Cottle Zero Energy Home
San Jose, CA

Designer: One Sky Homes
Builder: One Sky Homes
PH Consultant: Allen Gilliland

www.SiliconValleyZeroEnergyHome.com

“Homes heated with hair dryers”

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1. Project Overview
   - History & Design Goals
   - Climate, Site, PH Energy Balance, PH numbers
2. Building Envelope Design and Construction
   - Assemblies, Air Sealing, Windows/Doors
   - Construction Highlights
3. Mechanical Systems
   - HRV, Heat Pump, Night Ventilation Cooling
   - Duct systems
4. Net Zero Energy Design
   - Energy Budget, Fuel choices
   - Source Energy and Carbon Math
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Project Overview - History

- 2008 (Spring) Net Zero Energy Goal, Property Acquisition, start R & D

- 2008 Design Development

- 2009 Plan Check & Permits

- 2009 (mid) Discover PH, refine design

- 2010 (April) Start Deconstruction

- 2011 (April) Rough Inspections & Drywall

- 2011 (Fall) Completion and occupancy
Cottle ZEH - Design Goals

- Net Zero Energy
- 3200 sf Luxury Custom Home
  - Contemporary Regional Suburban Design
    - No butterfly roof; un-distinctive as Green home
  - Superior Comfort – thermal, acoustical, IAQ, etc.
  - Luxury Features – Chef’s Kitchen, premium finishes/conv., custom lighting, etc.
Climate Summary – San Jose

- 37° N Latitude, “Summer Dry” (Mediterranean)
- 2472 HDD / 811 CDD; ADT 51° winter, 71° summer
- High solar radiation
- Coastally-influenced
  - Unique summer night time lows in mid-50s
  - Ideal for Night Ventilation Cooling
- Significant extremes – “Heat Storms” & “Cold Snaps”
Beware designing to averages

Temperate Averages: ADT - 51° winter  71° summer
Key Climate Design Points – San Jose, CA

- Temperature extremes drive design requirements
- **Winter**
  - Sub-30° nights common
  - Interior glazing temps critical to comfort
- **Summer**
  - 100°+ days common, cooling important
  - Solar radiation is intense, shading design critical
  - Night ventilation cooling …a gift, use it
- **Other Bay Area Micro-climates different**
Site

- Long axis faces 23° E of South
- Unobstructed solar aperture
Passive House
"Buildings heated with hair dryers"

The PH Recipe:
1. Super-Insulate
2. Avoid Thermal Bridges
3. Air Seal (tight!)
5. Heat Recovery Ventilation (HRV)
6. Solar aware design
7. Use PHPP

<table>
<thead>
<tr>
<th>Specific Space Heat Demand</th>
<th>3.39 kBTU/(ft²·yr)</th>
<th>4.75 kBTU/(ft²·yr)</th>
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<tr>
<td>Pressurization Test Result</td>
<td>0.60 ACH₅₀</td>
<td>0.6 ACH₅₀</td>
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<tr>
<td>Specific Primary Energy Demand</td>
<td>25.3 kBTU/(ft²·yr)</td>
<td>38.0 kBTU/(ft²·yr)</td>
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</tbody>
</table>
PHPP Energy Balance Equation

GAINS

- Solar Heat Gains $Q_s$
- Internal Heat Gains $Q_i$
- Annual Heat Demand $Q_H$

LOSSES

- Transmission Heat Losses $Q_T$
- Ventilation Heat Losses $Q_V$
- Useful Cooling Demand $Q_K$

$
70_{\text{DEG}} = GAINS - LOSSES
$

- Varies with climate, site and season
- Goal: optimize passive energy flows across seasons
PH Design Variables Matrix

- **GAINS**
  - Solar Heat Gains $Q_S$
  - Internal Heat Gains $Q_I$
  - Location
  - Shape
  - Orientation
  - Glazing
  - SHGC
  - Shading
  - Occupants
  - Lighting
  - Electronics
  - Appliances
  - Mechanicals
  - HW storage

- **LOSSES**
  - Transmission Heat Losses $Q_T$
  - Ventilation Heat Losses $Q_V$
  - Insulation
  - Thermal Bridging
  - Windows/Doors
    - Glass U-val
    - Frames
    - Install
  - Air Sealing
  - HRV

- Gains
  $\left( Q_S + Q_I \right) - \left( Q_T + Q_V \right) = Q_H$

- Comfort criterion: interior glass temp. $\geq 63^\circ F$ at $68^\circ F$ room temp. ($\leq 5^\circ \Delta T$)
Cottle PHPP numbers

