Case Study in Long-Term Performance of Zero Energy Homes

Measured Performance of the NREL/Habitat Zero Energy Home over 9 Years

EEBA Excellence In Building Conference
The Cutting Edge of High Performance Homebuilding track
Denver, CO October 2015
Craig Christensen, National Energy Renewable Laboratory
Paul Kriescher, Lightly Treading
Paul Norton, Norton Energy Research and Development

Habitat for Humanity Metro Denver

Sustainability

- Since building their 1st ENERGY STAR home in 1997 they have built or remodeled 650 homes…all of which met or exceeded ENERGY STAR standards.
- This saved each family an estimated $433/year if they had only built the homes to meet Code!

It takes a village to build a home….

Design and Analysis: DOE's Building America Program

Home Sponsorship: NREL's Managing Partners, MRI and Battelle

Supporting Grants:
- Energy Outreach Colorado
- Governor's Energy Office
- Xcel Energy

Land Donation: The City of Wheat Ridge

Design Team

Craig Christensen, NREL

Paul Norton, NREL

Andy Blackmun, Habitat, Metro Denver

Bruce Carpenter, Habitat, Metro Denver

Paul Kriescher, Lightly Treading

Pete Beverly, Electrician and Photovoltaic Technician

NREL Director – Dan Arvisu

U.S. Secretary of Energy -- Samuel W. Bodman

ZEH Timeline

Super-insulation • PassivHaus • PHIUS

Passive solar

Off-grid PV

Net-metering ???

ZEH ???

EEBA

1970 1980 2010 2020

Saskatchewan House

My House

Denver ZEH

Design Criteria

1. Zero net annual source energy
2. Replicable by Habitat
3. Take advantage of volunteer labor
4. Take full material cost into account
5. No special operation of home needed
6. No prototypes: off-the-shelf equipment
7. Keep it simple!

Definition of ZEH

A building that produces as much energy as it consumes on an annual basis, on average.

Zero Energy Strategy

1) Dramatically reduce energy needs through super-insulation, air-tightness, efficiency, solar tempering, and solar water heating

2) Use PV to offset electrical energy consumption

3) Use some natural gas for space heating and back-up water heating

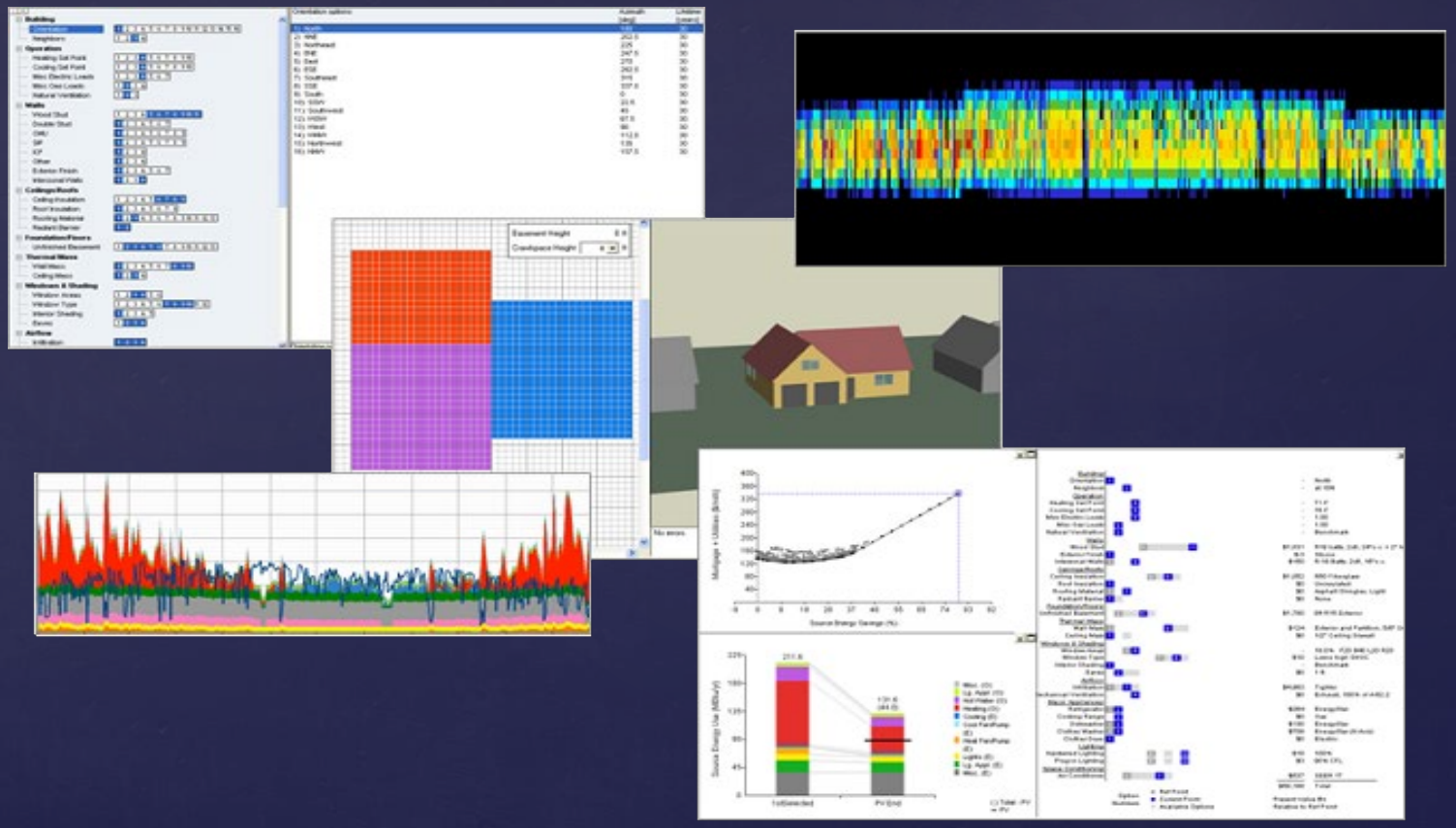
4) Produce excess PV electricity to **offset natural gas use** and provide Net Zero Energy performance on a source energy basis.

Site-to-source factors:

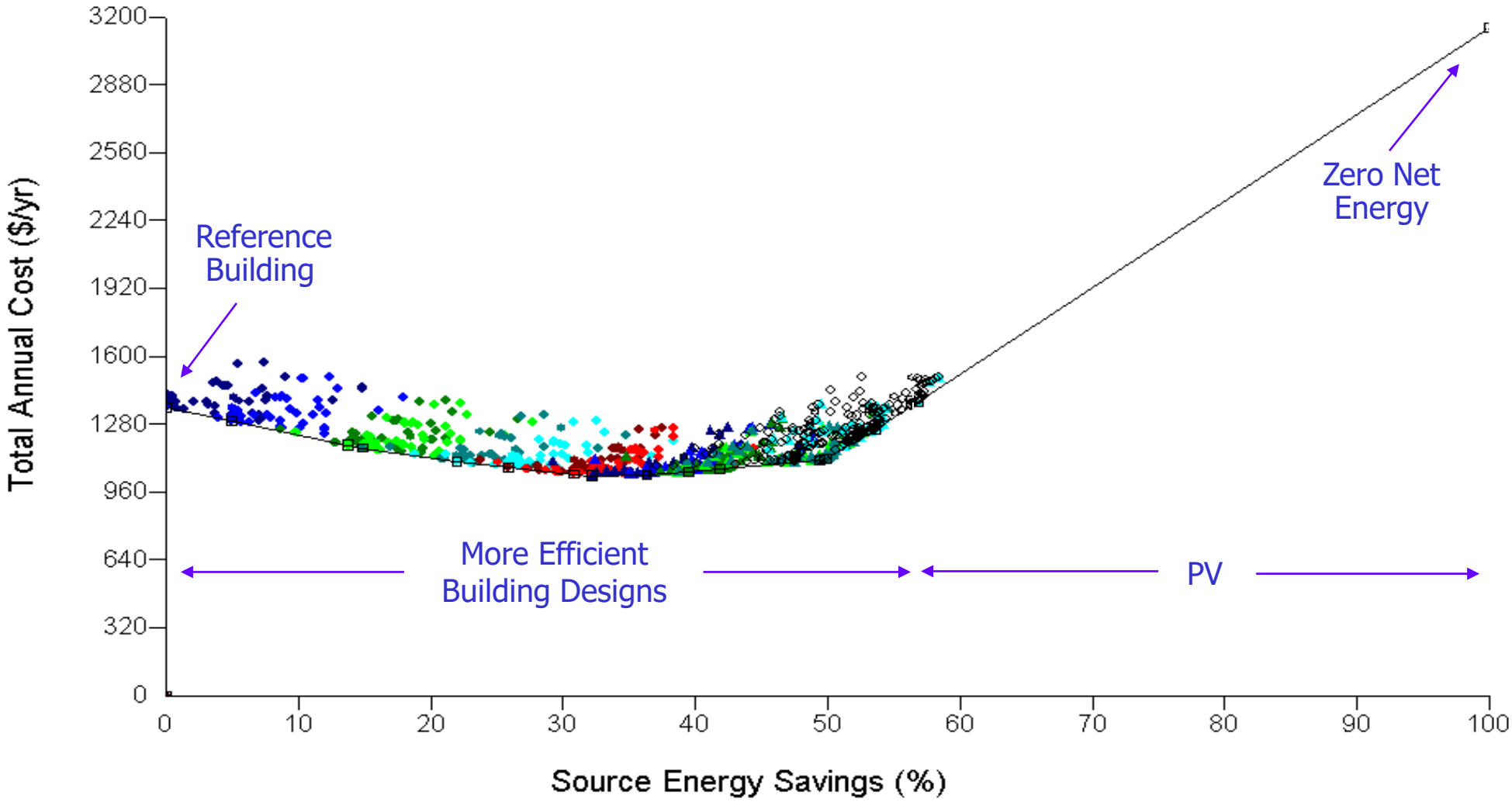
Electricity	3.318	(Colorado)
Natural Gas	1.092	(National Average)

Design Optimized with NREL's BEopt Software

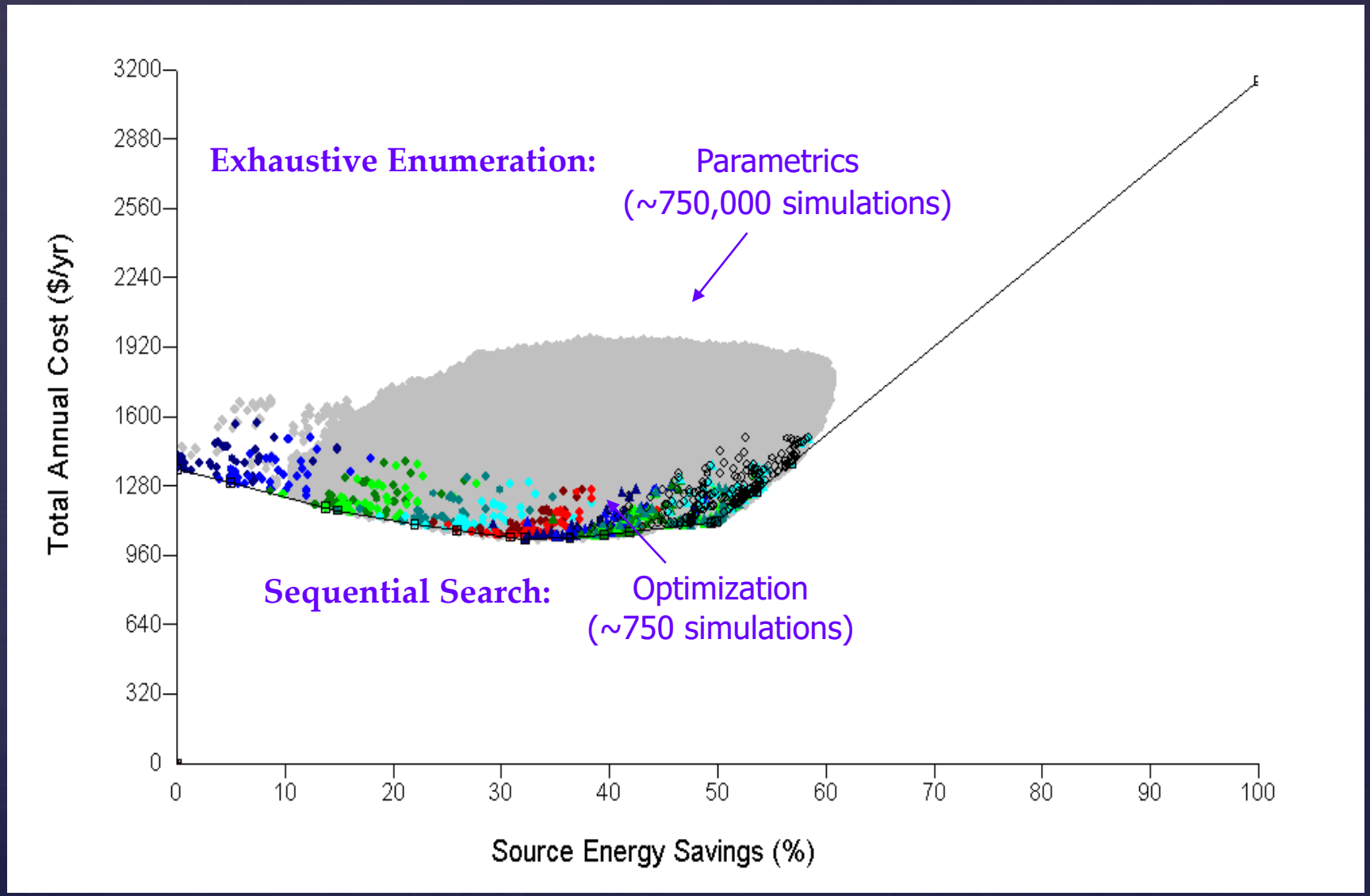
beopt.nrel.gov



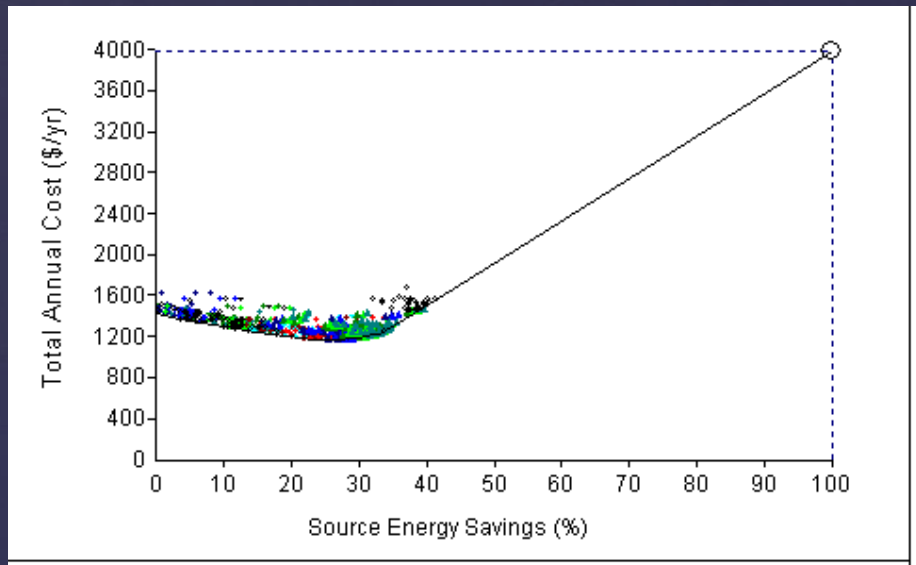
Validation

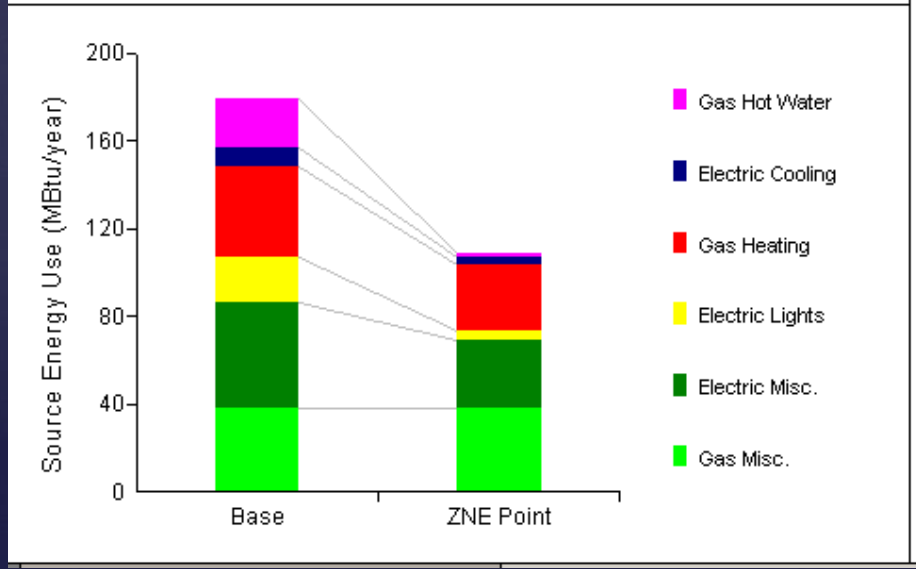

Total Annual Cost ($/yr)
3200
2880
2560
2240
1920
1600
1280
960
640
320
0
0
10
20
30
40
50
60
70
80
90
100
Source Energy Savings (%)
Reference Building
Zero Net Energy
More Efficient Building Designs
PV

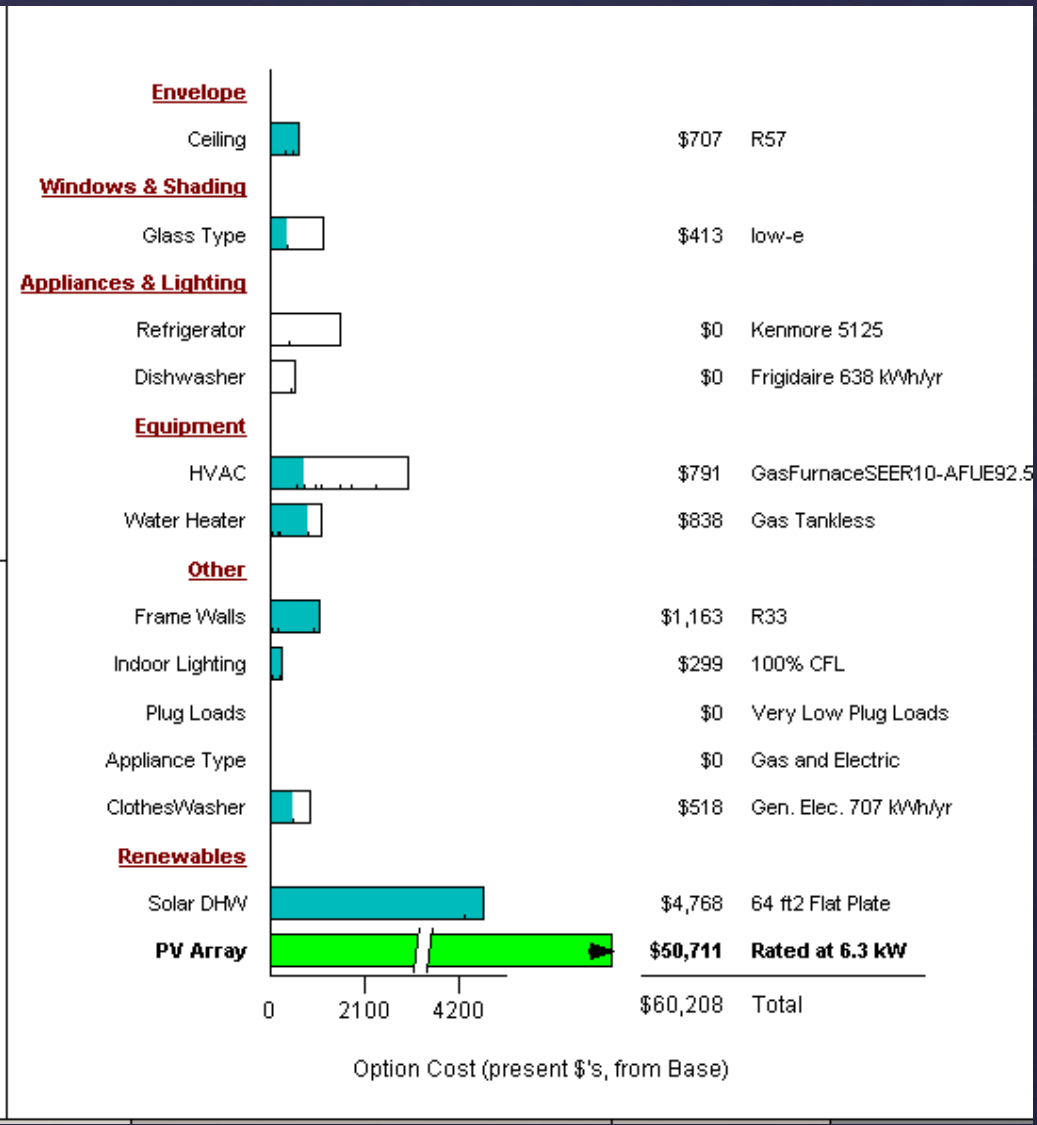
Validation of BEopt Search



BEopt Results for Habitat ZNE House Design







Home Features

1280 ft^2 finished floor area, 3 Bedroom, 1 Bath

Efficiency

- Superinsulated, tight building envelope:
  (Wall R-40, Ceiling R-60, Floor R-30)
- All equipment is in the thermal envelope
- Heat recovery ventilation
- Energy Star appliances
- CFL Lighting

Heating

- Point-source only – no distribution system
- Direct-vent gas heater in living room
- 750 W electric baseboard heater in each bedrooms

Home Features

1280 ft^2 finished floor area, 3 Bedroom, 1 Bath

No cooling

- Long-standing Habitat Metro Denver policy

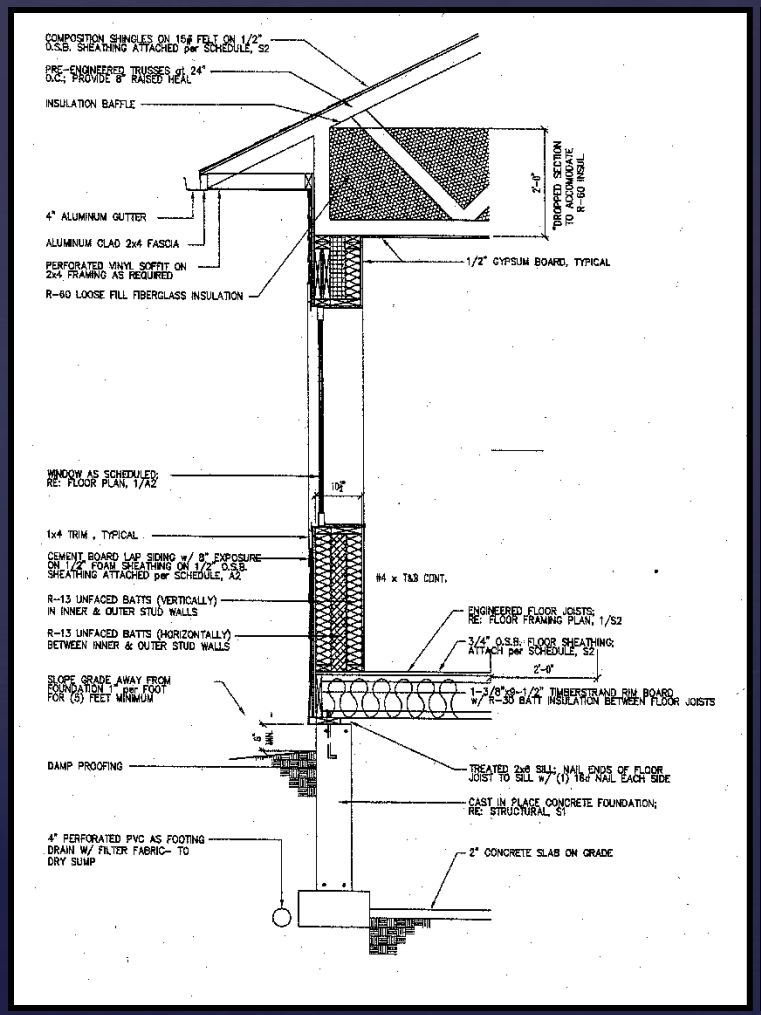
Renewables

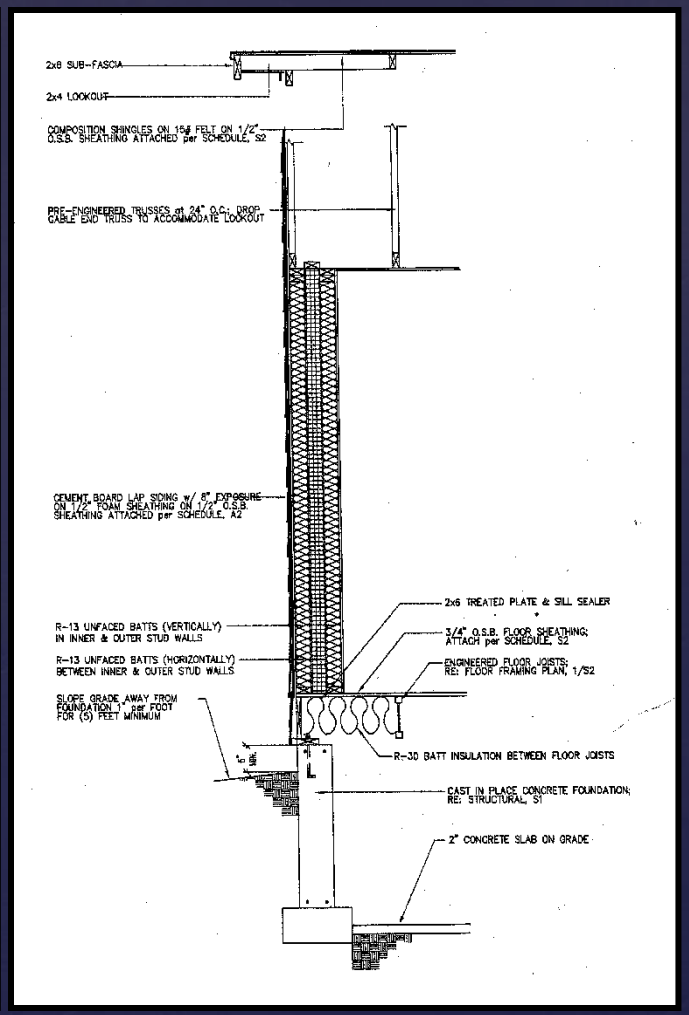
- Solar tempering with orientation specific windows
- 96 sq. ft. drainback solar water heating system
- 4 kW PV system

Back-up Water Heating

- Tankless natural gas

Superinsulated Construction

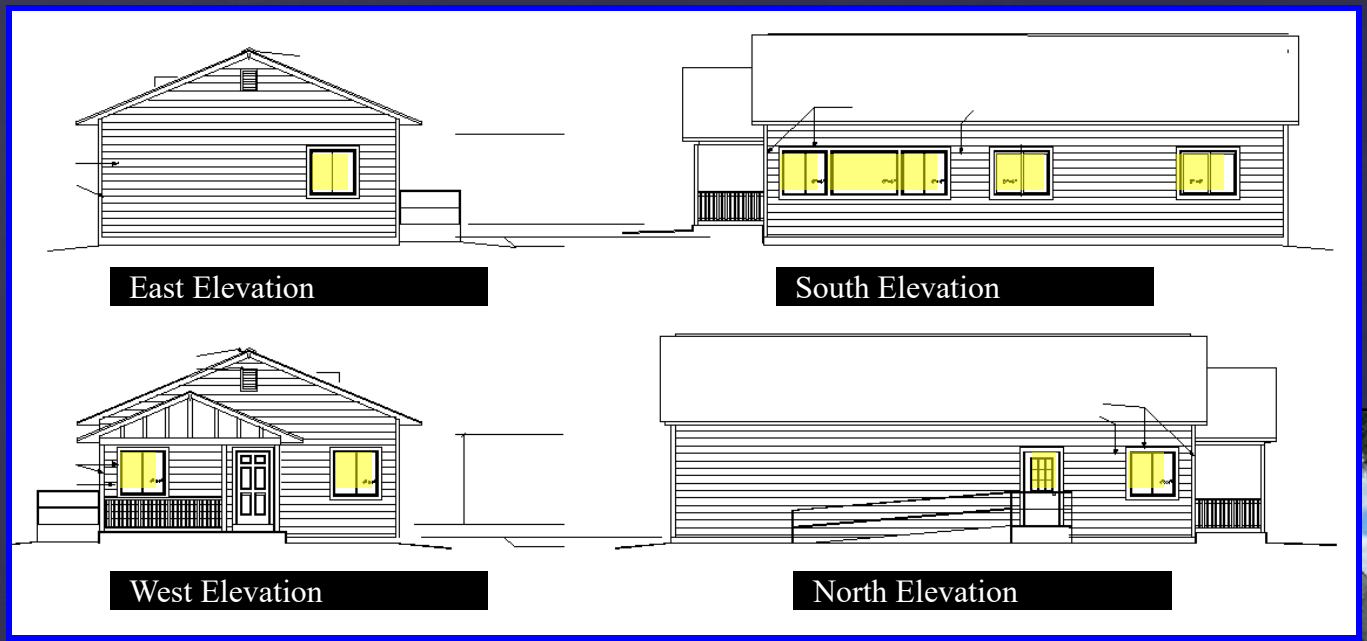




- Double Stud Wall
- Three layers of fiberglass batt insulation
- 24” Raised heel trusses
- Wall R-40
- Ceiling R-60
- Floor R-30
- Low-e windows

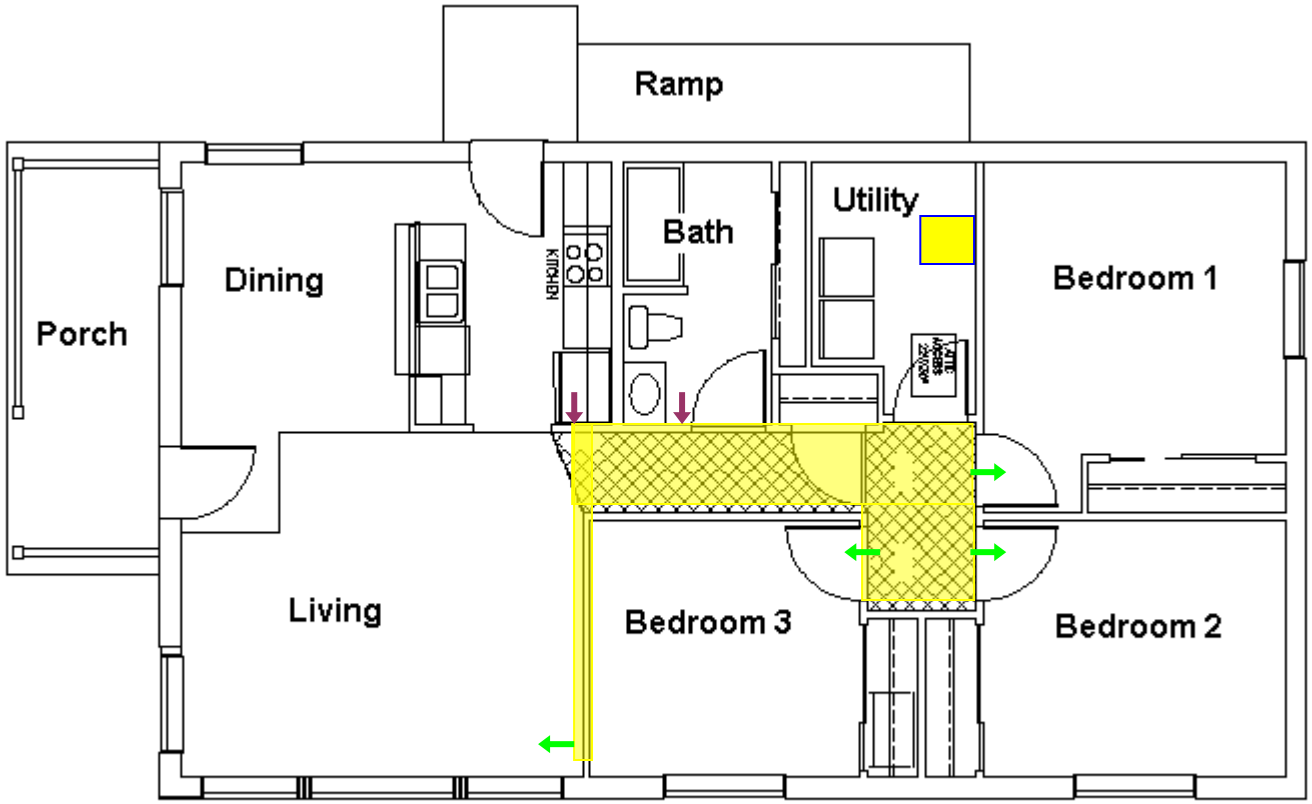

Tyvek

Solar Tempering



- **Window distribution**
- **Orientation specific glazing**
- **3’ overhang**

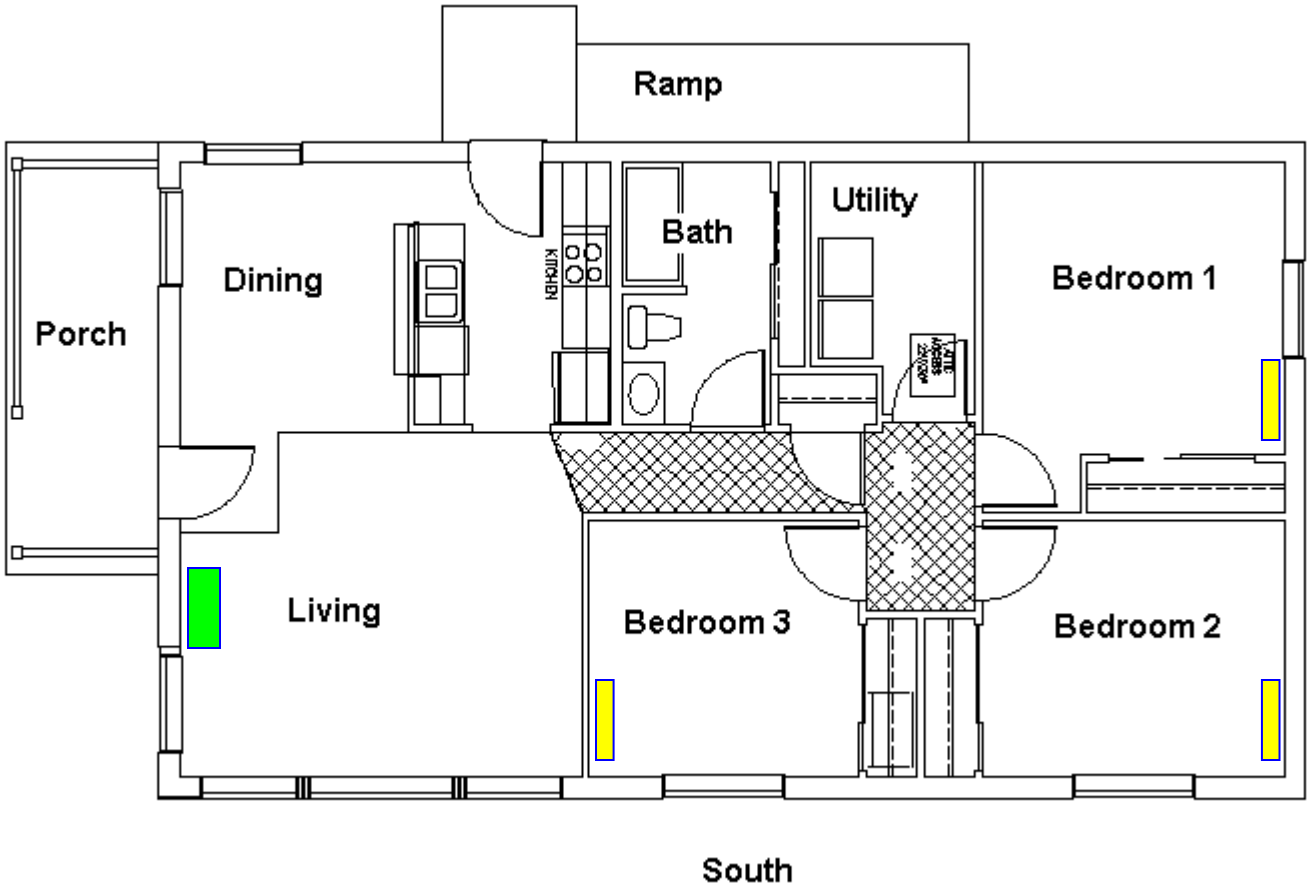
Energy Recovery Ventilation



- **Recovers heat from ventilation air**
- **6” ducts in hallway drop ceiling**


UltimateAir ™
by Stirling Technology, Inc.
CHECK FILTER
MED
LOW
HI
OFF
POWER
VENTILATION CONTROL

