Passive House As A Thermal Battery
Why the Shell Matters More than Ever

Building Carbon Zero California
Palo Alto, CA, November 13, 2015

Graham Irwin
Principal, Essential Habitat Architecture
www.essentialhabitat.com
BRINGING PASSIVE HOUSE TO THE WEST
SINCE 2008

[Map of the Western United States and Canada showing locations of Passive House projects]
A “Secret” Paradox

Energy is cheap

Constrained Efficiency

Synchronized Demand

...but supplying it is expensive.
Where’s the Money?

It’s in the power (kW)

...not the energy (kWh).
How Much Money?

• 10% US peak electrical load in < 1% of the year

• 10% peak load reduction

= $8-$28 billion/yr

5% Reduction ($3 Billion)

An Expensive Problem

TDV Multipliers, CZ3 (Oakland) Residential

Time Dependent Valuation (TDV) hourly multipliers mostly tied to cost.
CZ3 (Oakland): Max 276.54 (Aug. 30 5:00 PM), Min 10.68 (May 7 4:00 AM) = 26 to 1!
In the Future?

It’s getting worse.
Solar won’t help.
We need lots of solar!

Grid = “Big Battery?” Fuel Cell”

Yes
– Renewables offset fossil fuels

No
– “Storage” is unused fuel (except ~7% hydro)
– No “back feed” from distribution upward
Solar’s a Near Miss!

New record solar peak 1,003 MW

Tuesday, August 14th, 2012
Peak demand: 45,402 MW

Solar

AC-driven peak demand period

Hourly breakdown of solar

Source: CAISO
Solar’s a Near Miss!

New record solar peak 1,003 MW

Tuesday, August 14th, 2012
Peak demand: 45,402 MW

Hourly breakdown of wind & solar

Source: CAISO
The “Duck Curve” and the End of Net-Zero?

California Grid Load (March 31)

Energy: 13 GW x 3 hrs / 2 = 19,500,000 kWh / 10 kWh / 70% = 2,790,000 Tesla 10 kW Powerwalls
Power: 13 GW / 2 kW = 6,500,000 Tesla 10 kW Powerwalls
California: 12% Renewable in 2014, 33% by 2030, 50% Renewable by 2050
The “Nessie Curve” and the End of Net-Zero?

Tracking Change – 46kV Level

Average Transformer Load (MW) - December

- Backfeed occurring 10am-2pm

8/8/2013 Backfeed Condition

Hawaiian Electric
Maui Electric
Hawai'i Electric Light

Hawaii: Backfeed with 11% Rooftop PV (15-18% overall); 100% Renewable by 2045

instituteforenergyresearch.org/solar-energys-duck-curve/
The “Ente Curve”
and the End of Net-Zero?

[Graph showing price data]

Germany: Negative Prices with 27% Renewable in 2014; 80% Renewable by 2050

energytransition.de/2014/05/german-power-prices-negative-over-weekend/
It’s Not Just Solar
Wind can do it too.

Texas: 9% wind in 2014. Sept 13, 2015, 5:45 AM - $8.52/MWh
http://www.slate.com/articles/business/the_juice/2015/09/texas_electricity_goes_negative_wind_power_was_so_plentiful_one_night_that.html
...and Hydro!

80 Negative Spot Prices in Pacific Northwest (2011)
http://www.eia.gov/todayinenergy/detail.cfm?id=5110
What Happens to Net Zero
When the Price for Your Power is Negative?

How is this possible?

• Nuclear plants operate continuously at full power.
• Hydroelectric - water flow for fish, etc.
• Eligible renewable generators get a $22/MWh tax credit.
• Maintenance & fuel costs to stop & start large steam turbines.
So What About Storage?
Daily Storage

- Pumped Hydro
- Concentrated Solar Plants (CSP)
- Solar Thermal (Small Tank)
- Interruptible Tariff/Direct Load Control
- Dynamic Demand Appliances
- Smart Inverters (Curtailment & Correction)
- Batteries
- Passive House
The Dao of Tau

Unheated Building vs. $\tau$ (Palo Alto, CA, July)

- **Time Constant** ($\tau$) = Thermal Mass (Wh/K)/Conductance (W/K)
- $\tau +$ solar & int. gains + air changes = “reaction speed” of building to $\Delta T$.
- **Passive House**: $\tau = 5$-30+ days (120-720+ hrs.) - *Heating load in Passive Houses*, Passipedia
Proof in Practice:
a Passive House in a heat wave.

Midori Haus, Santa Cruz, CA
Summer Comfort without Air Conditioning!

Comfortable Inside During Heat Wave
example at 14-May-2014 14:35

Sensor data from WELserver

Midori Haus, Santa Cruz, CA
Summer Comfort without Air Conditioning!

www.midorihaus.com
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Now for the Hard Part...
Don’t Like the Duck?

