Passive House for ALL of California

North American Passive House Conference
Burlingame, CA, September 12, 2014

Graham Irwin
Principal, Essential Habitat
www.essentialhabitat.com
Perspective: Our California Projects

Av. Min. Temperature (deg. F)
01/1/2014 - 1/31/2014

Generated 2/1/2014 at WRCC using provisional data.
NOAA Regional Climate Centers
Perspective: Our California Projects
The Goal: Wider PH Adoption in California


2. How Does Passive House Compare with 2013 Title 24 (CA Energy Code)?

3. What is Generally Required in Other California Climates?

4. What are the Most Effective Improvements?
## Why This Matters: CO₂

### 2011/2012 Carbon Dioxide Emissions

<table>
<thead>
<tr>
<th>Country</th>
<th>kTonnes</th>
<th>% Total</th>
<th>Tonnes per Capita</th>
<th>Country</th>
<th>kTonnes</th>
<th>% Total</th>
<th>Tonnes per Capita</th>
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<td>World</td>
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<td>Mexico</td>
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References: EDGAR Database, US EPA, US EIA
The Study: CA 2013 Code vs. Passive House

I. Analysis of California Code-Minimum Construction in PH Energy Model (PHPP 8.4) by Climate Zone.

Representative Building: “Prototype” One Story House

Figure A-1: One Story Prototype Front View

Figure A-2: One Story Prototype Back View

Representative Building: 
“Prototype” One Story House

- Conditioned Floor Area: 2100 ft$^2$
- Ceiling Height: 9 ft
- Conditioned Volume: 18,900 ft$^3$
- Slab Area: 2100 ft$^2$
- Slab Perimeter: 162 ft
- Ceiling Area: 2100 ft$^2$

I. Title 24 Energy Modeling:
1. “Proposed” (Actual) Design

- No Landscape Shading – “Corbusian Plane”
- 12” Roof Overhang
- Glazing = 5% Exterior/“Conditioned Floor Area” (CFA) in Each Direction (108 ft²)
2. Study Adjustment – No Garage: Demising Walls Set As Ambient

- Conditions Heavily Dependent on Garage Door Operation = Unpredictable
- Deletion Likely to Make Winter Compliance More Difficult = Conservative
- Cooling Conditions w/ Cool Roof = Garage (Probably) Insignificant
3. “Standard” Design: Energy Budget for Compliance

- Identical Floor Area & Volume = Proposed Design
- Equal Wall Area in Each Cardinal Direction: N, E, S, W
- Glazing = Prototype = 5% Exterior Floor Area (CFA) in Each Direction (108 ft²)
- Overhangs Deleted
4. Set Location by Climate Zone: Locate Project in 1 of 16 Cities

16 Climate Zones (Desert to Subarctic)

CZ 1 (Arcata): 4403 HDD 7 CDD (Portland, OR 4400 HDD 390 CDD)
CZ 2 (Santa Rosa): 2689 HDD 529 CDD (Abilene, TX 2659 HDD 2386 CDD)
CZ 3 (Oakland): 2400 HDD 377 CDD (Wilmington, NC 2429 HDD 2017 CDD)
CZ 4 (San Jose-Reid): HDD CDD (Waco, TX 2164 HDD 2840 CDD)
CZ 5 (Santa Maria): 2774 HDD 123 CDD (Midland, TX 2716 HDD 2139 CDD)
CZ 6 (Torrance): 1611 HDD 561 CDD (Austin, TX 1648 HDD 2974 CDD)
CZ 7 (San Diego-Lindberg): 1063 HDD 866 CDD (Phoenix, AZ 1027 HDD 4364 CDD)
CZ 8 (Fullerton): 1444 HDD 1652 CDD (Norfolk, VA 3342 HDD 1630 CDD)
CZ 9 (Burbank-Glendale): 927 HDD 1506 CDD (Raleigh, NC 3465 HDD 1521 CDD)
CZ 10 (Riverside): 1674 HDD 1697 CDD (Huntsville, AL 3262 HDD 1671 CDD)
CZ 11 (Red Bluff): 2647 HDD 1926 CDD (Cape Hatteras, NC 2521 HDD 1737 CDD)
CZ 12 (Sacramento): 2563 HDD 1426 CDD (Greenville, SC 3272 HDD 1526 CDD)
CZ 13 (Fresno): 2433 HDD 1991 CDD (Wilmington, NC 2429 HDD 2017 CDD)
CZ 14 (Palmdale): 2820 HDD 1764 CDD (Atlanta, GA 2827 HDD 1810 CDD)
CZ 15 (Palm Springs-Intl): 1000 HDD 3895 CDD (Brownsville, TX 644 HDD 3874 CDD)
CZ 16 (Blue Canyon): 5652 HDD 414 CDD (Salt Lake City, UT 5607 HDD 1089 CDD)

