

California Solar Initiative

**RD&D**

■ Research, Development, Demonstration  
■ and Deployment Program



Final Project Report:

# BEopt Multifamily Modeling Capabilities for ZNE and iDSM in California

Grantee:

National Renewable Energy Laboratory



December, 2015

[www.CalSolarResearch.ca.gov](http://www.CalSolarResearch.ca.gov)

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*“Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the CPUC, Itron, Inc. or the CSI RD&D Program.”*

# Preface

The goal of the California Solar Initiative (CSI) Research, Development, Demonstration, and Deployment (RD&D) Program is to foster a sustainable and self-supporting customer-sited solar market. To achieve this, the California Legislature authorized the California Public Utilities Commission (CPUC) to allocate **\$50 million** of the CSI budget to an RD&D program. Strategically, the RD&D program seeks to leverage cost-sharing funds from other state, federal and private research entities, and targets activities across these four stages:

- Grid integration, storage, and metering: 50-65%
- Production technologies: 10-25%
- Business development and deployment: 10-20%
- Integration of energy efficiency, demand response, and storage with photovoltaics (PV)

There are seven key principles that guide the CSI RD&D Program:

1. **Improve the economics of solar technologies** by reducing technology costs and increasing system performance;
2. **Focus on issues that directly benefit California**, and that may not be funded by others;
3. **Fill knowledge gaps** to enable successful, wide-scale deployment of solar distributed generation technologies;
4. **Overcome significant barriers** to technology adoption;
5. **Take advantage of California's wealth of data** from past, current, and future installations to fulfill the above;
6. **Provide bridge funding** to help promising solar technologies transition from a pre-commercial state to full commercial viability; and
7. **Support efforts to address the integration of distributed solar power into the grid** in order to maximize its value to California ratepayers.

For more information about the CSI RD&D Program, please visit the program web site at [www.calsolarresearch.ca.gov](http://www.calsolarresearch.ca.gov).

## Acknowledgments

The California Solar Initiative (CSI) Research, Development, Demonstration, and Deployment (RD&D) Program provided the funding for this project, under Solicitation 5. The U.S. Department of Energy (DOE) Energy Efficiency and Renewable Energy, Building Technologies Office and Bonneville Power Administration provided match funding.

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## Abstract

The BEopt software tool finds the least cost combination of energy efficiency and solar PV, providing support to integrated demand side management (iDSM) and Zero Net Energy (ZNE) for residential buildings. Under a previous CSI RD&D project, NREL, with support from team members Davis Energy Group (DEG) and Energy and Environmental Economics (E3), added enhanced capabilities to BEopt including a California-specific mode with retrofit analysis, detailed utility tariffs, utility cost effectiveness tests, demand response options, TDV calculations, community characterization and bill analysis tools, and whole-house efficiency & PV incentive programs. The current project made these enhanced capabilities available for analysis and optimization of multifamily buildings, including duplexes, triplexes, townhouses, flats, and low-rise apartment buildings (up to five stories).

## Executive Summary

Under a previous CSI RD&D project by NREL, DEG and E3, the Building Energy Optimization (BEopt) software was enhanced to provide a specialized California version, “BEopt-CA (Ex)” that included the following features (Christensen et al. 2014):

- Existing home analysis
- Detailed cost database
- Detailed utility tariffs
- Utility cost effectiveness tests
- Demand response options
- Time Dependent Valuation (TDV) calculations
- Utility program efficiency incentives (whole-house)
- Solar incentives
- Net energy metering alternatives

Leveraging this previous CSI RD&D investment, the goal of the current project was to develop multifamily building analysis capabilities for BEopt. This will further facilitate integration of distributed solar energy into the grid in order to maximize its value to California ratepayers.

In October 2015, NREL released BEopt Version 2.5, which includes the new multifamily features funded by the CSI RD&D Program. These features include a multifamily drawing tool enabling users to quickly define the geometry of multifamily buildings, including duplexes, townhouses, flats, and low-rise apartment buildings (up to five stories). All of the enclosure and equipment options from BEopt’s single-family mode have been made available for multifamily analysis. New categories added for multifamily mode include central water heaters, central hot water recirculation loops/controls, central solar water heating, central solar photovoltaic systems with virtual net metering, steel stud wall constructions, door area/construction, and corridor lighting.

As a result of this project, the BEopt-CA features developed under CSI RD&D Solicitation 1 are now available for use on California’s 4 million (and growing) multifamily homes. The public benefits to California include:

- Building owners, remodelers, architects, and builders can use BEopt to comprehensively analyze and optimize multifamily buildings across resource categories (EE, DR, and PV), as opposed to optimizing these categories separately.
- Because it includes measure costs and automates utility cost effectiveness test calculations, BEopt will be an important tool for developing multifamily retrofit programs that serve utility and ratepayer objectives.
- The facility with which BEopt can identify optimal combinations of measures for California’s diverse climates and the power of the EnergyPlus engine make it a desirable tool for developing cost-effective designs that provide building owners and tenants the best value and that can help California achieve its ZNE new construction goals.
- For energy professionals, BEopt provides an analytically sound platform, enabling them to quantify the benefits of energy performance enhancing upgrades. BEopt could become a

“standard” for analytic tools in use to make recommendations to multifamily building owners by architects, designers, home rating professionals, and builders.

- Utility planners can use BEopt to develop preferred cost-optimal “packages” of EE/DR/PV in planning and designing demand-side programs for multifamily buildings. These can be tailored for particular climate zones and building types, and optimized for subsequent solar installation.
- BEopt is likely to serve as a valuable tool for developing new measures for California’s 2019 Title 24 ZNE standards for both single and multifamily building types, including duplexes, triplexes, townhouses, flats, and low-rise apartment buildings.

## Introduction

There are close to 4 million multifamily homes in California—32% of the housing stock (EIA 2009). Nationwide, multifamily construction has seen significant growth in recent years and is expected to continue growing (U.S. News 2013). This is especially true in California, where, in 2012, multifamily construction surpassed single-family new construction for the first time (California Department of Finance. 2012).

