallOffice prototype. It should be noted that the office model in CBES is rectangle shaped by default and has a fixed zoning layout with a core zone surrounded by four perimeter zones. We were not able to align the CBES model with the FLEXLAB layout completely by adjusting the available parameters. Considering that we will validate not only energy, but also TDD performance in the TDD space, it has higher requirements on the alignment of the area. Therefore, we adjusted the CBES model by aligning the area of the core zone with the area of the FLEXLAB's TDD space (also a core area). Since the areas of the 3 zone window (perimeter) space and core spaces in FLEXLAB (Figure 5) are not aligned with the 5 zone (4 perimeter and one core space) CBES model, we calculated and compared weighted EUI in the validation. The validation was performed in two parts: (1) the validation of the TDD EEM performance, (2) the validation of the full ZNE package performance, where two key subsystems, lighting and HVAC, were validated separately, and the entire system was validated as a whole as well. Finally, the ZNE potential of the experiment chamber was also evaluated utilizing the PV module in CBES.

For the TDD EEM comparison the illuminance levels under daylight only mode (without lights on) were compared between the simulation and FLEXLAB test in Figure 7. From the comparison, the simulated and measured illuminance levels on the working plane (0.8 meter above the ground) both vary with the global horizontal solar radiation in a very similar trend. From the energy perspective, Figure 8 shows that the lighting energy use was reduced due to harvested daylight from TDD. The higher global horizontal radiation is, the more energy TDD can save. The coefficient of variation of the root mean square error (CVRMSE) between simulated results and measured data was 25.3%, which met the calibration criteria of 30%

[1] This experimental evaluation did not include PV panels, so results don't take into account PV energy production.

CVRMSE using hourly data according to the American Society for Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Guideline 14 (ASHRAE, 2014). Figure 8 also shows a good alignment between simulation and experiment.

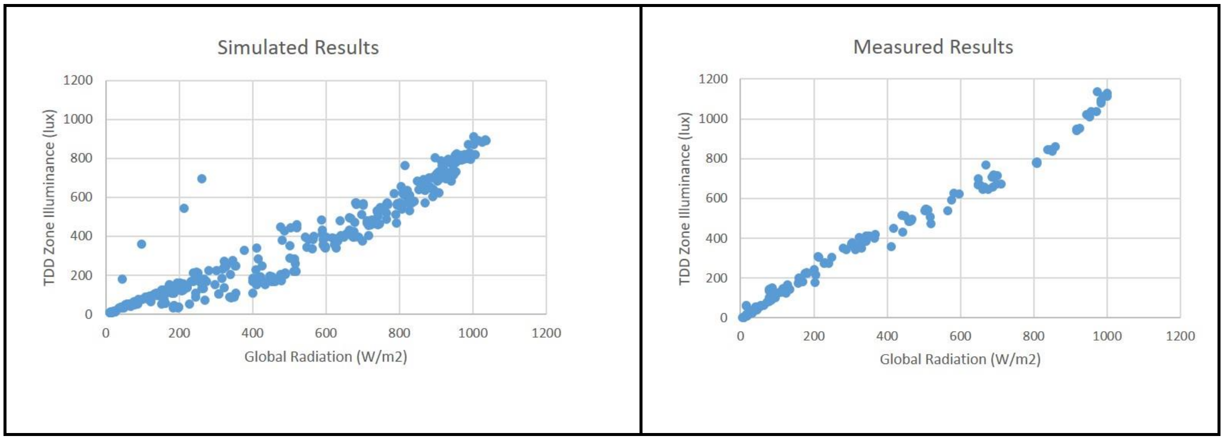

Figure 7. Variation of the TDD space illuminance with global radiation - simulated vs measured.