Statewide Extremes

Bodie, CA: 9770 HDD 4 CDD (Valdez, AK 9733 HDD 0 CDD)
Needles, CA: 1227 HDD 4545 CDD (Honolulu, HI 0 HDD 4561 CDD)
## 5. T24 Requirements/Assumptions

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<th>CEC Climate Zone</th>
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<th>15</th>
<th>16</th>
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<tr>
<td>Roof/Ceiling</td>
<td>R38</td>
<td>R30 (U 0.031)</td>
<td>R38 (U 0.026)</td>
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<tr>
<td>Walls</td>
<td>U 0.065&lt;sub&gt;total&lt;/sub&gt; (R15&lt;sub&gt;cavity&lt;/sub&gt;+R4 or R13&lt;sub&gt;cavity&lt;/sub&gt;+R5) equally distributed between N,E,S,W</td>
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<td>Slab (Unheated)</td>
<td>NR (3.5&quot;@R0.0833/in + 80% carpet 0.5&quot;@R4.1667/in)</td>
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<td>Raised Floor</td>
<td>R19 + 0.5&quot; carpet @R4.1667/in</td>
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<td>Radiant Barrier</td>
<td>NR (0.9) Required (Emissivity &lt;= 0.05)</td>
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<td>Reflectance</td>
<td>NR (0.08 asphalt shingles, 0.10 other materials) 0.20</td>
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<td>Emissivity</td>
<td>NR (0.85) 0.75</td>
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<td>Roof (2:12 pitch)</td>
<td>Max. U-Value</td>
<td>U 0.32 (R 3.125)</td>
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<td>Max. SHGC</td>
<td>0.50 0.25 0.50 0.25 0.50 0.25</td>
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<tr>
<td>Max. Area</td>
<td>20% of Conditioned Floor Area (exterior dimensions) equally distributed between N,E,S,W</td>
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<td>Max. West</td>
<td>NR 5% NR 5% NR 5%</td>
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<tr>
<td>Shading</td>
<td>No overhangs or interior blinds (12&quot; overhangs on prototype). Bug screens on windows (0.76 SHGC)</td>
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<tr>
<td>Entry Door(s)</td>
<td>Facing North, U 0.50 (R2), 3'0&quot;x6'8&quot;, 2 doors: exterior &amp; garage</td>
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<tr>
<td>Air Leakage</td>
<td>5 ACH&lt;sub&gt;50&lt;/sub&gt;</td>
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<tr>
<td>Ventilation (CFM)</td>
<td>0.01A&lt;sub&gt;floor&lt;/sub&gt; + 7.5(N&lt;sub&gt;br&lt;/sub&gt; + 1) = 53 CFM = 0.25 ACH (assuming 3 bedrooms)</td>
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<tr>
<td>Night Flushing</td>
<td>NR 2CFM/ft&lt;sup&gt;2&lt;/sup&gt;&lt;sub&gt;CFA&lt;/sub&gt; x 25% (Whole House Fan)</td>
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<tr>
<td>Natural Ventilation</td>
<td>Min. Temperature 68ºF, 5% of Fenestration Area, Height Difference: 2 ft (1 story), 8 ft (2-3 stories), 6AM - Midnight</td>
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II. Passive House Optimization:
1. “Baseline” Design