Considering California's policy goals for solar energy and energy efficiency: including a comprehensive energy efficiency strategic plan for existing buildings (AB 758), statewide policy goals on ZNE new construction, 33% renewable portfolio standard by 2020, climate goals (24,200 GWh of EE by 2020), and the potential for longer term clean energy goals (2030 and 2050); having an accurate modeling tool that can optimize deep efficiency and solar integration in multifamily buildings will be very important.

Under CSI RD&D Solicitation 1, NREL, with support from team members Davis Energy Group (DEG) and Energy and Environmental Economics (E3), added enhanced capabilities to BEopt including a California-specific mode with retrofit analysis, detailed utility tariffs, utility cost effectiveness tests, demand response options, TDV calculations, community characterization and bill analysis tools, and whole-house efficiency & PV incentive programs. This follow-on research made these enhanced capabilities available for BEopt analysis and optimization of multifamily buildings.

This project relates to the following CSI RD&D focus area:

- Cross-Cutting – demonstrations or other small projects that integrate energy efficiency, demand response and energy storage with PV.

This project relates to the following CSI RD&D key principals:

- Support efforts to address the integration of distributed solar power into the grid in order to maximize its value to California ratepayers;
- Fill knowledge gaps to enable successful, wide-scale deployment of solar distributed generation technologies;
- Focus on issues that directly benefit California, and that may not be funded by others;
- Overcome significant barriers to technology adoption;
- Take advantage of California's wealth of data from past, current, and future installations to fulfill the above

## Project Objectives

The project objective was to develop multifamily residential modeling capabilities for use in California, to facilitate integration of distributed solar energy into the grid in order to maximize its value to California ratepayers. This follow-on research leveraged the previous CSI RD&D investment in the BEopt software. BEopt facilitates finding the least cost combination of energy efficiency and renewables to support integrated DSM (iDSM) and Zero Net Energy (ZNE) in California residential buildings. The project included the following components:

### BEopt Modeling Enhancements:

1. Multifamily mode
2. Adiabatic surfaces
3. Input screen enhancements
4. Output screen enhancements
5. Utilize multithreading for multifamily

### Multifamily HVAC and DHW System Enhancements:

1. Addition of individual system types (e.g. PTACs) as necessary
2. Addition of common central HVAC and DHW systems
3. Enable central solar water heating analysis
4. Account for recirculation heat losses and sensitivity to loop designs

## Project Approach

### Tasks

The project involved the following tasks:

#### ***BEopt Modeling Enhancements***

The purpose of this task was to enhance the *BEopt* interface and underlying modeling framework with the addition of capabilities to model and optimize (low-rise, 3 floors and under) multifamily buildings, including duplexes, triplexes, townhouses, flats, and low-rise apartment buildings. The task included the technical work to produce the following enhancements:

#### **Multifamily Analysis Mode**

A multifamily analysis mode was added to the *BEopt* user interface. This mode provides access to features described below and triggers a multifamily-specific set of operating conditions (occupancy, hot water use, etc.).

#### **Adiabatic Surfaces**

This subtask was planned to enable modeling of shared walls, ceilings, and floors in the *BEopt* interface. However, this proved to be unnecessary due to the whole-building model approach taken.

#### **Input Screen Enhancements**

Major enhancements were made to the BEopt Geometry Screen to enable drawing multiple units. Some minor changes were made to the Options Screen and Site Screen.

### **Output Screen Enhancements**

The Output Screen was enhanced to show results for each unit as well as the building total. Hourly outputs were also made available for both individual units and the building as a whole.

### **Utilize Multithreading for Multifamily**

This subtask was eliminated because the whole-building modeling approach eliminated the need for multithreading.

## ***Multifamily HVAC and DHW Systems***

The purpose of this task was to develop and implement additional HVAC and DHW technology models, and to facilitate multifamily building analysis. NREL developed the models for BEopt. DEG supported the model development efforts by providing NREL with example EnergyPlus models of multifamily buildings and field monitoring data for multifamily central systems. Work completed under this task is summarized below, and resulted in the release of BEopt software with multifamily HVAC and DHW system models.

### **Individual Systems**

All HVAC system types available in BEopt (single-family mode) were implemented for multifamily mode. Modeling of Packaged Terminal Air Conditioners (PTACs), Packaged Terminal Heat Pumps (PTHP), and wall/floor furnaces was explored. In the end, these were determined to be a lower priority than other features.

### **Central Systems**

Central DHW systems have been added, including defaults for material and labor costs. Central HVAC systems were determined to be a lower priority than other features and were not included. The approach was to create detailed models of common central systems using EnergyPlus. The models were compared to field monitoring data from two multifamily buildings in California. The models were then used to develop models of central systems with simplified inputs for inclusion in BEopt.

### **Central Solar Water Heating Systems**

Central solar water heating analysis capabilities were developed for BEopt. The approach was similar to that described for Subtask 3.2: Central Systems.

### **Recirculation Heat Loss Modeling**

In multifamily buildings with central HVAC or DHW systems, distribution and recirculation heat losses can represent a significant portion of energy use. BEopt central system models will be made to account for the sensitivity of distribution pipe losses to piping layout and recirculation system design.

## ***Technical Guidance***

The purpose of this task was to ensure the above enhancements were implemented in a way that is most appropriate for California multifamily buildings. Davis Energy Group (DEG) provided technical input iteratively throughout the development process. DEG also provided testing and feedback on the software framework and user interface to ensure optimal functionality.

The BEopt Automated Residential Simulation Test Suite was used to check for errors in multifamily modeling mode. A systematic comparison was made between single-family results and multifamily

results to identify errors. The log of issues discovered during testing by NREL, DEG, and external BEopt users is attached in Appendix A.