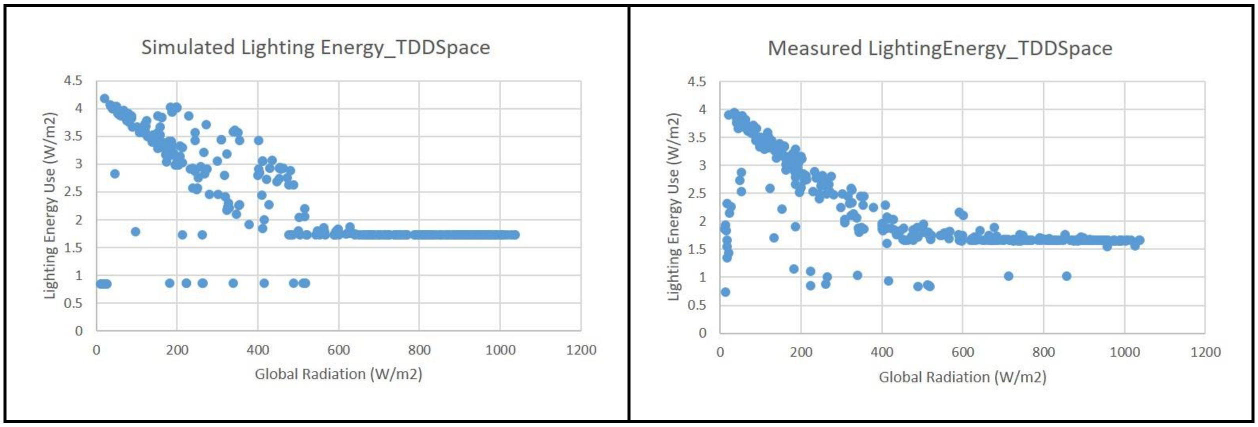

Figure 8. Variation of the TDD space lighting energy use with global radiation - simulated vs. measured.

The full ZNE package studied includes the retrofit of several aspects of the building, including lighting, plug load and HVAC. In the validation of the ZNE package, two key subsystems, lighting and HVAC, were validated separately. Finally, the entire building with the ZNE package was validated as a whole as well.

The lighting retrofit was evaluated in two parts: (1) for core zones with the TDD installed; (2) add daylighting control in the perimeter zones without a TDD. The performance of TDD has been validated in the section above. Figure 9 shows that the lighting energy use was reduced due to daylighting control. The higher global the horizontal radiation is, the more energy daylighting control can save. The CVRMSE between simulated results and measured data was 27.7%, which met the calibration criteria of 30% CVRMSE using hourly data according to ASHRAE Guideline 14 (ASHRAE, 2014).

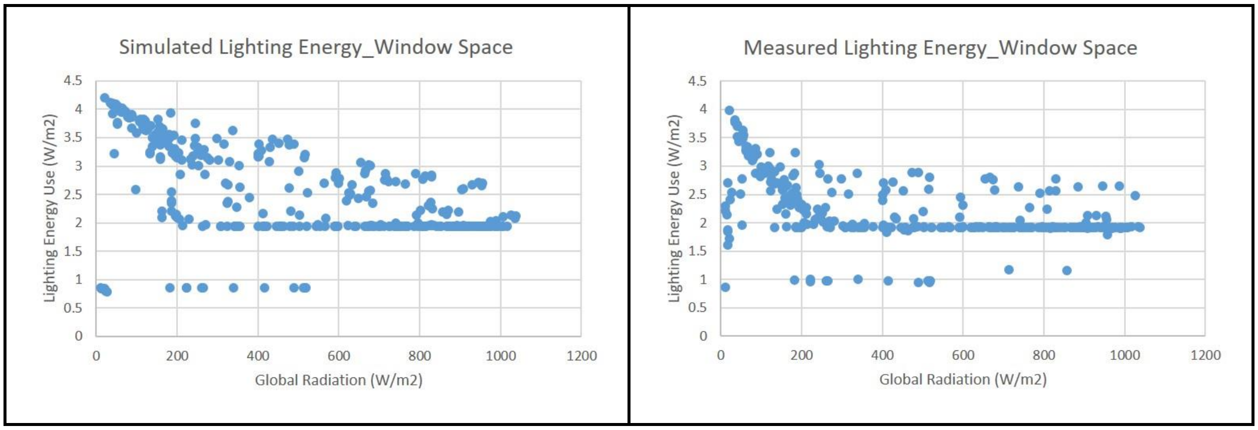

Figure 9. Variation of the window space lighting energy use with global radiation - simulated vs. measured.

The HVAC retrofit includes a high-efficiency 100% dedicated outside air heat pump, a widened deadband, setbacks during unoccupied hours, advanced control logic, and VAV diffusers. Cooling and heating thermal energy were compared between measurement and simulation. Figures 10, 11, 12, and 13 illustrate the hourly and daily comparison results of cooling and heating energy during the testing period. Overall, simulation results align well with measurement data, both hourly and daily. Meanwhile, some discrepancies are observed, such as a few cooling peak hours in June and the underestimated startup heating energy in early mornings of May and December. The reasons for the mismatches are elaborated below.