- Prototype Design w/ No Garage
- 2:12 Roof Pitch w/ Steep Slope Requirements
- Year ‘Round Bug Screens (76% SHGC) Removed (Sometimes Used In Summer)
- Whole House Fan (Where Required by Code) Removed
- Baseline Optimized w/ Raised Floor, Re-Optimized w/ Slab on Grade
- No Code Measures Reduced, Many Measures Upgraded to Typical PH Values
- Night Ventilation Cooling: Whole House Fan as “Last Resort”
Baseline Design & Optimization: Assumptions & Limitations

- No Thermal Brides (Eaves/Windows/Slab Edge?)
- No Landscape Shading
- Shell Focus Only: (Assume Best-in-Class PH Mechanicals, Appliances, Lighting)
- No Architectural Changes (i.e. Glazing Distribution)
- PHPP vs. T24 (HERS x Seasonal Multipliers) Internal Heat Gains
- Excessive Daily Temperature Swing Exceeded Static Modeling In Some Cases
2. Results, In Order of Focus

Environmental Impact

1. Heating & Cooling Demand (kBTU/ft²/yr)
2. Combined Demand (kBTU/ft²/yr)

Comfort & Equipment

3. Heating & Cooling Load (BTU/hr/ft²)
4. Fresh Air Heating & Cooling Deficit (BTU/hr)
5. % Overheating Without A/C (Hours/yr > 77ºF)

<table>
<thead>
<tr>
<th>Result</th>
<th>Demand (kBTU/ft²/yr)</th>
<th>Load (BTU/hr)</th>
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<tr>
<td>Heating</td>
<td>4.75</td>
<td>3.17</td>
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<tr>
<td>Cooling</td>
<td>4.75 – 6.66*</td>
<td>3.17</td>
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<tr>
<td>Overheating without A/C</td>
<td>&lt; 10%</td>
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</table>

*Cooling Demand Climate-Adjusted by PHPP 8.5 for CZ15 (Palm Springs)
3. Results Analysis - “Cool Tools”

**Heating Demand**
- Heat Gains (kWh/yr)
- Heat Losses (kWh/yr)
- Passive House

**Cooling Demand**
- Heat Gains (kWh/yr)
- Heat Losses (kWh/yr)
- Passive House

**Heating Load**
- Heat Gains (kWh/yr)
- Heat Losses (kWh/yr)
- Passive House

**Cooling Load**
- Heat Gains (kWh/yr)
- Heat Losses (kWh/yr)
- Passive House
3. Results Analysis - “Cool Tools”

**Overheating without A/C**

- **Outside Temperature (ºF)**
- **Inside Temperature (ºF)**
- **Indoor Comfort Limit (ºF)**

**Passive Cooling**

- **Ambient Ventilation (BTU/hr)**
- **Ground Ventilation (BTU/hr)**
- **Additional Window (BTU/hr)**
- **Additional Mechanical (BTU/hr)**
3. Results Analysis - “Cool Tools”
3. Results Analysis - “Cool Tools”

![Graph showing Cooling Demand vs. Design Value Adjustment]

- **Cooling Demand**
  - **Y-Axis**: 0.00 to 4.50
  - **X-Axis**: 10% to 190%

- **Variables**
  - **Factors Affecting Cooling Demand**
    - Roof Pitch (x:12)
    - Orientation
    - Roof Cavity Insulation
    - Roof Exterior Insulation
    - Wall Cavity Insulation
    - Wall Exterior Insulation
    - Floor Cavity Insulation
    - Floor Exterior Insulation
    - Frost Skirt Thickness
    - Frost Skirt Width/Depth
    - Standard Window % CFA
    - Standard Glazing U-Value
    - Standard Glazing SHGC
    - North Window % CFA
    - North Glazing U-Value
    - North Glazing SHGC
    - East Window % CFA
    - East Glazing U-Value
    - East Glazing SHGC
    - South Window % CFA
    - South Glazing U-Value
    - South Glazing SHGC
    - West Window % CFA
    - West Glazing U-Value
    - West Glazing SHGC
    - Roof Overhang
    - Entry Doors U-Value
    - Radiant Barrier Emissivity $\varepsilon$ (rafters or ceiling)
    - Roofing Reflectance $\rho$
    - Roofing Emissivity $\varepsilon$
    - Attic Air Changes
    - Crawl Space Vents (% of ext. floor area)
    - Air Tightness
    - Ventilation (CFM)
    - Heat Recovery Efficiency
    - Subsoil Heat Exchanger Efficiency
    - Thermal Mass
    - Min Indoor Summer Temperature
    - Additional Summer Night Ventilation (Windows)
    - Additional Summer Night Ventilation (Mechanical)
3. Results Analysis - “Cool Tools”