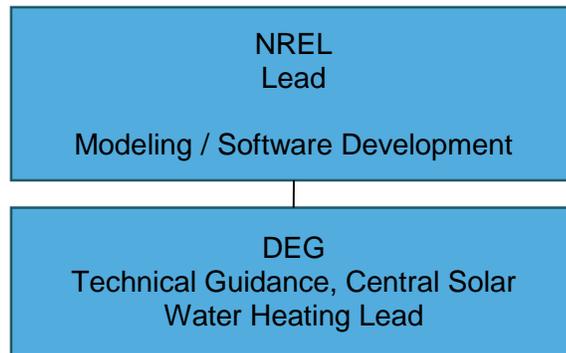
### ***Modifications to the Original Scope***

The approach taken to implement multifamily modeling changed from the original proposed Scope of Work, which led to a number of changes.

The original planned approach was to model each unit as a separate EnergyPlus simulation, utilizing a BEopt “Case” with a separate Geometry Screen for each unit. After exploring alternatives it was decided that an approach with a single Geometry Screen for the entire building would not be as difficult as expected, and would result in a more satisfying and user-friendly end product. Notably, this approach makes modeling central systems and corridors more straightforward.

### **Personnel**

The National Renewable Energy Laboratory served as the lead contractor on this project with partner Davis Energy Group. The team structure is shown below.



Team member overall roles:

- NREL was responsible for the overall management and technical direction of the project, leading the technology modeling and software development.
- Davis Energy Group provided technical support and guidance, and was involved in modeling of central water heating and recirculation losses.

## Project Outcomes

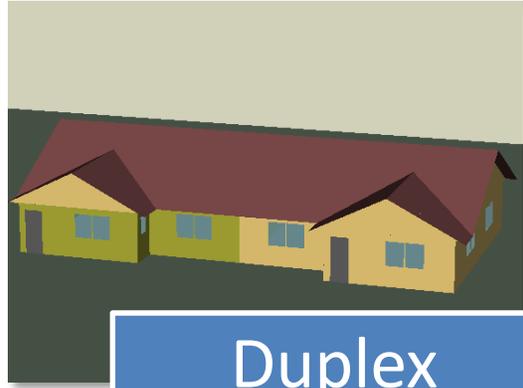
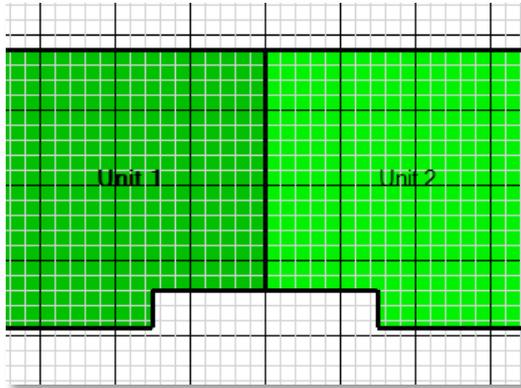
### Deliverables

In addition to the BEopt software, Version 2.5 of which is available at <https://beopt.nrel.gov>. A BEopt training webinar and this final report can be found at the same web page. Version 2.5 utilizes EnergyPlus 8.4, which was released in October 2015. The webinar can be downloaded from <https://beopt.nrel.gov/downloadBEopt2>.

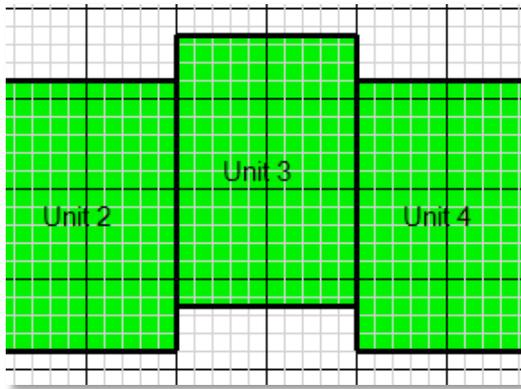
### Description of Multifamily Capabilities

#### *Geometry Screen*

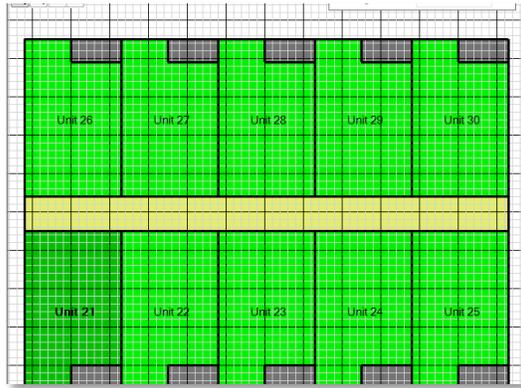
New drawing and display features facilitate user input of multiunit buildings including duplexes, townhouses and apartment buildings. Dwelling unit geometry can be drawn in detail. A Copy/Mirror button allows quick duplication of drawn units. It is now possible to draw up to five stories of living space, plus an attic level. Corridors can be drawn with a new corridor space type. Appendix D, Multifamily Drawing Tutorial, provides additional details on the new geometry screen features.



Duplex



Townhouse



Apartment

## *Modeling Features*

In multifamily mode, all of the drawn dwelling units are simulated together as a whole-building model. Dwelling units can include main living space, finished basements, and finished attics. Unconditioned space types (basements, attics, crawlspaces, garages) are each modeled as a single zone for simplicity.

## *HVAC Equipment*

All heating and cooling system types available in BEopt's single-family mode are now available as individual systems in multifamily mode. These include forced-air furnaces, central air conditioners, hot water/steam boilers, electric baseboard, air-source heat pumps, mini-split (ductless) heat pumps, and room/window air conditioners. Modeling of Packaged Terminal Air Conditioners (PTACs), Packaged Terminal Heat Pumps (PTHP), and wall/floor furnaces was explored. In the end, these were determined to have a very low market penetration and are not included in the model. Similarly, central heating systems such as hot water or steam boilers were determined to be a lower priority and were not included.

Ventilation systems available in multifamily mode include individual exhaust, supply, HRV, and ERV options. Central ventilation systems are uncommon in low-rise buildings and are not included.

## *Domestic Hot Water Equipment*

All DHW equipment types available in BEopt's single-family mode are now available as individual systems in multifamily mode. These include options for electric storage, electric tankless, gas storage (non-condensing and condensing), gas tankless (non-condensing and condensing), and heat pump water heaters.