(1) As mentioned earlier, the CBES model was adjusted to align the area of the core zone with the area of the FLEXLAB's TDD core space. In doing so, the predefined 5-zone geometric layout in CBES resulted in the perimeter areas in the CBES model being almost double that of the experiment setting, leading to a much higher ratio of perimeter to core zones. This can cause a mismatch of perimeter and core HVAC load distributions and may have resulted in some cases where the CBES model would have seen the HVAC system in cooling mode (which takes priority in controls) sooner than the experiment experienced.

(2) Some of the control logic used in the experiment are advanced and complex, which are beyond CBES's capability and also difficult to implement in EnergyPlus (CBES's simulation engine), unless complicated codes are written. For example, the 100% outdoor air system, uses integrated control logic to control the variable air volume diffuser (Thermafuser) valves based on indoor temperature while controlling the static pressure of Thermafusers via air handling unit (AHU) fans. However, in CBES/EnergyPlus, supply air temperature (SAT) is determined first in the HVAC calculation module, based on which supply air flow rate is calculated. Lower SAT is preferred by default to minimize supply flow rate, thus fan energy. This is the reason why, taking June 23rd as an example, the supply air flow in the early morning is maximum in experiment (inducing as much OA since it is cooler) but minimal in simulation. Overall however, the total energy use during the testing period from the simulation tool and from the measured data differ by 3.8% (Figure 14), indicating that this discrepancy caused by software simplification is well counterbalanced by other factors.

(3) For the discrepancies in heating energy specifically: Since an existing hydronic system in FLEXLAB was used to mimic the performance and operation of heat pump (heat pump was not available for testing), there was in fact embedded heat in the water pipes not dissipated during off operation hours. When the system turned on, this amount of heating energy would be provided to the space. This was not captured in simulation, which directly modeled the

heat pump instead. The overall result would be an appearance of additional heating load provided to the experiment.

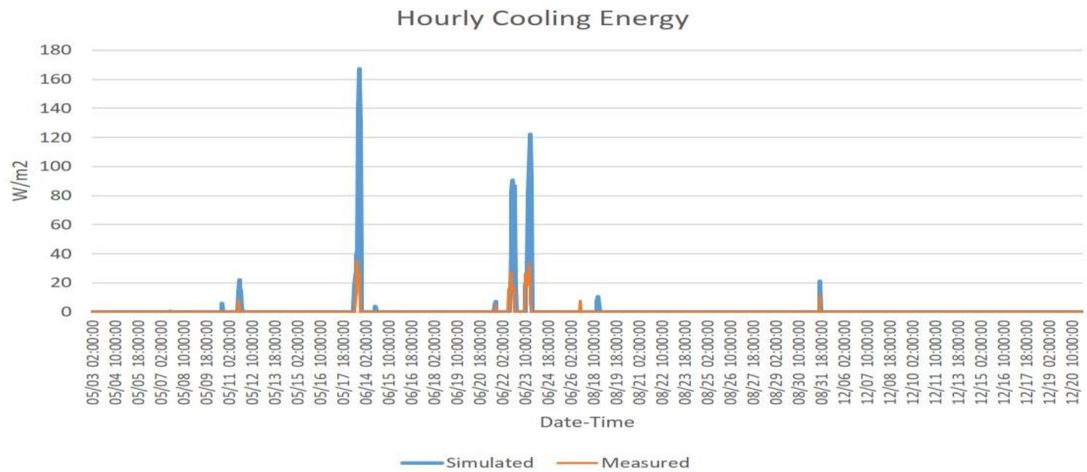

Figure 10. Hourly cooling energy comparison between simulation and measurement.

