Be Optimistic!
Modeling Multifamily Buildings with BEopt

Eric Wilson
Craig Christensen
National Renewable Energy Laboratory

Emerging Technologies Showcase
November 16, 2016
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Modeling Multifamily Buildings with BEopt

Eric Wilson, Craig Christensen

E3T Showcase Webinar

November 16, 2016
Acknowledgements

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Project roles:

• NREL: Lead modeling / software development
• Davis Energy Group: CSI project management, model development support, testing
Outline

• NREL Overview
• BEopt Overview
  o Design Mode
  o Optimization Mode
• Multifamily Capabilities
  o Drawing Tool
  o Technologies
  o Hourly Output
• Applications
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NREL is Dedicated Solely to Advancing Energy Efficiency and Renewable Energy

- Physical Assets Owned by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
- Operated by the Alliance for Sustainable Energy, LLC, a 501(c)(3) nonprofit, under contract to DOE
- 2400 staff and 17 world-class facilities
- Main campus located in Golden, CO
- More than 350 active industry partnerships annually
- Campus is a living model of sustainable energy
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Expertise Spanning Individual Building, District, City, and State Scales

Net Zero Buildings and Districts | Performance-Based Acquisition | Incentive Program Design
Location-Optimal Efficiency Measures | Building Energy Code Analysis
Rapid Assessment of Building Portfolios | Grid-Supportive Smart Buildings

www.nrel.gov/buildings
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**BEopt**

Building Energy Optimization Tool

- **Free, publicly available** software (at beopt.nrel.gov)
- Evaluate and optimize the energy performance of **new and existing residential buildings**
- Identify **cost-optimal efficiency packages** at various levels of savings along the path to zero net energy
- Uses **EnergyPlus**, DOE’s flagship simulation engine
EnergyPlus

- DOE’s open-source, whole-building simulation engine
- $2.5M/yr sustained investment from DOE
- Recent BPA-funded project improved residential models in BEopt/EnergyPlus (including MSHPs, HPWHs, infiltration)
- Multi-lab/university/industry collaboration:
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Step 1. Model geometry defined quickly and accurately

Elapsed time: ~1 min.
Step 2. Select building characteristics from 100s of built-in options
Step 2. Select building characteristics from 100s of built-in options

```
<table>
<thead>
<tr>
<th>Option</th>
<th>R-Assembly [h-ft(^2)-R/Btu]</th>
<th>Cavity Insulation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) None</td>
<td>4.0</td>
<td>fiberglass batt</td>
</tr>
<tr>
<td>2) Uninsulated, 2x4, 16 in o.c.</td>
<td>4.1</td>
<td>fiberglass batt</td>
</tr>
<tr>
<td>3) Uninsulated, 2x6, 24 in o.c.</td>
<td>9.3</td>
<td>fiberglass batt</td>
</tr>
<tr>
<td>4) R-7 Fiberglass Batt, 2x4, 16 in o.c.</td>
<td>16.0</td>
<td>fiberglass batt</td>
</tr>
<tr>
<td>5) R-11 Fiberglass Batt, 2x4, 16 in o.c.</td>
<td>10.9</td>
<td>fiberglass batt</td>
</tr>
<tr>
<td>6) R-13 Fiberglass Batt, 2x4, 16 in o.c.</td>
<td>11.9</td>
<td>fiberglass batt</td>
</tr>
<tr>
<td>7) R-15 Fiberglass Batt, 2x4, 16 in o.c.</td>
<td>12.7</td>
<td>fiberglass batt</td>
</tr>
<tr>
<td>8) R-19 Fiberglass Batt, 2x6, 24 in o.c.</td>
<td>16.0</td>
<td>fiberglass batt</td>
</tr>
<tr>
<td>9) R-21 Fiberglass Batt, 2x6, 24 in o.c.</td>
<td>17.7</td>
<td>fiberglass batt</td>
</tr>
</tbody>
</table>
```

Wood stud walls are standard wood stud framed walls with cavity insulation. When batt insulation must be compressed to fit within the cavity (e.g. R19 in a 5.5’x2x6 cavity), R-values reflect this effect.

Grade of batt installation quality (1, 2, or 3) is described in RESNET’s "2006 Mortgage Industry National Home Energy Rating Systems Standards."
Step 2. Select building characteristics from 100s of built-in options

For the above-grade living space (including finished attic), air leakage is specified either by ACH50 (air changes per hour at 50 Pascal), or constant annual averageACH (air changes per hour). BEopt uses the AIM-2 method to determine hourly, weather-dependent infiltration flow rates.

In addition to above-grade living space, options here also specify the garage air leakage. All other spaces (e.g. crawlspace, finished/unfinished basement, unfinished attic) have their leakage/ventilation specified in their respective categories.