Central water heaters and recirculation systems are now available. Gas, propane, and electric resistance fuel types are available. The tank volume, input capacity, recirculation pipe lengths, flow rate, and pump size can be autosized using methods from the ASHRAE Handbook of HVAC Applications and the 2013 Residential Alternative Calculation Method Reference Manual. Three options for recirculation pump control are available: continuous, timer, and demand. Recirculation loop location and insulation levels can be customized. Default material and labor costs are included in BEopt so that central systems can be optimized or compared to individual systems before obtaining detailed cost estimates.

Solar DHW systems are available both for individual units and for central water heating systems.

Multiple draw profiles are necessary to achieve a proper diversity of hot water draw and avoid coincident draw peaks, which would have an unrealistic effect on central DHW system performance. A total of 50 minute-based draw profiles (10 unique profiles for five different numbers of bedrooms) were generated using NREL's [DHW Event Schedule Generator](#) (Hendron et al. 2010). The set of 10 unique profiles repeat for buildings with more than 10 units.

## *Solar Photovoltaic Systems*

PV systems are modeled as shared by all units of the building. In California, electricity generated by central (shared) solar PV systems is commonly allocated to individual dwelling unit accounts according to the allocation percentages specified on forms submitted to utility companies for virtual net metering (e.g., [Form 14-654 for SCE's MASH-VNM schedule](#) (Southern California Edison 2014) and [Appendix A of Form 79-1142 for PG&E's NEMV schedule](#) (Pacific Gas and Electric Company 2015)). We are currently assuming the allocation is based on the relative square footage of each unit; however, other allocation schemes could be implemented at a later date.

## Steel Stud Walls

To accommodate multifamily building that use steel stud wall construction, a “Steel Stud” category with 14 options steel stud wall options was added to BEopt.

## Options Screen Behavior

Options selected on the Options Screen apply across all units; however, the way the options are modeled can vary between units:

- **Window Areas** – The window areas for each façade are allocated to units based on their exposed wall areas.
- **Air Leakage** – The whole-building ACH50 value is converted to equivalent leakage area (ELA), which is allocated to each unit proportionally based on exposed surface areas. All leakage is modeled to or from the outside as opposed to between adjacent units.
- **Mechanical Ventilation** – ASHRAE 62.2 flow rates are calculated for each unit based on finished floor area and number of bedrooms.
- **Space Conditioning Equipment** – Autosizing of heating, cooling, and dehumidifying equipment is unit-specific. User-specified fixed sizes are applied to all units. The heating and cooling capacities shown on the Output screen are averages across all units.
- **Ducts**
  - Duct surface areas are unit-specific, based on finished floor area and number of returns.
  - Duct locations can be unit-specific. If ‘auto’ is selected for duct location, the primary location of each unit’s ducts will be determined based on the usual priority: finished basement, unfinished basement, crawlspace, pier & beam, unfinished attic, garage, finished attic, and living. For unfinished spaces, the unit must be adjacent to that space. Thus, the ‘auto’ algorithm can be used to model the scenario where top-floor units have ducts in an unfinished attic, and the other units have ducts within conditioned plenums (living space).
- **Individual Water Heaters** – Autosizing of water heater tank volume and input capacity is unit-specific, based on number of bedrooms and bathrooms in each unit using the methods described in the 2014 Building America House Simulation Protocols.
- **Central Water Heaters** – The method of sizing was derived from ASHRAE 2015 HVAC Applications, Chapter 50. The boiler input rating is calculated based on the assumed occupancy, 20 peak minutes, medium use for multifamily buildings, and the entered boiler efficiency (see Table 7 in the ASHRAE reference); the hot water tank volume is sized to allow 70% of the stored hot water to be extracted at a useful temperature.
- **Lighting, appliance energy, hot water usage, and miscellaneous electric and gas loads** are calculated for each unit (usually a function of finished floor area and/or number of bedrooms).

In addition to the above parameters, the number of occupants is unit-specific, based on the number of bedrooms. Note that a different equation for number of occupants is used in multifamily mode, as specified by the 2014 [Building America House Simulation Protocols](#) (Wilson et al. 2014). This results in more occupants per bedroom, as shown in the figure below.

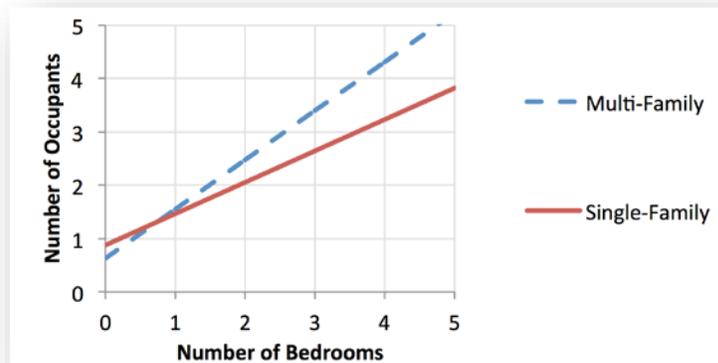


Figure 1. The number of occupants is a function of the number of bedrooms in each dwelling unit.

### Site Input Screen

On the Site Input Screen, the “Centrally Metered” checkboxes are used to specify whether gas and electricity are centrally or individually metered. When individually metered, fixed charges will be applied to each unit.