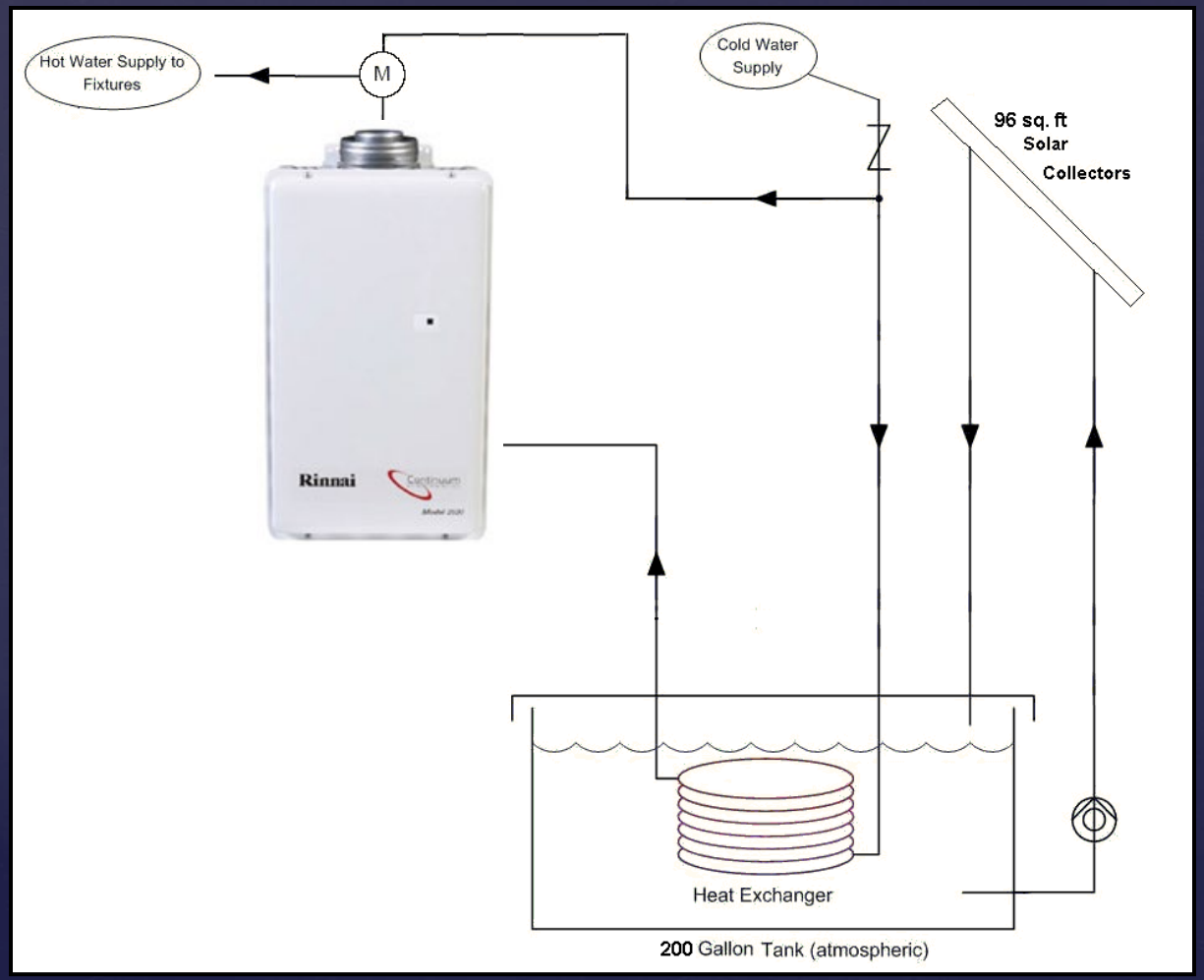
Hybrid NG/Electric Space Heating System



- **Direct vent, single point NG heater**
- **Small electric baseboards in bedrooms**


4100

Solar Water Heating System



- **Drainback system**
- **96 sq. ft. collector**
- **200 gal storage tank**
- **Tankless backup heater**


Rinnai

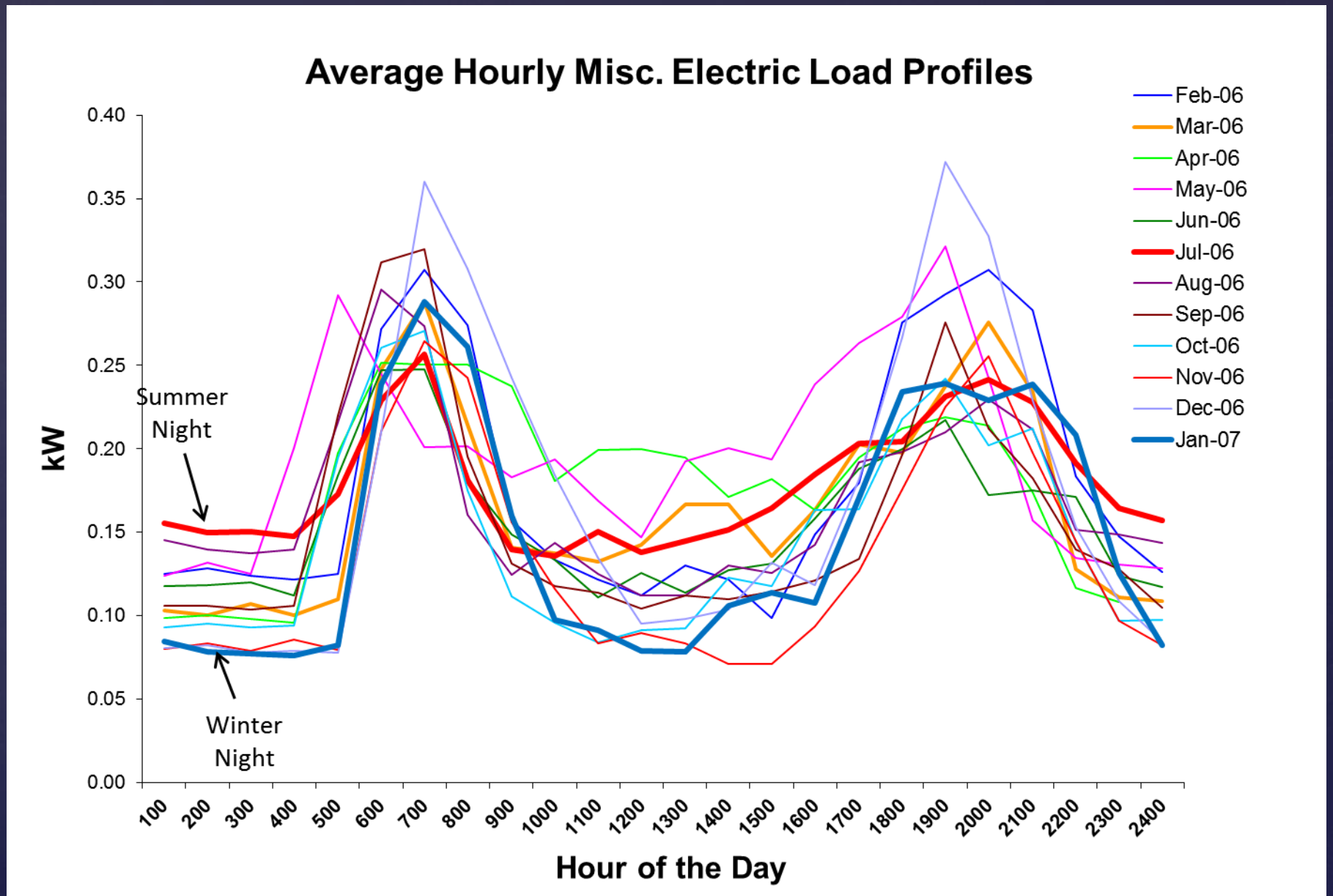

ENERGY GUIDE
Rinnai
Continuum
Model 2532

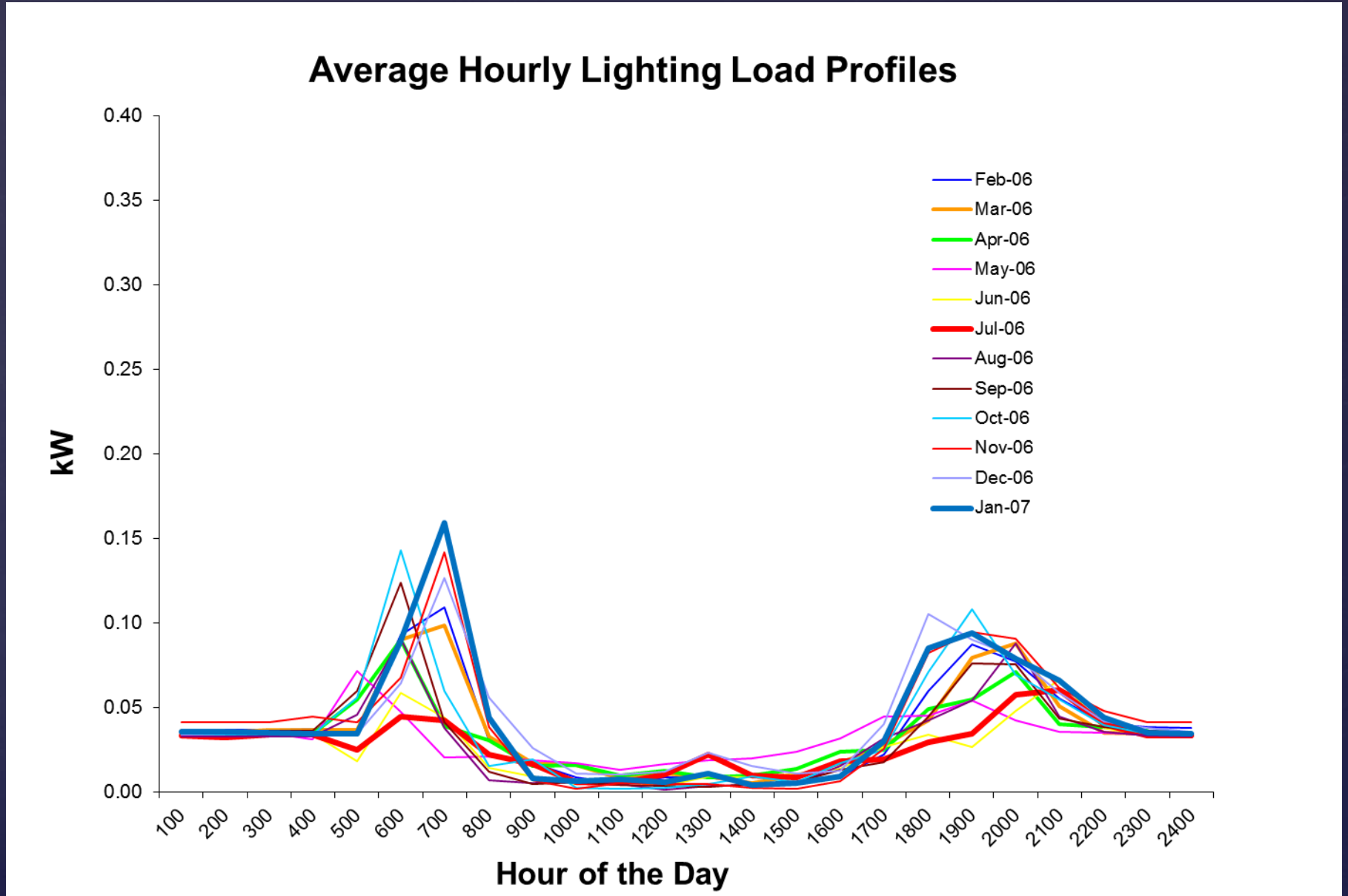
PV System

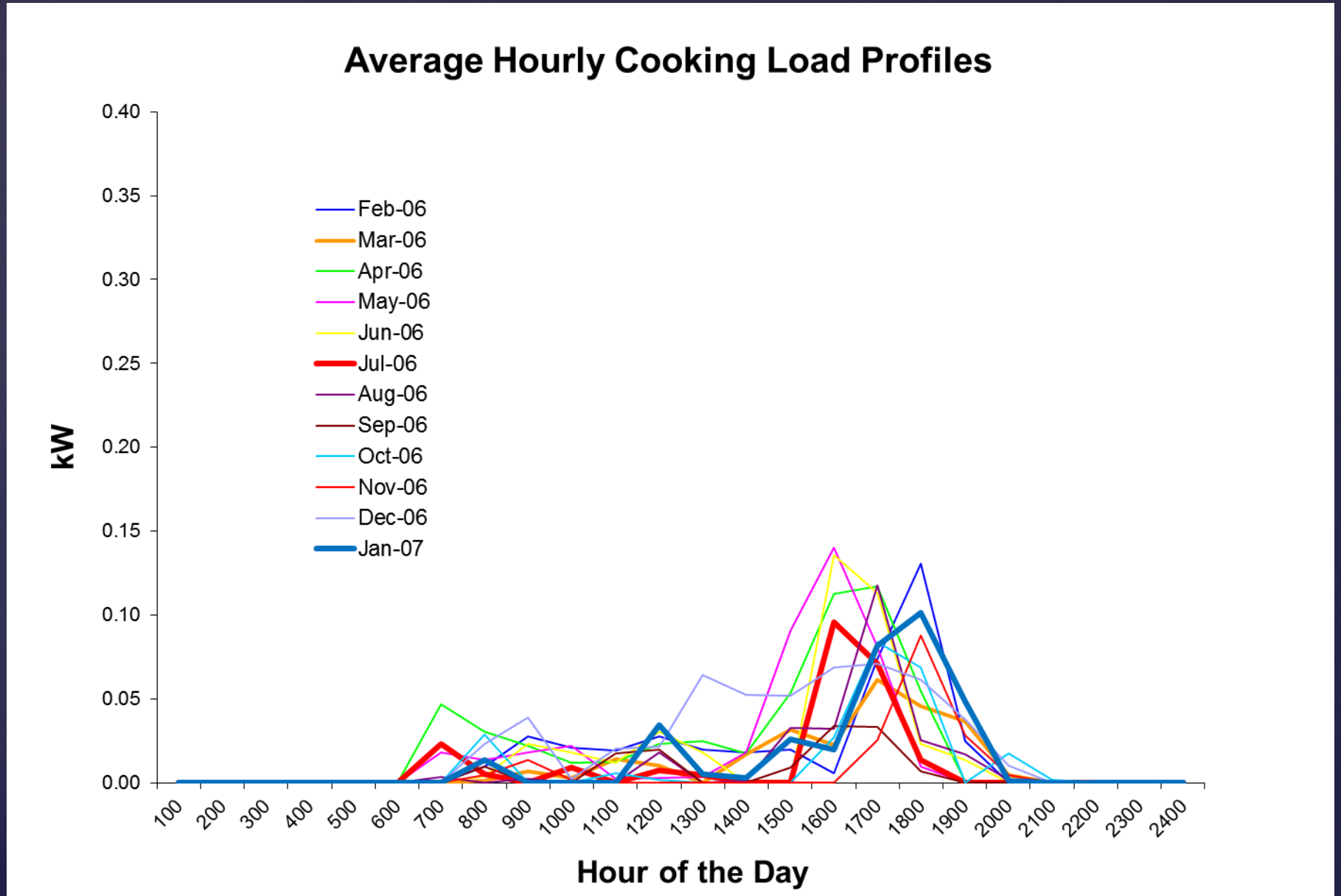
4 kW System

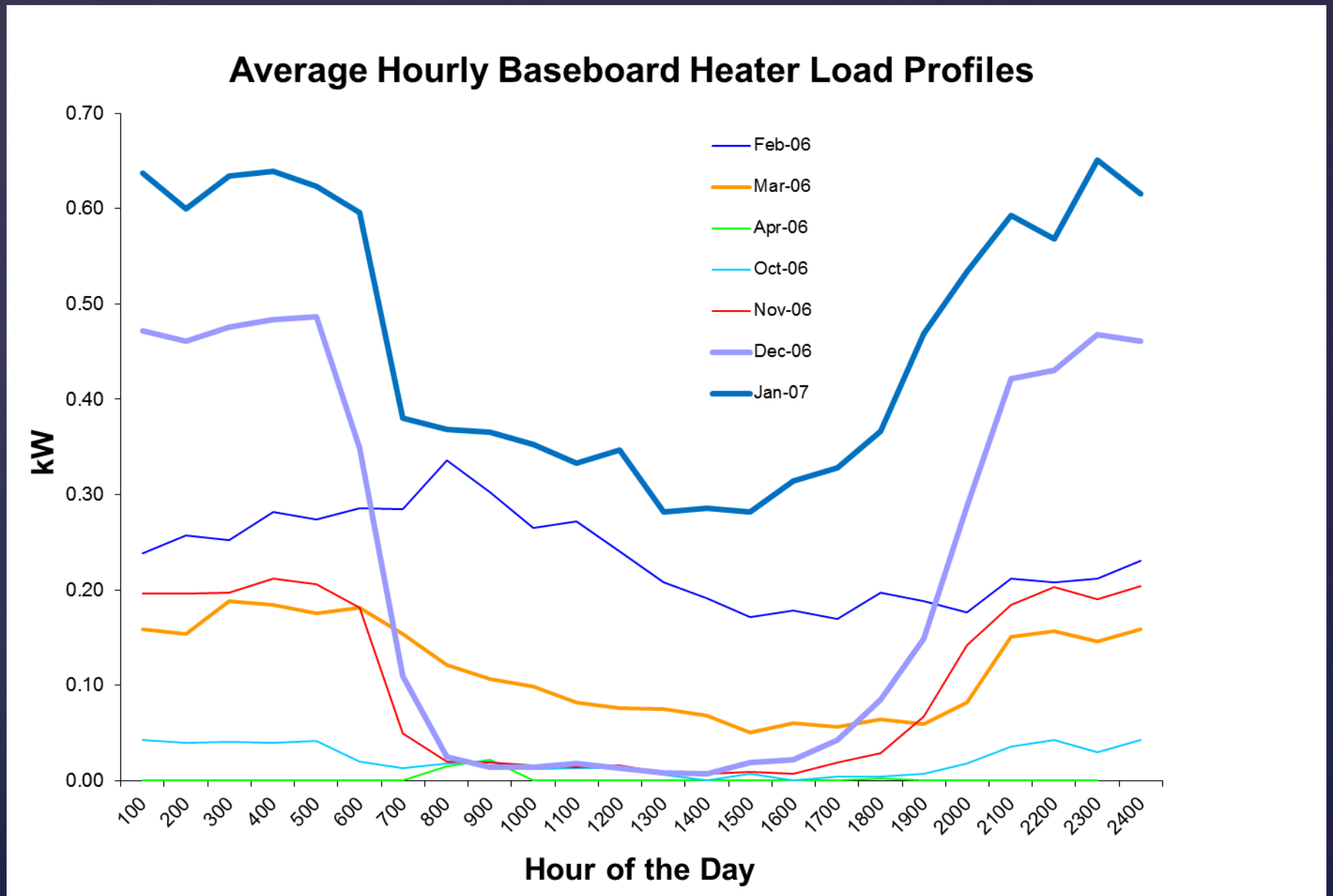
for net zero energy

First Year

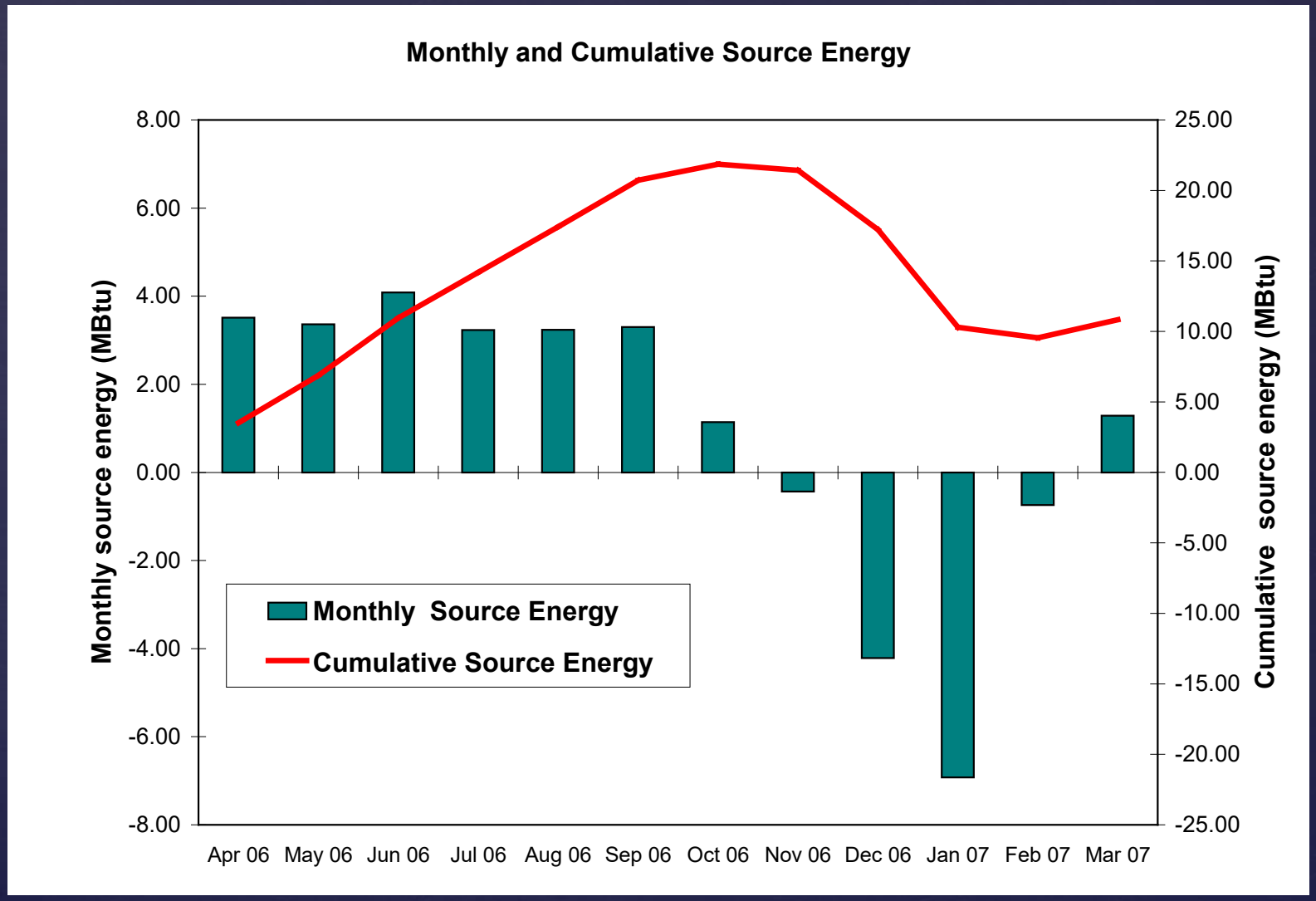

Average Hourly Misc. Electric Load Profiles
kW
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Summer Night
Winter Night
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
Hour of the Day
Feb-06
Mar-06
Apr-06
May-06
Jun-06
Jul-06
Aug-06
Sep-06
Oct-06
Nov-06
Dec-06
Jan-07


Average Hourly Lighting Load Profiles
kW
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
Hour of the Day
Feb-06
Mar-06
Apr-06
May-06
Jun-06
Jul-06
Aug-06
Sep-06
Oct-06
Nov-06
Dec-06
Jan-07


Average Hourly Cooking Load Profiles
kW
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Feb-06
Mar-06
Apr-06
May-06
Jun-06
Jul-06
Aug-06
Sep-06
Oct-06
Nov-06
Dec-06
Jan-07
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
Hour of the Day


Average Hourly Baseboard Heater Load Profiles
kW
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Feb-06
Mar-06
Apr-06
Oct-06
Nov-06
Dec-06
Jan-07
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
2100
2200
2300
2400
Hour of the Day

Habitat ZEH
First Year Performance



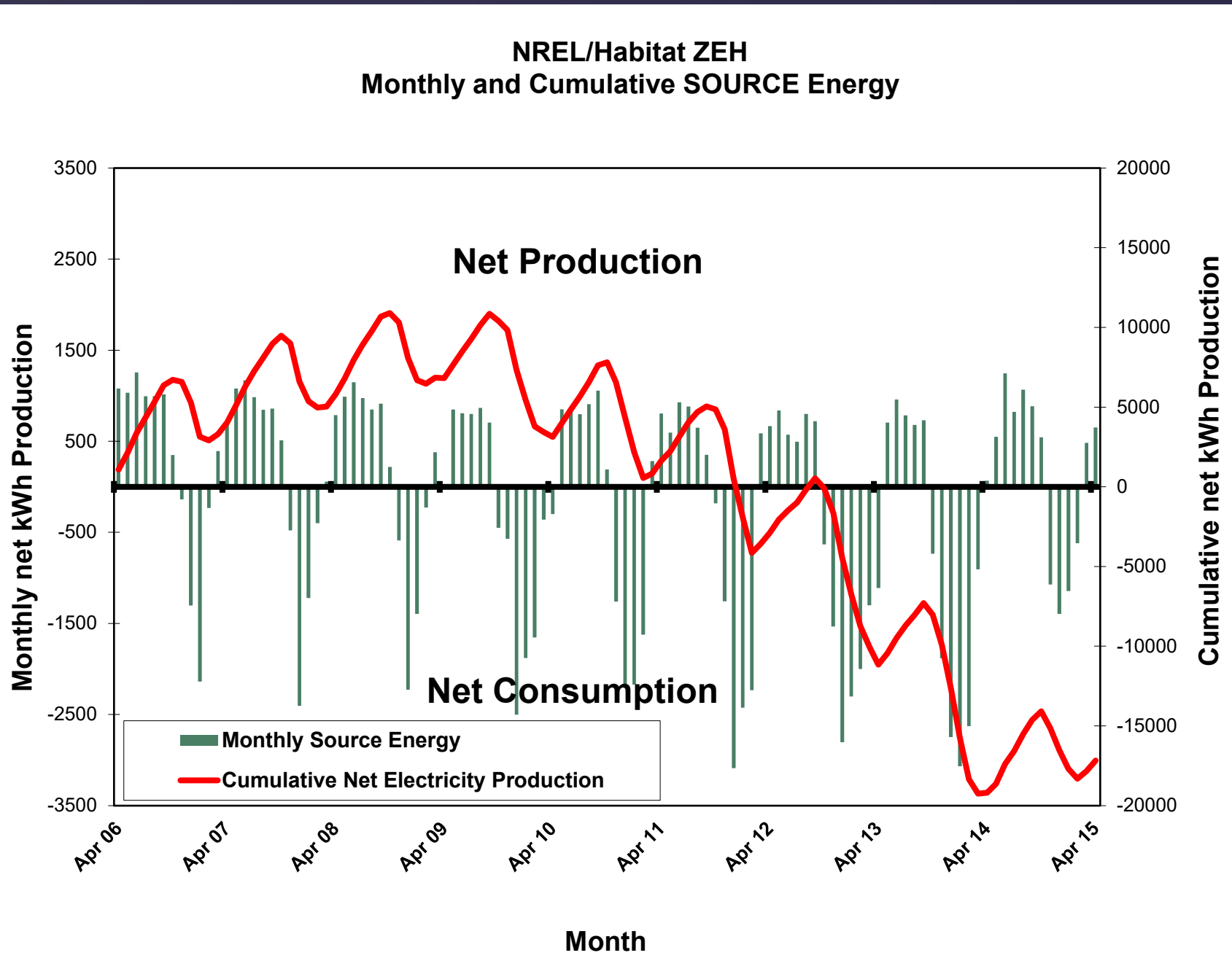
Yes, It's A Zero-Energy House

EDU is pleased to congratulate the Metro Denver chapter of Habitat for Humanity and engineers at the National Renewable Energy Laboratory (NREL) for having built what appears to be the first zero-energy house in the US. (Meanwhile, at Eric Doub's house in Boulder, Colorado, incomplete monitoring data indicate that Doub's home is likely to become the next house in the US to attain the zero-energy goal. Doub's house was profiled in the September 2005 issue of ***EDU***.)