[Graph showing various design value adjustments against total demand. Each line represents a different variable such as roof pitch, orientation, roof cavity insulation, etc., with corresponding labels on the y-axis (Total Demand) and x-axis (Design Value Adjustment).]
3. Results Analysis - “Cool Tools”

![Graph showing heating load vs design value adjustment.](image-url)
3. Results Analysis - “Cool Tools”

![Graph showing the relationship between Fresh Air Heating Deficit and Design Value Adjustment]

- Roof Pitch (x:12)
- Orientation
- Roof Cavity Insulation
- Roof Exterior Insulation
- Wall Cavity Insulation
- Wall Exterior Insulation
- Floor Cavity Insulation
- Floor Exterior Insulation
- Frost Skirt Thickness
- Frost Skirt Width/Depth
- Standard Window % CFA
- Standard Glazing U-Value
- Standard Glazing SHGC
- North Window % CFA
- North Glazing U-Value
- North Glazing SHGC
- East Window % CFA
- East Glazing U-Value
- East Glazing SHGC
- South Window % CFA
- South Glazing U-Value
- South Glazing SHGC
- West Window % CFA
- West Glazing U-Value
- West Glazing SHGC
- Roof Overhang
- Entry Doors U-Value
- Radiant Barrier Emissivity ε (rafters or ceiling)
- Roofing Reflectance ρ
- Roofing Emissivity ε
- Attic Air Changes
- Crawl Space Vents (% of ext. floor area)
- Air Tightness
- Ventilation (CFM)
- Heat Recovery Efficiency
- Subsoil Heat Exchanger Efficiency
- Thermal Mass
- Min Indoor Summer Temperature
- Additional Summer Night Ventilation (Windows)
- Additional Summer Night Ventilation (Mechanical)
3. Results Analysis - “Cool Tools”
3. Results Analysis - “Cool Tools”

![Graph showing design value adjustment vs. fresh air cooling deficit](image)

### Design Value Adjustment vs. Fresh Air Cooling Deficit

- **Fresh Air Cooling Deficit**
- **Design Value Adjustment**

Legend:
- Roof Pitch (x:12)
- Orientation
- Roof Cavity Insulation
- Roof Exterior Insulation
- Wall Cavity Insulation
- Wall Exterior Insulation
- Floor Cavity Insulation
- Floor Exterior Insulation
- Frost Skirt Thickness
- Frost Skirt Width/Depth
- Standard Window % CFA
- Standard Glazing U-Value
- Standard Glazing SHGC
- North Window % CFA
- North Glazing U-Value
- North Glazing SHGC
- East Window % CFA
- East Glazing U-Value
- East Glazing SHGC
- South Window % CFA
- South Glazing U-Value
- South Glazing SHGC
- West Window % CFA
- West Glazing U-Value
- West Glazing SHGC
- Roof Overhang
- Entry Doors U-Value
- Radiant Barrier Emissivity $\epsilon$ (rafters or ceiling)
- Roofing Reflectance $\rho$
- Roofing Emissivity $\epsilon$
- Attic Air Changes
- Crawl Space Vents (% of ext. floor area)
- Air Tightness
- Ventilation (CFM)
- Heat Recovery Efficiency
- Subsoil Heat Exchanger Efficiency
- Thermal Mass
- Min Indoor Summer Temperature
- Additional Summer Night Ventilation (Windows)
- Additional Summer Night Ventilation (Mechanical)
3. Results Analysis - “Cool Tools”

![Percentage Overheating without A/C graph](image-url)

Design Value Adjustment
3. Results Analysis - “Cool Tools”

![Graph showing results analysis for various design factors](image)