Electricity | Natural Gas | Oil | Propane

Utility Rates

Simple  Detailed

User Specified

State Average

National Average

Fixed: 8.00 \$/month

Marginal: 0.1076 \$/kWh

Average: 0.1146 \$/kWh

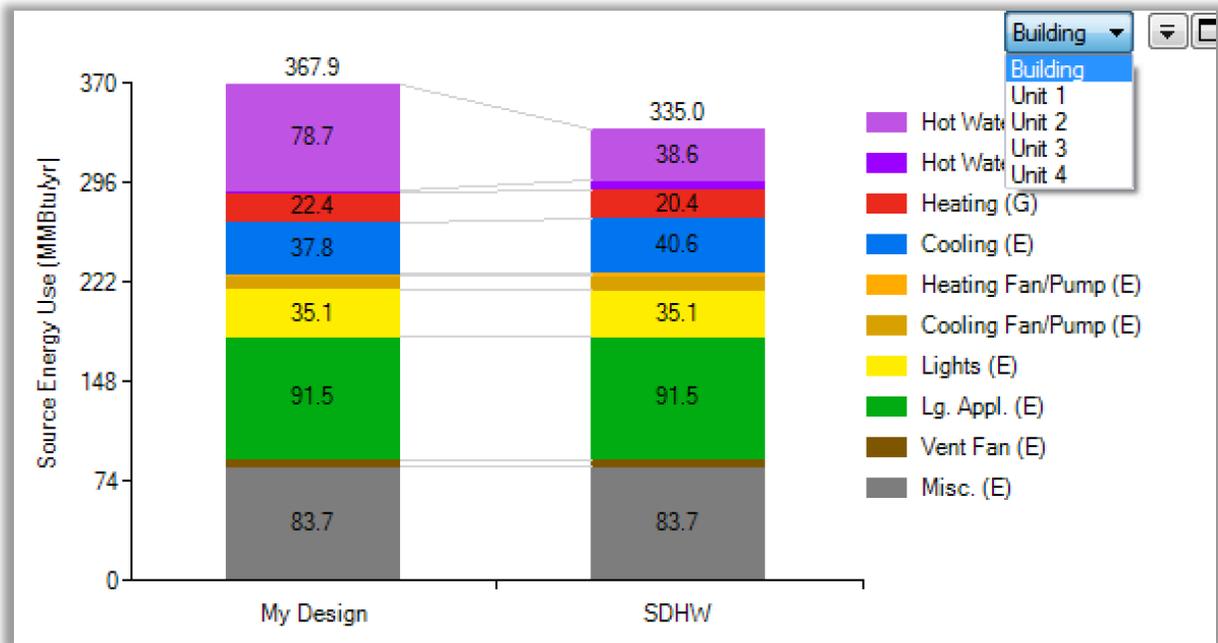
Fuel Escalation (Real): 0.00 %/year

Centrally Metered

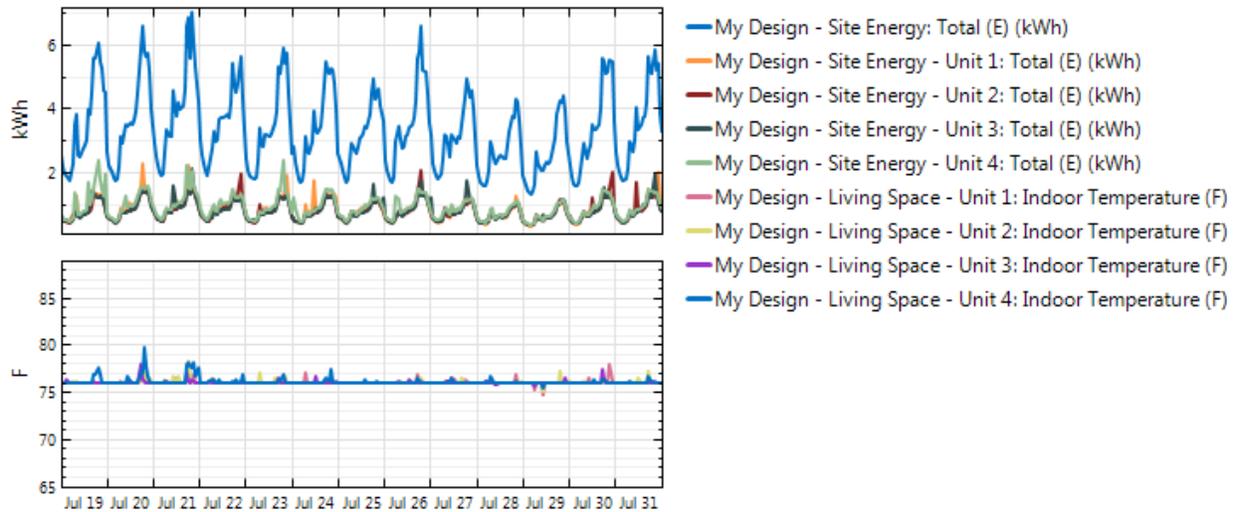
Tiered electricity rates are now supported in multifamily mode.

### Output

The Output screen shows results for each unit as well as the building total. Unit-specific outputs are accessed via the drop-down control in the upper right of the end-use graph. Unit-specific and building total heating and cooling capacities are now available from this graph as well.



Hourly outputs are available for both individual units and the building as a whole:



## EnergyPlus Bugs

A number of minor EnergyPlus bugs were identified through this work:

- [Custom meters assigned to a custom meter are read as all zeros](#)
- [Output: Table: Monthly "Invalid/Undefined" meter caused by similarly named custom meters](#)
- [Multiple Ground-Source Heat Pumps cause buggy output](#)

These have been reported to the EnergyPlus development team and will improve the software for all EnergyPlus users.

## Links to BEopt and Other Expanded Features

Version 2.5 of BEopt is available at <https://beopt.nrel.gov>. This version incorporates user feedback from the BEopt 2.4 Beta version. In addition to multifamily modeling capability it includes the following new features:

- New options/technologies:
  - Central water heaters and recirculation (multifamily)
  - Steel stud walls
  - Enhanced heat pump water heater models
  - Heat pump clothes dryers
  - Premium electric/gas clothes dryers
  - Condensing tank water heaters
  - Door construction and area
  - Window areas defined by façade-specific WWRs
  - 2013 ASHRAE 62.2 mechanical ventilation
  - Expanded solar water heating inputs
- Expanded simulation outputs
- Updated heat pump sizing
- PV cost multipliers on the site screen
- PV monthly grid connection fee
- Updated costs for PV, windows, and radiant barriers
- Updated to EnergyPlus v8.4

## Multifamily Drawing Tutorial

A tutorial on the use of the drawing tool to develop multifamily building models is provided in Appendix B.