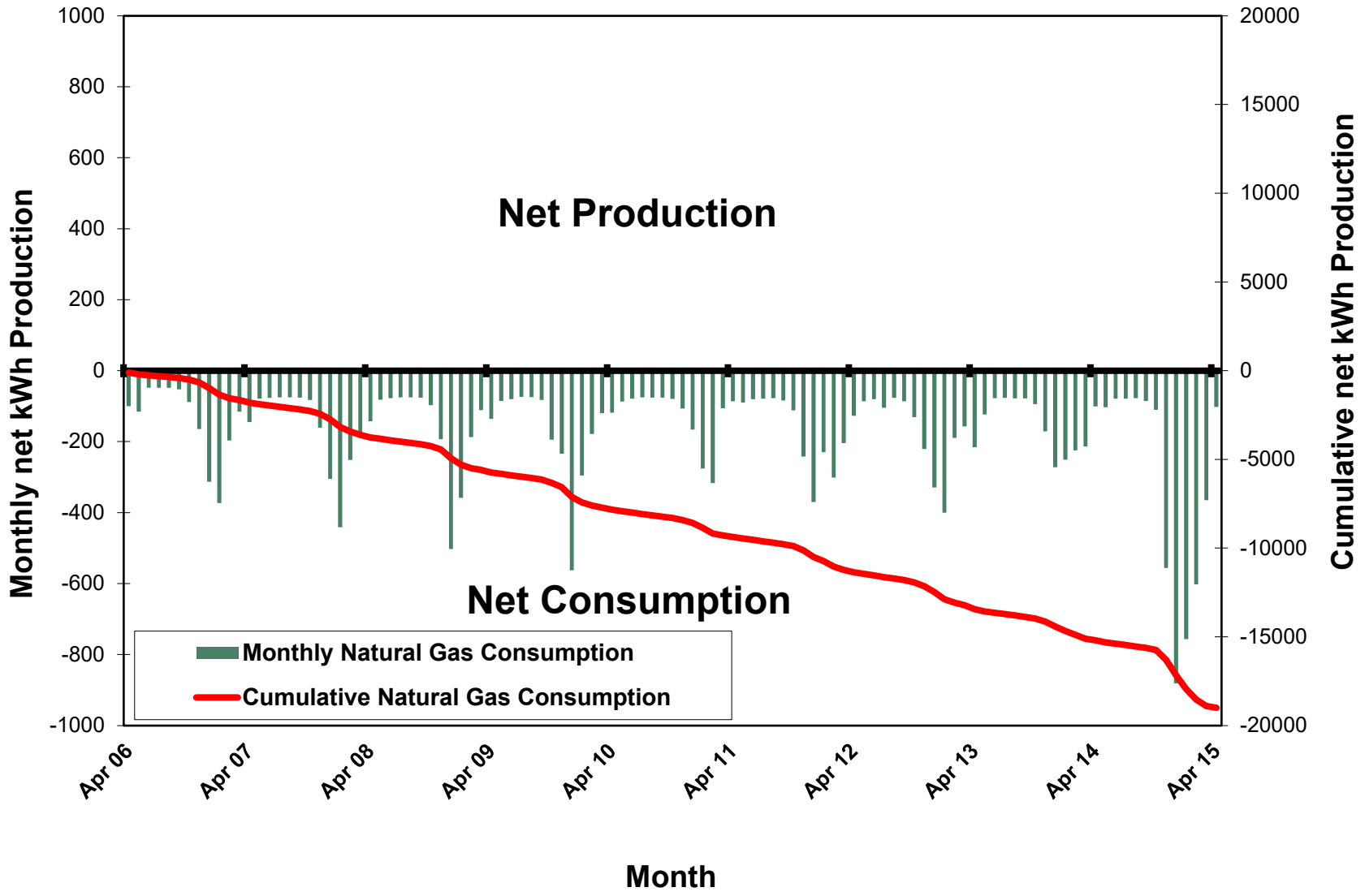
Paul Norton, a senior engineer at NREL, has released 12 full months of monitoring data for the Habitat for Humanity house in Wheat Ridge, Colorado (see ***EDU***, June 2006). Norton writes, "During the 12 months since the utility electric meter was installed in the beginning of October 2005 to the end of September 2005, the photovoltaic system has produced 2,347 kWh more than the electricity used in the home. Only 49 therms of natural gas [equivalent to 1,436 kWh] were used during this period. About 560 kWh of excess electric-

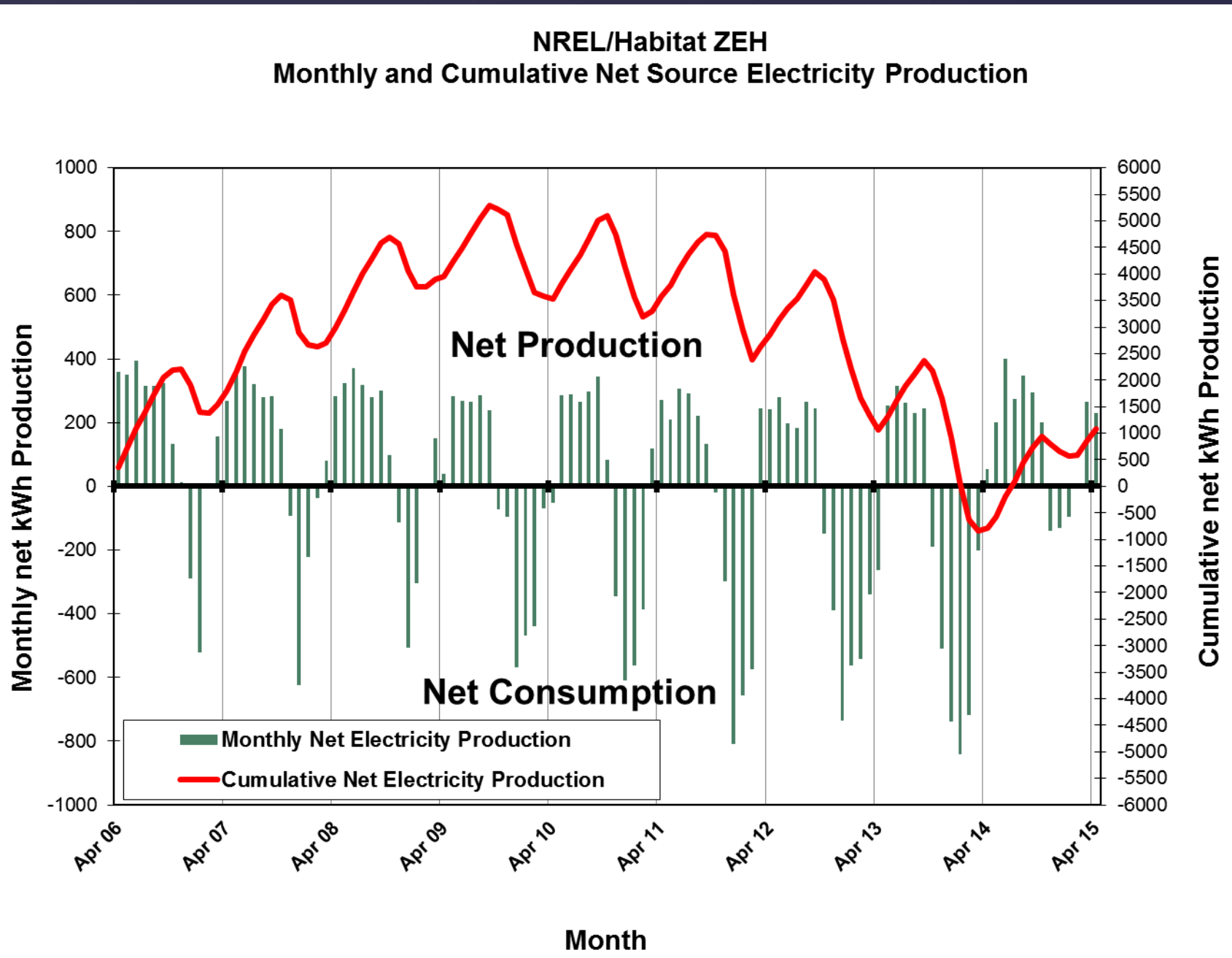
Figure 2. Twelve months of monitoring data confirm that the Habitat for Humanity house in Wheat Ridge, Colorado, is the first zero-energy home in the US. [Photo credit: National Renewable Energy Laboratory]

Percent of Source Energy Consumption that was offset by PV Production Annually


NREL/Habitat ZEH
Monthly and Cumulative SOURCE Energy
Net Production
Net Consumption
Monthly Source Energy
Cumulative Net Electricity Production
Monthly net kWh Production
Cumulative net kWh Production
Month
3500
2500
1500
500
-500
-1500
-2500
-3500
20000
15000
10000
5000
0
-5000
-10000
-15000
-20000
Apr 06
Apr 07
Apr 08
Apr 09
Apr 10
Apr 11
Apr 12
Apr 13
Apr 14
Apr 15

NREL/Habitat ZEH
Monthly and Cumulative SITE Natural Gas Consumption




NREL/Habitat ZEH
Monthly and Cumulative Net Source Electricity Production
Monthly net kWh Production
Cumulative net kWh Production
Net Production
Net Consumption
Monthly Net Electricity Production
Cumulative Net Electricity Production
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000
-5500
-6000
Apr 06
Apr 07
Apr 08
Apr 09
Apr 10
Apr 11
Apr 12
Apr 13
Apr 14
Apr 15
Month

What the heck happened??

Production down? 

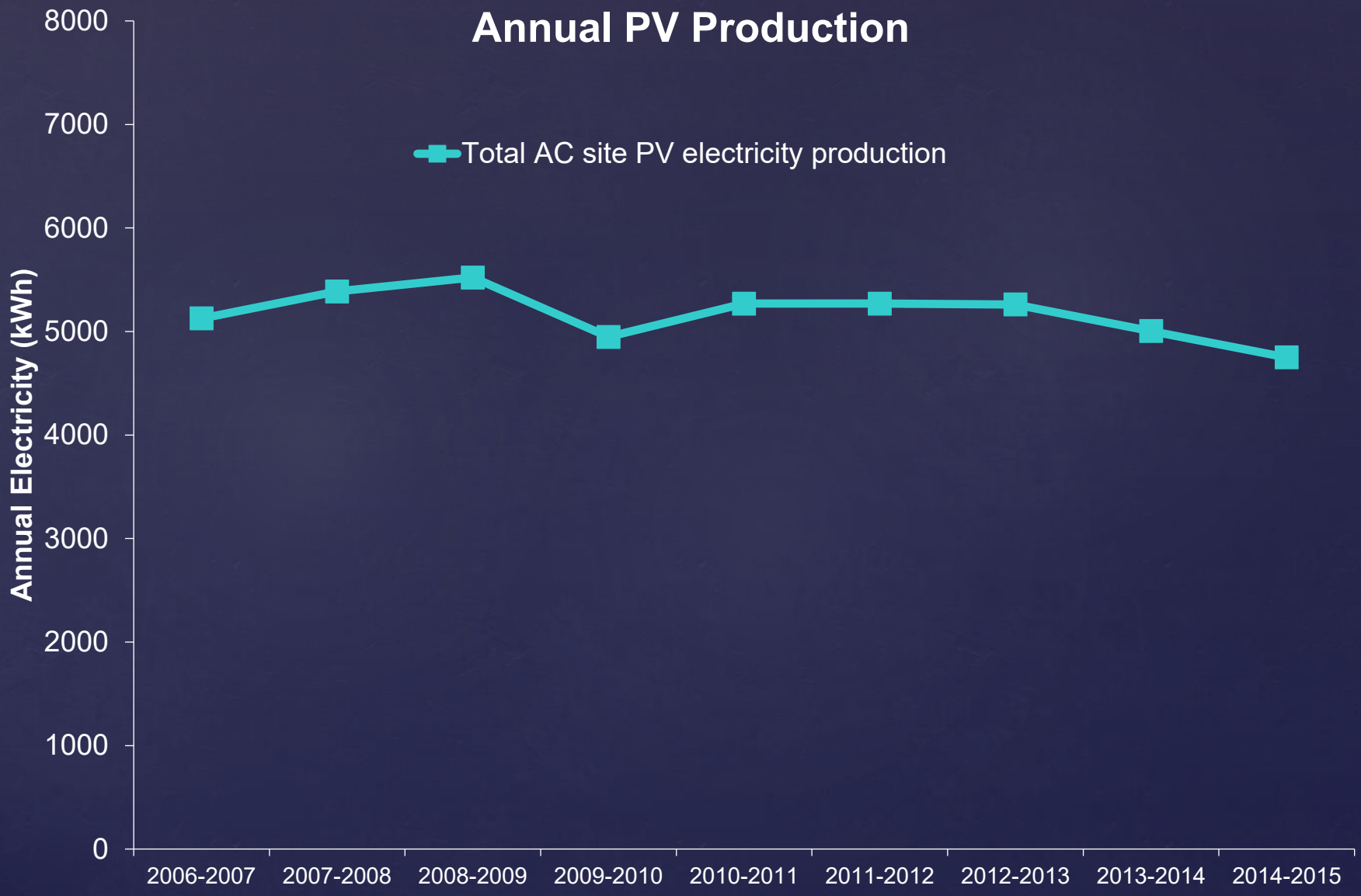
Consumption up? 

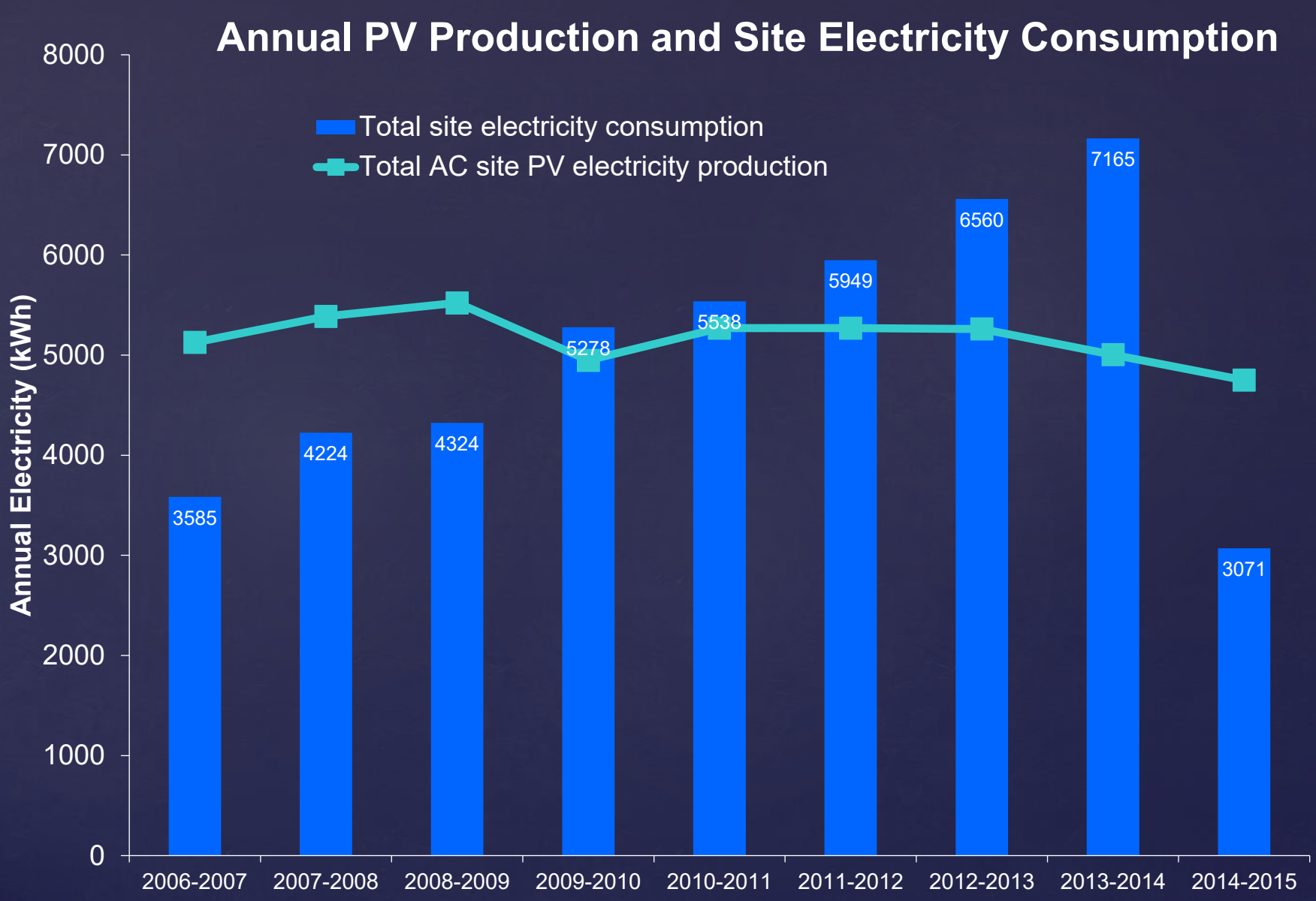
Equipment failure?

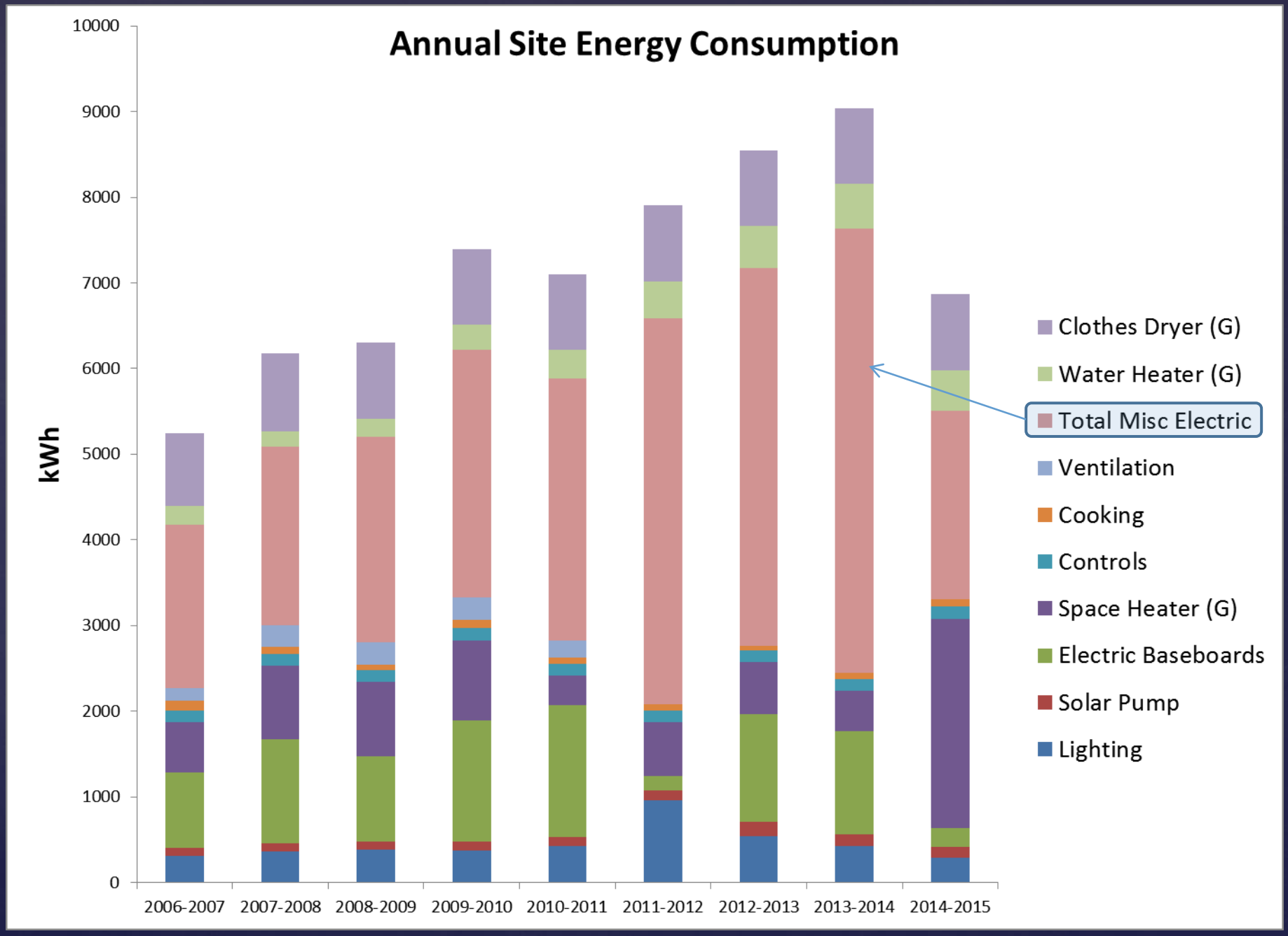
- PV producing less
- Solar water heater performance
- Space conditioning performance
- ERV went haywire

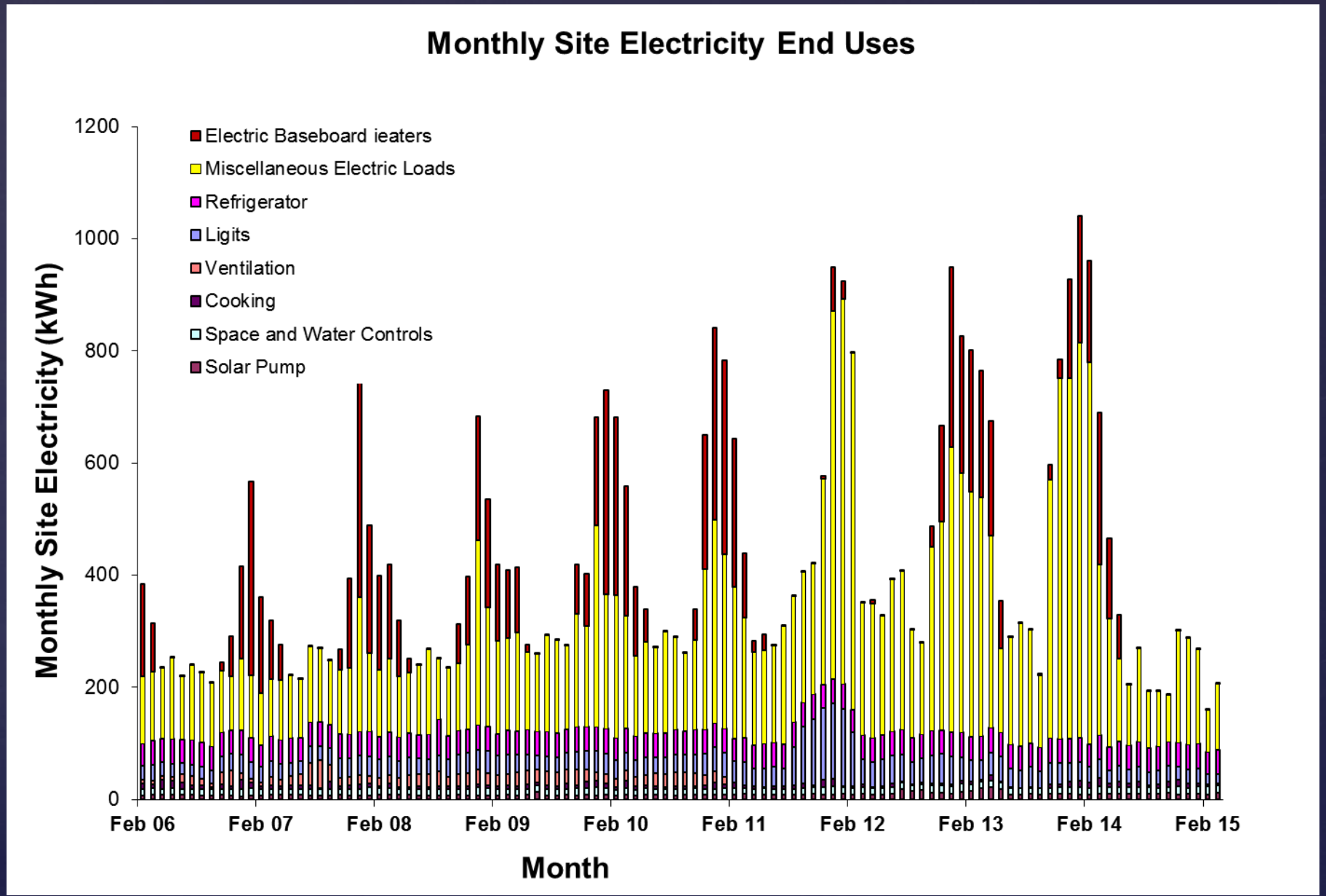
Occupant Changes?

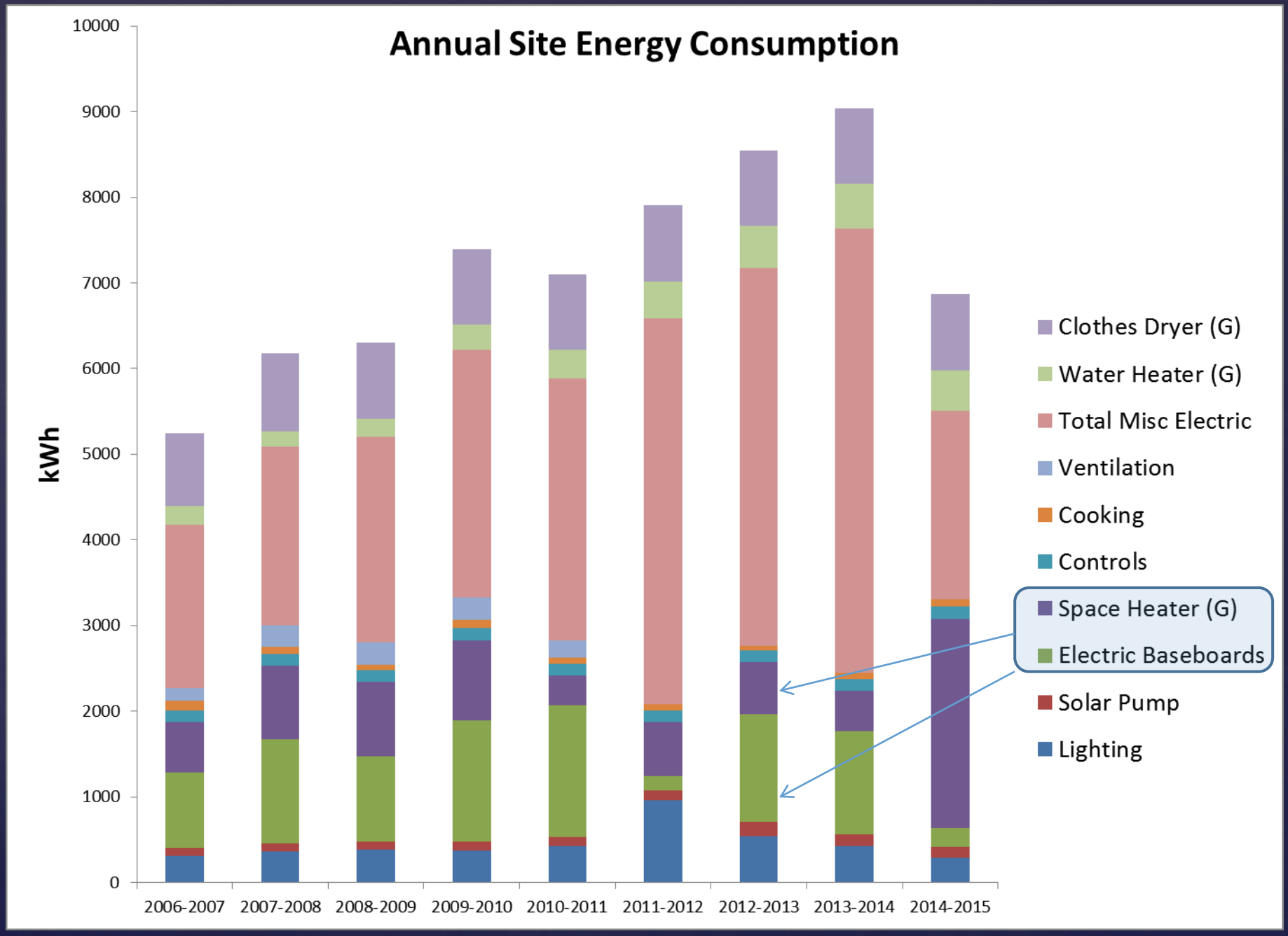
- More people are living there
- Temperature set points changed
- Air conditioner installed
- More hot water used
- Cooking a lot more
- Small boys turned into teenagers!


Annual PV Production
Total AC site PV electricity production
Annual Electricity (kWh)
8000
7000
6000
5000
4000
3000
2000
1000
0
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011
2011-2012
2012-2013
2013-2014
2014-2015

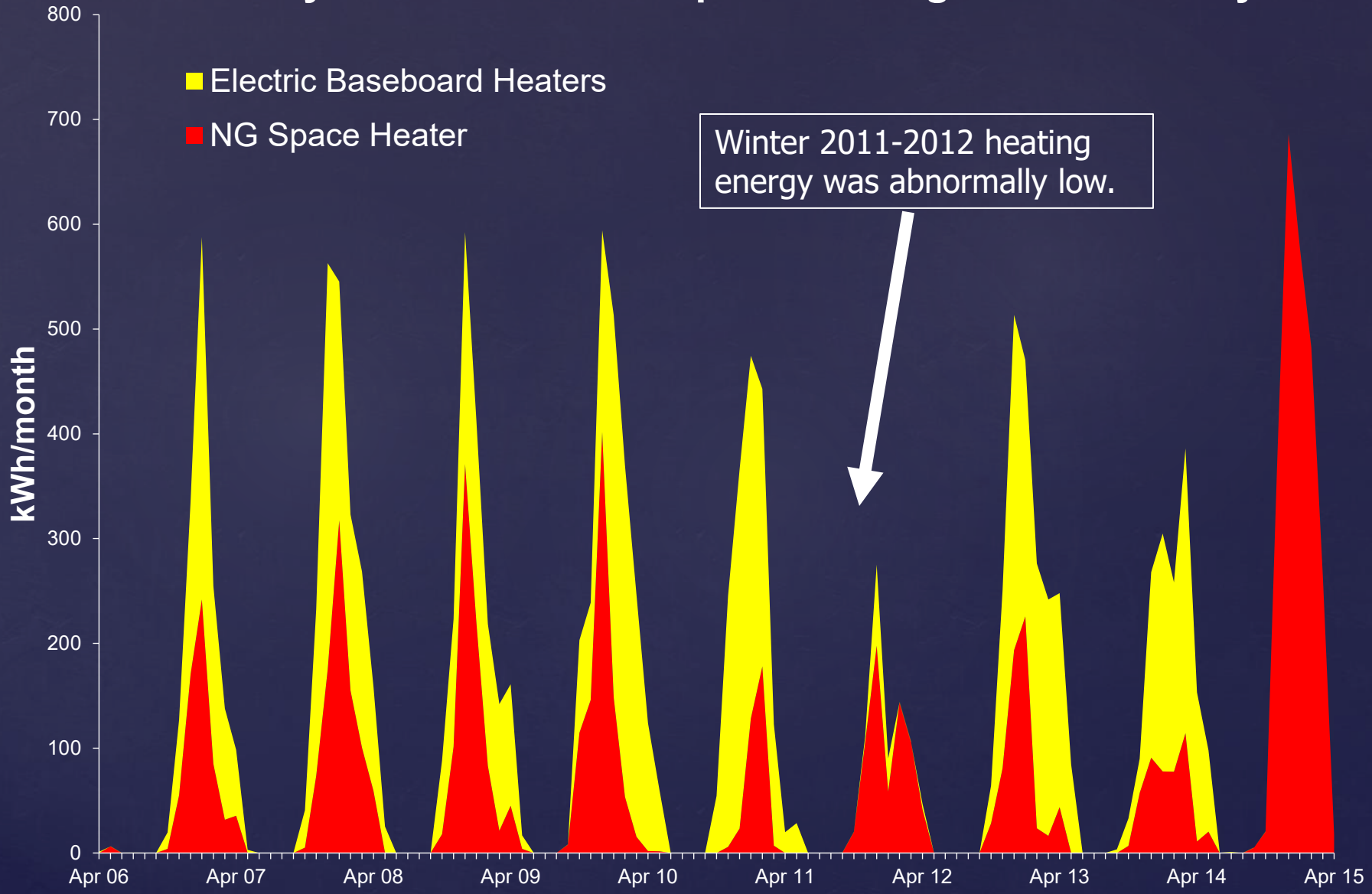

Annual PV Production and Site Electricity Consumption
Total site electricity consumption
Total AC site PV electricity production
Annual Electricity (kWh)
8000
7000
6000
5000
4000
3000
2000
1000
0
3585
4224
4324
5278
5538
5949
6560
7165
3071
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011
2011-2012
2012-2013
2013-2014
2014-2015


Annual Site Energy Consumption
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011
2011-2012
2012-2013
2013-2014
2014-2015
Clothes Dryer (G)
Water Heater (G)
Total Misc Electric
Ventilation
Cooking
Controls
Space Heater (G)
Electric Baseboards
Solar Pump
Lighting

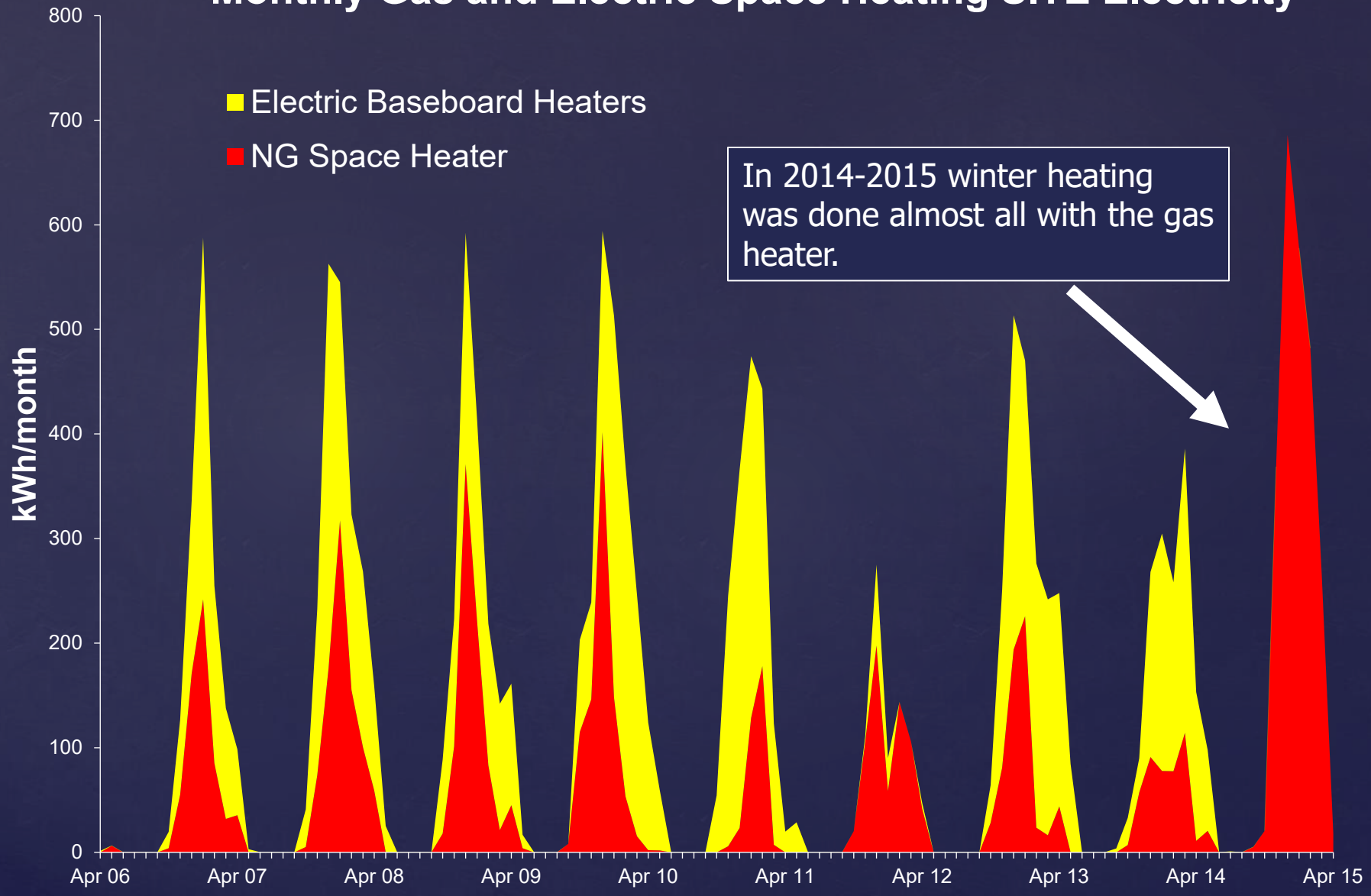

Monthly Site Electricity End Uses
Electric Baseboard ieaters
Miscellaneous Electric Loads
Refrigerator
Ligits
Ventilation
Cooking
Space and Water Controls
Solar Pump
Monthly Site Electricity (kWh)
1200
1000
800
600
400
200
0
Feb 06
Feb 07
Feb 08
Feb 09
Feb 10
Feb 11
Feb 12
Feb 13
Feb 14
Feb 15
Month