- **Design Value Adjustment** vs **Total Demand - Baseline**
- **Factors** include:
  - Roof Pitch (x:12)
  - Orientation
  - Roof Cavity Insulation
  - Roof Exterior Insulation
  - Wall Cavity Insulation
  - Wall Exterior Insulation
  - Floor Cavity Insulation
  - Floor Exterior Insulation
  - Frost Skirt Thickness
  - Frost Skirt Width/Depth
  - Standard Window % CFA
  - Standard Glazing U-Value
  - Standard Glazing SHGC
  - North Window % CFA
  - North Glazing U-Value
  - North Glazing SHGC
  - East Window % CFA
  - East Glazing U-Value
  - East Glazing SHGC
  - South Window % CFA
  - South Glazing U-Value
  - South Glazing SHGC
  - West Window % CFA
  - West Glazing U-Value
  - West Glazing SHGC
  - Roof Overhang
  - Entry Doors U-Value
  - Radiant Barrier Emissivity $\varepsilon$ (rafters or ceiling)
  - Roofing Reflectance $\rho$
  - Roofing Emissivity $\varepsilon$
  - Attic Air Changes
  - Crawl Space Vents (% of ext. floor area)
  - Air Tightness
  - Ventilation (CFM)
  - Heat Recovery Efficiency
  - Subsoil Heat Exchanger Efficiency
  - Thermal Mass
  - Min Indoor Summer Temperature
  - Additional Summer Night Ventilation (Windows)
  - Additional Summer Night Ventilation (Mechanical)
3. Results Analysis - “Cool Tools”
4. PH Optimization: Combined
5. PH Optimization: Heating Demand
6. PH Optimization: Cooling Demand

The graph illustrates the cooling demand in kBTU/yr for various design scenarios. The green line labeled "PH (CZ 15)" shows a significant reduction in cooling demand compared to other scenarios. The PH limit is indicated by the horizontal dashed line, which suggests that the green line is well below the limit, indicating an optimized design.
7. PH Optimization: Cooling Demand
8. PH Optimization: Cooling Demand
9. PH Optimization: Heating Load
10. PH Optimization: Cooling Load
11. PH Optimization: % Overheating
# PH Demand Reduction Over Code

## Specific Demand (kBTU/ft²/yr) - Single Family, 1 Story, 2044 ft² TFA

<table>
<thead>
<tr>
<th>Climate Zone &amp; Location</th>
<th>Standard Design (T24 “Budget”)</th>
<th>Optimized Design (Passive House)</th>
<th>Combined Demand Reduction (kBTU/yr)</th>
<th># Optimized Buildings (w/ 80% Heat Recovery)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Heating</td>
<td>Cooling</td>
<td>Comb.</td>
<td>Heating</td>
</tr>
<tr>
<td>CZ01 Arcata</td>
<td>18.84</td>
<td>0.47</td>
<td>19.31</td>
<td>4.60</td>
</tr>
<tr>
<td>CZ02 Santa Rosa</td>
<td>14.85</td>
<td>0.36</td>
<td>15.21</td>
<td>3.40</td>
</tr>
<tr>
<td>CZ03 Oakland</td>
<td>8.78</td>
<td>1.33</td>
<td>10.11</td>
<td>4.50</td>
</tr>
<tr>
<td>CZ04 San Jose</td>
<td>10.77</td>
<td>0.61</td>
<td>11.38</td>
<td>4.65</td>
</tr>
<tr>
<td>CZ05 Santa Maria</td>
<td>8.61</td>
<td>1.13</td>
<td>9.74</td>
<td>4.12</td>
</tr>
<tr>
<td>CZ06 Torrance/LAX²</td>
<td>4.24</td>
<td>0.92</td>
<td>5.16</td>
<td>2.93</td>
</tr>
<tr>
<td>CZ07 San Diego</td>
<td>3.06</td>
<td>1.64</td>
<td>4.70</td>
<td>1.41</td>
</tr>
<tr>
<td>CZ08 Fullerton</td>
<td>4.79</td>
<td>0.82</td>
<td>5.61</td>
<td>2.01</td>
</tr>
<tr>
<td>CZ09 Burbank</td>
<td>5.15</td>
<td>1.48</td>
<td>6.63</td>
<td>2.41</td>
</tr>
<tr>
<td>CZ10 Riverside</td>
<td>5.96</td>
<td>0.83</td>
<td>6.79</td>
<td>2.73</td>
</tr>
<tr>
<td>CZ11 Red Bluff</td>
<td>13.32</td>
<td>3.7</td>
<td>17.02</td>
<td>2.50</td>
</tr>
<tr>
<td>CZ12 Sacramento</td>
<td>12.15</td>
<td>0.65</td>
<td>12.80</td>
<td>2.24</td>
</tr>
<tr>
<td>CZ13 Fresno</td>
<td>10.83</td>
<td>4.4</td>
<td>15.23</td>
<td>2.03</td>
</tr>
<tr>
<td>CZ14 Palmdale</td>
<td>12.08</td>
<td>4.19</td>
<td>16.27</td>
<td>1.70</td>
</tr>
<tr>
<td>CZ15 Palm Springs</td>
<td>1.27</td>
<td>22.43</td>
<td>23.70</td>
<td>0.01</td>
</tr>
<tr>
<td>CZ16 Blue Canyon</td>
<td>25.95</td>
<td>1.13</td>
<td>27.08</td>
<td>4.30</td>
</tr>
</tbody>
</table>