## Conclusions

This project targeted the development of multifamily building analysis capabilities for the Building Energy Optimization (BEopt) software. This follow-on research leveraged the previous CSI RD&D Solicitation 1 investment in the BEopt software. BEopt facilitates finding the least cost combination of energy efficiency and renewables to support integrated DSM (iDSM) and Zero Net Energy (ZNE) in California residential buildings. Prior to this project, BEopt was limited to modeling single-family houses and did not include satisfactory capabilities for modeling multifamily homes.

In October, NREL released BEopt Version 2.5, which includes the new multifamily features funded by the CSI RD&D Program. These features include a multifamily drawing tool enabling users to quickly define the geometry of multifamily buildings, including duplexes, townhouses, flats, and low-rise apartment buildings (up to five stories). All of the enclosure and equipment options from BEopt's single-family mode have been made available for multifamily analysis. New categories added for multifamily mode include central water heaters, central hot water recirculation loops/controls, central solar water heating, central solar photovoltaic systems with virtual net metering, steel stud wall constructions, door area/construction, and corridor lighting.

As a result of this project, the BEopt-CA features developed under CSI RD&D Solicitation 1—including existing home retrofit analysis, retrofit measures and costs, utility tariff capabilities, utility cost-effectiveness tests, incentives for PV and whole-house efficiency, and demand response—are now available for use on California's 4 million (and growing) multifamily homes.

## Recommendations

It is recommended that current and potential users of BEopt in California be made aware of the new capabilities. Potential users may include builders, remodelers, architects, home energy raters, consultants, utility planners, and state and local government energy offices.

To this end, a webinar was held on July 13, 2015. A recording of the webinar is available on the BEopt website:

**BEopt 2.4 Beta Updates (July 13, 2015):** The webinar describes new multifamily building capabilities funded by this CSI RD&D project and available in the BEopt 2.4-2.5 releases.  
<https://beopt.nrel.gov/webinar24beta>

Potential users may also review the EE/DR/ES+PV integration features added under the previous CSI RD&D Solicitation 1 investment in the BEopt software, which can now be applied to the multifamily building sector:

### **BEopt-CA (EX): A Tool for Optimal Integration of EE/DR/ES+PV for California Homes**

- Final project report. (Christensen et al. 2014). (4 MB)<sup>1</sup>
- Final project webinar (March 5, 2014) slide deck<sup>2</sup> and recording<sup>3</sup>

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<sup>1</sup> [http://calsolarresearch.ca.gov/images/stories/documents/Sol1\\_funded\\_proj\\_docs/BEopt/CSI-RDD\\_S1-NREL-DEG\\_FinalRpt\\_Mar2014.pdf](http://calsolarresearch.ca.gov/images/stories/documents/Sol1_funded_proj_docs/BEopt/CSI-RDD_S1-NREL-DEG_FinalRpt_Mar2014.pdf)

<sup>2</sup> [http://calsolarresearch.ca.gov/images/stories/documents/Sol1\\_funded\\_proj\\_docs/BEopt/CSI\\_RDD\\_BEopt\\_webinar\\_Mar5-2014.pdf](http://calsolarresearch.ca.gov/images/stories/documents/Sol1_funded_proj_docs/BEopt/CSI_RDD_BEopt_webinar_Mar5-2014.pdf)

<sup>3</sup> [http://calsolarresearch.ca.gov/images/stories/documents/Sol1\\_funded\\_proj\\_docs/BEopt/CSI\\_RDD\\_BEopt\\_webinar\\_Mar2014.wmv](http://calsolarresearch.ca.gov/images/stories/documents/Sol1_funded_proj_docs/BEopt/CSI_RDD_BEopt_webinar_Mar2014.wmv)

## Public Benefits to California

As this project builds on the previous CSI RD&D investment in the BEopt software, the public benefits to California are similar to those from the previous project, but with a greater scope since BEopt can now be used for new and existing multifamily buildings in California. These benefits include:

- Building owners, remodelers, architects, and builders can use BEopt to comprehensively analyze and optimize multifamily buildings across resource categories (EE, DR, and PV), as opposed to optimizing these categories separately.
- Because it includes measure costs and automates utility cost effectiveness test calculations, BEopt will be an important tool for developing multifamily retrofit programs that serve utility and ratepayer objectives.
- The facility with which BEopt can identify optimal combinations of measures for California's diverse climates and the power of the EnergyPlus engine make it a desirable tool for developing cost-effective designs that provide building owners and tenants the best value and that can help California achieve its ZNE new construction goals.
- For energy professionals, BEopt provides an analytically sound platform, enabling them to quantify the benefits of energy performance enhancing upgrades. BEopt could become a "standard" for analytic tools in use to make recommendations to multifamily building owners by architects, designers, home rating professionals, and builders.
- Utility planners can use BEopt to develop preferred cost-optimal "packages" of EE/DR/PV in planning and designing demand-side programs for multifamily buildings. These can be tailored for particular climate zones and building types, and optimized for subsequent solar installation.
- Because the California energy compliance model (CBECC-Res) lacks the diverse modeling capabilities of the EnergyPlus engine that is behind BEopt, BEopt is likely to serve as a valuable tool for developing new measures for California's 2019 Title 24 ZNE standards for both single and multifamily building types, including duplexes, triplexes, townhouses, flats, and low-rise apartment buildings.