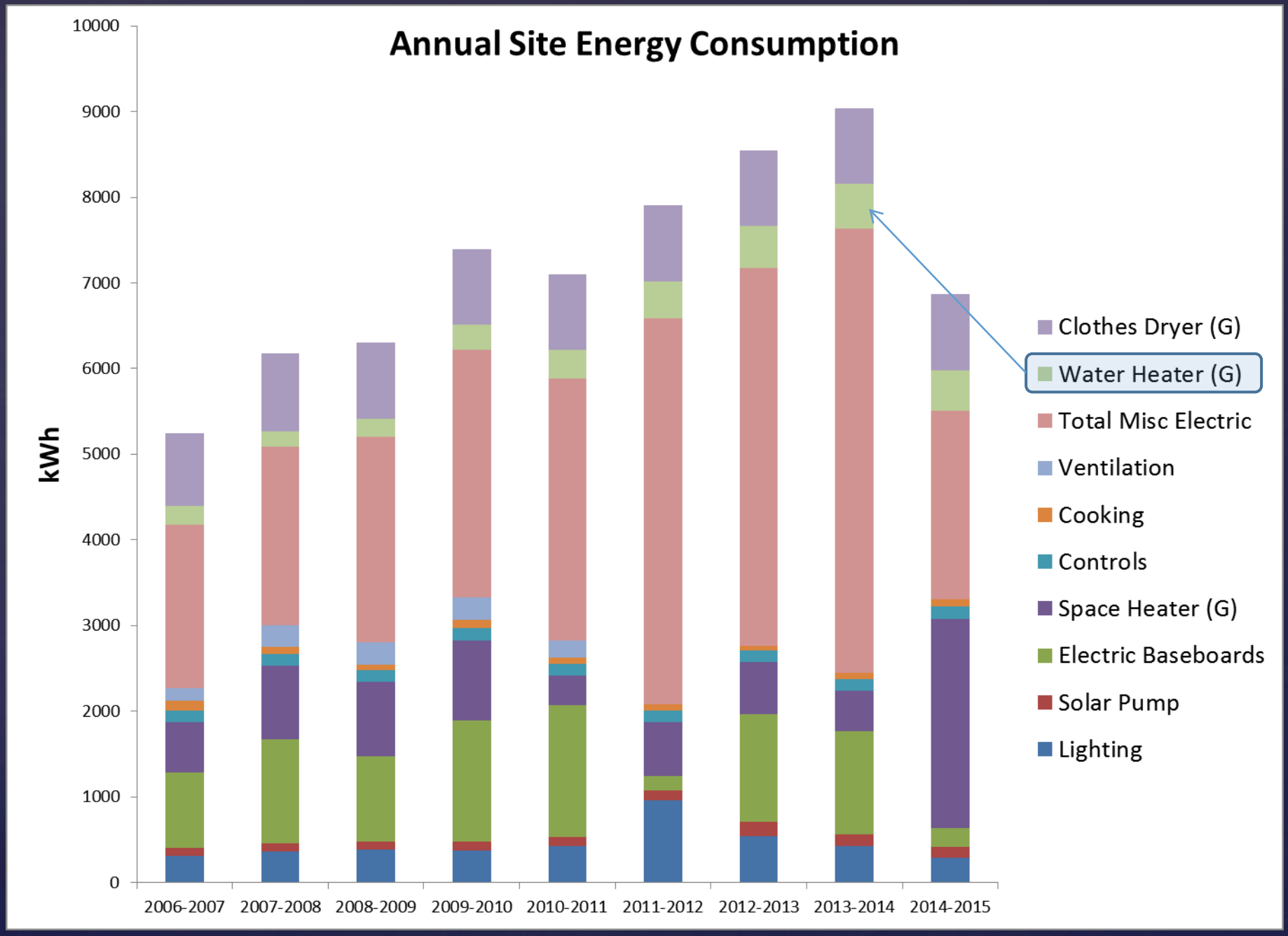

Annual Site Energy Consumption
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011
2011-2012
2012-2013
2013-2014
2014-2015
Clothes Dryer (G)
Water Heater (G)
Total Misc Electric
Ventilation
Cooking
Controls
Space Heater (G)
Electric Baseboards
Solar Pump
Lighting

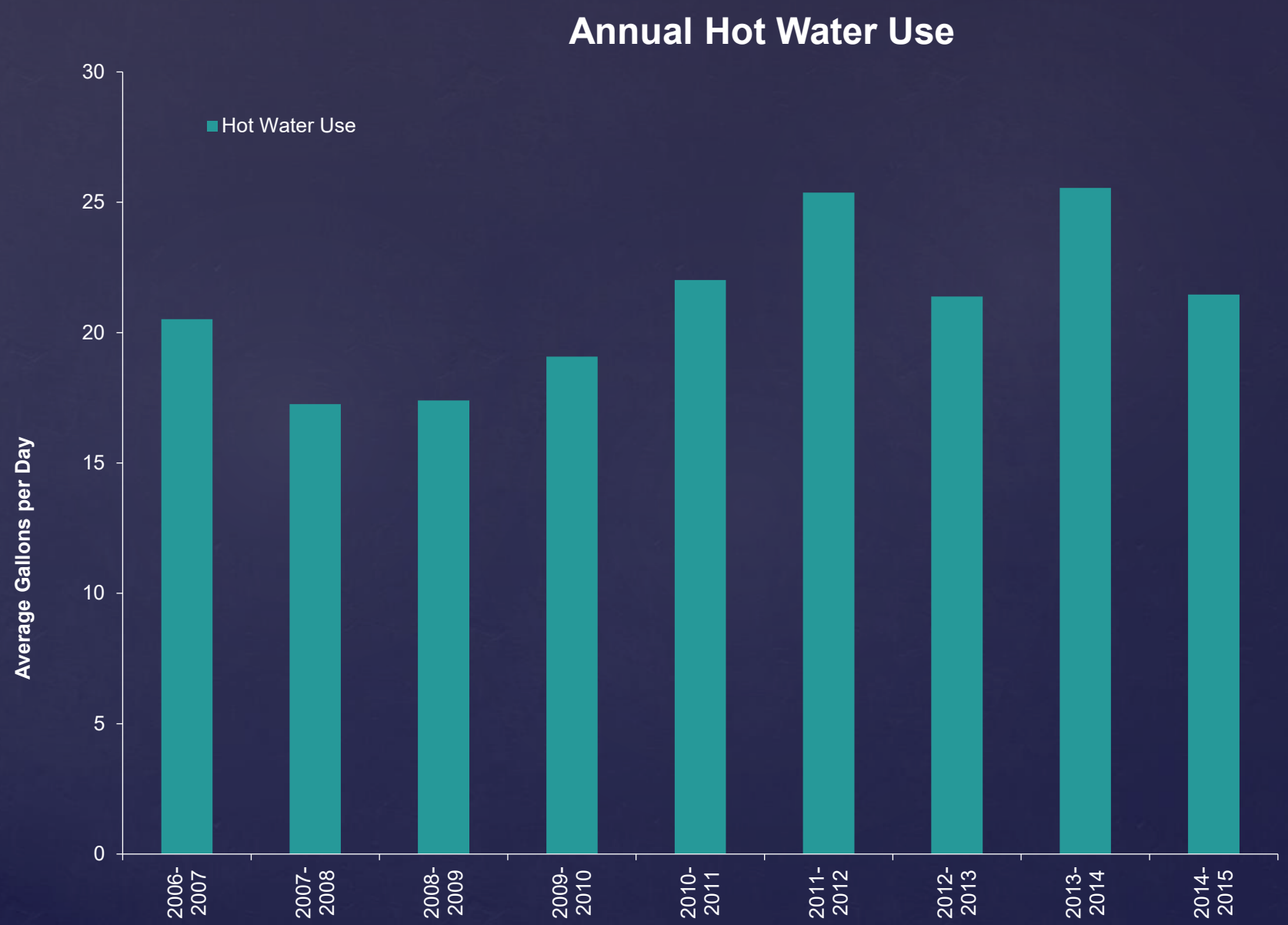
Monthly Gas and Electric Space Heating SITE Electricity

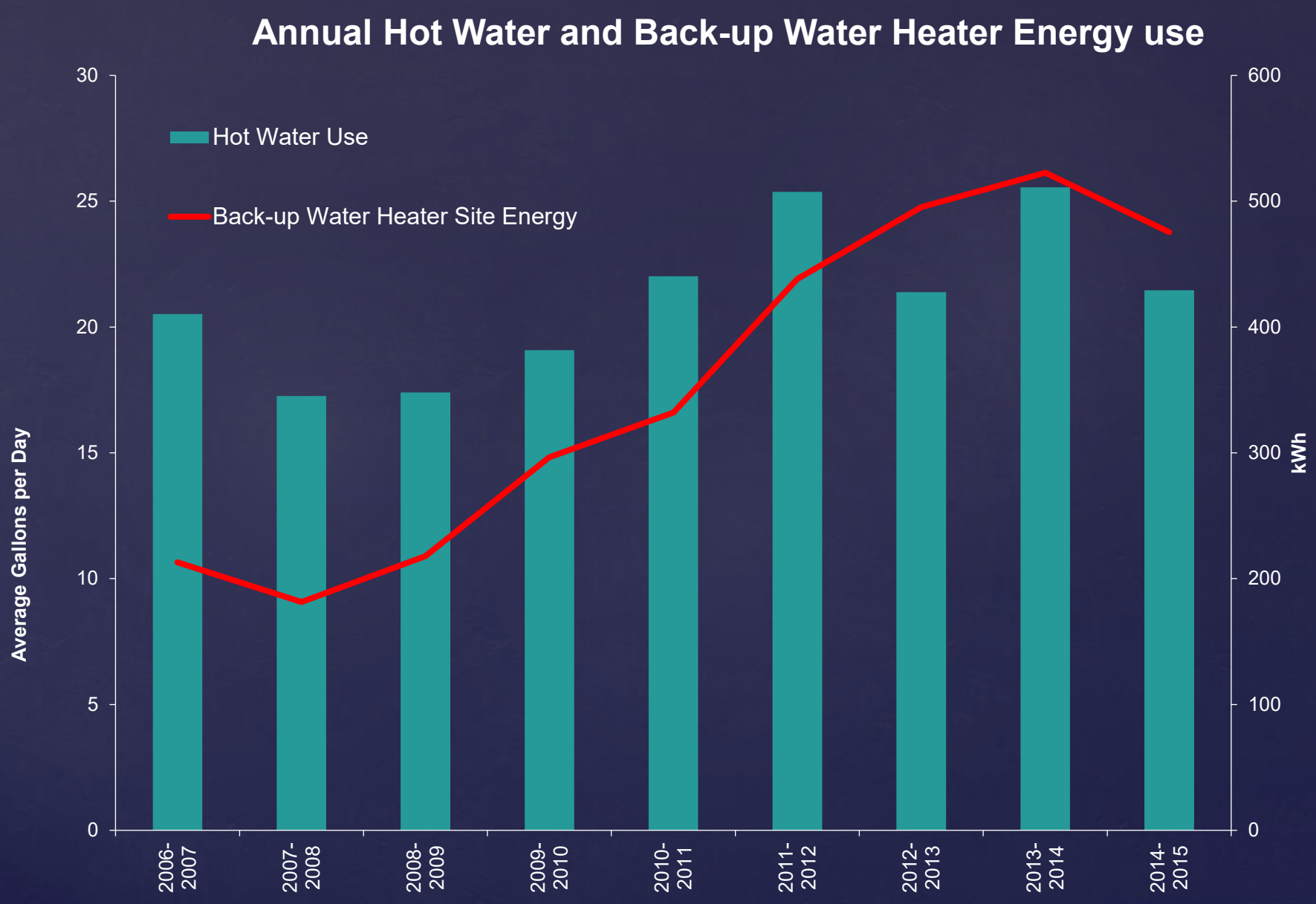


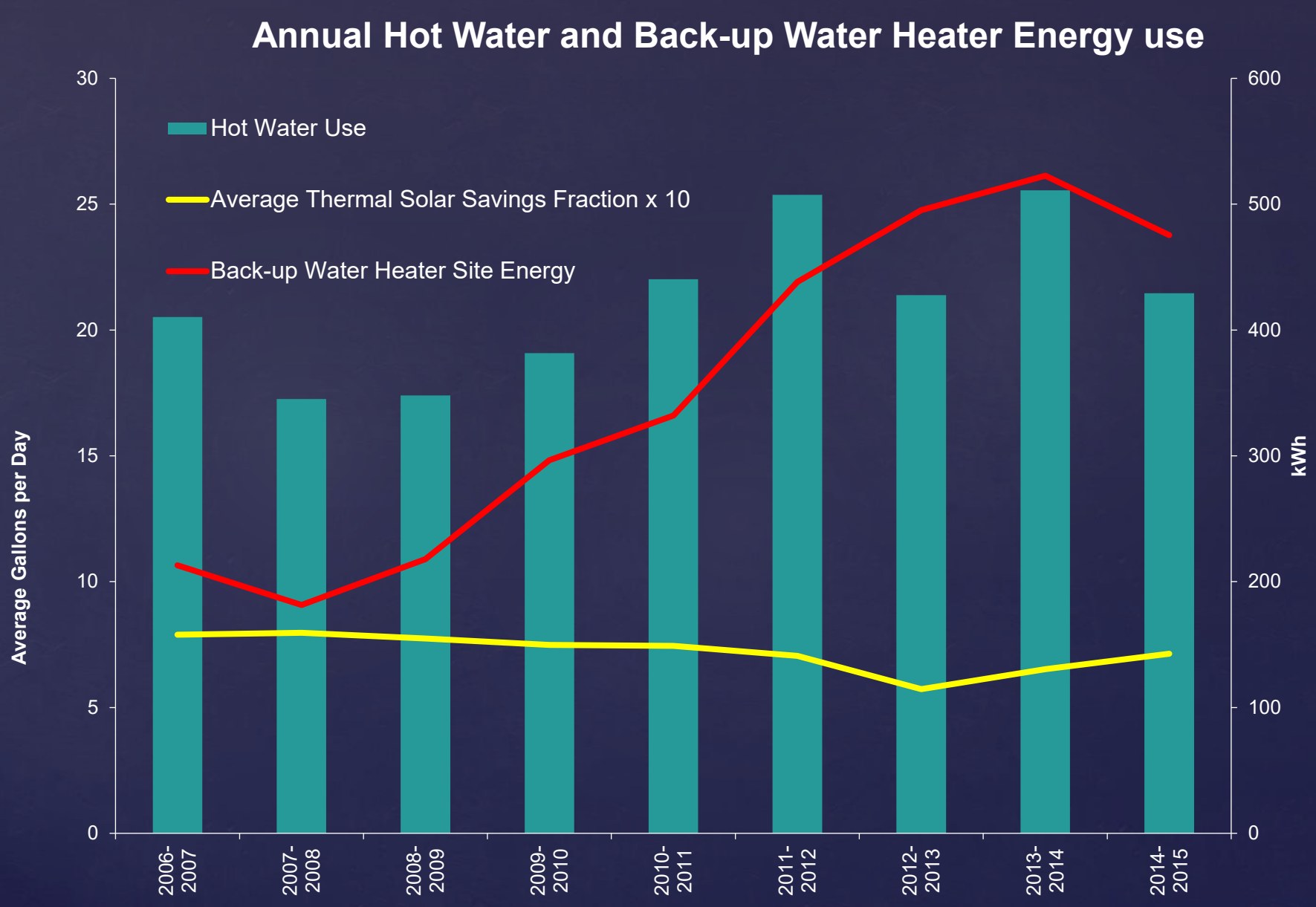
Monthly Gas and Electric Space Heating SITE Electricity

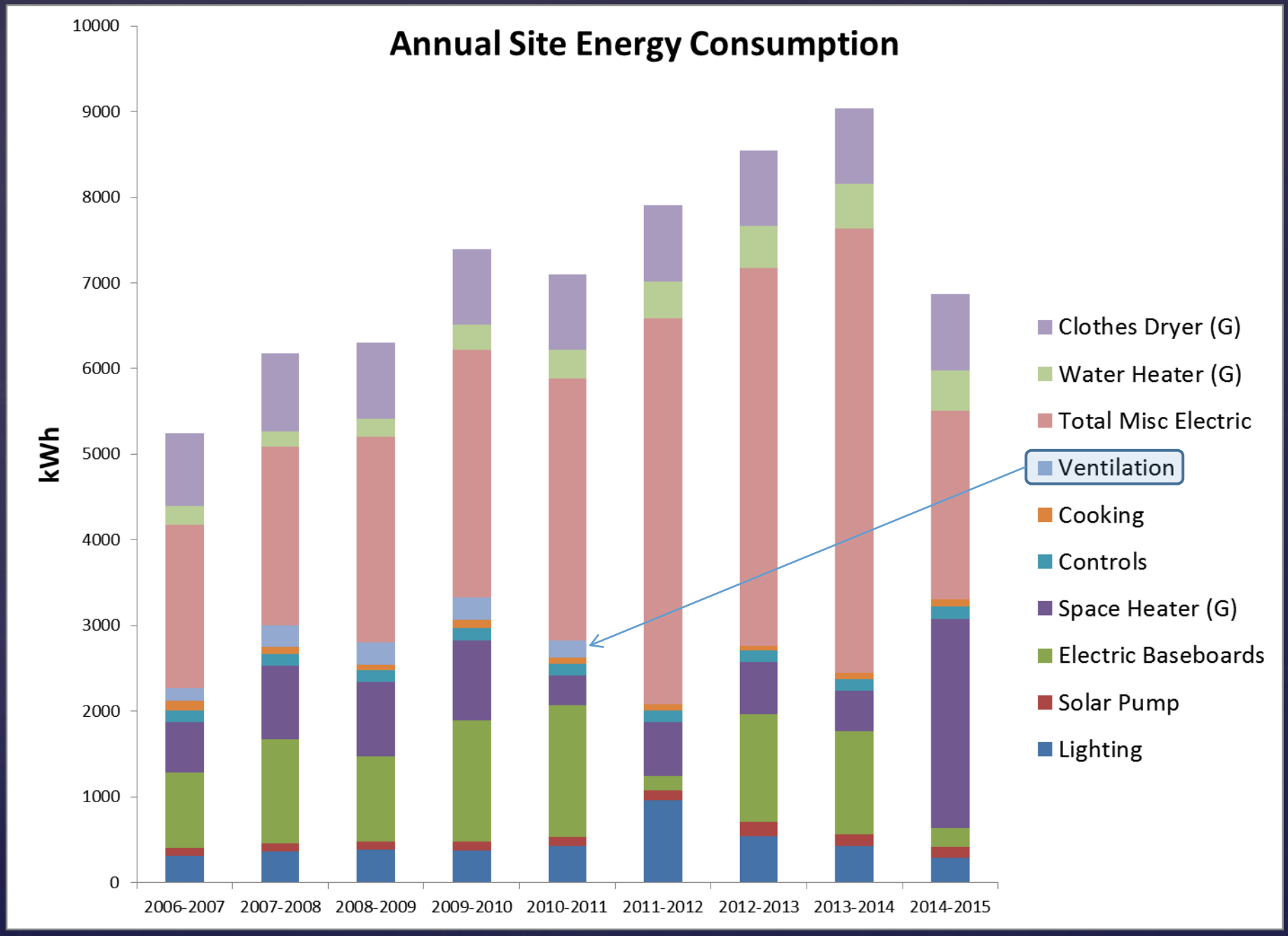


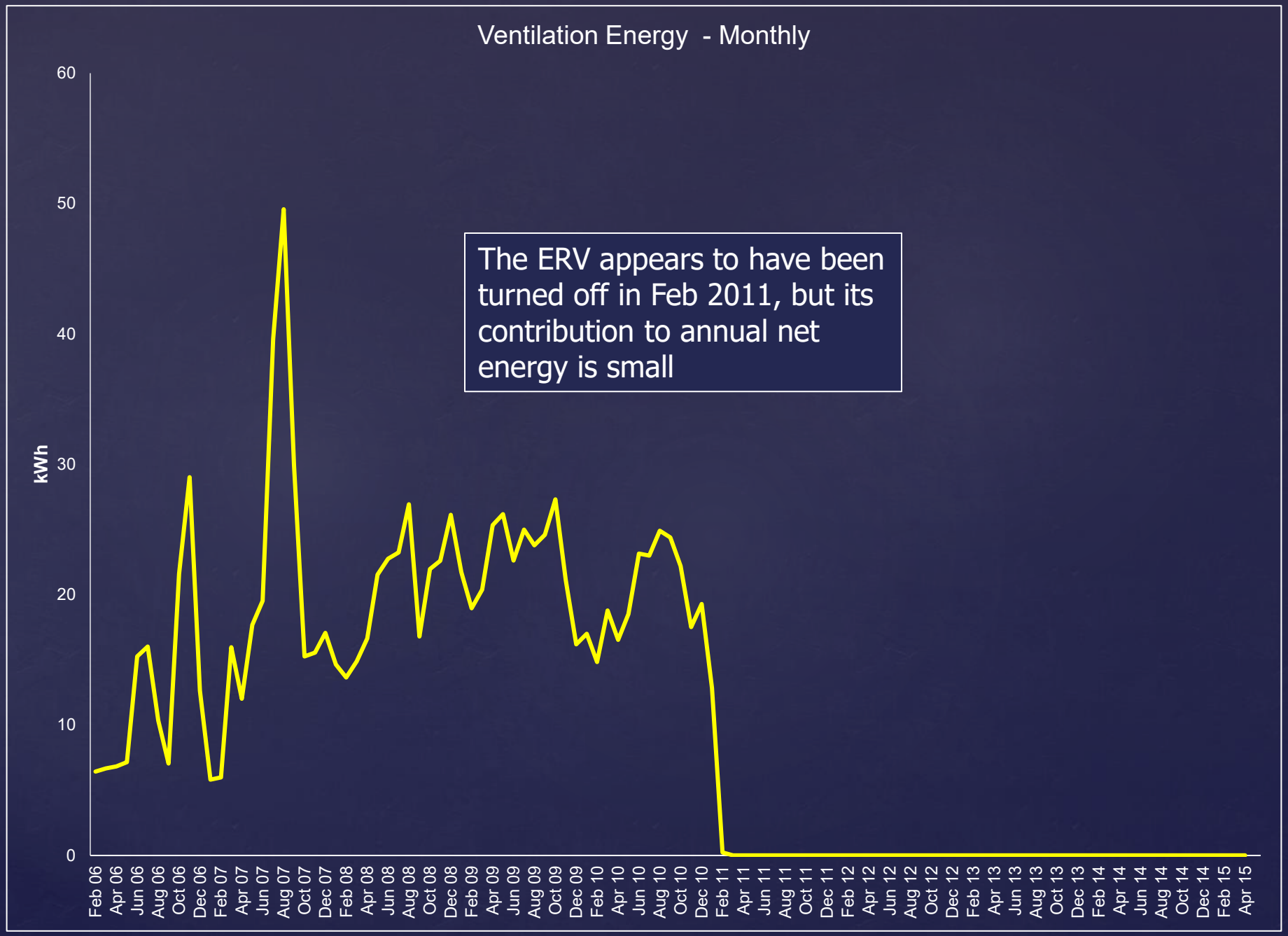

Annual Site Energy Consumption
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011
2011-2012
2012-2013
2013-2014
2014-2015
Clothes Dryer (G)
Water Heater (G)
Total Misc Electric
Ventilation
Cooking
Controls
Space Heater (G)
Electric Baseboards
Solar Pump
Lighting


Annual Hot Water Use
Hot Water Use
Average Gallons per Day
30
25
20
15
10
5
0
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011
2011-2012
2012-2013
2013-2014
2014-2015


Annual Hot Water and Back-up Water Heater Energy use
Hot Water Use
Back-up Water Heater Site Energy
Average Gallons per Day
kWh
30
25
20
15
10
5
0
600
500
400
300
200
100
0
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011
2011-2012
2012-2013
2013-2014
2014-2015


Annual Hot Water and Back-up Water Heater Energy use
Hot Water Use
Average Thermal Solar Savings Fraction x 10
Back-up Water Heater Site Energy
Average Gallons per Day
kWh
0
5
10
15
20
25
30
0
100
200
300
400
500
600
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011
2011-2012
2012-2013
2013-2014
2014-2015


Annual Site Energy Consumption
kWh
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
2006-2007
2007-2008
2008-2009
2009-2010
2010-2011
2011-2012
2012-2013
2013-2014
2014-2015
Clothes Dryer (G)
Water Heater (G)
Total Misc Electric
Ventilation
Cooking
Controls
Space Heater (G)
Electric Baseboards
Solar Pump
Lighting


Ventilation Energy - Monthly
kWh
60
50
40
30
20
10
0
The ERV appears to have been turned off in Feb 2011, but its contribution to annual net energy is small
Feb 06
Apr 06
Jun 06
Aug 06
Oct 06
Dec 06
Feb 07
Apr 07
Jun 07
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Dec 07
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Apr 08
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Aug 13
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Feb 14
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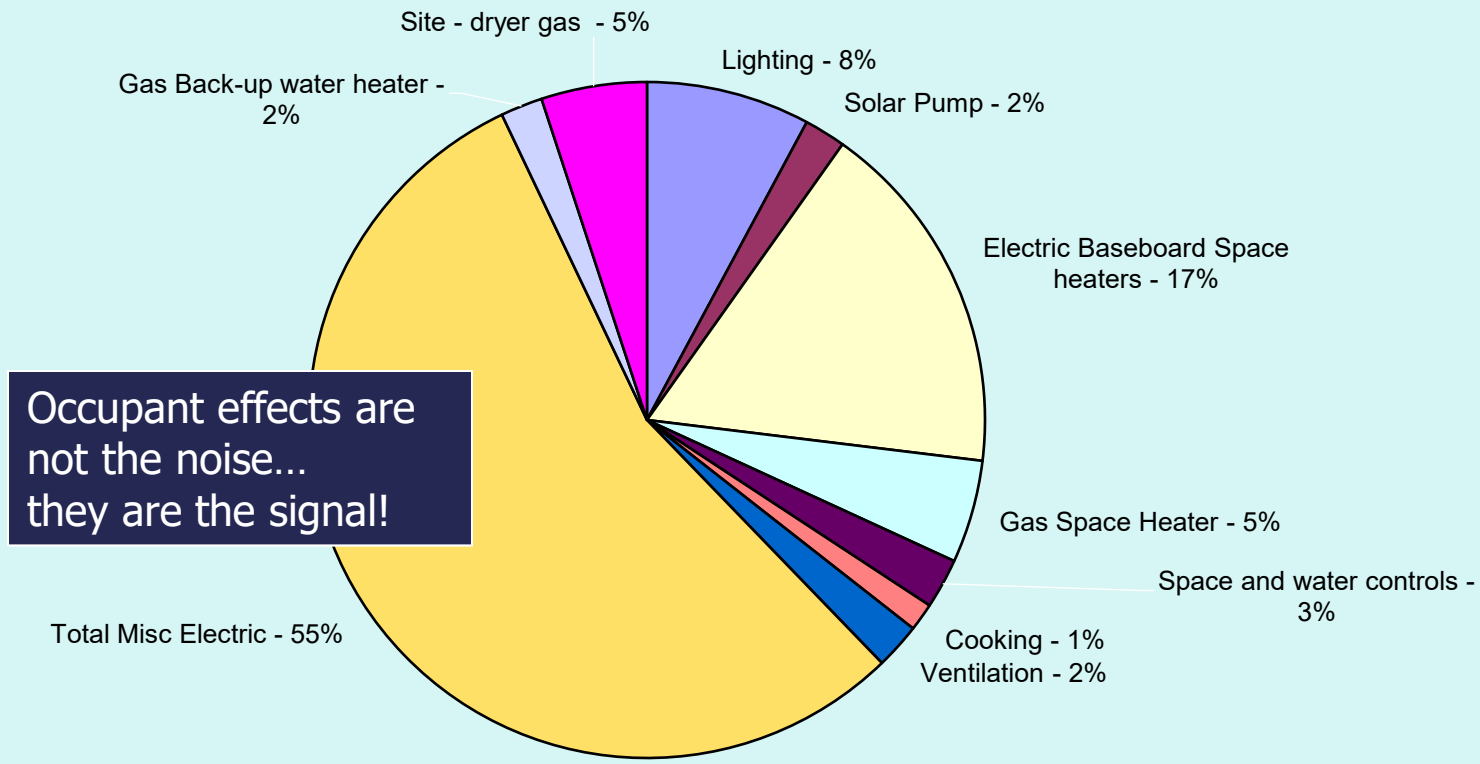
Dec 14
Feb 15
Apr 15

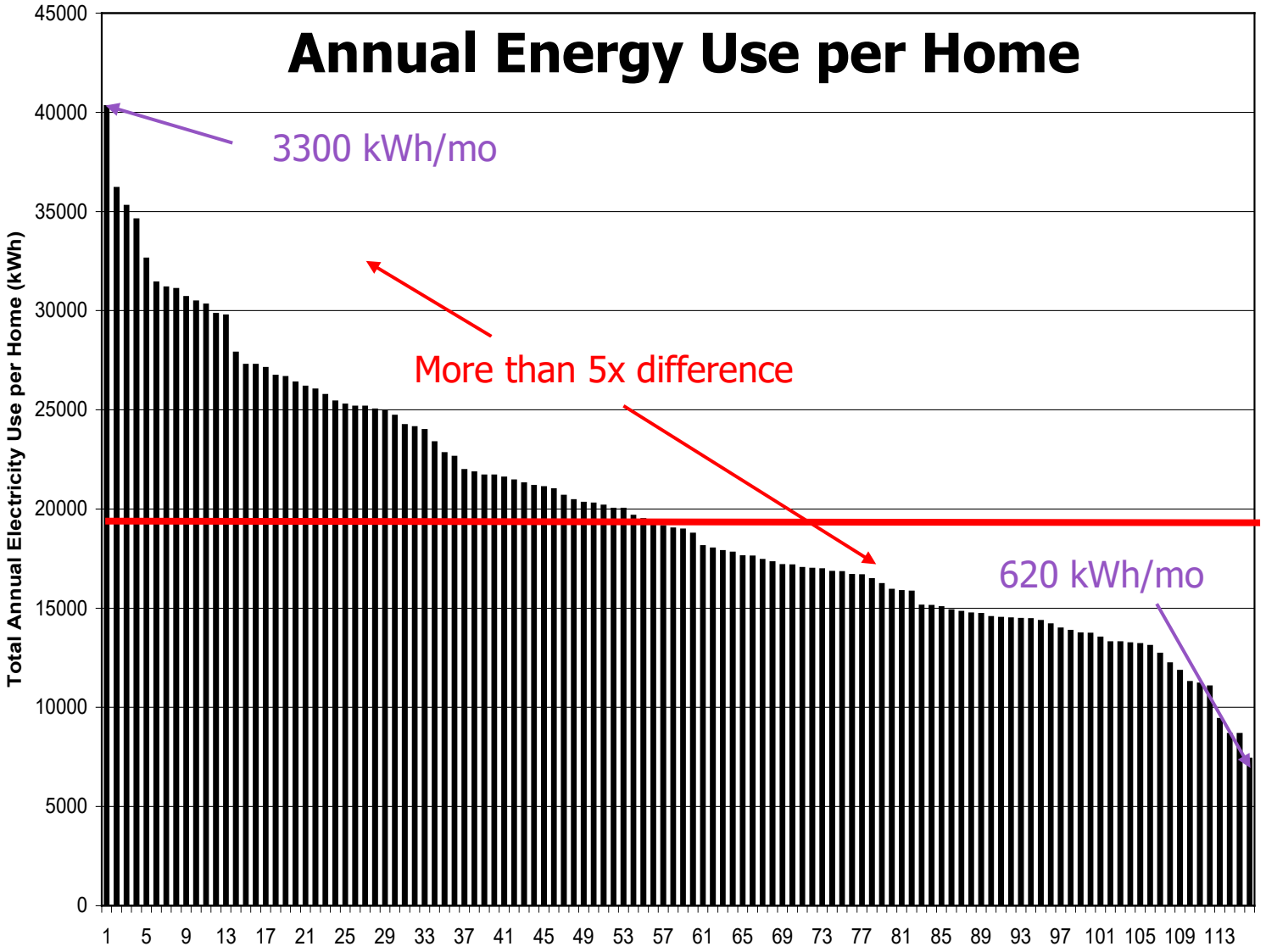
Year-to-year Variations appear to be largely due to occupant effects

- Growth in MELs contributed most to the reduced net energy performance
- MELs increased in the winter and offset some space heating
- Heating fuel switching occurred from year-to-year affecting the source energy consumption
- The hot water use went up; back-up water heater energy went up more quickly
- The ERV was turned off in 2011 (or there is something wrong with the ERV or the measurement).