### Annual Heat Demand

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Heat Demand $Q_H$</td>
<td>$9420$ kBTU/yr $3.39$ kBTU/(ft² yr)</td>
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</tbody>
</table>

### Heating Load

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Load $P_H$</td>
<td>$9275$ BTU/hr</td>
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</tbody>
</table>

### Energy Demands with Reference to the Treated Floor Area

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated Floor Area</td>
<td>2776 ft²</td>
</tr>
<tr>
<td>Specific Space Heat Demand</td>
<td>$3.39$ kBTU/(ft² yr)</td>
</tr>
<tr>
<td>Specific Primary Energy Demand (DHW, Heating, Cooling, Auxiliary and Household)</td>
<td>$25.3$ kBTU/(ft² yr)</td>
</tr>
<tr>
<td>Pressurization Test Result</td>
<td>$0.60$ ACH$_{50}$</td>
</tr>
<tr>
<td>Specific Primary Energy Demand (DHW, Heating and Auxiliary Electricity)</td>
<td>$8.9$ kBTU/(ft² yr)</td>
</tr>
<tr>
<td>Specific Primary Energy Demand (Energy Conservation by Solar Electricity)</td>
<td>$24.6$ kBTU/(ft² yr)</td>
</tr>
<tr>
<td>Heating Load</td>
<td>$3.34$ BTU/(ft² hr)</td>
</tr>
<tr>
<td>Frequency of Overheating</td>
<td>% over $77.0$ °F</td>
</tr>
<tr>
<td>Specific Useful Cooling Energy Demand</td>
<td>$0.16$ kBTU/(ft² yr)</td>
</tr>
<tr>
<td>Cooling Load</td>
<td>$1.09$ BTU/(ft² hr)</td>
</tr>
</tbody>
</table>

< 340 cfm$_{50}$
Agenda

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   - Source Energy and Carbon Math
Cottle ZEH - Assembly Details

Foundation - R-23 ICF Stem Wall / R-15 CS Floor
- Conditioned crawl space
- 2.5” slab over 3” EPS (2#)

Walls – R23
- 2 x 6 @ 24”o.c. Adv. Framing
- 3” SF @ rim joists, garage ceiling
- Insul. HDRs, BIBs Fiberglass
- 1 inch external EPS
- Tyvek + ¼” monofilament Rain Screen
- Stucco/siding/veneer stone

Ceiling - R-50 Loose-fill Cellulose
- Gable roof trusses, 13” raised heel
- Radiant Barrier roof sheathing
- Continuous eave & ridge vent
Air Sealing – Foundation to Wall

- 10 mil poly int.-ext. sheet barrier
Air Sealing – Walls

- Primary Air Barrier = ½” Ply. Ext. Sheathing
- Taped seams - 3M 8067
Air Sealing – Walls

- Caulked seams - Ecosseal
Air Sealing – Wall-to-ceiling

- Sheathing to top plate taped
- Drywall to plates gasketed
- Top plate penetrations foam/taped
- Airtight drywall, elec. boxes, down lights
Air Sealing – Attached Garage

- Airtight ceiling drywall & 2nd flr subfloor
- Airtight int. shear walls @ garage

Air sealing: 2nd flr wall to garage ceiling at perimeter floor beam

It’s ugly!
Cottle ZEH - Windows

- Triple Glazed Fenestration
  - Sorpetaler tilt/turn (R7 gls/R4 fr)
  - Serious 525, fixed (R7 gls/R5 fr)
    - Big $+, big comfort +, Min. int. glass temp. > 63°
  - Avg R5 installed (PHPP)
  - Install o/ ext. EPS, foamed, taped

- Passive Solar Design
  - 411 sf glass, %=58s, 15n, 17e, 9w
  - Engineered shading, all elevations
  - Vert. shade screens, west elev.
  - 13M btu usable SHG (PHPP)
Windows/Doors – the Comfort Factor

- PH std: int. glass temp. $\geq 63^\circ F$ (17$^\circ C$) @68$^\circ F$ ambient
- Or temp. $\Delta$ betw opaque & transparent surfaces $\leq 3^\circ C$ (5.4$^\circ F$)
- @70 $^\circ F$, int glass temp $\geq 64.6^\circ F$
- = ASHRAE comfort guidelines
- = ISO 7730 comfort std
- Triple-glazed windows required in Bay Area to meet standard
Construction Highlights

- Video slide show
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Cottle – PHPP
Ventilation, Heating & Cooling numbers