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## Appendix A. Software Testing and Evaluation Log

Date	Issue	Description/Fix	Status
4/30/15	Test suite errors/duct leakage bug	Fix for minimal test suite errors and fix EMS issue causing ~3 MBtu discrepancy (related to duct leakage subroutine).	Fixed
5/1/15	ZeroDivisionError	Fix ZeroDivisionError in cases with no heating or cooling (seen in MF test suite run).	Fixed
5/1/15	Shelter class bug	Fix bug in shelter class calculation discovered in MF branch test suite runs (0.03 MBtu impact).	Fixed
5/5/15	MSHP, GSHP meter bugs	Fix MSHP and GSHP test suite differences.	Fixed
5/5/15	Recirc pump meter bug	Add recirc pump Custom:Meter. Somehow got left out during merge. Resolves HW Dist test suite differences.	Fixed
5/5/15	Highest roof pitch	For SDHW, use geometry.highest_roof_pitch instead of unit.highest_roof_pitch, which was only getting assigned for finished roofs. Fixes test suite difference in SDHW categories.	Fixed
5/13/15	Unfinished basement and garage furniture errors	Seen in test suite	Fixed
5/20/15	Living space height calculation	Fix to make sure the finished attic contributes to the living space height. Caused test suite differences in the air leakage category.	Fixed
5/20/15	Num stories for duct location	Fix to include unfinished basement in number of stories for duct location fraction (if unit is adjacent to the unfinished basement). Caused test suite differences in the ducts category.	Fixed
5/20/15	HPWH test suite error	Fix HPWH error from test suite 004.	Fixed
5/22/15	roofType test suite error	Fix roof error (AttributeError: 'roofType' object has no attribute 'space_above_id') from test suite. Roofs never have spaces above them	Fixed
6/16/15	<a href="#">Error when creating or deleting case</a>	Caused by a particular series of events	Fixed
6/23/15	<a href="#">Finished basement supply air flow rates different for identical units</a>	For autosizing, finished basement supply air flow rates are different (factor of 2) for identical units. Total cfm is for the two units is the same.	Fixed
6/25/15	<a href="#">Garage roof behavior</a>	The bug occurs drawing garage space that replaces living space in MF mode. It would get a garage roof (incorrect), while newly added garage space would get a flat roof (correct).	Fixed
6/28/15	<a href="#">Copy/mirror after erase</a>	Caused by a particular series of events	Fixed

Date	Issue	Description/Fix	Status
6/28/15	<a href="#">E+ invalid construction</a>	Caused by corridor above a unit	Fixed
6/29/15	<a href="#">Stale EnergyPlus processes</a>	ReadVarsESO process doesn't get killed when simulations are aborted	Fixed
6/29/15	<a href="#">Rendering bug</a>	Caused by switching cases in particular situations	Fixed
6/29/15	<a href="#">LastAtticSpace/LastFoundationSpace not being preserved</a>	These case-specific properties are not being preserved either as a result of opening an existing project file or creating a new case.	Fixed
6/29/15	<a href="#">Multifamily performance</a>	Two performance bottlenecks have been identified for very large multifamily buildings. One has been fixed resulting in 70% reduction in time to generate E+ idf.	Fixed
7/1/15	<b>Beta Release</b>		
7/2/15	3rd party library error	Causes "Object reference not set to an instance of an object."	Communicating via email
7/7/15	EnergyPlus fan power error	EnergyPlus coil objects were incorrectly using the "Installed Supply Fan Power" instead of "Rated Supply Fan Power". Small impact on net-to-gross conversion of performance curves.	Fixed
7/9/15	Switch to CA metrics mode	Projects created in Standard or Building America mode can get access to California-specific metrics simply by using a California CZ weather file.	Resolved
7/10/15	<a href="#">Medium Windows font size/non-standard dpi error</a>	Handle non-standard dpi (i.e., "Medium" or "Large" Windows font size) by scaling fonts back to normal. This prevents a crash under certain circumstances and fixes a large number of layout issues due to resized controls.	Fixed
7/13/15	<a href="#">Unfinished attic island error</a>	Draw unfinished attic island within flat roof. Error appears.	Fixed
7/22/15	EnergyPlus error for electric baseboards	User was likely using incorrect EnergyPlus version	Pending user response
7/23/15	Multiple geometry errors	Caused multiple errors: <a href="https://cbr.nrel.gov/BEopt2/trac/ticket/1007">https://cbr.nrel.gov/BEopt2/trac/ticket/1007</a> Unfinished attic island error <a href="https://cbr.nrel.gov/BEopt2/trac/ticket/1009">https://cbr.nrel.gov/BEopt2/trac/ticket/1009</a> MF staggered-unit roof-type drawing bug <a href="https://cbr.nrel.gov/BEopt2/trac/ticket/972">https://cbr.nrel.gov/BEopt2/trac/ticket/972</a> Geometry Index out of bounds (partial fix)	Fixed
7/28/15	HPWH Psychrometric error	Error caused by high COP = 4.0 user input without changing flow rate	Resolved
7/30/15	"Window area for the facade differs from user input" error message.	Fix: Add a decimal place to the window/door error messages.	Fixed

Date	Issue	Description/Fix	Status
8/3/15	<a href="#">PV cost migration</a>	In some cases, PV costs were not being migrated (from \$ to \$/W) properly.	Fixed
8/26/15	<a href="#">PV credit for FITs</a>	Fix for bug that causes PV credit to be zero when you have a detailed electric rate and feed-in tariff type PV compensation.	Fixed

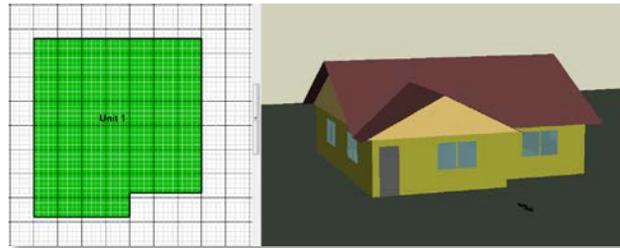
## Appendix B. Multifamily Drawing Tutorial

### Basic Drawing Methods for Multiunit Buildings

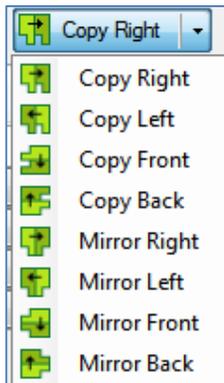
New drawing and display features facilitate user input of multiunit buildings including duplexes, townhouses and apartment buildings. Dwelling unit geometry can be drawn in detail. The following tutorial introduces the steps to draw a multiunit building.