9-Year Cumulative SOURCE Energy End Uses



Energy use varies HIGHLY with occupants

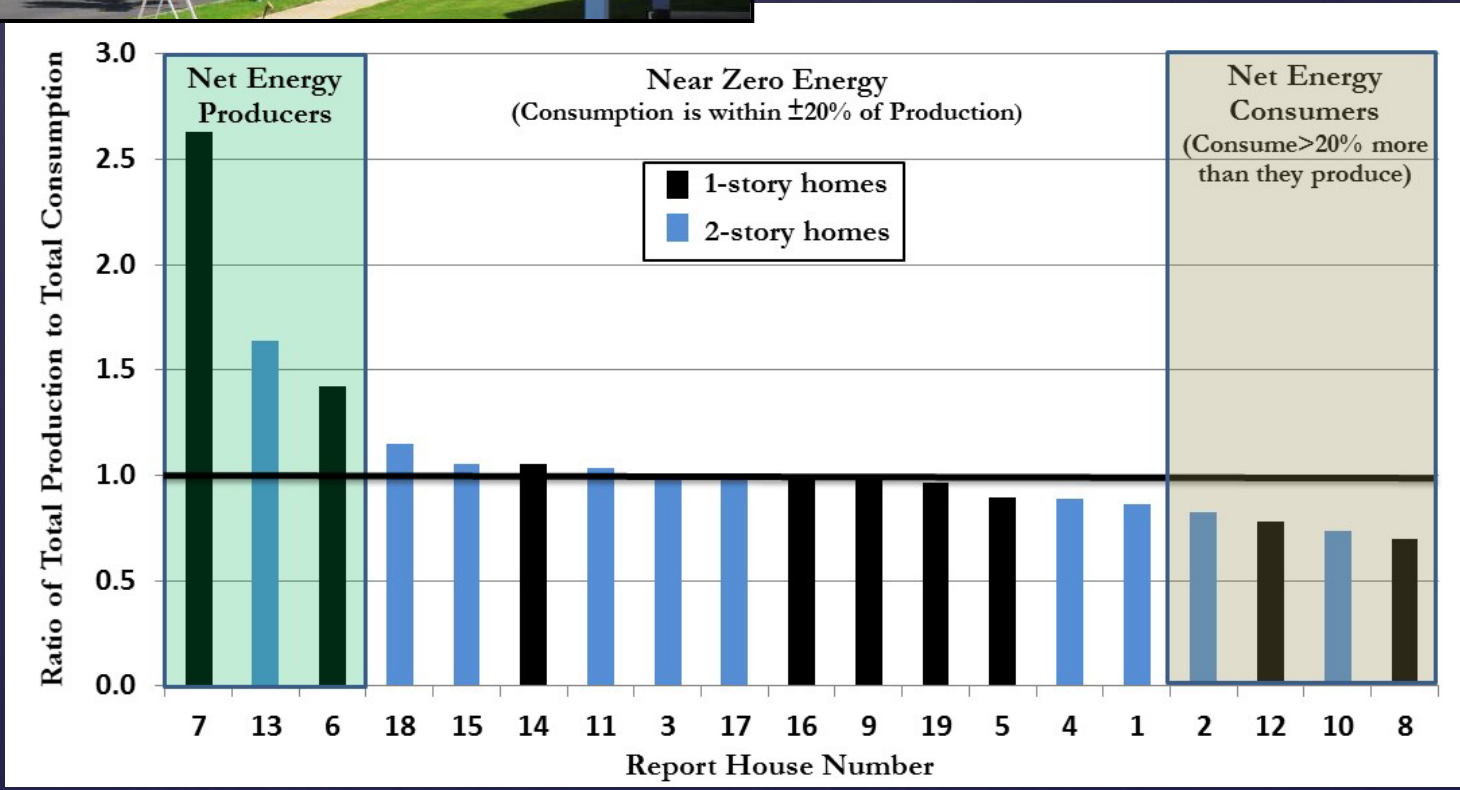


Las Vegas Homes with identical energy efficiency features

Energy use varies HIGHLY with occupants

Kaupuni
Affordable ZEH Community
All-electric homes w/AC
Waianae, Oahu, Hawaii
(6 kW PV per house)

Community as a whole produced 99% of consumption



Can we really design homes that *perform* as zero energy homes?

Will it *really* be ZERO??

If we do our job perfectly, the chances of meeting or exceeding zero energy performance in a single ZEH is

50%

It could be!

In any given year, it depends on….

- **Plug loads**
  (TVs, DVDs, Microwave, computers, stereo, toaster, electric blanket, hair dryer, …. the list goes on!)
- **Specific weather conditions**
- **Temperature set points**
- **Hot water use**

The house AND the occupants
meet or miss the zero energy target *TOGETHER*

Occupant Variability Thoughts

- It's not realistic to predict a single number for home energy use. A bell curve is much more realistic.
- Perhaps each occupant assumption needs to be represented by a probability density rather than a typical or average number and we should be doing Monte Carlo building simulations.
- Occupant variability (occupant-to-occupant and year-to-year) deserves more attention as a research topic rather than treating it as noise in the signal. It is the signal!
- It is completely unrealistic to try to measure effects of efficiency features by comparing the performance of a few *occupied* homes.

ZEH with Natural Gas

- ZEH can be made at a lower first cost by heating with natural gas and offsetting the source energy of the natural gas with excess PV electricity production.
- ZEH performance with gas offset leads to PV overproduction which is economically unfavorable with most net-metering rates.

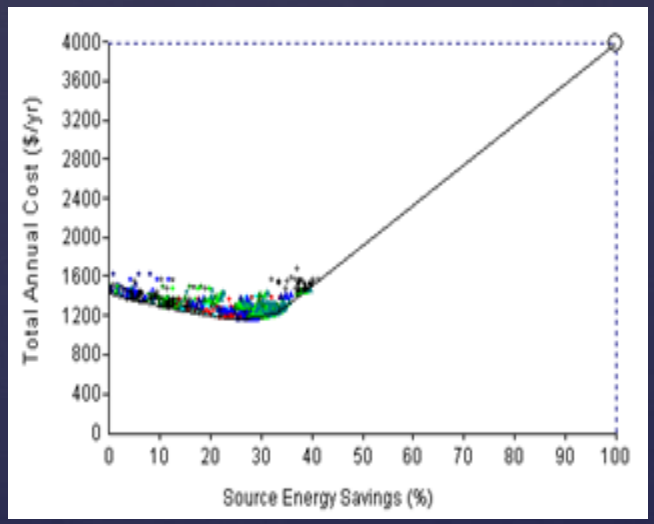
ZEH Retrofits….

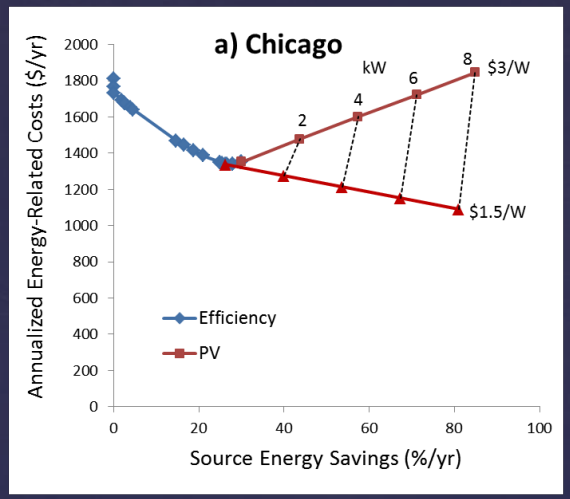
- Very high efficiency is more expensive to achieve in existing homes than in new homes, therefore the balance of investments shifts towards larger PV systems

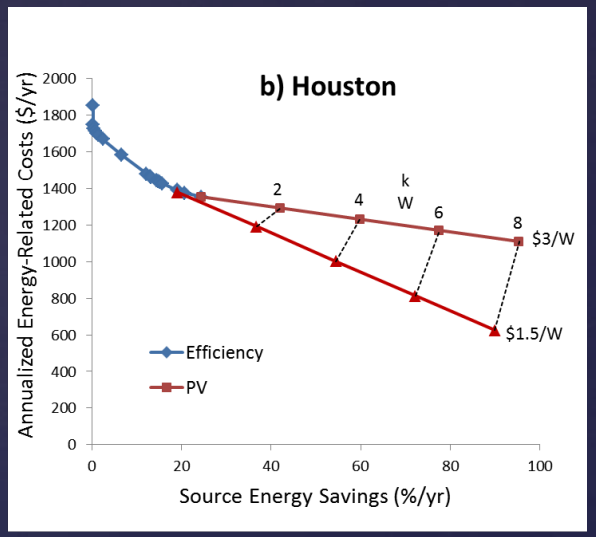
- A significant percentage of existing homes are not ideal for active solar thermal or PV systems due to lack of roof area, wrong orientation, or excessive shading

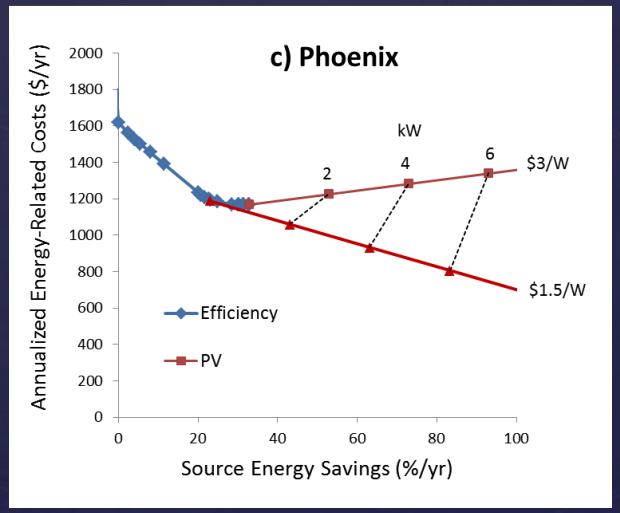
Impact of Low-Cost PV

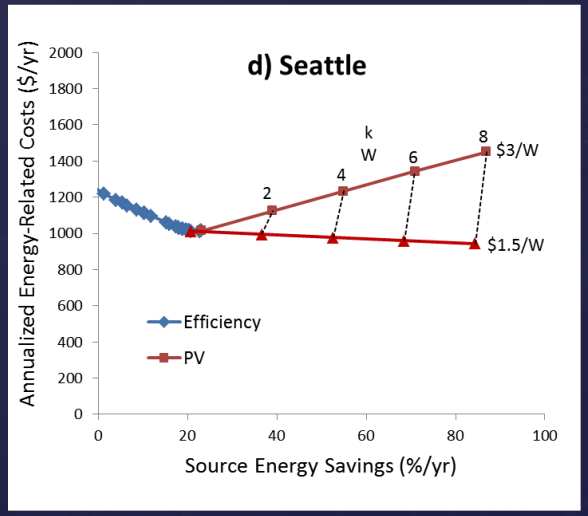
1985











ZEH/Utility thoughts

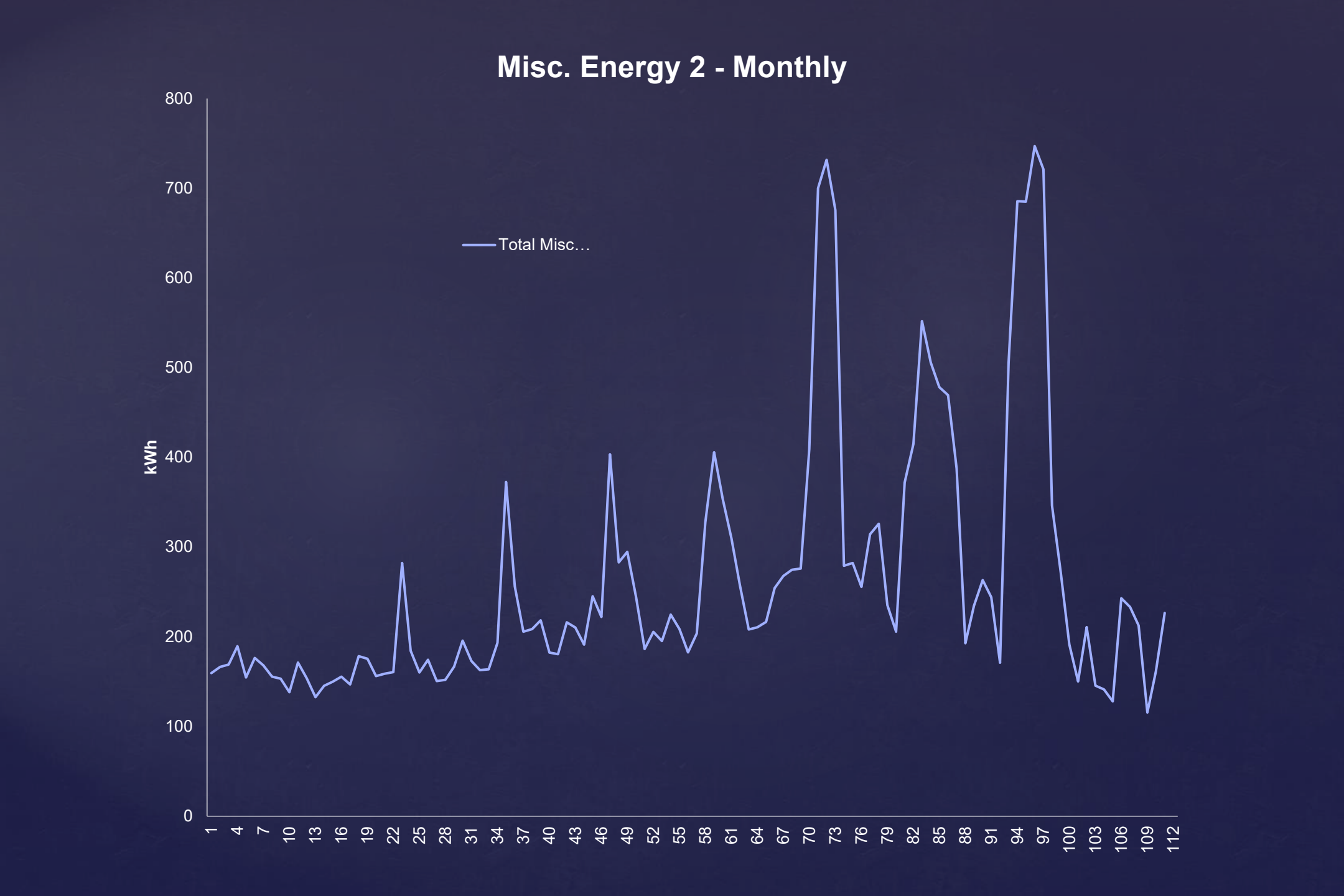
- Peak PV production does not coincide with most utility demand peaks
- Distributed PV cannot currently be curtailed which could lead to more curtailment of centralized RE at higher RE penetrations
- Cost of small rooftop PV can be twice that of utility-scale PV and much more expensive than utility-scale wind.
- Voltage regulation on distribution lines with high penetration of PV
- Why are ZEH designers so fixated on rooftop PV? Why not long-term contracts with utility-scale RE?
- How can ZEH be designed to better support the grid? Can we design in more dispatchable loads or peak shifting strategies?

Questions ??????

PaulK@LightlyTreading.com

craig.christensen@nrel.gov

The remaining slides are back-ups in case of specific questions. They will not be used in the main presentation.


Misc. Energy 2 - Monthly
kWh
Total Misc…
800
700
600
500
400
300
200
100
0
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
46
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94
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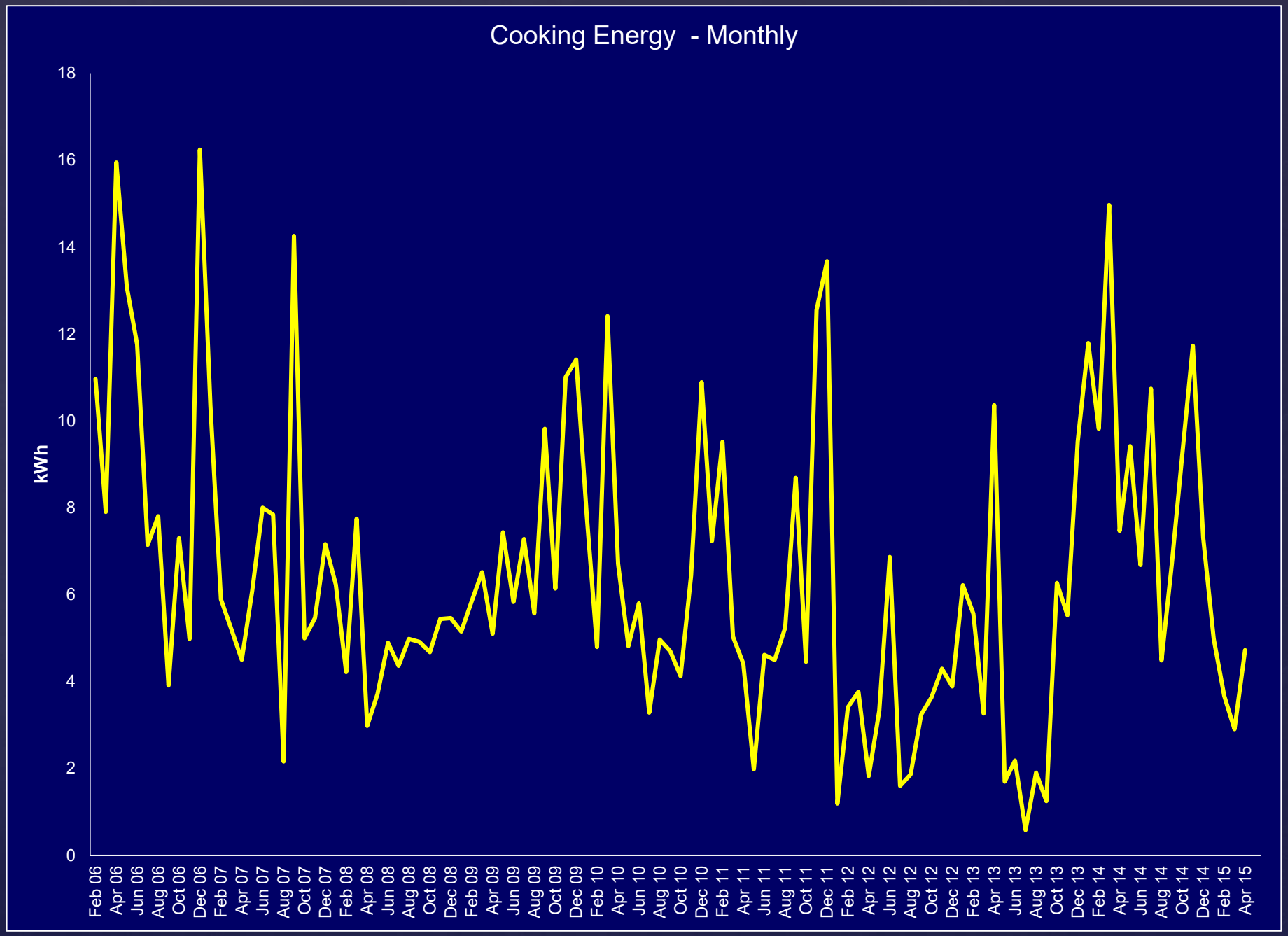
100
103
106
109
112


Cooking Energy - Monthly
kWh
0
2
4
6
8
10
12
14
16
18
Feb 06
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Oct 06
Dec 06
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Feb 15
Apr 15

Source Energy Conversions

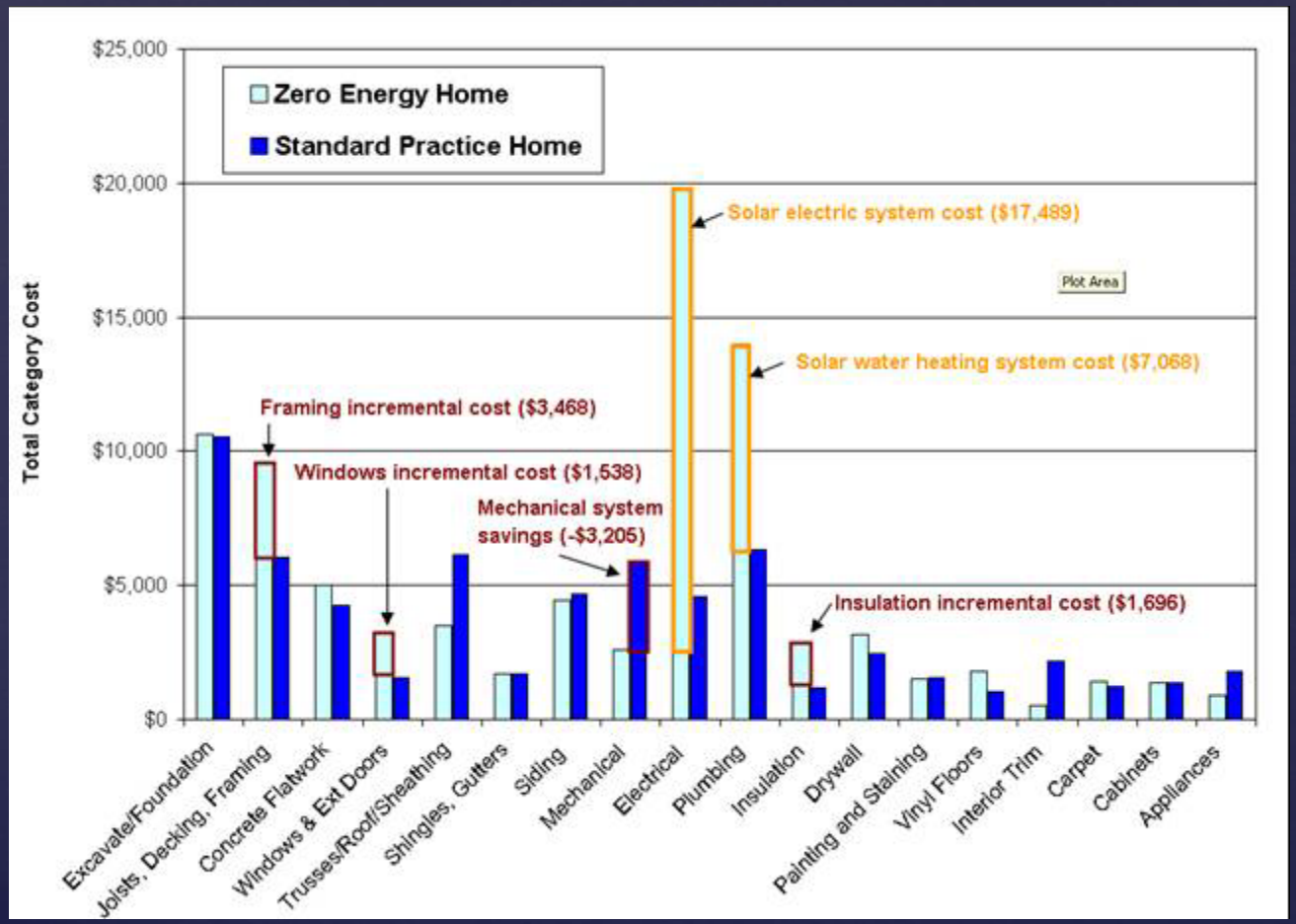
Source Energy Offset =
Total PV electricity production x 3.318

Source Energy Consumption =
Site Electricity x 3.318 * Site NG x 1.092

Overall Source Energy Produced or Consumed =
Source Energy Offset – Source Energy Consumption

Source Energy Ratio =
Source Energy Offset/Source energy Consumption

Habitat ZEH Economics



- Incremental cost of ZEH features about $28,000 (21%) over builder standard practice home
- Annual energy cost savings vs. BA Benchmark = $879
  vs. Builder st. pr. = $745

Habitat ZEH Economics

Incremental costs for ZEH			
PV system - full retail	$32,000		
PV system - actual cost	$17,489		
PV system - discounts and rebates = free PV	$0		
Solar water heater - actual cost	$7,068		
Framing	$3,468		
Insulation	$1,696	**Annual Cost on a 30 yr loan at 7%**	**BA Cost Index**
Windows	$1,538		
Mechanical systems	-$3,205		
Total with retail cost of PV	$42,565	$3,399	3.87
Total with actual cost of PV	$28,054	$2,240	2.55
Total with discounts and rebates = free PV	$10,565	$844	0.96

Habitat ZEH
Predicted Performance

BA Assumptions, Boulder TMY2

	Site Energy		Source Energy	
Increment	kWh	therms	MBTU	Savings %
Base (Bldg America)	6093	628.0	126.5	
Base (Regional Std Practice)	5678	699	129.5	-2%
Base (Builder Std Practice)	4614	602	108.7	14%
Base + Imp. Wall Insulation	4580	561	104.2	18%
Base + Imp. Ceiling Ins	4542	544	102.1	19%
Base ++ Crawlspace Ceiling Insulation	4767	491	99.0	22%
Base ++ ERV	5017	443	96.6	24%
Base ++ High SC Glass on South	5208	428	97.0	23%
Base ++ Improved DHW (tankless)	5208	332	87.2	31%
Base ++ Improved Heating (ductless)	5291	277	82.5	35%
Base ++ Lighting, Appl. & Plug	4486	287	75.2	41%
Base ++ Solar DHW	4486	169	63.2	**50%**
Prototype + 4.0 kW PV	-788	169	9.2	**93%**

Compared to BA Benchmark with BA Analysis Procedure:

- 50% efficiency savings
- 93% total savings

Emission Factors used in previous publications

Site to source conversion factors:

Electricity	3.70	Colorado
Natural Gas used on site	1.116	National Average

(Source Energy and Emission Factors for Energy Use in Buildings, Deru and Torcellini, 2006).

Habitat ZEH
First Year Performance

- Hot water used was reduced to 20.4 gal/day. (BA assumption = 65.6 gal/day)
- Appliance and plug loads were reduced to a total of 2079 kWh/year.(BA assumption = 3053 kWh/yr)
- Dryer energy use was reduced to 28 therms/yr. (BA assumption = of 76 therms/yr)
- Cooking was changed from natural gas (which was originally anticipated) to electric (which was actually installed).
- Base lighting kWh adjusted down by 30% and impact of compact fluorescent increased from 60% reduction to 75% reduction based on measured data.
- Lighting schedule adjusted based on monitored data.
- Plug load and miscellaneous electric use schedule adjusted based on monitored data.
- Hot water usage schedule adjusted based on monitored data.
- Thermostat settings were adjusted based on monitored data.
- Monthly PV adjusted to monitored values (from 5274 kWh/yr to 5127 kWh/yr).
- Ventilation energy lowered from 298 kWh/yr to 144 kWh/yr.
- Solar DHW effectiveness adjusted to 80% solar savings fraction annually.

TOUR OF SOLAR HOMES
Avenson Home
Burrows Home
Healey Home
Jones Home
Zero Energy Habitat for Humanity Home

National Solar Tour
www.ases.org

Zero Energy Habitat For Humanity Home

The newly built zero-energy Habitat for Humanity Home is Energy Star rated at five stars and is expected to produce as much energy as it consumes in a typical year. The home contains 1,300 square feet of floor area, and utility bills are expected to be about $30 a month. Half of the utility bill, $15, is the monthly meter charge. Other features include:

Solar hot water system with a drain-back 96 square foot solar collector and 200-gallon storage tank. High efficiency Rinnai on-demand water heater as back-up for the solar system.

- PV system rated at 4 kilowatts and interconnected with the utility grid.
- Energy recovery system for mechanically introducing outside air.
- R-40 fiberglass insulated walls, R-60 blown fiberglass roof, R-30 under floor
- Double wall construction with one layer of vapor barrier per wall.
- Windows are double-paned with low-e coatings and with vinyl construction; west windows are triple-paned with a Mylar coating; south windows have a solar heat gain coefficient of 0.58.
- Energy Star refrigerator, which was donated by Maytag.
- Compact fluorescent lamps.
- Low flow toilets.

Construction waste reduction: recycled all cardboard; Used on-site river rock for landscaping; 2' x 4' lumber waste was turned into mulch.

Habitat for Humanity of Metro Denver built the home in 2005 with support from the National Renewable Energy Laboratory in Golden, the U.S. Department of Energy, the U.S. Department of Housing and Urban Development, Energy Outreach Colorado, and the City of Arvada. Altair Energy in Golden donated the PV system, and Industrial Solar Technologies donated the solar hot water system. Habitat for Humanity of Denver has won the Energy Star Efficient and Affordable Housing award for the last four years.

For more information, see NREL's September 15 press release:
http://www.nrel.gov/news/press/2005/3105_habitat_house.html

Public y 9, 2006Awareness Summary

Visits from Dignitaries

•June 13, 2005 – U.S. Secretary of Energy, Samuel Bodman
•July 9, 2005 – U.S. Congress Representative Bob Beauprez

Press coverage

•June 14, 2005 - "Raising the Conservation Ceiling," Denver Post
•June 14, 2005 – "New home to be its own power plant," Rocky Mountain News
•June 15, 2005 - "Energy Secretary Bodman Visits "Net-Zero Energy Home" Near Denver," U.S. DOE EERE Network News.
•August 2005 - "Colorado Homes Hopes to Use Zero Net Energy," Energy Design Update
•September 15, 2005 – "Owner Receives Keys to Net Zero Energy Habitat for Humanity House: Home to Produce as Much Energy as it Consumes Annually," NREL Press Release
•September 19, 2005 – "Solar a Key Component of Habitat for Humanity Home," Renewable Energy Access, www.renewableenergyaccess.com
•September 20, 2005 – "Smart Net Zero Energy Home Unveiled," Smart Buildings, www.smarteconomy.typepad.com
•September 20, 2005 – "Net Zero Energy Habitat for Humanity House," Unplugged Living, www.unpluggedliving.com
•September 23, 2005 – "Zero Net Energy Habitat For Humanity," WorldChanging, www.worldchanging.org.
•September 27, 2005 – "Net-Zero House is Affordable, Too," Oikos Green Building News, www.oikos.com
•September 28, 2005 – "Habitat for Humanity Dedicates ZEH," Toolbase E-News, www.toolbase.org
•October 2005 – "Zero-energy building makes housing even more affordable," Western Area Power Administration Energy Services Bulletin
•October 22, 2005 – "Energy Tab: Zero: Futuristic homes rely on the power of the sun and high-tech construction," Denver Post
•October 2005 – "Zero Energy Habitat for Humanity Home," on *Highlight of the 2005 Denver Tour of Solar Homes*, Colorado Renewable Energy Society, http://www.cres-energy.org/about_tsh_2005.html
•October 2005 – "Zero-energy building makes housing even more affordable," in *Energy Services Bulletin*, Western Area Power Administration, Vol. 24, No. 5.
•February 6, 2006 – "President to Honor Volunteer: Arapahoe Man Builds Homes that are Energy Efficient," Rocky Mountain News
•February 21, 2006 – "President Participates in Energy Conservation & Efficiency Panel," White House News Release, www.whitehouse.gov

Magazine and Journal Articles

•"Keeping it Simple," in Energy Design Update, June 2006
•"The Little House that Could," in *Home Energy*, November/December 2006
•"Yes, It's a Zero Energy House," in Energy Design Update, February 2007

Papers

•Norton, P. and Christensen, C., A Cold Climate Case Study for Affordable Zero Energy Homes, Proceedings of Solar 2006, American Solar Energy Society, 2006.
•"Case Study – Habitat for Humanity ZEH, Wheat Ridge, CO," in the *Building America Best Practices Guide*, Pacific Northwest National Laboratory, date TBD
•Norton, P. and Christensen, C., Performance Results from a Cold Climate Case Study for Affordable Zero Energy Homes, ASHRAE How Low Can You Go Seminar, New York, NY, expected January 2008.
•Norton, P. and Christensen, C., A Cold Climate Case Study for Affordable Zero Energy Homes, NREL technical report – draft expected June 2007.