Ventilation

<table>
<thead>
<tr>
<th>Average Air Flow Rate (cfm)</th>
<th>Average Air Change Rate (1/hr)</th>
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</thead>
<tbody>
<tr>
<td>113</td>
<td>0.30</td>
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<tr>
<td>Minimum air change rate 0.3 1/hr.</td>
<td></td>
</tr>
</tbody>
</table>

Heating

Heating Load $P_H = 9275$ BTU/hr

@ 68°

Annual Heat Demand $Q_H = 9420$ kBTU/yr 3.39 kBTU/(ft²yr)

Cooling

Cooling Demand $Q_K = 3019$ kBTU/yr 1.09 kBTU/(ft²yr)

Cooling Load $P_C = P_T + P_V + P_S + P_I = 6717$ BTU/hr

(Without NVC)

Frequency of Overheating $h_3 \geq h_{max}$ 18.7% at the overheating limit $h_{max} = 75 ^\circ F$
Mechanical Systems – Keep it Simple!
HRV–Zehnder ComfoAir 350
- 84% HR efficiency, PHI certified
- 70 / 110* / 200 cfm
Cottle ZEH – Mechanical Systems Summary

- Heat / Cool – “Un-forced” Air
  - Lennox 2-stage, 18 seer Ht Pump, 13/22 kbtu

Mini-Split; not suitable for large, 12 supply registers home
Cottle ZEH – Mechanical Systems Summary

- Heat / Cool – “Un-forced” Air
  - Lennox 2-stage, 18 seer Ht Pump, 13/22 kbtu
  - Night Breeze Night Vent. Cooling (NVC)
Cottle ZEH – Mechanical Systems Summary

- **HRV–Zehnder ComfoAir 350**
  - 84% HR efficiency, PHI certified
  - 70 / 110* / 200 cfm
- **Heat / Cool – “Un-forced” Air**
  - Lennox 2-stage, 18 seer Ht Pump, 13/22 kbtu
  - Night Breeze Night Vent. Cooling
- **Ductwork - Open Web Trusses**
  - Separate HRV & HP/NVC ducts
  - ACCA Manual D Design
  - Rigid & Flex, 3” & 8”, RAPs

<table>
<thead>
<tr>
<th>CFM</th>
<th>TOTAL</th>
<th>REG</th>
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<tbody>
<tr>
<td>HRV</td>
<td>110</td>
<td>10</td>
</tr>
<tr>
<td>HP</td>
<td>600</td>
<td>50</td>
</tr>
<tr>
<td>NVC</td>
<td>800</td>
<td>70</td>
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</table>
## Cottle ZEH
### Mechanical Systems Energy Forecast

### Estimated Ann. Space Conditioning Energy (kWh)

<table>
<thead>
<tr>
<th></th>
<th>HRV</th>
<th>HEATING</th>
<th>COOLING</th>
<th>NVC</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 hrs opn</td>
<td>350</td>
<td>1510</td>
<td>30</td>
<td>115</td>
<td>2005</td>
</tr>
</tbody>
</table>

- **< 1 TV + 1 DVR**: $25 \text{ hrs opn} < \$3$
- **Typ. 3000 sf house > 15,000**: $10$

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Cooling - Building Design Features

- **Building Envelope (passive)**
  - Extended eaves (show sun angles & analysis)
  - Extended shading for patio doors - 6’ overhangs
  - Minimal glazing E&W vs max S
  - Low shgc glazing E & W vs high shgc south
  - Vertical shading on W windows
  - Tilt & Turn windows – easy, secure manual night vent

- **Mechanical (active)**
  - HRV w/ bypass mode (economizer)
  - Integrated NVC
Night Ventilation Cooling – PHPP numbers

Without NVC

<table>
<thead>
<tr>
<th></th>
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</tr>
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<tbody>
<tr>
<td></td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>/ 0.024</td>
<td>/ 0.024</td>
</tr>
<tr>
<td></td>
<td>= 0</td>
<td>= 0</td>
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Frequency of Overheating $h_{\theta} \geq \theta_{\text{max}}$ $18.7\%$ at the overheating limit $\theta_{\text{max}} = 75^\circ F$

With NVC

(@ 2 ACH = 800 cfm)

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<td>= 0</td>
<td>= -3681</td>
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</table>

Frequency of Overheating $h_{\theta} \geq \theta_{\text{max}}$ $0.0\%$ at the overheating limit $\theta_{\text{max}} = 75^\circ F$
Cottle ZEH - NVC Energy Performance