¹ The specific cooling demand for CZ15 (Palm Springs) was climate-adjusted by PHPP v8.4 to 6.66 kBTU/ft²/yr maximum.

2. Passive House uses “TMY-3” weather stations to derive climate data. The closest TMY-3 station to Torrance is Los Angeles International Airport (LAX).
## PH Load Reduction Over Code

<table>
<thead>
<tr>
<th>Climate Zone &amp; Location</th>
<th>Specific Load (BTU/hr/ft²) - Single Family, Single Story, 2044 ft² TFA</th>
<th>Load (BTU/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard Design (T24 “Budget”)</td>
<td>Optimized Design (Passive House)</td>
</tr>
<tr>
<td></td>
<td>Heating</td>
<td>Cooling</td>
</tr>
<tr>
<td>Passive House Max.</td>
<td>3.17</td>
<td>3.17</td>
</tr>
<tr>
<td>CZ01 Arcata</td>
<td>6.86</td>
<td>-4.12</td>
</tr>
<tr>
<td>CZ02 Santa Rosa</td>
<td>8.41</td>
<td>-1.04</td>
</tr>
<tr>
<td>CZ03 Oakland</td>
<td>5.23</td>
<td>0.09</td>
</tr>
<tr>
<td>CZ04 San Jose</td>
<td>6.43</td>
<td>-1.03</td>
</tr>
<tr>
<td>CZ05 Santa Maria</td>
<td>4.67</td>
<td>-2.05</td>
</tr>
<tr>
<td>CZ06 Torrance/LAX¹</td>
<td>4.49</td>
<td>-1.69</td>
</tr>
<tr>
<td>CZ07 San Diego</td>
<td>3.17</td>
<td>0.33</td>
</tr>
<tr>
<td>CZ08 Fullerton</td>
<td>4.04</td>
<td>0.99</td>
</tr>
<tr>
<td>CZ09 Burbank</td>
<td>5.09</td>
<td>3.01</td>
</tr>
<tr>
<td>CZ10 Riverside</td>
<td>5.47</td>
<td>2.24</td>
</tr>
<tr>
<td>CZ11 Red Bluff</td>
<td>7.71</td>
<td>4.82</td>
</tr>
<tr>
<td>CZ12 Sacramento</td>
<td>7.71</td>
<td>3.11</td>
</tr>
<tr>
<td>CZ13 Fresno</td>
<td>8.88</td>
<td>3.84</td>
</tr>
<tr>
<td>CZ14 Palmdale</td>
<td>8.97</td>
<td>3.95</td>
</tr>
<tr>
<td><strong>CZ15 Palm Springs</strong></td>
<td>3.71</td>
<td>8.58</td>
</tr>
<tr>
<td>CZ16 Blue Canyon</td>
<td>13.67</td>
<td>1.39</td>
</tr>
</tbody>
</table>

1. Passive House uses “TMY-3” weather stations to derive climate data. The closest TMY-3 station to Torrance is Los Angeles International Airport (LAX).
2. Excessive daily temperature swing – cooling demand and overheating percentage calculations unreliable.
Why Reduce Loads?
Mechanical Reductions & Savings