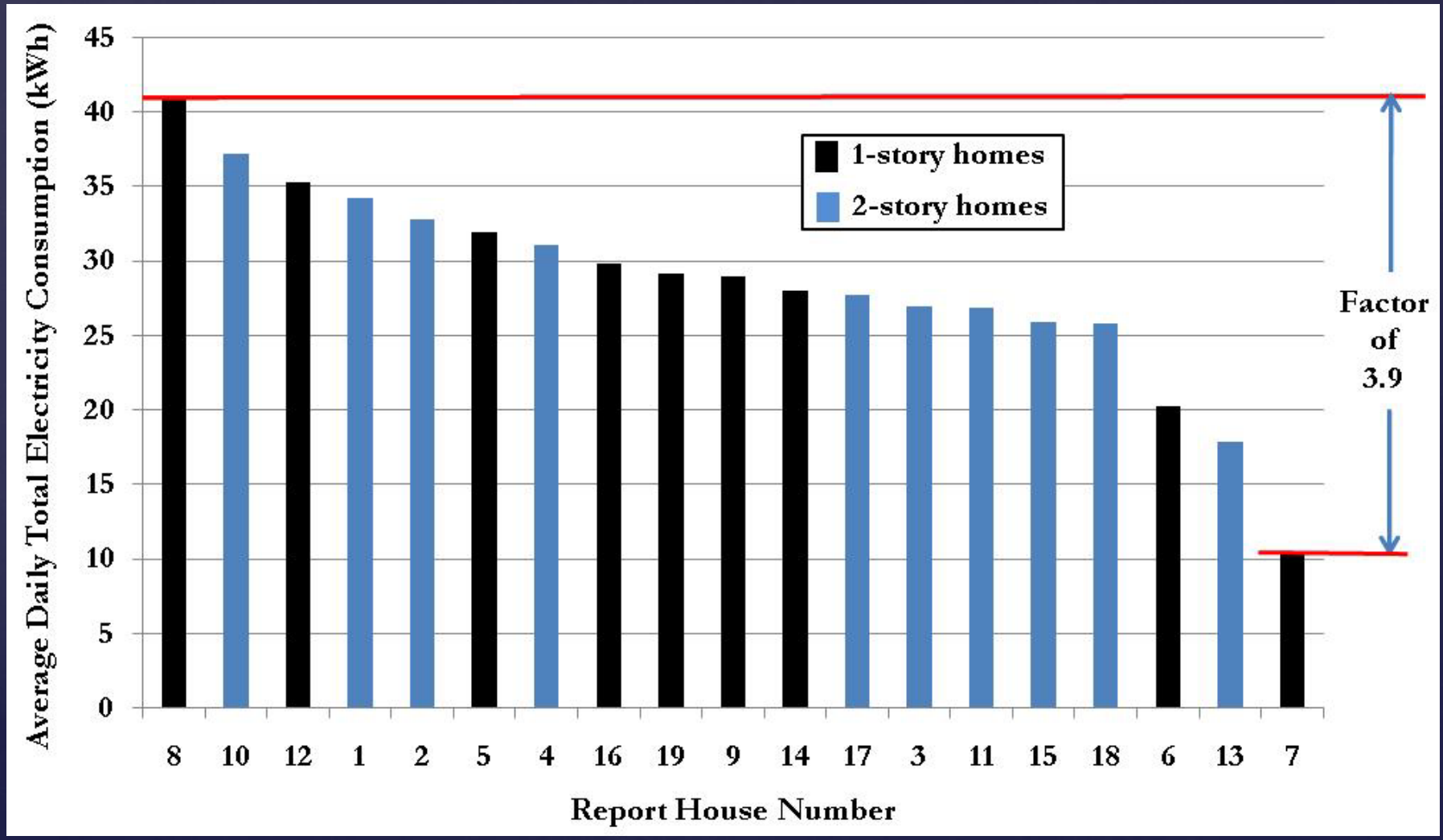
Selected presentations on the project

•May 17, 2005 – Public presentation at the NREL Visitors Center
•June 10, 2005 – CRES Conference
•September 17, 2005 – Public presentation at the Denver Public Library
•July 12, 2006 – ASES Solar 2006 Conference, Denver
•September 21, 2006 – University of Colorado, Boulder Building Systems Seminar
•April 23, 2007 – ACI Home Performance Conference, Cleveland, OH
•Jan 2008 – ASHRAE "How low can you go" Symposium, New York City (planned)

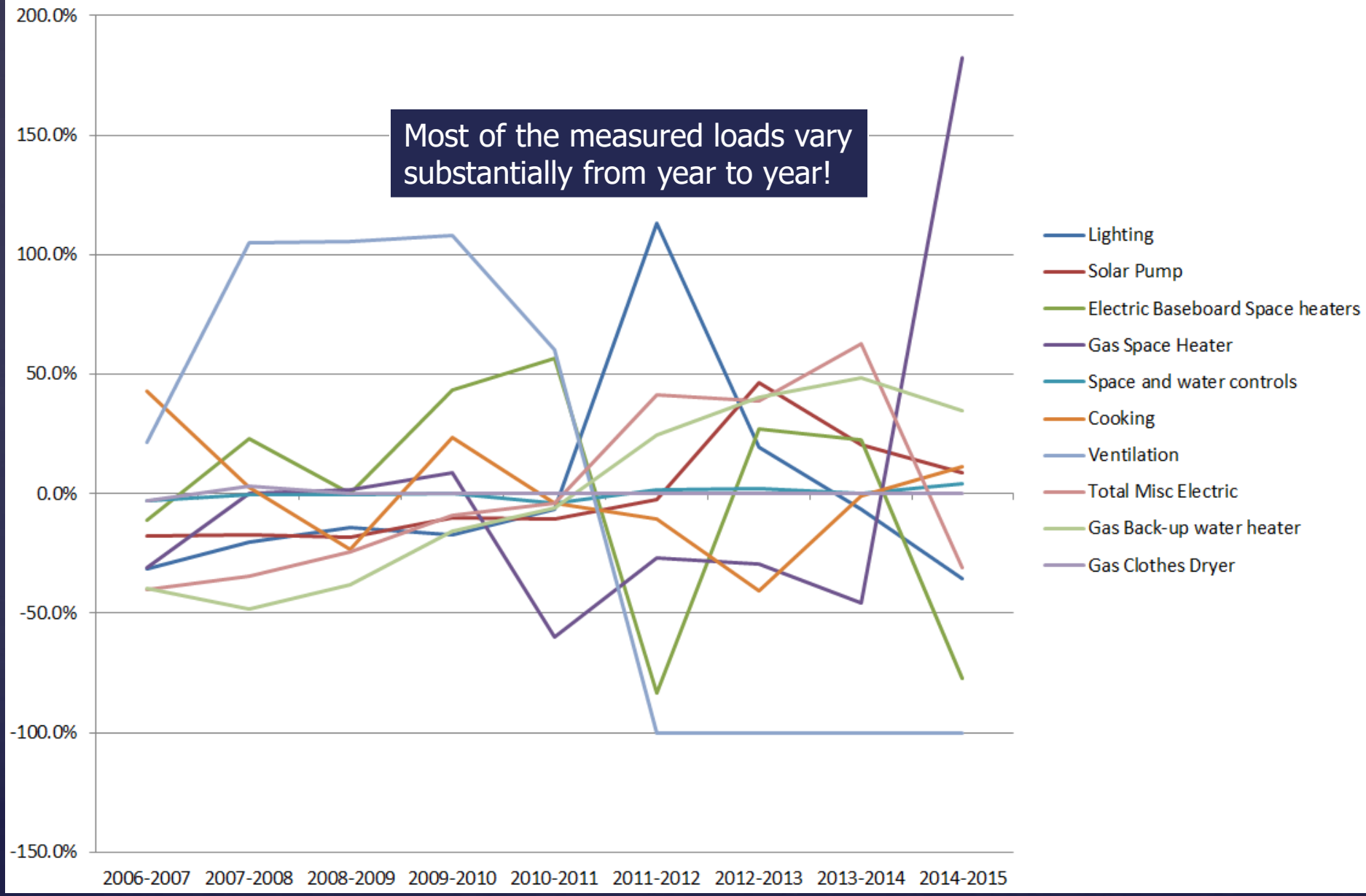
Other exposure

•The home was discussed directly with President George W. Bush during his visit to NREL in February 2006.
•The home was featured on Fox news both statewide and nationally.

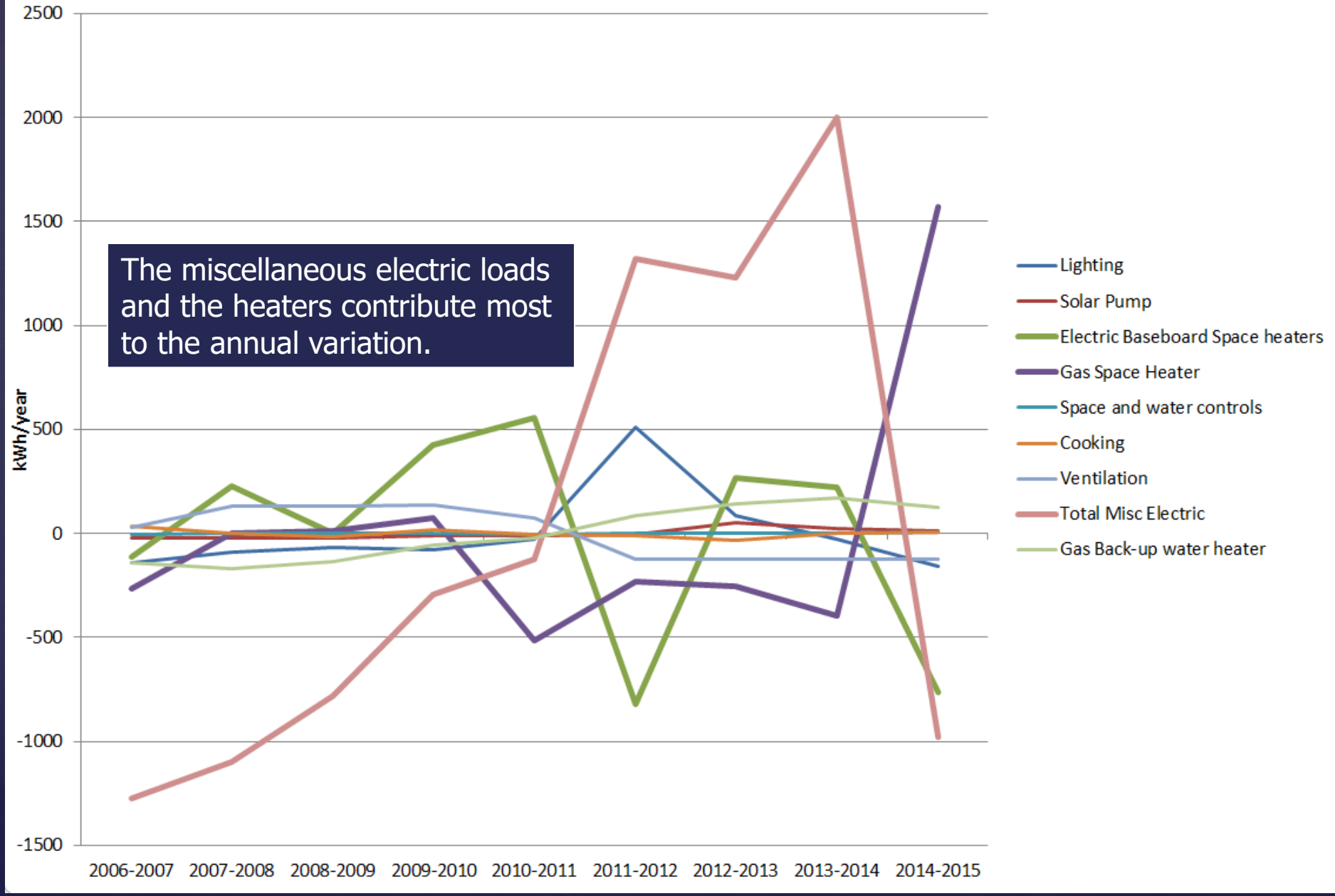
There are large home-to-home variations in energy use



Percent Annual Energy Variation from 9-year Mean by End Use

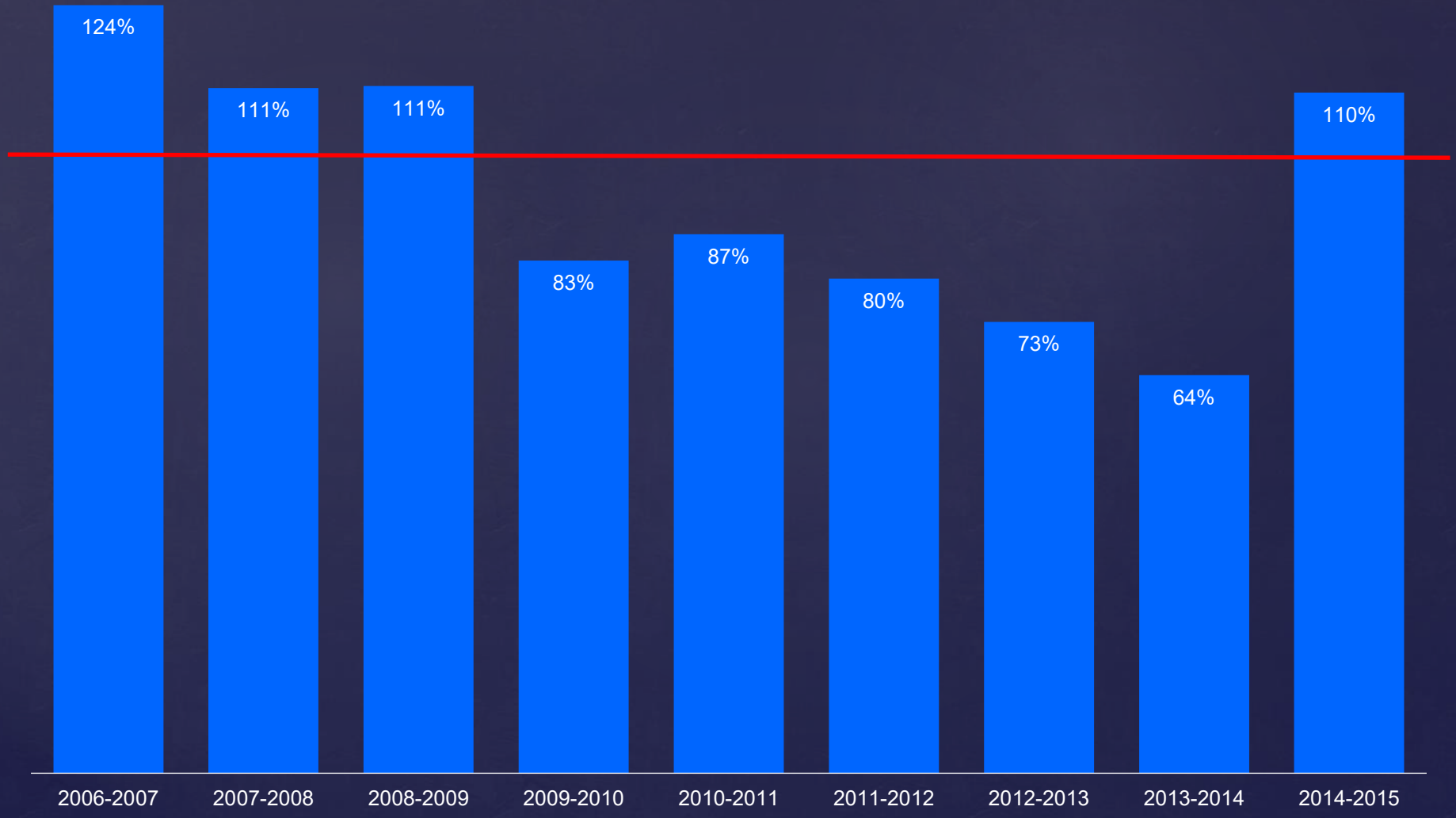


Annual Energy Variation from 9-year Mean by End Use

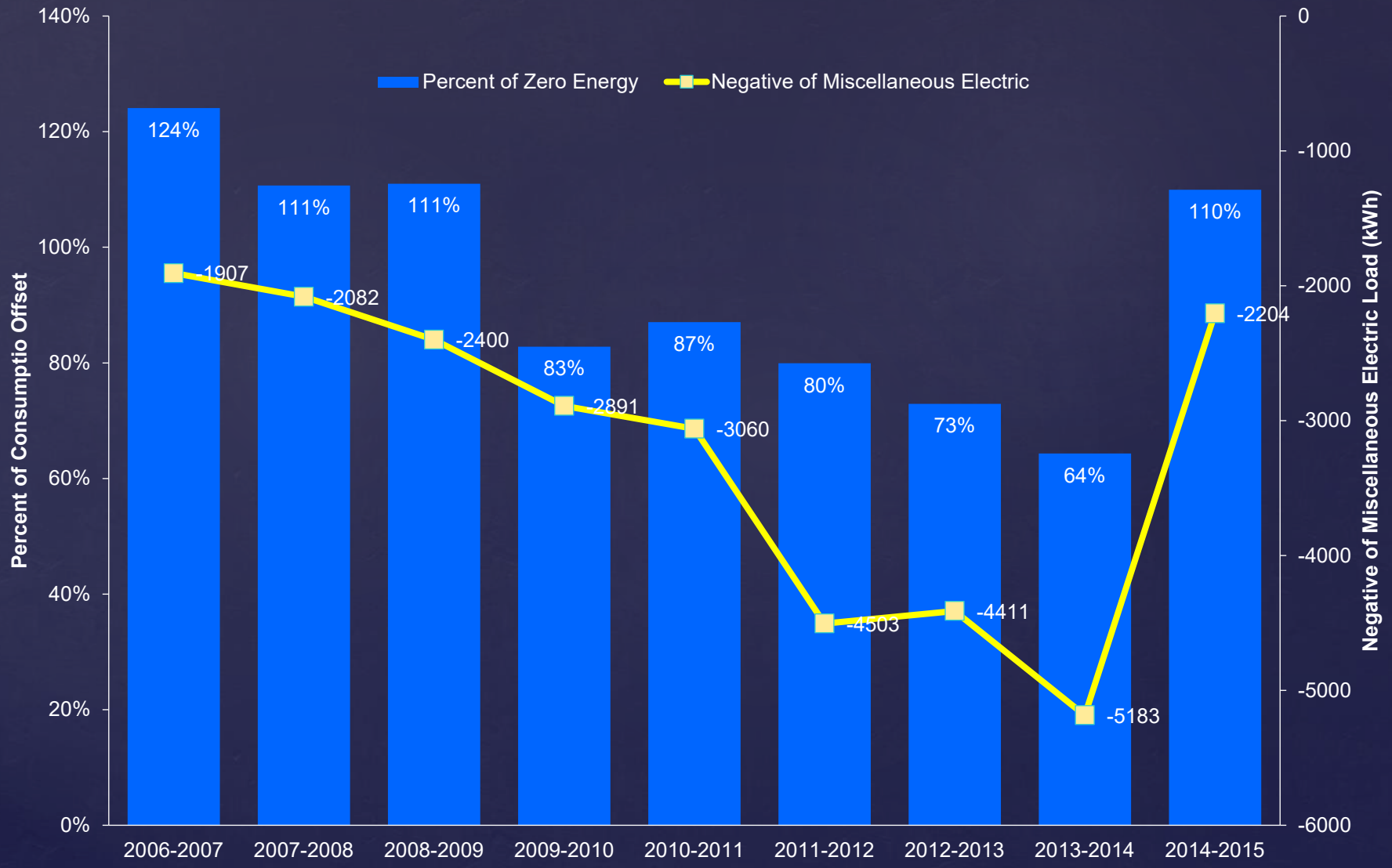


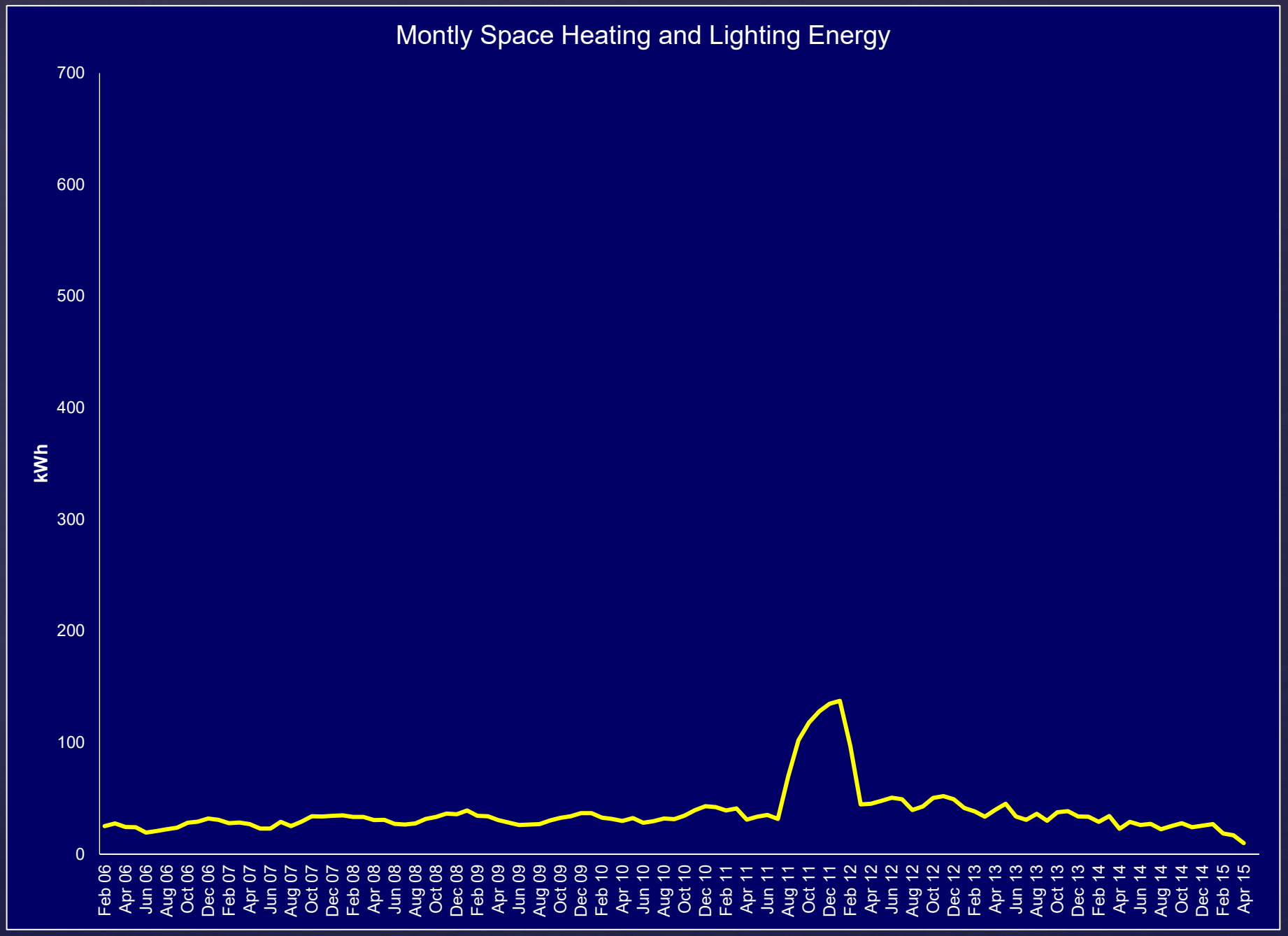
The miscellaneous electric loads and the heaters contribute most to the annual variation.

Percent of Source Energy Consumption that was offset by PV Production Annually



Percent of Source Energy Consumption that was offset by PV Production Annually




Montly Space Heating and Lighting Energy
kWh
700
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Feb 06
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Dec 06
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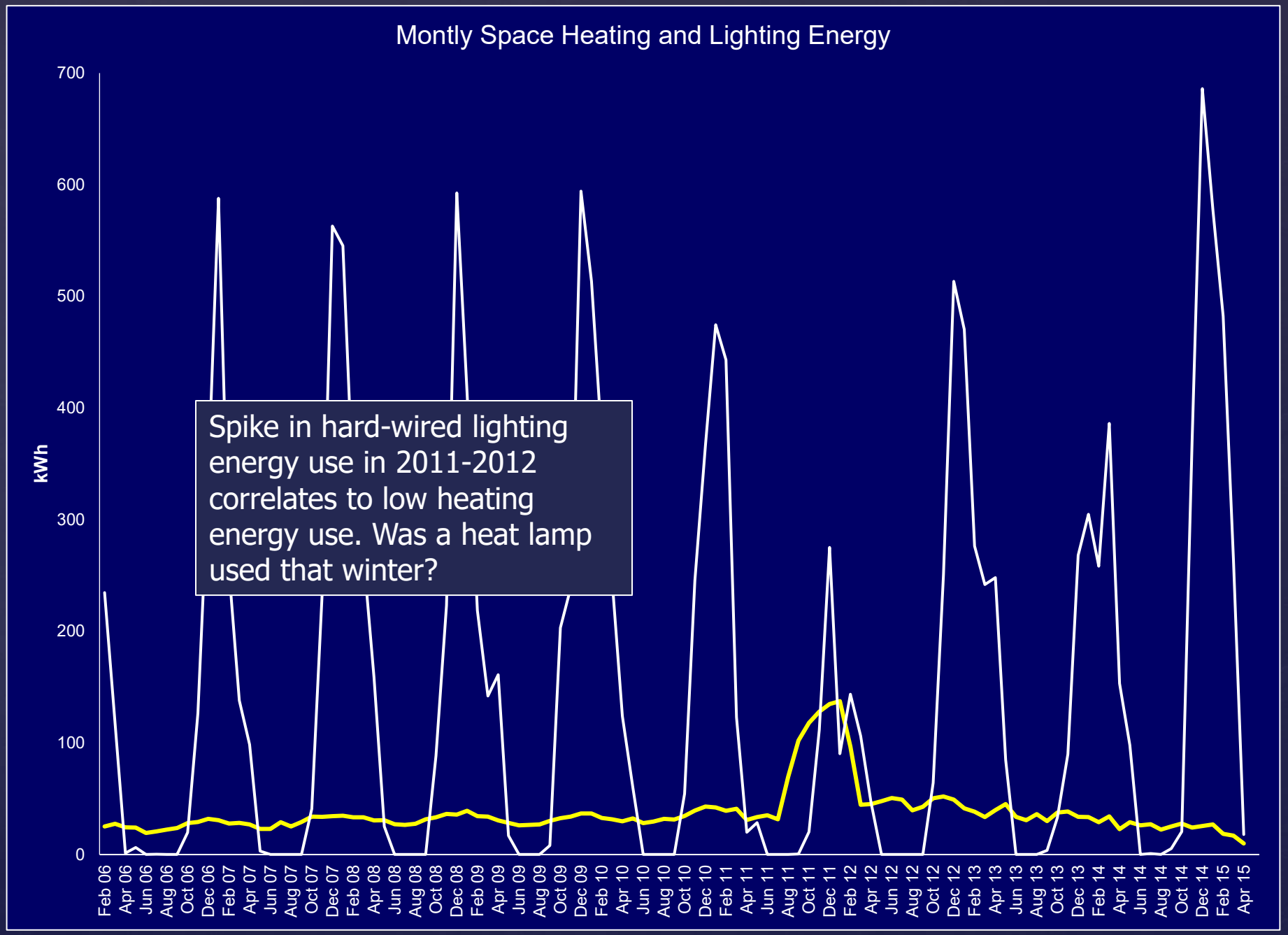
Montly Space Heating and Lighting Energy
kWh
700
600
500
400
300
200
100
0
Spike in hard-wired lighting energy use in 2011-2012 correlates to low heating energy use. Was a heat lamp used that winter?
Feb 06
Apr 06
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Dec 14
Feb 15
Apr 15

What the heck happened??

Equipment failure?

- PV not producing as much electricity
- Space conditioning system is broken
- Solar water heater is not working anymore
- ERV went haywire

What the heck happened??

Occupant Changes

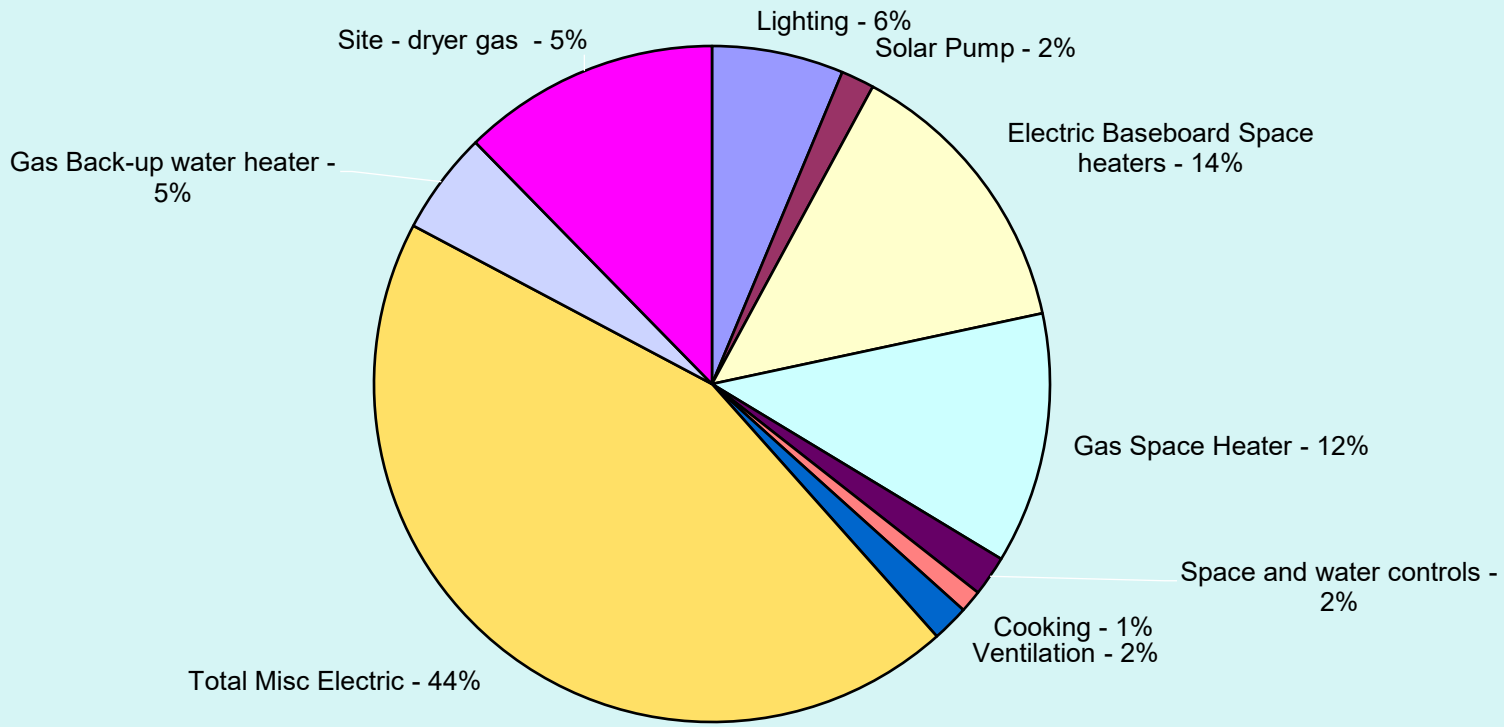
- More people are living there
- They changed temperature set points
- They installed an Air Conditioner
- They are using more hot water
- They are cooking a lot more
- The small boys turned into teenagers!

Overview of data acquisition

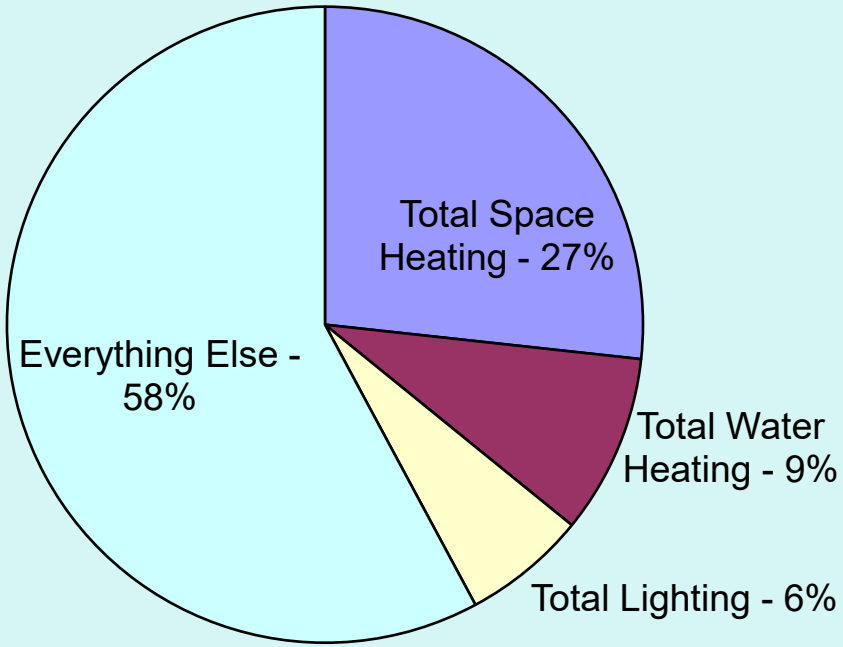
Summary

Nearly all of the year-to-year variation appears to be occupant effect.