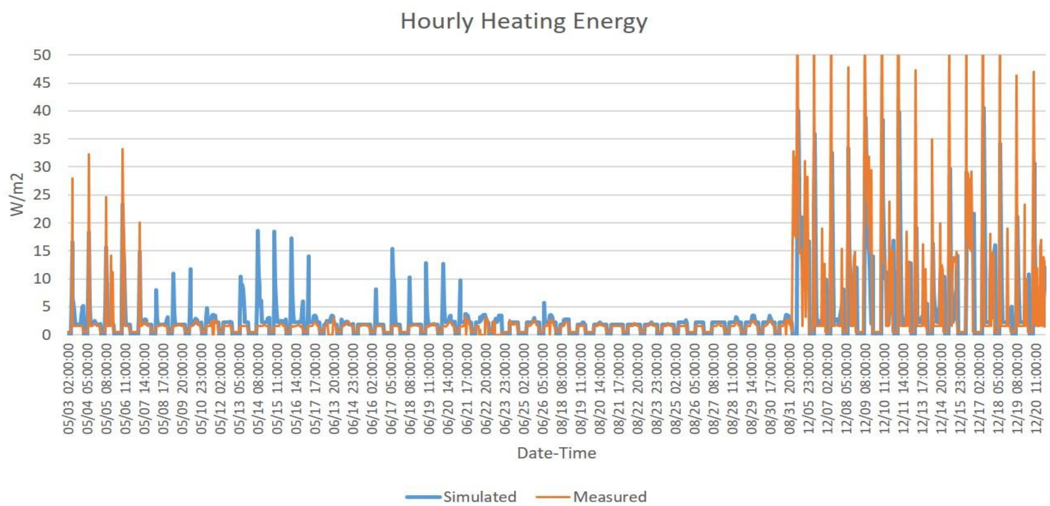

Figure 11. Hourly heating energy comparison between simulation and measurement.

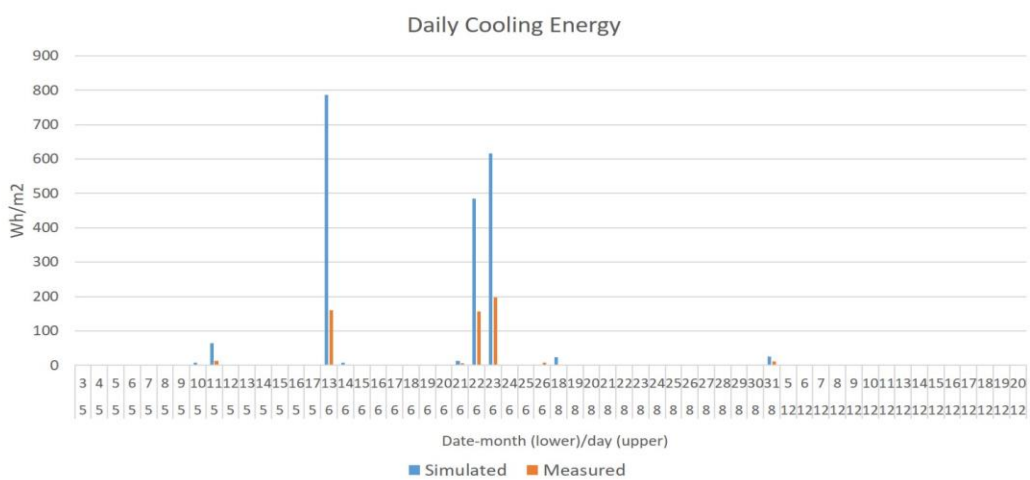

Figure 12. Daily cooling energy comparison between simulation and measurement.

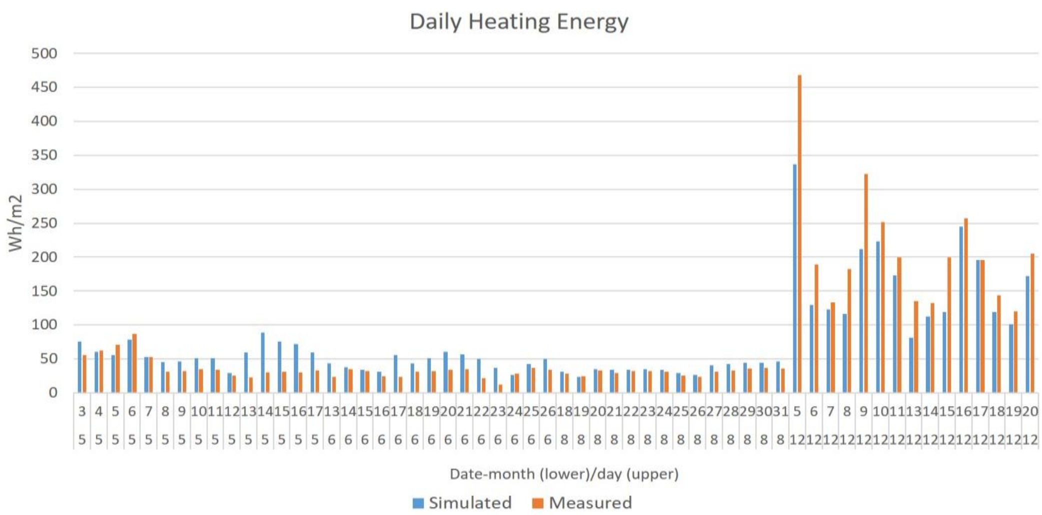

Figure 13. Daily heating energy comparison between simulation and measurement.