For multifamily buildings, the air leakage is specified for the entire building. The building’s effective leakage area is then apportioned to each unit according to the unit’s exposed exterior wall area.
Step 2. Select building characteristics from 100s of built-in options
Step 2. Select building characteristics from 100s of built-in options

![Building characteristics selection interface](image_url)
Step 2. Select building characteristics from 100s of built-in options
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![Screen capture of BEopt software with highlighted PV system and table options]

<table>
<thead>
<tr>
<th>Option</th>
<th>Size [kW]</th>
<th>Module Type</th>
<th>System Losses [frac]</th>
<th>Inverter Efficiency [frac]</th>
<th>Cost [$/W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>6.0 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$3.00</td>
</tr>
<tr>
<td>14</td>
<td>6.5 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.99</td>
</tr>
<tr>
<td>15</td>
<td>7.0 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.98</td>
</tr>
<tr>
<td>16</td>
<td>7.5 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.96</td>
</tr>
<tr>
<td>17</td>
<td>8.0 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.94</td>
</tr>
<tr>
<td>18</td>
<td>8.5 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.93</td>
</tr>
<tr>
<td>19</td>
<td><strong>9.0 kW</strong></td>
<td><strong>c-si</strong></td>
<td><strong>0.14</strong></td>
<td><strong>0.96</strong></td>
<td><strong>$2.92</strong></td>
</tr>
<tr>
<td>20</td>
<td>9.5 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.90</td>
</tr>
<tr>
<td>21</td>
<td>10.0 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.89</td>
</tr>
<tr>
<td>22</td>
<td>10.5 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.88</td>
</tr>
<tr>
<td>23</td>
<td>11.0 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.87</td>
</tr>
<tr>
<td>24</td>
<td>11.5 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.84</td>
</tr>
<tr>
<td>25</td>
<td>12.0 kW</td>
<td>c-si</td>
<td>0.14</td>
<td>0.96</td>
<td>$2.83</td>
</tr>
</tbody>
</table>

PV options are in kW DC.

Displayed costs excluded any incentives, which are specified on the Site input screen.

For multifamily buildings, the PV system is assumed to be shared by all units of the building and energy production is allocated to each unit based on finished floor area.
Step 2. Select building characteristics from 100s of built-in options

Elapsed time: ~11 min.
Step 3. Easy selection of climate, utility rates, economic parameters

Elapsed time: ~12 min.
Step 4. Run simulation to get results

Elapsed time: ~12 min.
Results (Design Mode)

Elapsed time: ~30 min.

Annual Electricity Consumption by End Use

Site Electricity Use [kWh/yr]

<table>
<thead>
<tr>
<th>Code</th>
<th>Better Ins.</th>
<th>+ Air Sealing</th>
<th>+ DHP</th>
<th>+ HPWH</th>
<th>+ E-STAR Appl. &amp; Ltg.</th>
<th>+ PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>26052</td>
<td>3453</td>
<td>23528</td>
<td>18939</td>
<td>3450</td>
<td>12186</td>
<td>10208</td>
</tr>
<tr>
<td>20844</td>
<td>14953</td>
<td>12532</td>
<td>881</td>
<td>3450</td>
<td>1295</td>
<td>1339</td>
</tr>
<tr>
<td>15633</td>
<td>12532</td>
<td>2116</td>
<td>881</td>
<td>3450</td>
<td>1295</td>
<td>1339</td>
</tr>
<tr>
<td>10422</td>
<td>2497</td>
<td>2116</td>
<td>1158</td>
<td>1193</td>
<td>1419</td>
<td>1419</td>
</tr>
<tr>
<td>5211</td>
<td>2116</td>
<td>1193</td>
<td>1377</td>
<td>1377</td>
<td>1377</td>
<td>1377</td>
</tr>
<tr>
<td>0</td>
<td>2705</td>
<td>2705</td>
<td>2705</td>
<td>2705</td>
<td>2705</td>
<td>2705</td>
</tr>
</tbody>
</table>

Previous runtime: 5m 41s
Results (Design Mode)

Elapsed time: ~30 min.

Annual Utility Bills by Type

- Code: $2483
- Better Ins.: $2153
- Air Sealing: $1698
- DHP: $1136
- HPWH: $944
- E-STAR Appliances: $789
- PV: $695

Previous runtime: 5m 41s
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Optimization Mode – Option Selection

The image shows a software interface with various options for selecting materials and configurations in a building model. The interface includes sections for Building, Walls, Ceilings/Roofs, Foundation/Floors, Thermal Mass, Windows & Doors, Airflow, and Space Conditioning. Each section lists different options and properties for selecting materials, such as R-values for insulation and ventilation options.

The table on the right side of the interface lists various ceiling and roof assembly options with corresponding R-values. The options include different types of insulation materials and configurations, such as fiberglass, cellulose, and ventilated options. Each option is accompanied by an R-value indicating its thermal resistance.