Monthly Average Grid Load vs. % Solar Energy

You’ll Hate the “Duck Pond!”
Seasonal Storage
Seasonal Storage

- Heating Demand
- Insolation
Seasonal Storage

- September 23: Autumnal Equinox
- December 22: Winter Solstice
- March 21: Vernal Equinox
- June 22: Summer Solstice

http://science.howstuffworks.com
Seasonal Storage

- Pumped Hydro
- Biomass
- Solar Thermal (LARGE Tank, Sand Pit, etc.)
- Synthetic Methane ("Power to Gas")
- Ground Tempering/Ground Source HP
- Passive House
Seasonal Storage

[Diagram showing seasonal storage for heating and insolation with months from January to December]
Seasonal Storage
Seasonal Storage
Seasonal Storage
Note to Self

2007 (Pre-Passive House) email

...I am becoming more convinced that it is not practical to heat a home with PV alone, even with a geothermal heat-pump, and that passive solar, as well as solar thermal and PV are required...

Cheers,
Graham
Note to Self
2007 (Pre-Passive House) email

...I am becoming more convinced that it is more practical to heat a home with a geothermal heat-pump than solar, as well as solar thermal, required...

Cheers,
Graham
Proof in Practice:
Passive House Seasonal Energy Use.

2869 kWh Elec. + 50 Therms (1,465 kWh) Nat. Gas = 4,334 kWh (before PV!)
Before Retrofit 21,928 kWh/yr, Similar CA Home 19,596 kWh/yr

www.midorihaus.com
Proof in Practice: Passive House Seasonal Energy Use.

2869 kWh Elec. + 50 Therms (1,465 kWh) Nat. Gas = 4,334 kWh (before PV!)
Before Retrofit 21,928 kWh/yr, Similar CA Home 19,596 kWh/yr
Where Does Our Energy Go?
Average PG&E Household (1584 ft²)

**PG&E Household Electricity Use**
- Electronics: 18%
- Refrigerator/Freezers: 20%
- Misc.: 24%
- Lighting: 9%
- Pool/Spa: 6%
- Cooking: 4%
- Laundry: 6%
- Heating: 3%
- Cooling: 6%
- Hot Water: 4%

**Electricity:** 6446 kWh/yr

**PG&E Household Natural Gas Use**
- Hot Water: 41%
- Heating: 51%
- Laundry: 2%
- Cooking: 4%
- Misc.: 0%
- Pool/Spa: 2%

**Natural Gas:** 399 Therms/yr

Reference: 2009 Residential Appliance Saturation Survey (RASS), California Energy Commission (CEC)
Where Does Our Energy Go?
Average PG&E Household (1584 ft²)

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**PG&E Household Natural Gas Use**
- Hot Water: 41%
- Heating: 51%
- Laundry: 2%
- Cooking: 4%
- Pool/Spa: 2%
- Misc.: 0%

**Electricity:** 6446 kWh/yr

**Natural Gas:** 11,683 kWh/yr

Reference: 2009 Residential Appliance Saturation Survey (RASS), California Energy Commission (CEC)
Where Does Our Energy Go?
Average PG&E Household (1584 ft²)

PG&E Household Site Energy

- Heating: 34%
- Hot Water: 28%
- Natural Gas: 65%
- Electricity: 35%
- Miscellaneous: 9%
- Lighting: 3%
- Pool/Spa: 3%
- Refrigerator/Freezers: 7%
- Cooking: 4%
- Laundry: 3%

Site Energy: 18,263 kWh/yr

Reference: 2009 Residential Appliance Saturation Survey (RASS), California Energy Commission (CEC)
## PH Demand Reduction