Figure 6: Schematic of the packaged heat pump unit.
## Optimized (bold) vs. Baseline (Code)

<table>
<thead>
<tr>
<th>Ceiling</th>
<th>Walls</th>
<th>Floor</th>
<th>Rad. Barrier</th>
<th>Roof</th>
<th>Rad.</th>
<th>Ohang</th>
<th>U_{IP}</th>
<th>SHGC</th>
<th>Shade_{Summer}</th>
<th>Door</th>
<th>ACH_{50}</th>
<th>Heat Rec.</th>
<th>Night Vent.</th>
</tr>
</thead>
<tbody>
<tr>
<td>CZ01</td>
<td>R38</td>
<td>R21+4</td>
<td>R19</td>
<td>R14</td>
<td>0.9</td>
<td>0.1</td>
<td>0.85</td>
<td>12&quot;</td>
<td>0.14</td>
<td>100%</td>
<td>0.2</td>
<td>0.6</td>
<td>80%</td>
</tr>
<tr>
<td>CZ02</td>
<td>R30</td>
<td>R21+4</td>
<td>R19</td>
<td>R14</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>30&quot;</td>
<td>0.14</td>
<td>76%</td>
<td>0.2</td>
<td>0.6</td>
<td>80%</td>
</tr>
<tr>
<td>CZ03</td>
<td>R30</td>
<td>R15+4</td>
<td>R19</td>
<td>R13</td>
<td>0.05</td>
<td>0.1</td>
<td>0.85</td>
<td>12&quot;</td>
<td>0.32</td>
<td>100%</td>
<td>0.5</td>
<td>0.6</td>
<td>80%</td>
</tr>
<tr>
<td>CZ04</td>
<td>R30</td>
<td>R15+4</td>
<td>R19</td>
<td>R13</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>30&quot;</td>
<td>0.32</td>
<td>76%</td>
<td>0.5</td>
<td>0.6</td>
<td>80%</td>
</tr>
<tr>
<td>CZ05</td>
<td>R30</td>
<td>R15+4</td>
<td>R19</td>
<td>R12</td>
<td>0.05</td>
<td>0.1</td>
<td>0.85</td>
<td>12&quot;</td>
<td>0.32</td>
<td>100%</td>
<td>0.5</td>
<td>0.6</td>
<td>80%</td>
</tr>
<tr>
<td>CZ06</td>
<td>R30</td>
<td>R15+4</td>
<td>R19</td>
<td>R10</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>30&quot;</td>
<td>0.32</td>
<td>76%</td>
<td>0.5</td>
<td>0.6</td>
<td>0%</td>
</tr>
<tr>
<td>CZ07</td>
<td>R30</td>
<td>R15+4</td>
<td>R19</td>
<td>R18(^1)</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>36&quot;</td>
<td>0.32</td>
<td>50%</td>
<td>0.5</td>
<td>0.6</td>
<td>0%</td>
</tr>
<tr>
<td>CZ08</td>
<td>R30</td>
<td>R15+4</td>
<td>R19</td>
<td>R19(^1)</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>36&quot;</td>
<td>0.32</td>
<td>50%</td>
<td>0.5</td>
<td>0.6</td>
<td>0%(^2)</td>
</tr>
<tr>
<td>CZ09</td>
<td>R30</td>
<td>R15+4</td>
<td>R19</td>
<td>R19(^1)</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>36&quot;</td>
<td>0.32</td>
<td>50%</td>
<td>0.5</td>
<td>0.6</td>
<td>0%(^2)</td>
</tr>
<tr>
<td>CZ10</td>
<td>R30</td>
<td>R15+4</td>
<td>R19</td>
<td>R19(^1)</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>36&quot;</td>
<td>0.32</td>
<td>50%</td>
<td>0.5</td>
<td>0.6</td>
<td>0%(^2)</td>
</tr>
<tr>
<td>CZ11</td>
<td>R38</td>
<td>R21+4</td>
<td>R19</td>
<td>R14</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>36&quot;</td>
<td>0.14</td>
<td>50%</td>
<td>0.2</td>
<td>0.6</td>
<td>80%(^2)</td>
</tr>
<tr>
<td>CZ12</td>
<td>R38</td>
<td>R21+4</td>
<td>R19</td>
<td>R19(^1)</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>36&quot;</td>
<td>0.14</td>
<td>50%</td>
<td>0.2</td>
<td>0.6</td>
<td>80%(^2)</td>
</tr>
<tr>
<td>CZ13</td>
<td>R38</td>
<td>R21+4</td>
<td>R19</td>
<td>R13</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>36&quot;</td>
<td>0.14</td>
<td>50%</td>
<td>0.2</td>
<td>0.6</td>
<td>80%(^2)</td>
</tr>
<tr>
<td>CZ14</td>
<td>R38</td>
<td>R21+4</td>
<td>R19</td>
<td>R12</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>36&quot;</td>
<td>0.14</td>
<td>50%</td>
<td>0.2</td>
<td>0.6</td>
<td>80%(^2)</td>
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<td>R38</td>
<td>R21+4</td>
<td>R19</td>
<td>R16</td>
<td>0.05</td>
<td>0.8</td>
<td>0.85</td>
<td>36&quot;</td>
<td>0.14</td>
<td>10%</td>
<td>0.2</td>
<td>0.6</td>
<td>80%(^2)</td>
</tr>
<tr>
<td>CZ16</td>
<td>R62</td>
<td>R21+20</td>
<td>R19+4</td>
<td>R18</td>
<td>0.9</td>
<td>0.1</td>
<td>0.85</td>
<td>36&quot;</td>
<td>0.14</td>
<td>50%</td>
<td>0.2</td>
<td>0.6</td>
<td>80%(^2)</td>
</tr>
</tbody>
</table>