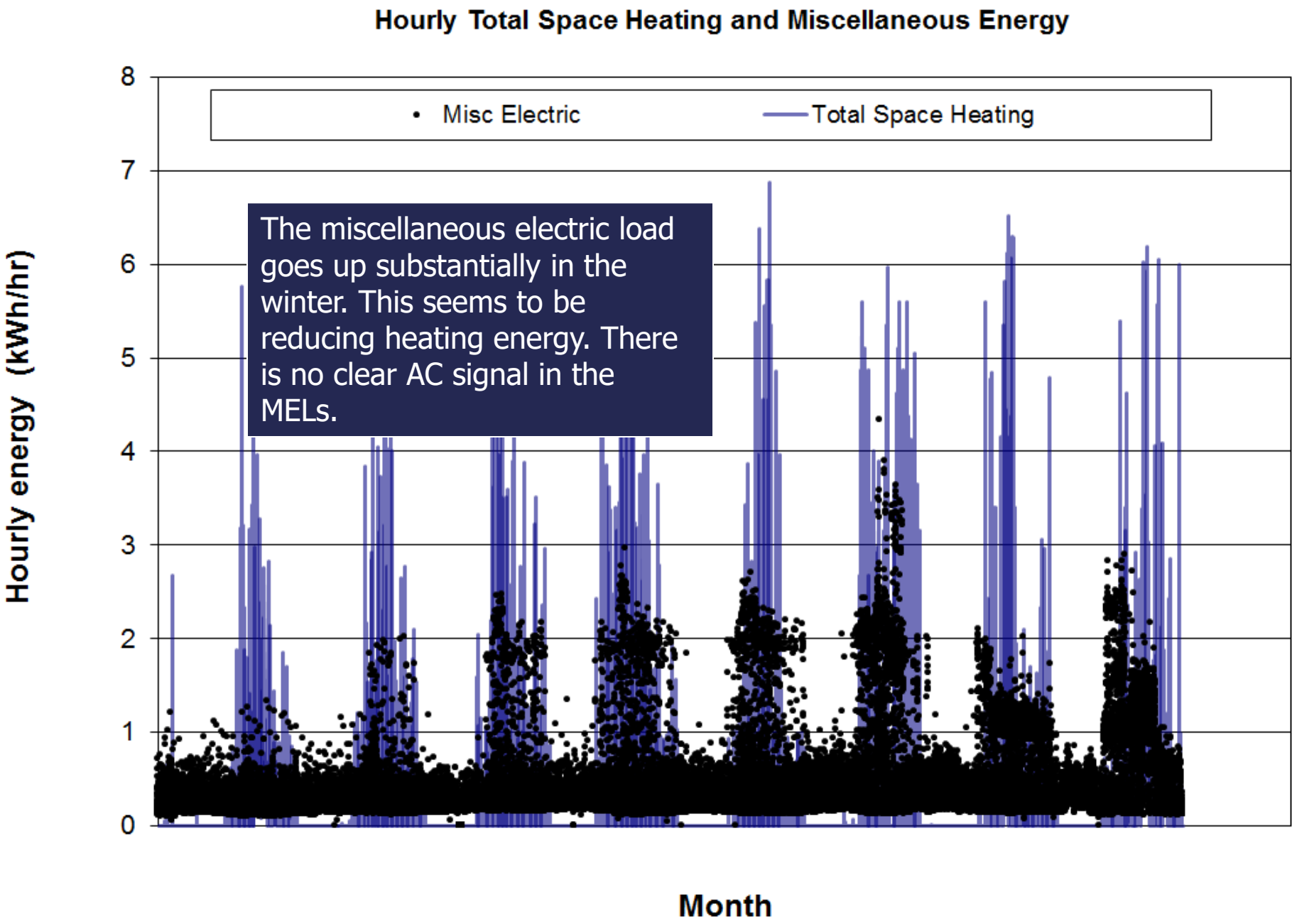
9-Year Cumulative SITE Energy End Uses



9-Year Cumulative SITE Energy End Uses



What the heck happened??


Hourly Total Space Heating and Miscellaneous Energy
Misc Electric
Total Space Heating
The miscellaneous electric load goes up substantially in the winter. This seems to be reducing heating energy. There is no clear AC signal in the MELs.
Hourly energy (kWh/hr)
0
1
2
3
4
5
6
7
8
Month

Habitat for Humanity

of Metro Denver

Among the first Ten Affiliates

Habitat for Humanity of Metro Denver's Growth since 1979

1979-80
1st Family

1988
10 Families

1994
100 Families

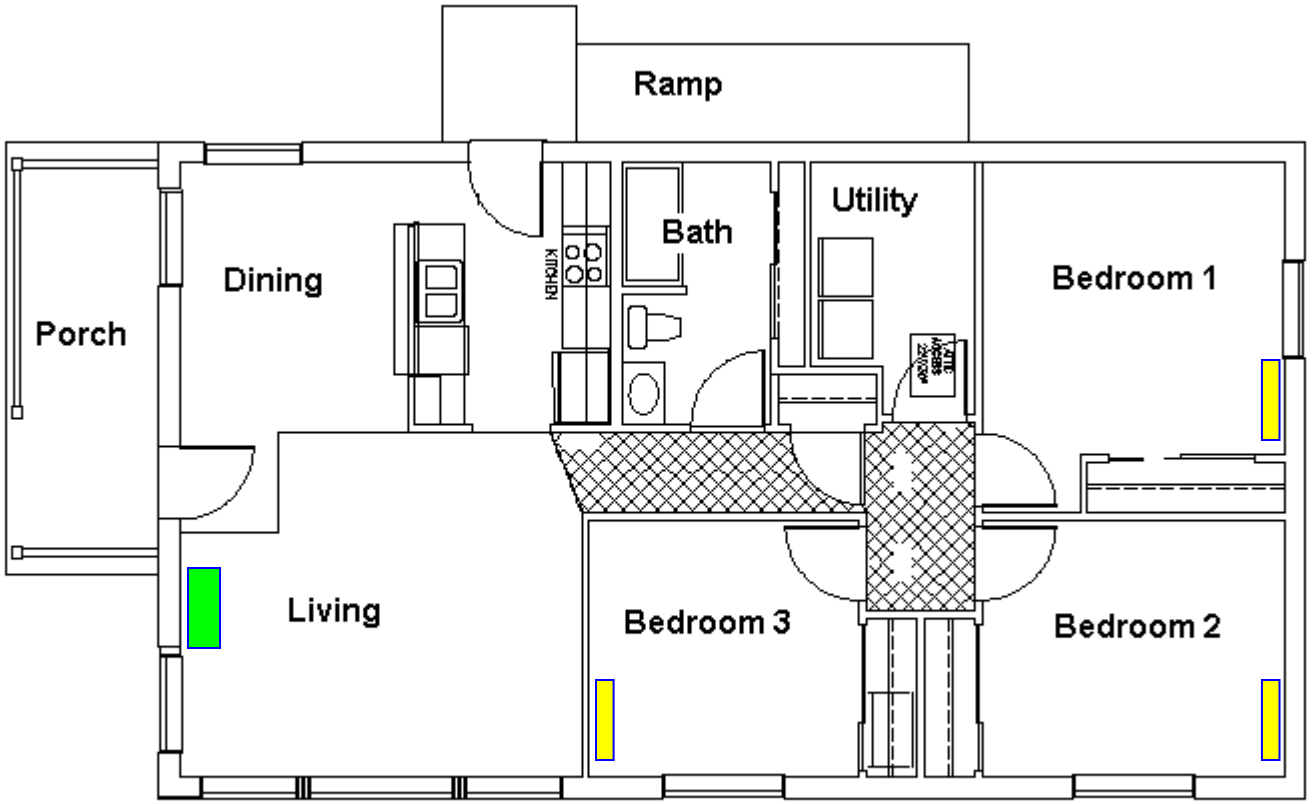
2003
200 Families

2006
300 Families

2012
500 Families

2015
600 Families

Hybrid NG/Electric Space Heating System

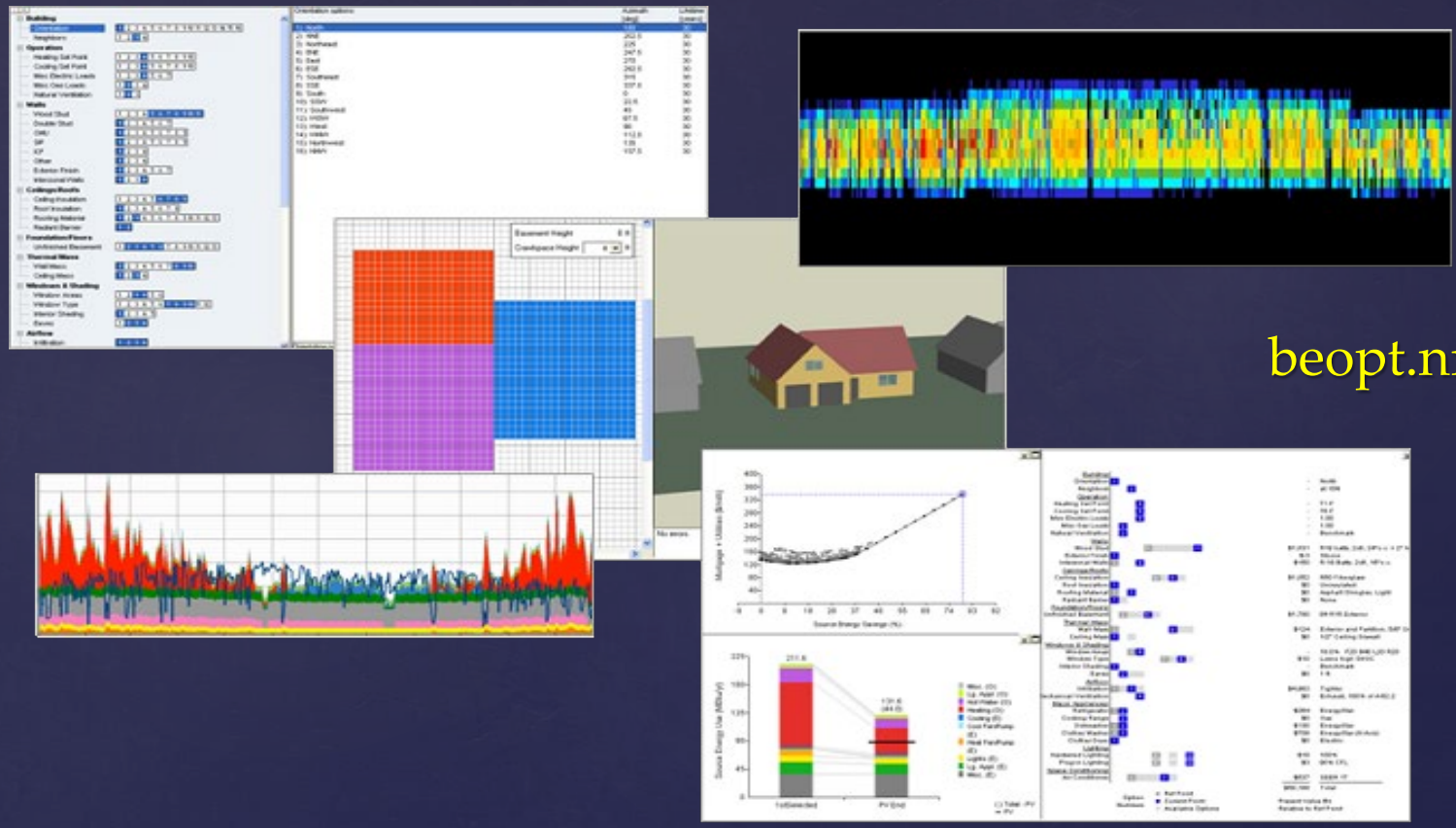


- **Direct vent, single point NG heater**
- **Small electric baseboards in bedrooms**


Rinnai ENERGYSAVER 556WT
ON/OFF


4100

BEopt (Building Energy Optimization)



beopt.nrel.gov

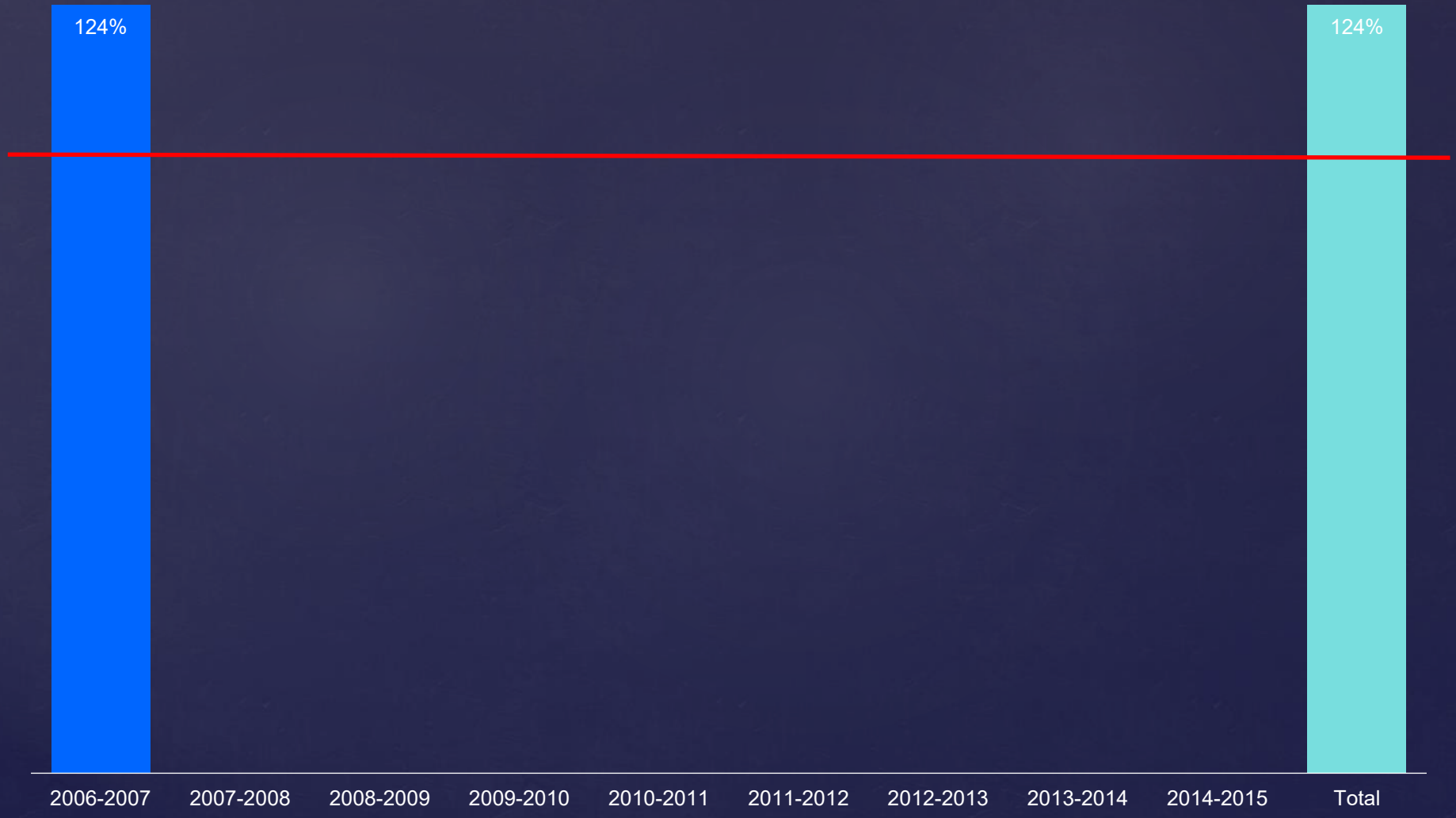
Identifies cost-optimal zero net energy (ZNE) residential building designs

Evaluates cost and energy savings for energy efficiency and PV measures

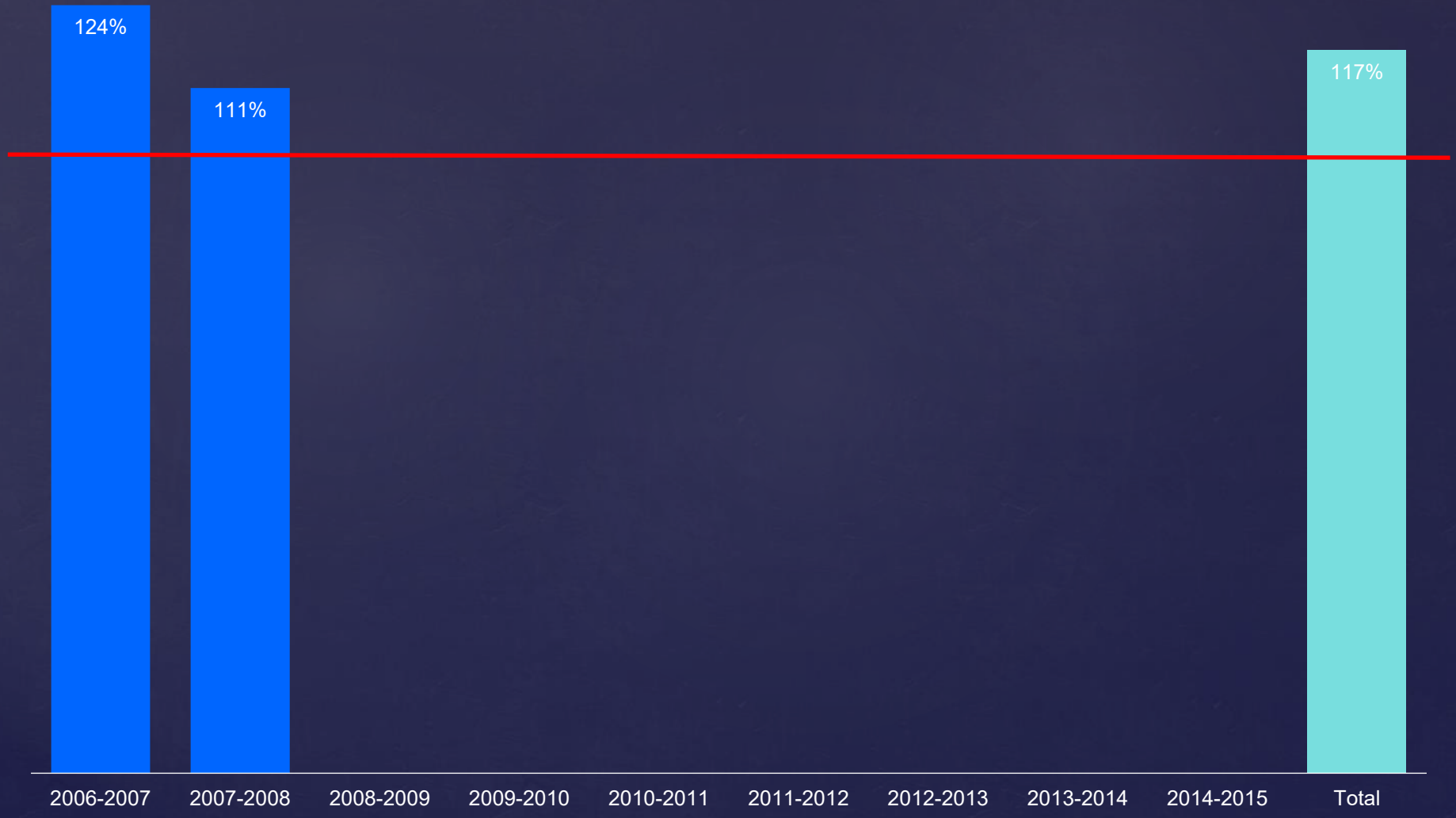
Simulates demand response; calculates utility efficiency and solar cost-benefit tests

Net Zero Energy Definition

Percent of Source Energy Consumption that was offset by PV Production Annually



Percent of Source Energy Consumption that was offset by PV Production Annually



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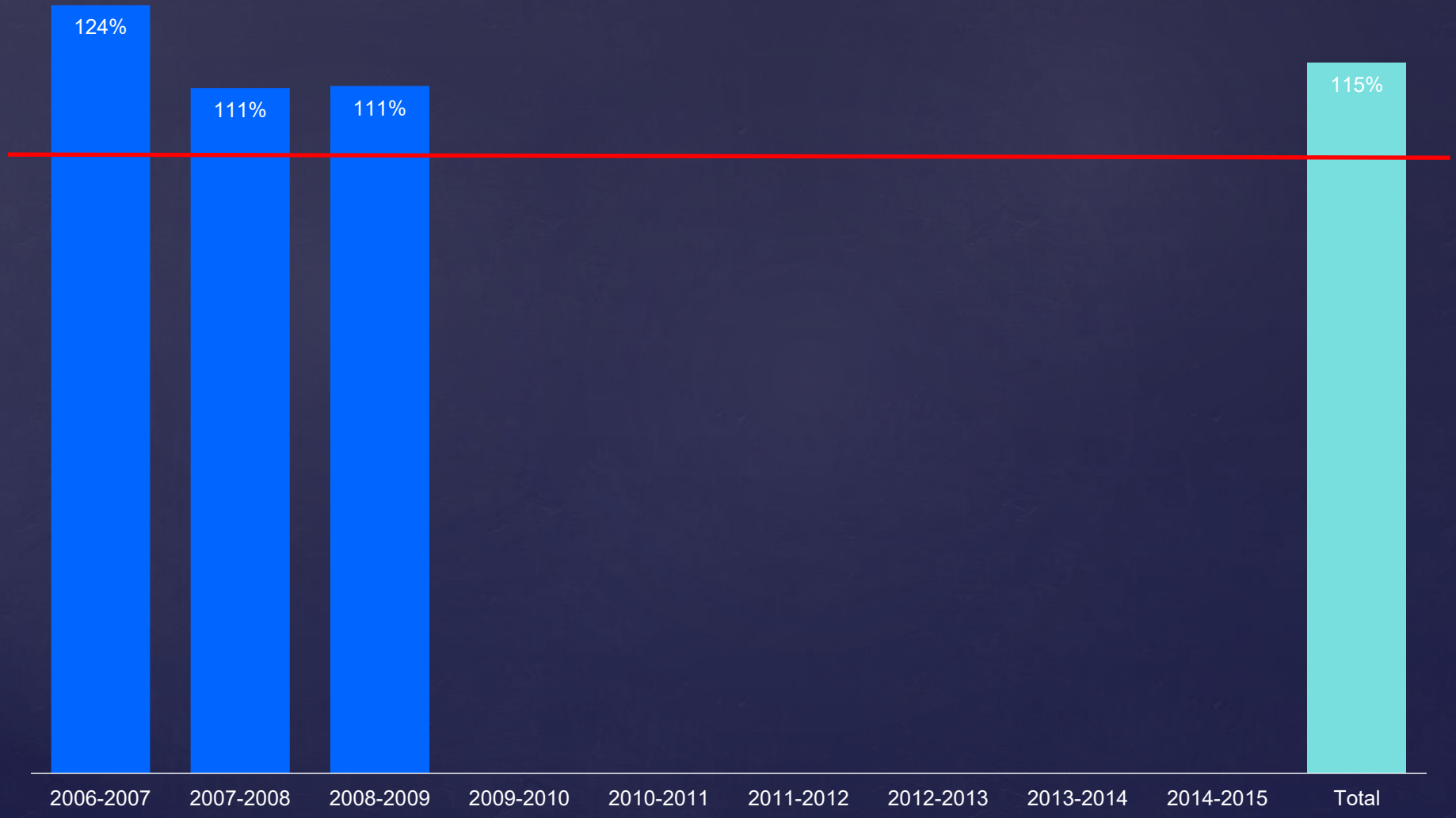
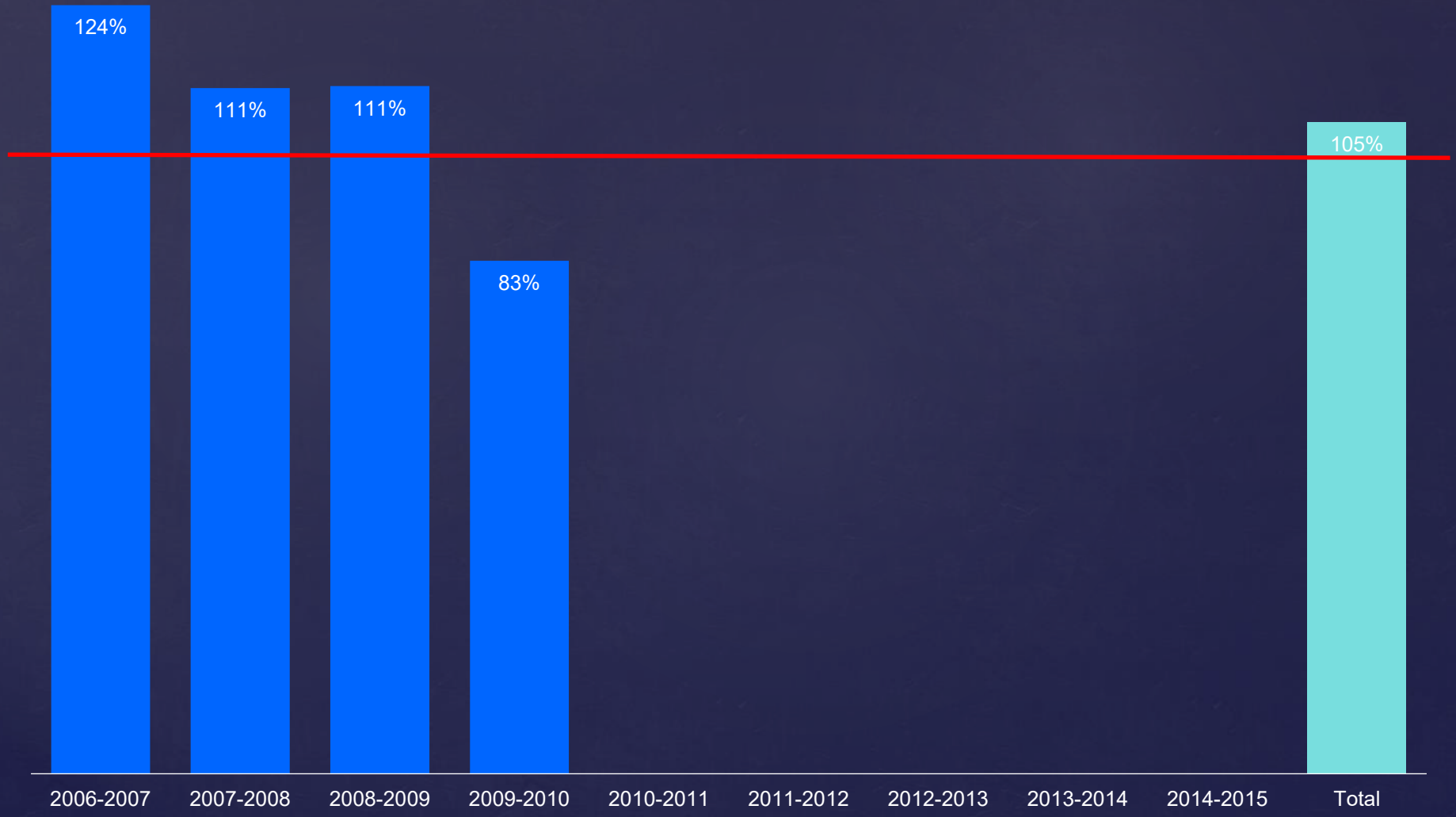
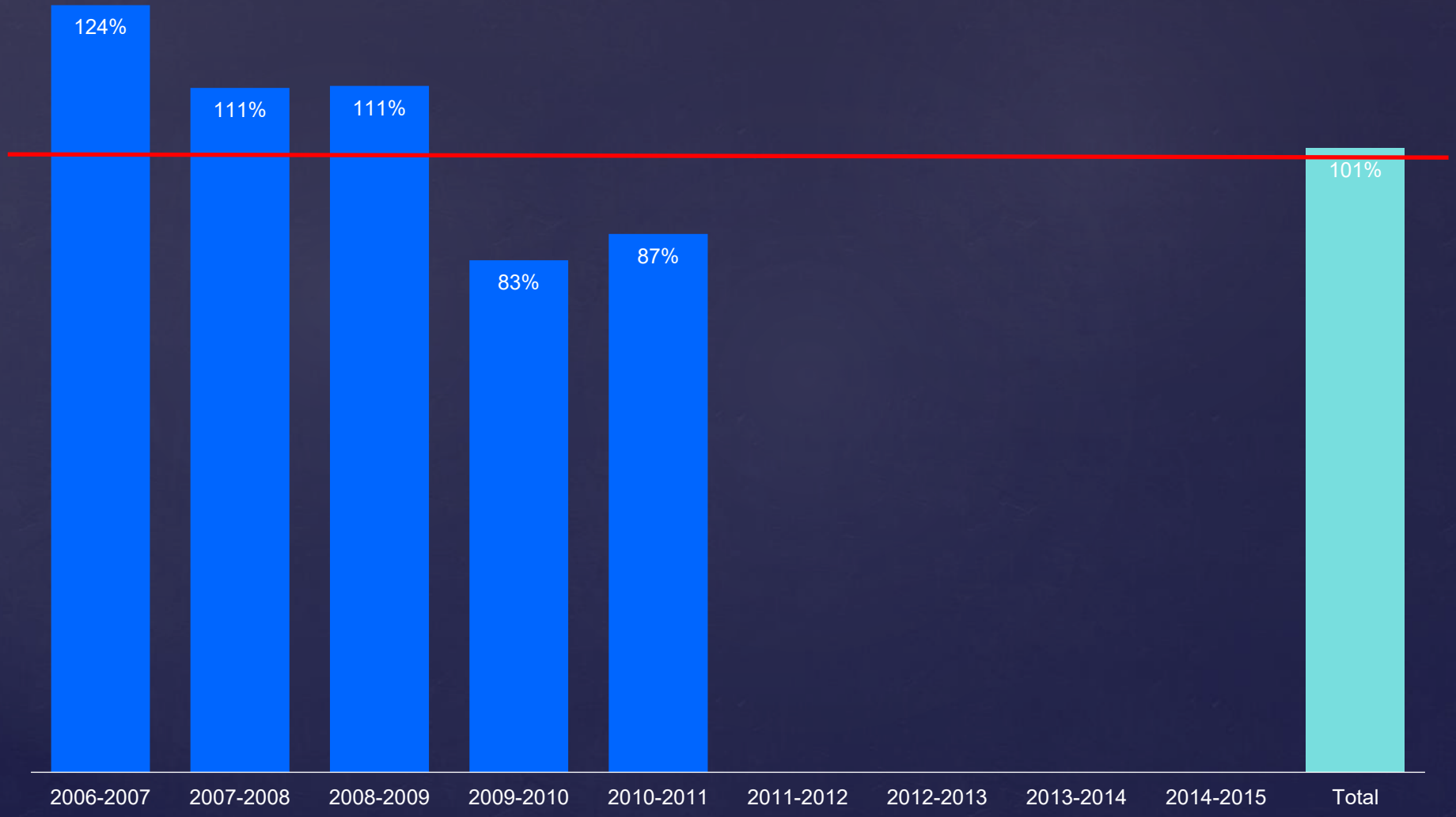


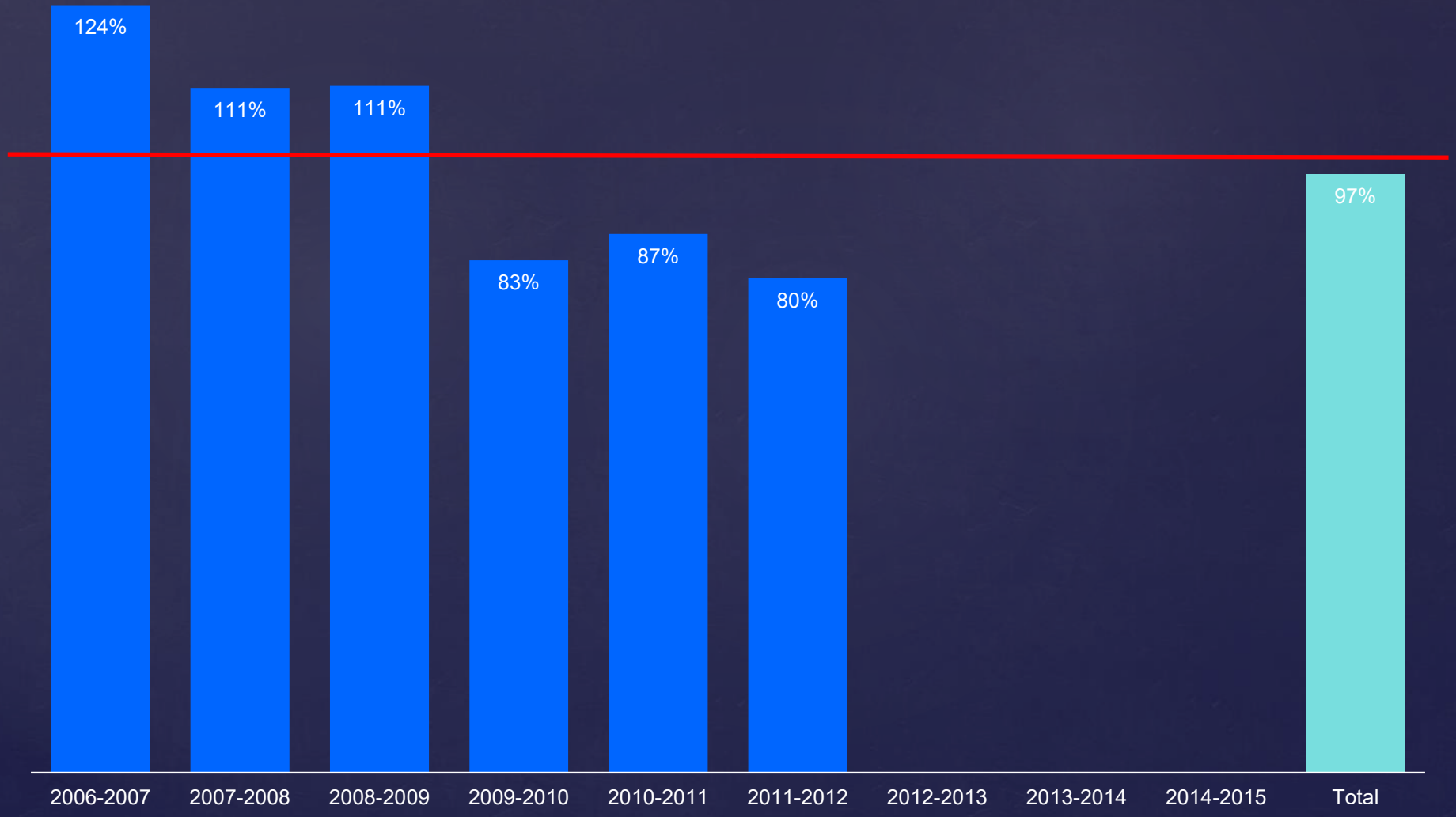
Percent of Source Energy Consumption that was offset by PV Production Annually