(a) Whole building

The discrepancy between simulated and measured data during the testing period for the whole building total EUI is -3.8%, as shown in Figure 14. This is less than 5%, which is the calibration criteria defined by ASHRAE Guideline 14.

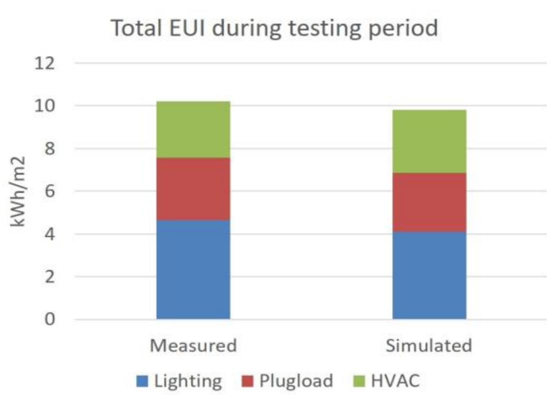

Figure 14. Comparison of total EUI during testing period - simulation and measurement.

In summary, the simulated results match well with the measurement data on lighting energy, HVAC energy, and whole building EUI. Therefore, it is reasonable to conclude that the accuracy of CBES is validated through experimental data and that CBES has the capability to well simulate ZNE measures and packages.

Demonstration Site Field Testing

A further goal of the study was to validate the performance of one of the ZNE packages in a field demonstration, garnering data on energy performance, thermal and visual comfort, occupant experience and ZNE operations. The City of Berkeley's Mental Health Services building was the site for this work, consisting of a single story ~8,000ft^2 historic building as shown in Figure 15. The building houses offices and counseling space for the local community.

Figure 15. Site Demonstration at City of Berkeley Mental Health Services, 2640 Martin Luther King Jr Way - street view and roof layout

Prior to retrofit the building had a low ENERGY STAR score of 63, and an EUI of 118.5 kBtu/sf/year[2], making it a prime candidate for an energy efficiency upgrade. A couple of unique challenges to this small commercial retrofit made it a further suitable stress test for a ZNE package. The first issue was the fact that the building itself was a historic structure and certain features could not be retrofitted, including the clay tile roof, and most exterior windows. Furthermore, the building was sited such that two exterior walls were located directly on property lines, meaning that no new windows could be provided in these locations. The project did want to introduce more daylight into the space however, and a couple dozen TDD were installed, providing daylighting but taking up considerable amount of the available roof space, hindering the space for photovoltaic panels. The new HVAC equipment would also be located on the roof, further reducing PV available space.

A simulation analysis of the building was first conducted to assess which package elements would achieve ZNE cost effectively. Two permutations of Packages 2 and 3 were selected since most major envelope retrofits found in Package 1 would not be viable due to the historic condition of the building. One package did include window replacement in select locations for comparison. The results of the CBES simulation analysis are shown in Figure 16, illustrating the evolution of the design process as well from Design Development through to Construction Documents. In all cases the retrofit is projected to meet ZNE annually. Site data was unavailable at time of publishing to show actual performance.

[2] This EUI is in the top 20% of highest consuming pre-1980s commercial buildings in California with floor area under 10,000ft^2, according to the U.S. Department of Energy’s Building Performance Database (U.S. DOE, 2020).