1. w/ "Mixed" Thermal Mass (132 Wh/m²K)  
2. w/ 60% Subsoil Heat Exchanger
CZ15 (Palm Springs): “Houston, We Have A Problem”

Cooling Demand: Baseline

- Heat Gains (kBTU/yr)
- Heat Losses (kBTU/yr)
- Passive House
CZ15 (Palm Springs): “Houston, We Have A Problem”
CZ15 (Palm Springs): “Houston, We Have A Problem”
Takeaway Thoughts

- **Airtightness**
  Universal 1st Measure, for Heating Load and/or Demand

- **Heat Recovery Ventilation**
  Generally Effective, Questionable in CZ6-10 (CZ7 = 50% Heating Demand Reduction)

- **Insulation Levels**
  Roof & Floor (Raised) Worked Everywhere but CZ16
  Cool Roof (80% Reflective) Helpful in Most Locations
  Walls Varied In Efficacy (Code OK in CZ3-CZ10)
  Slab Insulation Effective (Necessary Everywhere but CZ7)

- **Glazing & Shading**
  Critical in Winter & Summer
  Summer Shading Partly Corrected for Orientation-Agnostic Design
  Improved Glazing Distribution Would Improve Performance/Feasibility, Reduce Heating/Cooling “Tradeoff”
  Standard U-Value Adequate in CZ3-CZ10
  High SHGC Glazing Often Helpful On South Facades

- **Thermal Mass**
  Generally Effective, Produces Most of Slab-on-Grade Improvement (in Mild Climates)

- **Night Ventilation Cooling**
  Generally Effective, Design for More Window Venting (>5% of Windows @2ft)?
  Additional Ventilation More Persistently Effective for % Overheating than Demand/Load
  (When are Large Fans Less Effective than Small Compressors?)
Passive House Performance: Don’t Forget the Hot Water!

Average CA Residential Site Energy Use

- Heating: 31%
- Hot Water: 31%
- Refrigerator/Freezers: 6%
- Lighting: 7%
- Electronics: 5%
- Misc.: 5%
- Pool/Spa: 2%
- Cooking: 6%
- Laundry: 4%
- Cooling: 3%

Reference: CEC 2004 Residential Appliance Saturation Survey (RASS)
Thank You! Questions?

Acknowledgements

Martha Brook, P.E.
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California Energy Commission

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Alisha, Finley and Lucas Irwin

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