The text in the interface indicates that the software is currently only showing options deemed appropriate and for which costs exist. Users can view additional options if necessary. The interface also notes that attic space that is not directly conditioned, insulation can be applied on the attic floor (the ceiling of the space below) or at the roof plane. Options can also specify whether the attic is vented or not.

The software is designed to help users optimize building designs by selecting materials and configurations that maximize energy efficiency and cost-effectiveness.
Optimization Mode – Option Selection

Heat pumps provide both heating and cooling in one integrated system. Mini-split heat pumps are also called ductless heat pumps, multi-split, or variable refrigerant flow (VRF) heat pump systems. Like air source heat pumps, they have two main components: an outdoor compressor/condenser and an indoor air handling unit. The indoor and outdoor units are linked via conduit that houses the refrigerant and power cables. Mini-split heat pumps do not use a duct system.

The following inputs for this model are available in, or can be derived from, NEEP's Cold Climate Air-Source Heat Pump Specification Listing spreadsheet: Rated SEER, Rated HSPF, Heating Capacity Offset, Minimum Heating Capacity [frac], Maximum Heating Capacity [frac], Heating Capacity Retention Fraction/Temperature, and Pan Heater Power. These properties are related and one should not be changed without changing the others. In general, the remaining inputs related to airflow, SHR, etc. can be left at their default values.

All BEopt options are modeled as variable-speed systems. Note that efficiency and retention of heating capacity at colder temperatures is highly related to system size; therefore, the system size (nominal cooling capacity) is included in each option name.

Options are assumed to condition the entire building unless they are denoted as, e.g., “30% Conditioned”. Options in the Electric: Baseboard category may also be selected to allow supplemental heating.

For multifamily buildings, the selected option(s) apply to each unit.
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Multifamily Capabilities

- BEopt originally developed for single-family detached
- In 2014–15, DOE and the California PUC provided funding to add multifamily capabilities to BEopt
- In 2015, BPA provided additional funding to further enhance multifamily modeling capabilities
- Focus is low-rise multifamily (up to 5 stories)

Source: TRC Solutions. California Multi-Family New Homes Case Studies
Motivation

• Over 500,000 multifamily buildings in the Pacific Northwest

• Growing faster than single-family

• Complements BPA & NW Council interest in saving energy in multifamily buildings

• Existing tools for multifamily are time-intensive or lack necessary features
Multifamily Enhancements

The Residential Building Stock Assessment (RBSA) Multifamily Characteristics were used to prioritize technologies and features.
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Drawing Tool Example – Townhomes
Drawing Tool Example – Townhomes
Drawing Tool Example – Townhomes
Drawing Tool Example – Townhomes
Drawing Tool Example – Apartment Building
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Technology Models

Heating/cooling systems available
(individual systems for each unit)
- Furnace
- Boiler
- Electric baseboard
- Central heat pump
- Ductless heat pump
- Ground-source heat pump
- Central AC
- Room/window AC

Ventilation systems available
(individual systems for each unit)
- Exhaust
- Supply
- HRV
- ERV
Domestic Hot Water systems

• Individual
  o Storage
  o Tankless
  o Heat pump water heater

• Central
  o Storage
  o Solar DHW
  o Recirculation loop

• Draw profile diversity

Source: Davis Energy Group
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Electric demand in four townhomes
During a peak event in July

![Graph showing hourly output](Path_to_graph_image)
Whole-building electric demand (kW)
24-hour profiles for all 365 days of year
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Example Application

- **Seattle, WA firm has used BEopt** to calculate monthly utility bill allowances for **several low-income multifamily developments**
- Better estimates of utility bills extend the value of low-income housing tax credits (LIHTC) and other financing, thereby enabling greater investments in energy/water efficiency.

**ARBORA COURT: LIVING WITH DIGNITY**

In Seattle’s University District, an exciting new project is underway. Congratulations to Bellwether Housing, University Christian Church and the rest of the Arbora Court project team on the ceremonial groundbreaking of this much-anticipated apartment building. Thanks to you, over a hundred low-income families will soon call this dignified building home.
Next Steps: PNW Regional Tool

- Active BPA-funded project to develop an **open-source regional analysis tool** for the PNW
- Builds upon **BEopt/EnergyPlus models**
- Evaluates **wide range of energy efficiency measures** across thousands of simulations representing the **entire region’s housing stock**
- Calibrated to **RBSA data**
- Leverages **cloud computing**
- Hoping to target **both SFD and MF buildings**
Thank you!

Download BEopt:  
https://beopt.nrel.gov/

User forum:  
https://beopt.nrel.gov/forum

Training videos:  
https://www.youtube.com/playlist?list=PLHC0xDtkdjgEec8QhVt7exJY3tpSLEFk-d

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