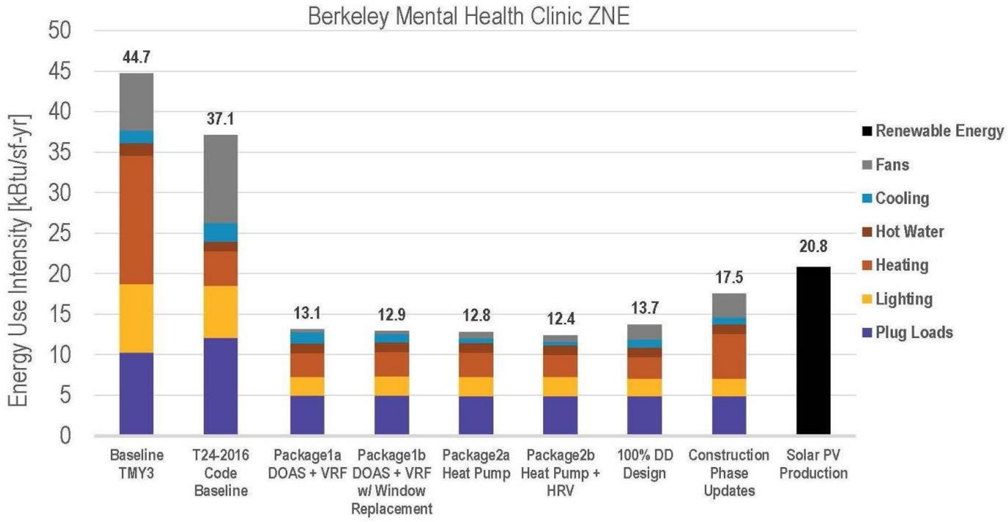

Figure 16. Site Demonstration Site Simulation Analysis of Several ZNE Packages and Comparison with Title 24 Energy Code and On-Site PV Production

Conclusion

The ZNE retrofit packages developed have shown that they can be done cost-effectively when attention is paid to the technologies used and closely tailored to the scope of the retrofit, leveraging situations where work might have needed to be done for other reasons (e.g. old, failing windows or end-of-life equipment). Small commercial buildings will remain a challenging sector to support though, given the relatively small energy cost savings potential and high investment value needed to conduct energy simulations, audits and design for ZNE performance. The technologies exist however to achieve ZNE performance, and to meet the State of California's energy goals, which include all new commercial construction ZNE by 2030, tools like CBES and cost-effective approaches to deployment will be critical to success.

Appendix

Table 2. List of new EEMs implemented in CBES for ZNE evaluation

EEM Name	
Add tubular daylighting device	Add storm window layer
Add exterior overhang Shades	Widen zone temperature deadband
Efficient electric instantaneous water heater (0.95) and low-flow fixtures (20% reduction)	VRF heat recovery with DOAS enthalpy wheel plus demand control ventilation
High efficiency exterior light fixture (50W)	Add window film
Apply demand response strategy of thermostat Reset	Packaged heat pump system with thermafuser (11.0 EER, 3.3 COP)
VRF heat recovery with DOAS energy recovery	Use plug load controller to make it 30% more

EEM Name	
ventilator plus demand control ventilation	efficient from baseline

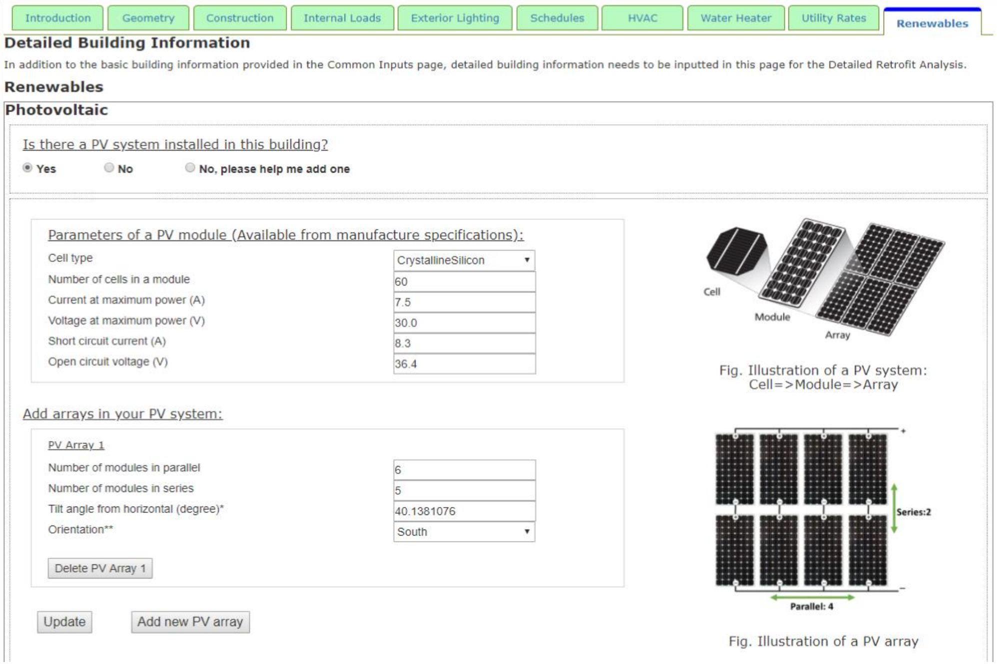

Figure 3. Screenshot of the PV system setting in CBES Web App.

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