<table>
<thead>
<tr>
<th>Climate Zone &amp; Location</th>
<th>Specific Demand (kBTU/ft²/yr) - Single Family, 1 Story, 2044 ft² TFA</th>
<th>Combined Demand Reduction (kBTU/yr)</th>
<th># Optimized Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard Design (T24 “Budget”)</td>
<td>Optimized Design (Passive House)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Heating</td>
<td>Cooling</td>
<td>Comb.</td>
</tr>
<tr>
<td>Passive House Max.</td>
<td>4.75</td>
<td>4.75–6.66¹</td>
<td>4.75</td>
</tr>
<tr>
<td>CZ01 Arcata</td>
<td>18.84</td>
<td>0.47</td>
<td>19.31</td>
</tr>
<tr>
<td>CZ02 Santa Rosa</td>
<td>14.85</td>
<td>0.36</td>
<td>15.21</td>
</tr>
<tr>
<td>CZ03 Oakland</td>
<td>8.78</td>
<td>1.33</td>
<td>10.11</td>
</tr>
<tr>
<td>CZ04 San Jose</td>
<td>10.77</td>
<td>0.61</td>
<td>11.38</td>
</tr>
<tr>
<td>CZ05 Santa Maria</td>
<td>8.61</td>
<td>1.13</td>
<td>9.74</td>
</tr>
<tr>
<td>CZ06 Torrance/LAX²</td>
<td>4.24</td>
<td>0.92</td>
<td>5.16</td>
</tr>
<tr>
<td>CZ07 San Diego</td>
<td>3.06</td>
<td>1.64</td>
<td>4.70</td>
</tr>
<tr>
<td>CZ08 Fullerton</td>
<td>4.79</td>
<td>0.82</td>
<td>5.61</td>
</tr>
<tr>
<td>CZ09 Burbank</td>
<td>5.15</td>
<td>1.48</td>
<td>6.63</td>
</tr>
<tr>
<td>CZ10 Riverside</td>
<td>5.96</td>
<td>0.83</td>
<td>6.79</td>
</tr>
<tr>
<td>CZ11 Red Bluff</td>
<td>13.32</td>
<td>3.7</td>
<td>17.02</td>
</tr>
<tr>
<td>CZ12 Sacramento</td>
<td>12.15</td>
<td>0.65</td>
<td>12.80</td>
</tr>
<tr>
<td>CZ13 Fresno</td>
<td>10.83</td>
<td>4.4</td>
<td>15.23</td>
</tr>
<tr>
<td>CZ14 Palmdale</td>
<td>12.08</td>
<td>4.19</td>
<td>16.27</td>
</tr>
<tr>
<td>CZ15 Palm Springs</td>
<td>1.27</td>
<td>22.43</td>
<td>23.70</td>
</tr>
<tr>
<td>CZ16 Blue Canyon</td>
<td>25.95</td>
<td>1.13</td>
<td>27.08</td>
</tr>
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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

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<th>Optimized Design (Passive House) Heating/Cooling</th>
<th># Optimized = 1 Baseline</th>
<th>✔ = “Fresh Air”</th>
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<tbody>
<tr>
<td>Passive House Max.</td>
<td></td>
<td>3.17 3.17 10.00%</td>
<td>3.17 3.17 10.00%</td>
<td>6480</td>
<td></td>
</tr>
<tr>
<td>CZ01 Arcata</td>
<td>6.86 -4.12 0.01%</td>
<td>3.40 -4.86 0.00%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ02 Santa Rosa</td>
<td>8.41 -1.04 1.37%</td>
<td>2.37 -0.81 0.01%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ03 Oakland</td>
<td>5.23 0.09 3.30%</td>
<td>2.47 -0.43 0.01%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ04 San Jose</td>
<td>6.43 -1.03 2.07%</td>
<td>2.80 -1.18 0.16%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ05 Santa Maria</td>
<td>4.67 -2.05 0.68%</td>
<td>2.07 -2.52 0.00%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ06 Torrance/LAX¹</td>
<td>4.49 -1.69 3.53%</td>
<td>2.75 -2.03 0.00%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ07 San Diego</td>
<td>3.17 0.33 10.66%</td>
<td>1.52 -0.49 1.68%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ08 Fullerton</td>
<td>4.04 0.99 9.93%</td>
<td>1.93 -0.31 0.16%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ09 Burbank</td>
<td>5.09 3.01 11.51%</td>
<td>2.50 1.48 3.92%</td>
<td>✔ ✔</td>
<td></td>
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<td>CZ10 Riverside</td>
<td>5.47 2.24 11.14%</td>
<td>2.61 0.66 1.28%</td>
<td>✔ ✔</td>
<td></td>
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<tr>
<td>CZ11 Red Bluff</td>
<td>7.71 4.82 19.73%²</td>
<td>2.39 2.43 13.70%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
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<tr>
<td>CZ12 Sacramento</td>
<td>7.71 3.11 9.79%</td>
<td>2.05 1.12 0.29%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ13 Fresno</td>
<td>8.88 3.84 22.11%²</td>
<td>2.57 1.83 15.25%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ14 Palmdale</td>
<td>8.97 3.95 20.92%²</td>
<td>2.07 1.81 14.26%</td>
<td>✔ ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CZ15 Palm Springs</td>
<td>3.71 8.58 53.88%²</td>
<td>0.22 4.48 39.47%²</td>
<td>✔ ✔</td>
<td>x17</td>
<td></td>
</tr>
<tr>
<td>CZ16 Blue Canyon</td>
<td>13.67 1.39 4.97%</td>
<td>3.37 0.27 0.21%</td>
<td>✔ ✔</td>
<td>x5</td>
<td></td>
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</tbody>
</table>
Grid Business Model

• Buy Power
  – 1 Day Ahead
  – Price Varies Hourly

• Sell Energy
  – Bill Monthly
  – Priced After the Fact

• Not for Long! (TOU $ in CA by 2019)
  – For now we buy energy; soon we’ll buy (and sell) power on an hourly basis.
EMBRACE CONTRARIAN DEMAND
Thank You! Questions?

House as a battery or house of batteries?

Graham Irwin
Principal, Essential Habitat Architecture
www.essentialhabitat.com