Night Breeze
Night Ventilation Cooling: Energy Performance vs Cooling Capacity

- Projected NVC performance
- Typ. AC Performance
- Cottle predicted avg daily cooling load > 60,000 btu's

* 8 hr night ventilation cycle @ 10° avg ΔT
ESP = 0.4 IWC

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Secondary Mechanical Systems

- **Hot Water** (33M btu - 3x energy needed for space conditioning!)
  - Enerworks 3-panel Solar Thermal System (est. 75% SF)
  - AOS “Vertex” 96% AFUE gas condensing HW heater

![Total Heat Demand of DHW system](image)

![Gas Water Heater](image)

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Secondary Mechanical Systems

- **Hot Water** (33M btus - 3x energy needed for space conditioning!)
  - Enerworks 3-panel Solar Thermal System (est. 75% SF)
  - AOS “Vertex” 96% AFUE gas condensing HW heater
  - On-demand HW recirc system
- **Clothes Drying** – vented, premium back draft prevention
- **Cooking** – Pro style gas range w/grill
- **Cooking Exhaust** – vented, high capacity
  - Make-up air system, premium damper control
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Cottle – Energy Consumption Comparison

Average 3000 sf Home
Annual Energy Usage = 40,000 kWh

- LIGHTS/PLUGS: 10,000
- HOT WATER/COOKING: 10,000
- HVAC: 20,000

≈ 65% GAS (CA)

Cottle 3200 sf Zero Energy Home
Estimated Annual Energy Usage 10,000 kWh

- HVAC 2,000
- HOT WATER/COOKING 3,000
- LIGHTS/PLUGS 5,000
- CONSERVED ENERGY 30,000

Standard 3000 sf Home 40,000 kWh
Cottle Net Zero Energy Home
Summary Annual Energy Usage Forecast (Kwh)

- ELECTRONICS: 19% (1870 Kwh)
- HVAC: 21% (2030 Kwh)
- GAS: 15% (1465 Kwh)
- HOT WATER: 15% (800 Kwh)
- COOKING: 6% (645 Kwh)
- LIGHTING: 8% (3011 Kwh)

Total Usage: 9,821 Kwh
Production: 10,016 Kwh
# Cottle Zero Energy Budgeting

## Passive House Planning

### Electricity Demand

<table>
<thead>
<tr>
<th>Column Nr.</th>
<th>Application</th>
<th>Used? (10)</th>
<th>Within the Thermal Envelope? (10)</th>
<th>Norm Demand</th>
<th>Utilization Factor</th>
<th>Frequency</th>
<th>Reference Quantity</th>
<th>Useful Energy (kWh/yr)</th>
<th>Electric Fraction</th>
<th>Non-Electric Fraction</th>
<th>Electricity Demand (kWh/yr)</th>
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<td>11</td>
<td>Dishwashing</td>
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<td>1</td>
<td>0.80 kWhUse</td>
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<td>0.85</td>
<td>365 /yr</td>
<td>7.4 kWh /yr</td>
<td>100%</td>
<td>0%</td>
<td>105 kWh /yr</td>
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<tr>
<td>12</td>
<td>DHW Connection</td>
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<td>13</td>
<td>Clothes Washing</td>
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<td>1</td>
<td>0.80 kWhUse</td>
<td>1.00</td>
<td>0.85</td>
<td>365 /yr</td>
<td>7.4 kWh /yr</td>
<td>100%</td>
<td>0%</td>
<td>105 kWh /yr</td>
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<td>14</td>
<td>DHW Connection</td>
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<tr>
<td>15</td>
<td>Clothes Drying with</td>
<td>1</td>
<td>1</td>
<td>3.00 kWhUse</td>
<td>1.00</td>
<td>0.85</td>
<td>365 /yr</td>
<td>7.4 kWh /yr</td>
<td>100%</td>
<td>0%</td>
<td>105 kWh /yr</td>
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<tr>
<td>16</td>
<td>Electric/Heat Dryer</td>
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<tr>
<td>17</td>
<td>Energy Consumed by Equipment</td>
<td>1</td>
<td>1</td>
<td>3.13 kWhUse</td>
<td>1.00</td>
<td>0.60</td>
<td>365 /yr</td>
<td>7.4 kWh /yr</td>
<td>100%</td>
<td>0%</td>
<td>105 kWh /yr</td>
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<tr>
<td>18</td>
<td>Refrigerating</td>
<td>1</td>
<td>1</td>
<td>2.00 kWh/day</td>
<td>1.00</td>
<td>365 /yr</td>
<td>1 HH</td>
<td>438 kWh /yr</td>
<td>100%</td>
<td>0%</td>
<td>105 kWh /yr</td>
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<td>1</td>
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<td>100%</td>
<td>0%</td>
<td>105 kWh /yr</td>
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<tr>
<td>20</td>
<td>or Combined Unit</td>
<td>1</td>
<td>1</td>
<td>1.90 kWhUse</td>
<td>1.00</td>
<td>365 /yr</td>
<td>1 HH</td>
<td>694 kWh /yr</td>
<td>100%</td>
<td>0%</td>
<td>105 kWh /yr</td>
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<td>21</td>
<td>Cooking with:</td>
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<td>1.00</td>
<td>500 /day</td>
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<tr>
<td>23</td>
<td>Lighting</td>
<td>1</td>
<td>1</td>
<td>26 W</td>
<td>1.00</td>
<td>2.90 kBTU/yr</td>
<td>7.4 kWh</td>
<td>549 kWh /yr</td>
<td>100%</td>
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<td>24</td>
<td>Consumer Electronics</td>
<td>1</td>
<td>1</td>
<td>200 W</td>
<td>1.00</td>
<td>0.55 kBTU/yr</td>
<td>7.4 kWh</td>
<td>810 kWh /yr</td>
<td>100%</td>
<td>0%</td>
<td>105 kWh /yr</td>
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<tr>
<td>25</td>
<td>Small Appliances, etc.</td>
<td>1</td>
<td>1</td>
<td>50 kWh</td>
<td>1.00</td>
<td>1.00 kBTU/yr</td>
<td>7.4 kWh</td>
<td>368 kWh /yr</td>
<td>100%</td>
<td>0%</td>
<td>105 kWh /yr</td>
</tr>
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</table>
Cottle ZEH - Renewables