As a user begins to draw, Unit 1 is created (similar to in single-family mode). Inputs for number of bedrooms and bathrooms are provided in a table, along with the calculated finished floor area:

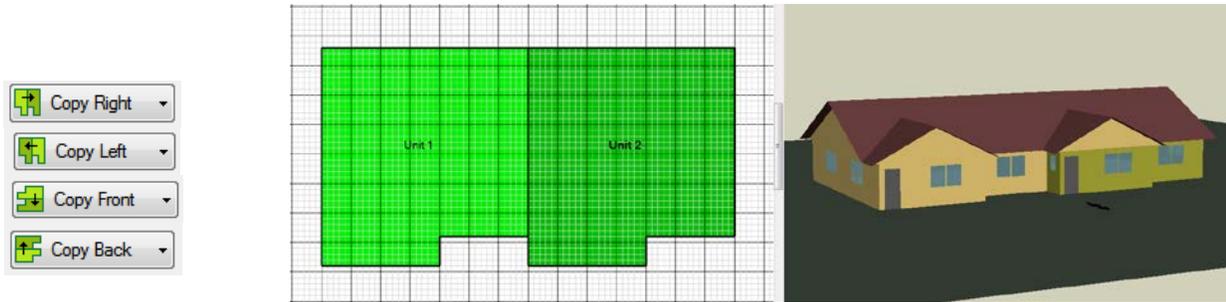
#	Beds	Baths	Finished (sqft)
Total	2	1	832
1	2	1	832



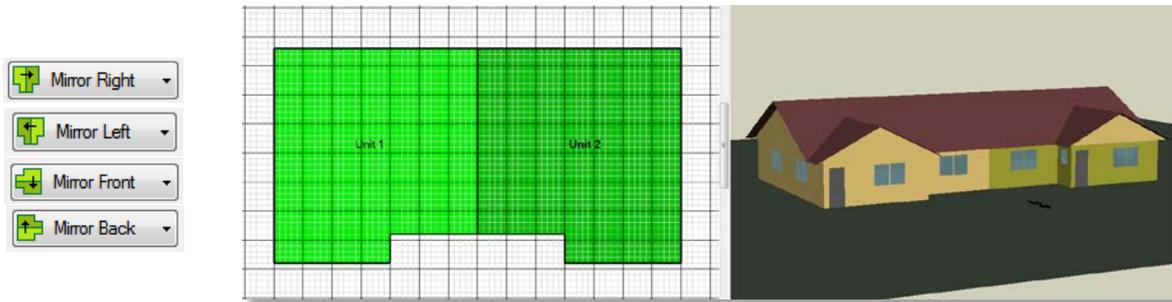
The copy/mirror button can be used to quickly duplicate units:



The copy buttons (right, left, front, or back) place a copy of the selected unit at the far edge of the current building:



Similarly, the mirror buttons (right, left, front, or back) place a mirrored copy of the selected unit at the far edge of the current building:



Alternatively, a new unit (that is not a copy) can be added and drawn:



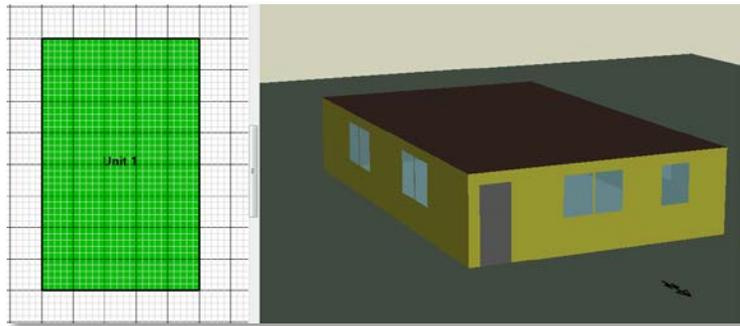
Characteristics are displayed for multiple units:

	#	Beds	Baths	Finished (sqft)	
Total		16	9	6544	
<input type="radio"/>	1	2	1	832	X
<input type="radio"/>	2	3	2	1276	X
<input type="radio"/>	3	2	1	832	X
<input checked="" type="radio"/>	4	3	2	1276	X
<input type="radio"/>	5	2	1	832	X
<input type="radio"/>	6	4	2	1496	X

## Multistory Units or Stacked Units

After drawing the first level of a unit,

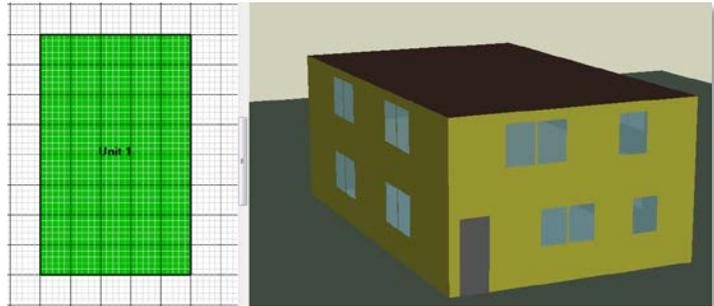
#	Beds	Baths	Finished (sqft)
Total	3	2	1000
1	3	2	1000



There are two ways to proceed with multistory buildings, depending on the objective:

To create a multistory unit (e.g., a townhouse) proceed as for a single-family home:

#	Beds	Baths	Finished (sqft)
Total	3	2	2000
1	3	2	2000

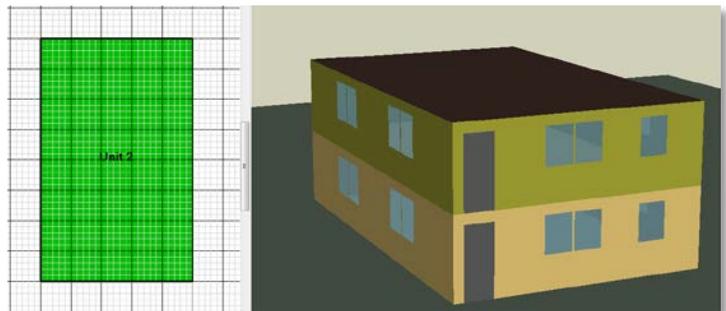


To create stacked units (e.g., apartment flats), go to the second level, click



and draw

#	Beds	Baths	Finished (sqft)
Total	6	4	2000
1	3	2	1000
2	3	2	1000



Note: Copying or mirroring operates on a selected individual unit, either 1-story or 2-story.