- 6.3 kW, 30 x 210w panels, 530sf
- 332 kWh/panel = 10,000 KWh/yr
Fuel Choices – Gas vs Electricity

1. Performance of appliance …how well does it work?
2. Gas 1.1x vs. Electric 3x source energy factor (US)

- Space conditioning – HW (gas) vs. HP (elec.)
- Gas HW heaters function better than Elec HP
  - Faster reheat
  - Continuous HW
  - Compatible w/ Solar HW
  - Lower cost, simpler to maintain
  - More energy efficient
- Cooking

<table>
<thead>
<tr>
<th>Primary Energy Factors:</th>
<th>Electricity</th>
<th>Natural Gas</th>
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</thead>
<tbody>
<tr>
<td>kBTU/kBTU</td>
<td>2.7</td>
<td>1.1</td>
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</tbody>
</table>

Energy Carrier for Space Heating/DHW:

<table>
<thead>
<tr>
<th></th>
<th>Electricity</th>
<th>Natural Gas</th>
</tr>
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<tbody>
<tr>
<td>kWh/kWh</td>
<td>2.7</td>
<td>1.1</td>
</tr>
</tbody>
</table>

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Cottle – Gas Energy Offset Math

<table>
<thead>
<tr>
<th></th>
<th>GAS</th>
<th>ELEC.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 THERM=29.3 kWh</td>
<td>THERMS (100k btu’s)</td>
<td>kWh (=3412 btu’s)</td>
</tr>
<tr>
<td></td>
<td>SITE</td>
<td>SOURCE</td>
</tr>
<tr>
<td></td>
<td>( x1.1 )</td>
<td>( x3 )</td>
</tr>
<tr>
<td>HOT WATER</td>
<td>50</td>
<td>1465</td>
</tr>
<tr>
<td>COOKING</td>
<td>22</td>
<td>645</td>
</tr>
<tr>
<td>TOTAL GAS</td>
<td>72</td>
<td>79</td>
</tr>
<tr>
<td></td>
<td>2110</td>
<td>6330</td>
</tr>
</tbody>
</table>

Source energy conserved from using gas:

6330 – 2320 = 4010 kWh (12.5M btu)
Car Charging w 2110 kWh surplus solar PV energy
- $\times 4$ miles/kWh = 8440 miles/yr (Nissan Leaf)
- $\div 21$ mpg = 400 gal/yr gasoline offset / saved
- $\times 125,000$ btu/gal = 50M btu heat energy saved
- $\times 20\#$ CO$_2$/gal emissions = 4 tons CO$_2$/yr saved
Lessons and conclusions

- Beware of averages, know your climate
- Good mechanical design essential
- Cooling matters! Design carefully for it
- Condensing dryers in our climate are problematic
- PH well-suited to large buildings
- Use source energy math - ? cut off the gas line
- Beware “irrational exuberance”