Percent of Source Energy Consumption that was offset by PV Production Annually



Percent of Source Energy Consumption that was offset by PV Production Annually

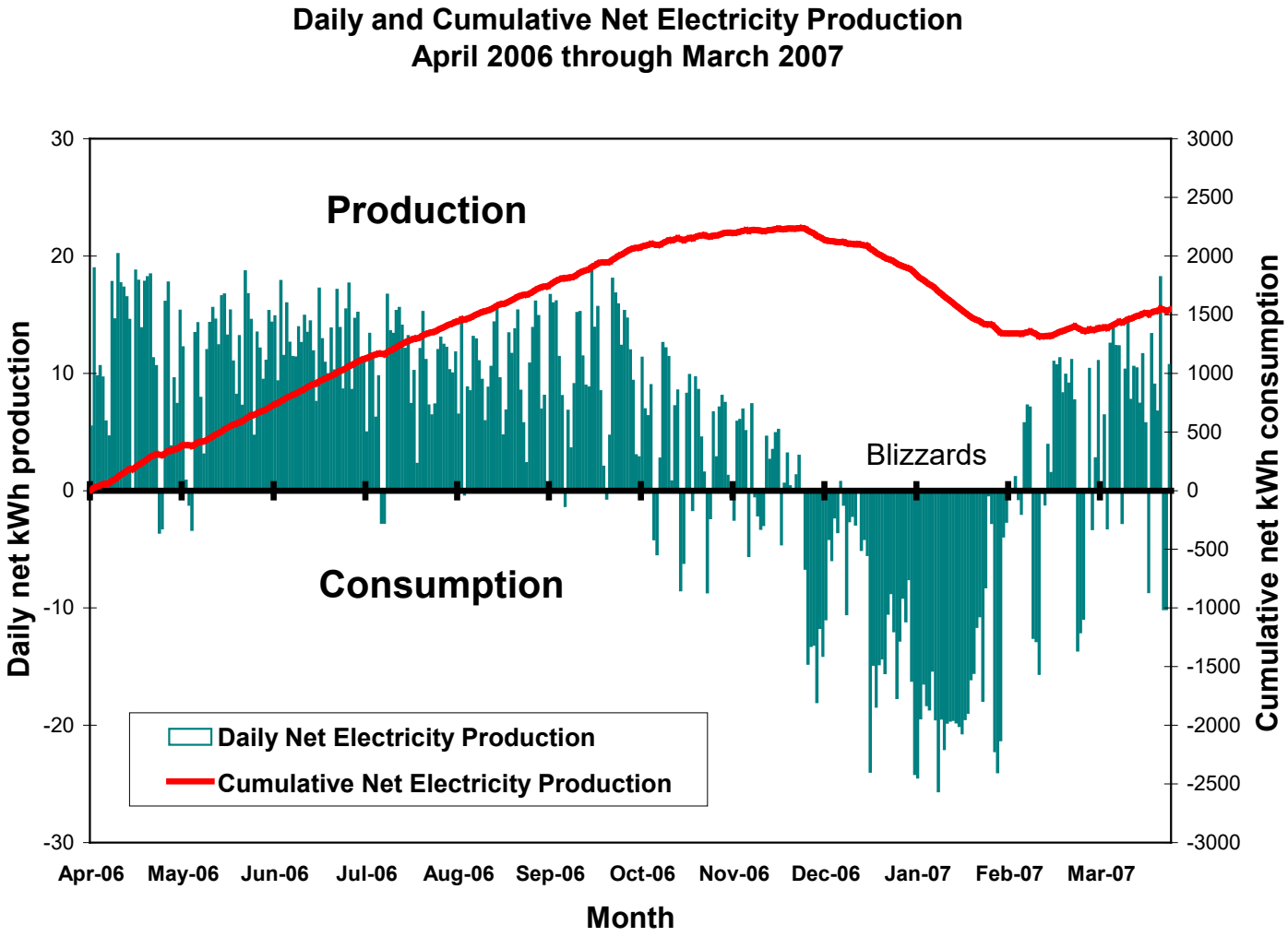


Percent of Source Energy Consumption that was offset by PV Production Annually

Percent of Source Energy Consumption that was offset by PV Production Annually

Percent of Source Energy Consumption that was offset by PV Production Annually

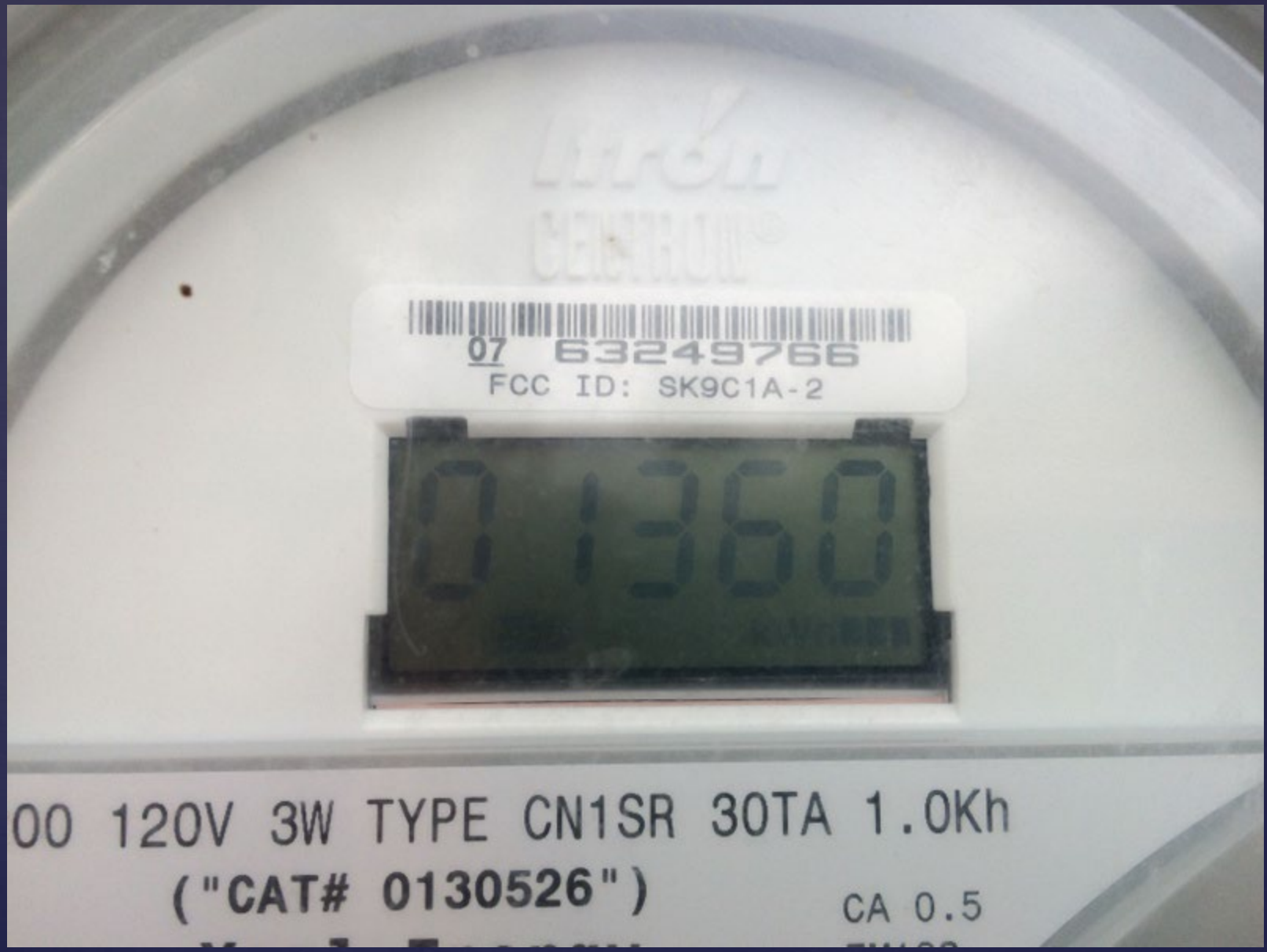
Habitat ZEH
First Year Performance



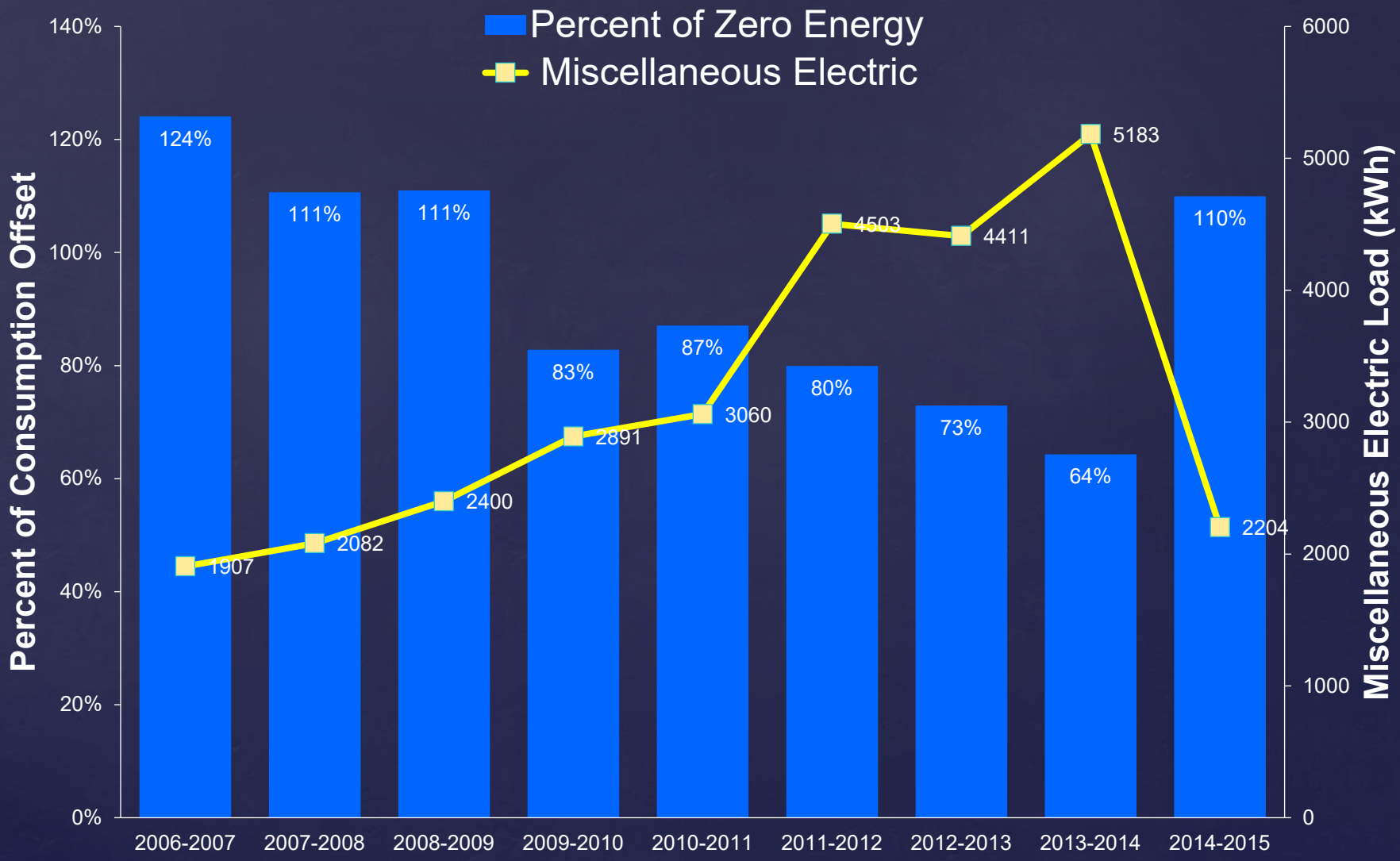
Percent of Source Energy Consumption that was offset by PV Production Annually

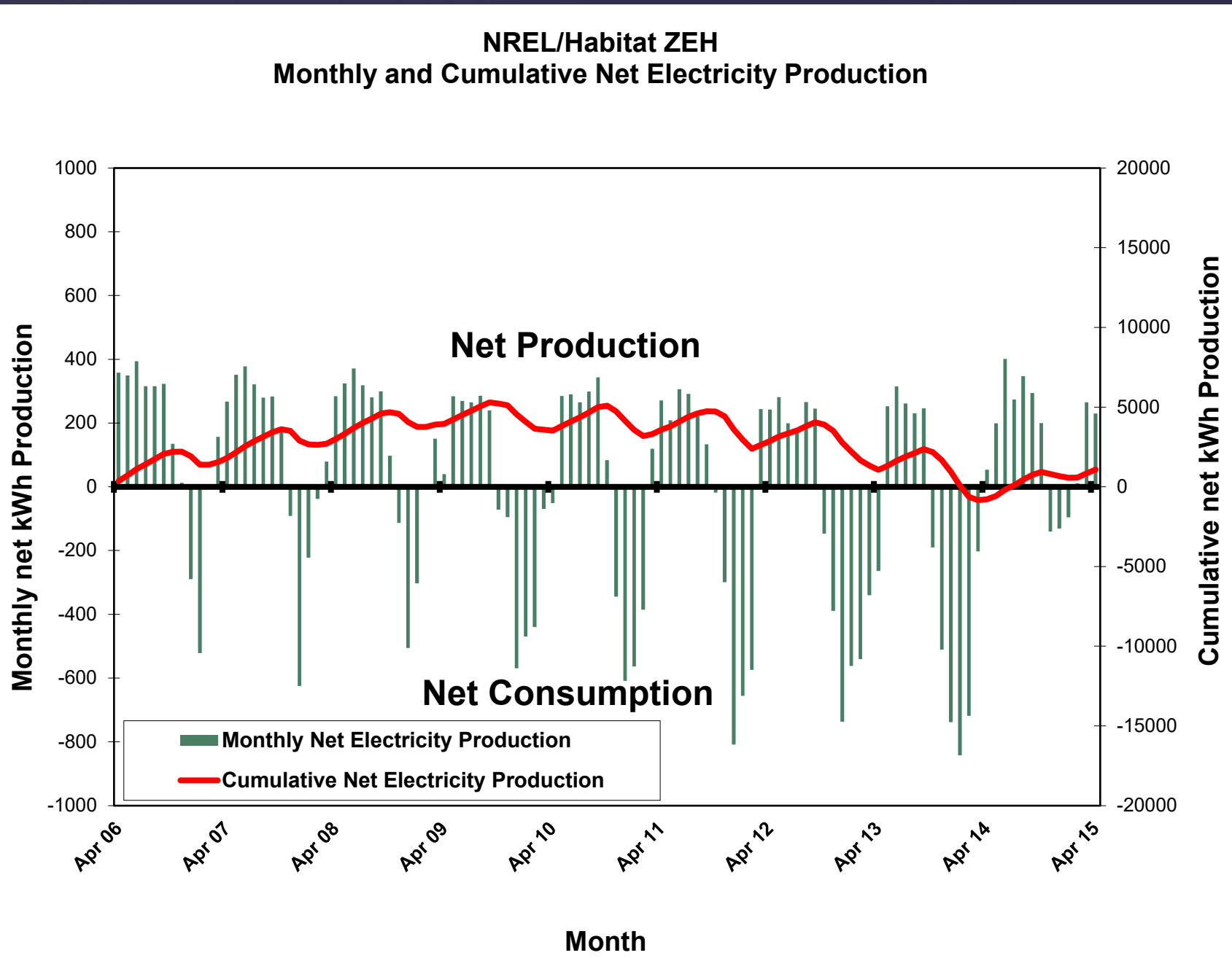
	Therms	kWh	MBtu
Site Energy Summary			
Total site electricity consumption		3585	12
Total AC site PV electricity production		5127	17
Net site electricity production		1543	5.3
Total site natural gas consumption	57	1665	5.7
Source Energy Summary			
Total source* energy consumption		13025	44
Total source energy offset		16201	55
Net source energy offset		3176	11
Percent of source energy consumption offset via on site renewable production		124%	124%

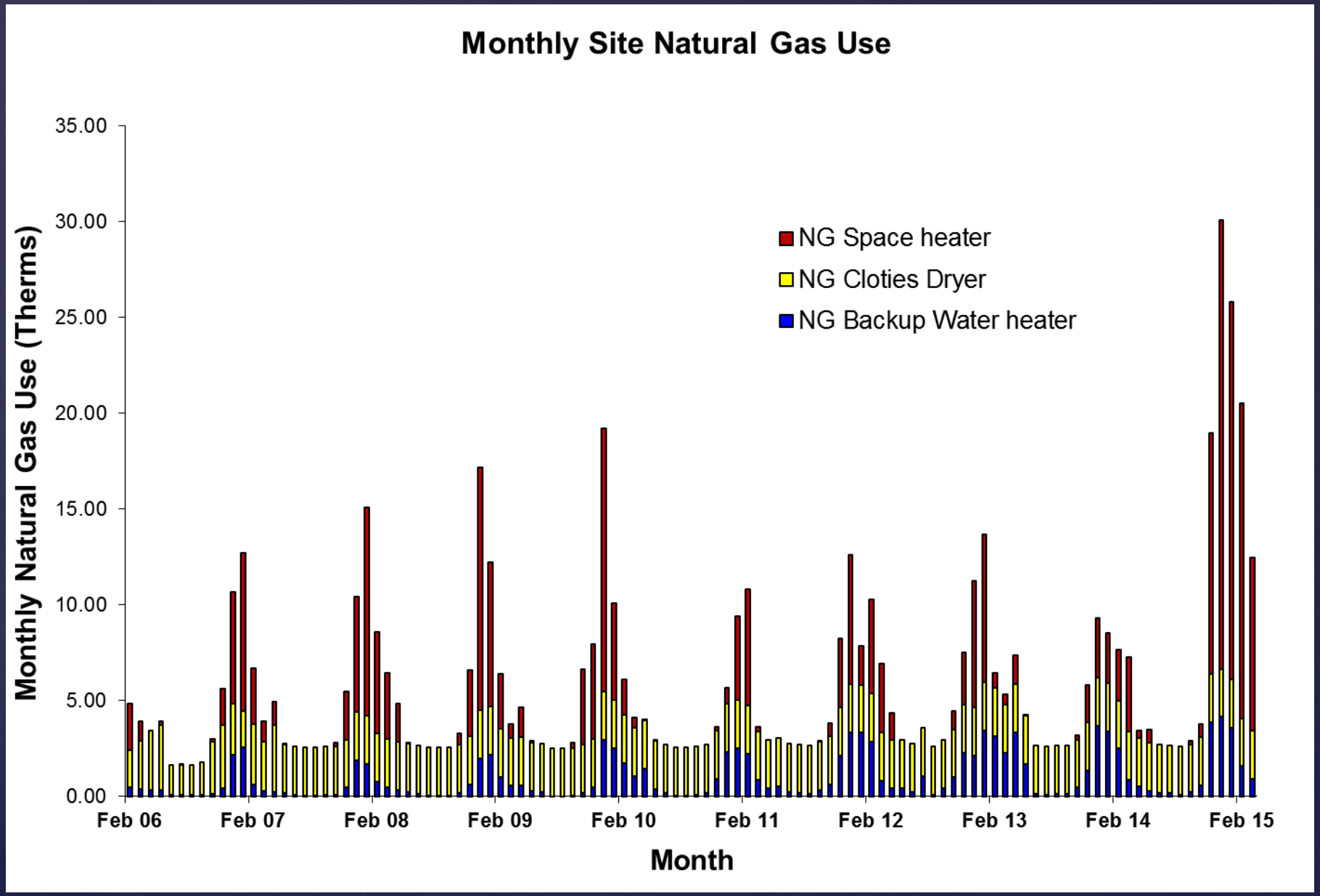
2006-2007 2007-2008 2008-2009 2009-2010 2010-2011 2011-2012 2012-2013 2013-2014 2014-2015

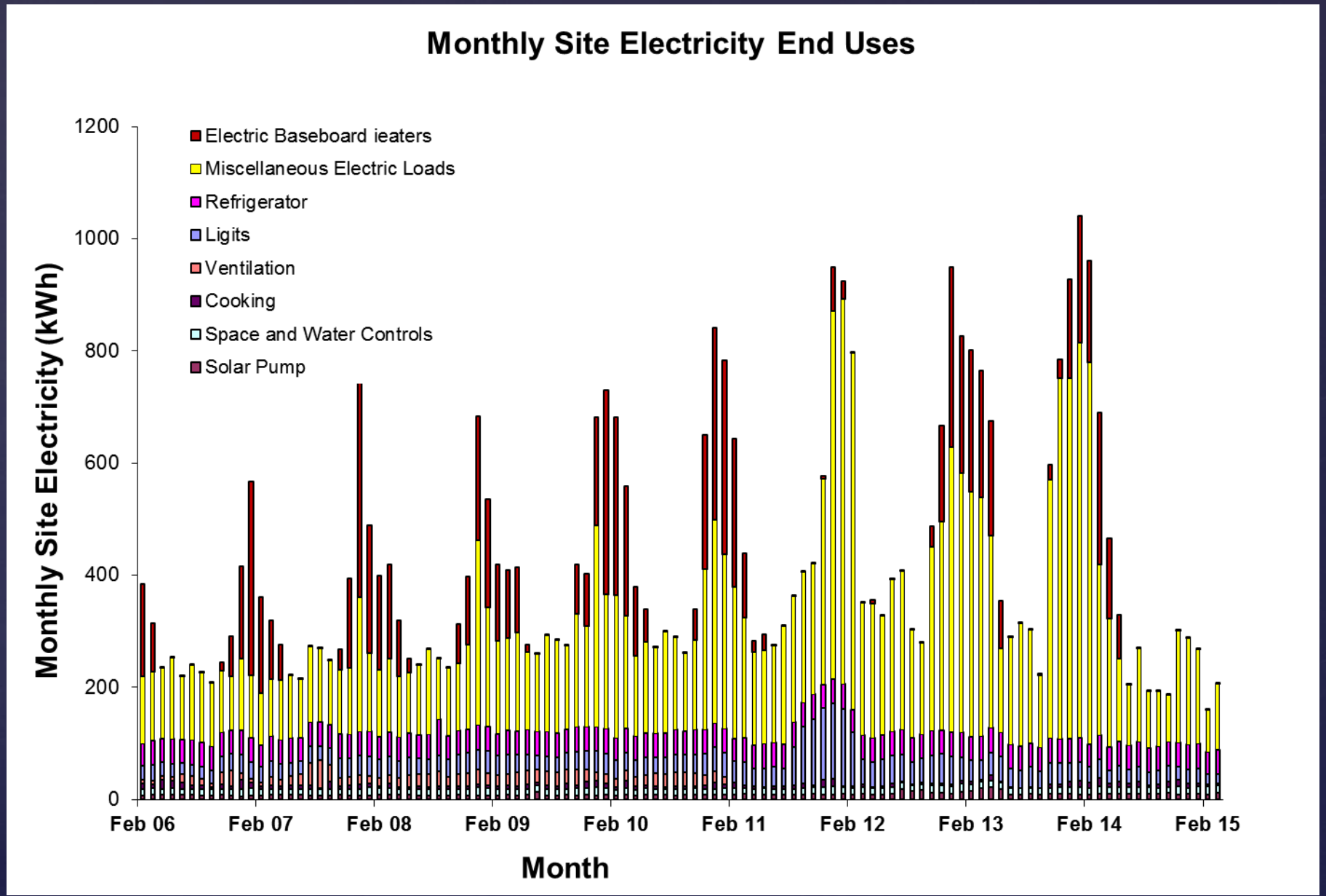

07 63249766
FCC ID: SK9C1A-2
01360
00 120V 3W TYPE CN1SR 30TA 1.0Kh
("CAT# 0130526")
CA 0.5

Percent of Source Energy Consumption that was offset by PV Production Annually




NREL/Habitat ZEH
Monthly and Cumulative Net Electricity Production
Net Production
Net Consumption
Monthly Net Electricity Production
Cumulative Net Electricity Production
Monthly net kWh Production
Cumulative net kWh Production
Month
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
20000
15000
10000
5000
0
-5000
-10000
-15000
-20000
Apr 06
Apr 07
Apr 08
Apr 09
Apr 10
Apr 11
Apr 12
Apr 13
Apr 14
Apr 15


Monthly Site Natural Gas Use
Monthly Natural Gas Use (Therms)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
NG Space heater
NG Cloties Dryer
NG Backup Water heater
Feb 06
Feb 07
Feb 08
Feb 09
Feb 10
Feb 11
Feb 12
Feb 13
Feb 14
Feb 15
Month


Monthly Site Electricity End Uses
Electric Baseboard ieaters
Miscellaneous Electric Loads
Refrigerator
Ligits
Ventilation
Cooking
Space and Water Controls
Solar Pump
Monthly Site Electricity (kWh)
1200
1000
800
600
400
200
0
Feb 06
Feb 07
Feb 08
Feb 09
Feb 10
Feb 11
Feb 12
Feb 13
Feb 14
Feb 15
Month

What the heck happened??

Production down, or consumption up?

ZEH/Utility thoughts

- Peak PV production does not coincide with most utility demand peaks
- How can ZEH be designed to better support the grid? Can we design in more dispatchable loads or peak shifting strategies?
- Why are ZEH designers so fixated on rooftop PV? Why not long-term contracts with utility-scale RE?

Source Energy Conversions

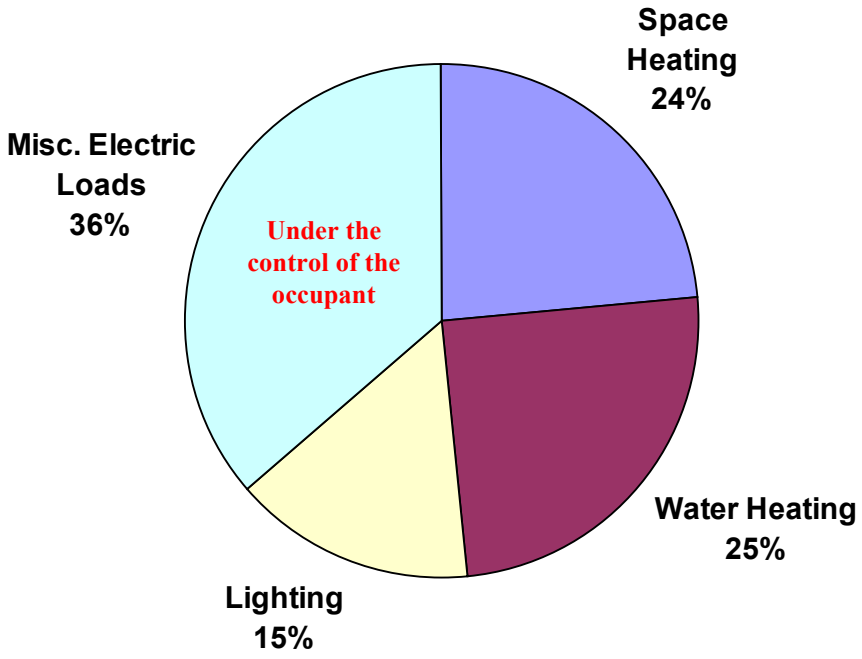
Site to source conversion factors:

Electricity	3.318	Colorado
Natural Gas used on site	1.092	National Average

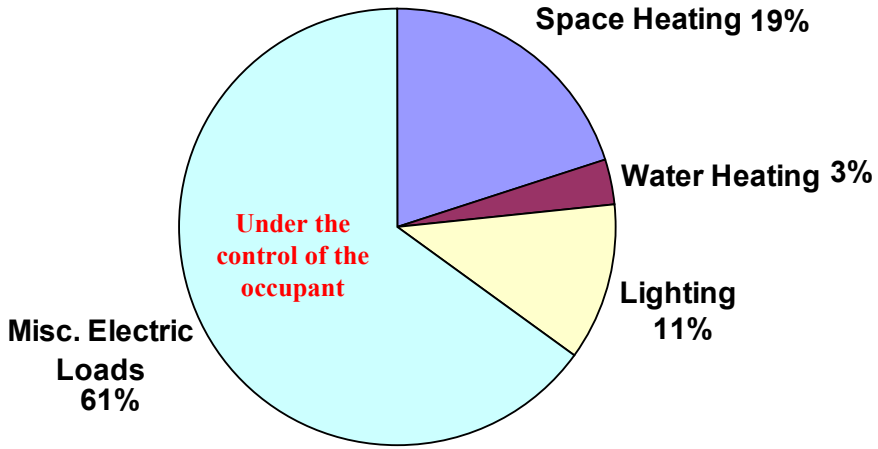
(Source Energy and Emission Factors for Energy Use in Buildings Deru and Torcellini , Tables B-9 and 5, 2007 (Supercedes 2006 version)

Annual PV Production

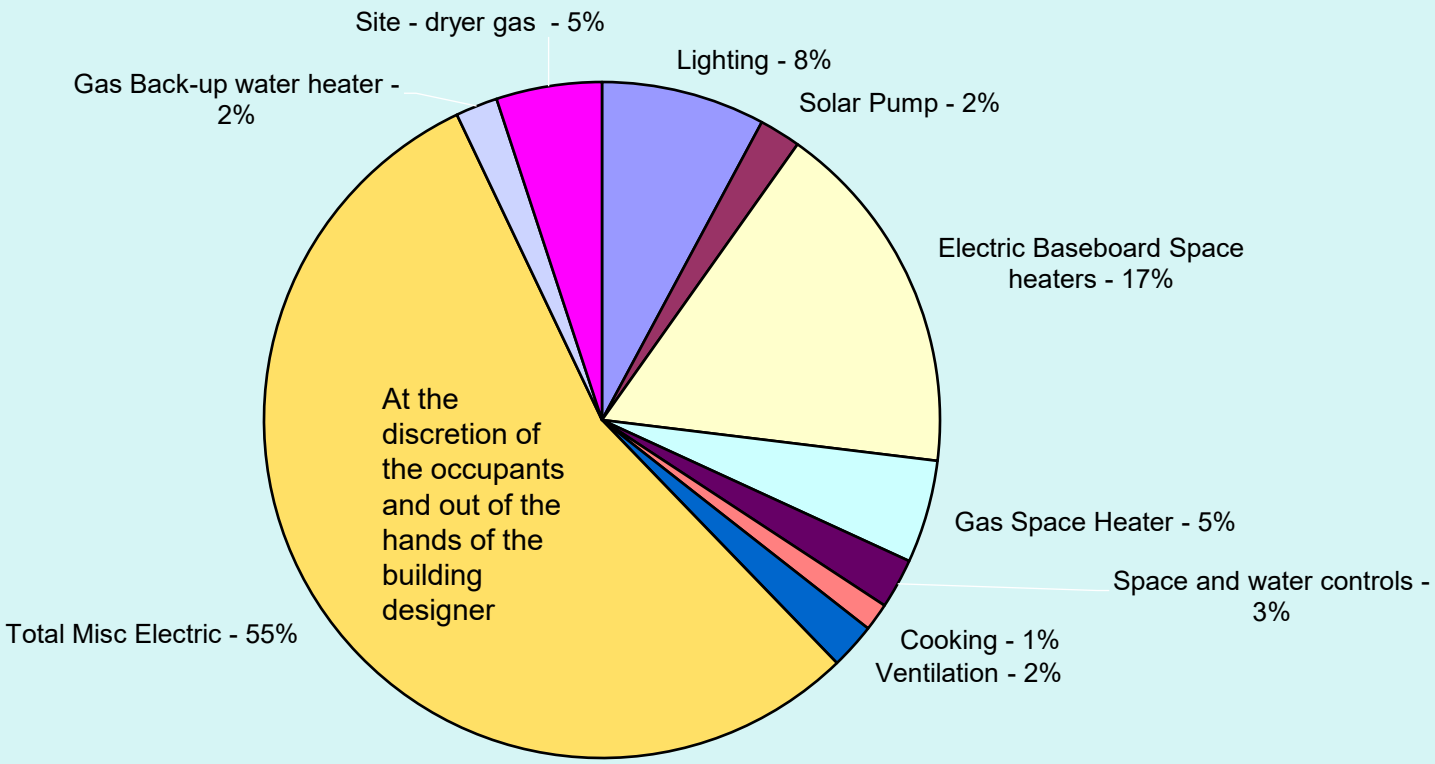
Energy Use in Habitat BA Benchmark House



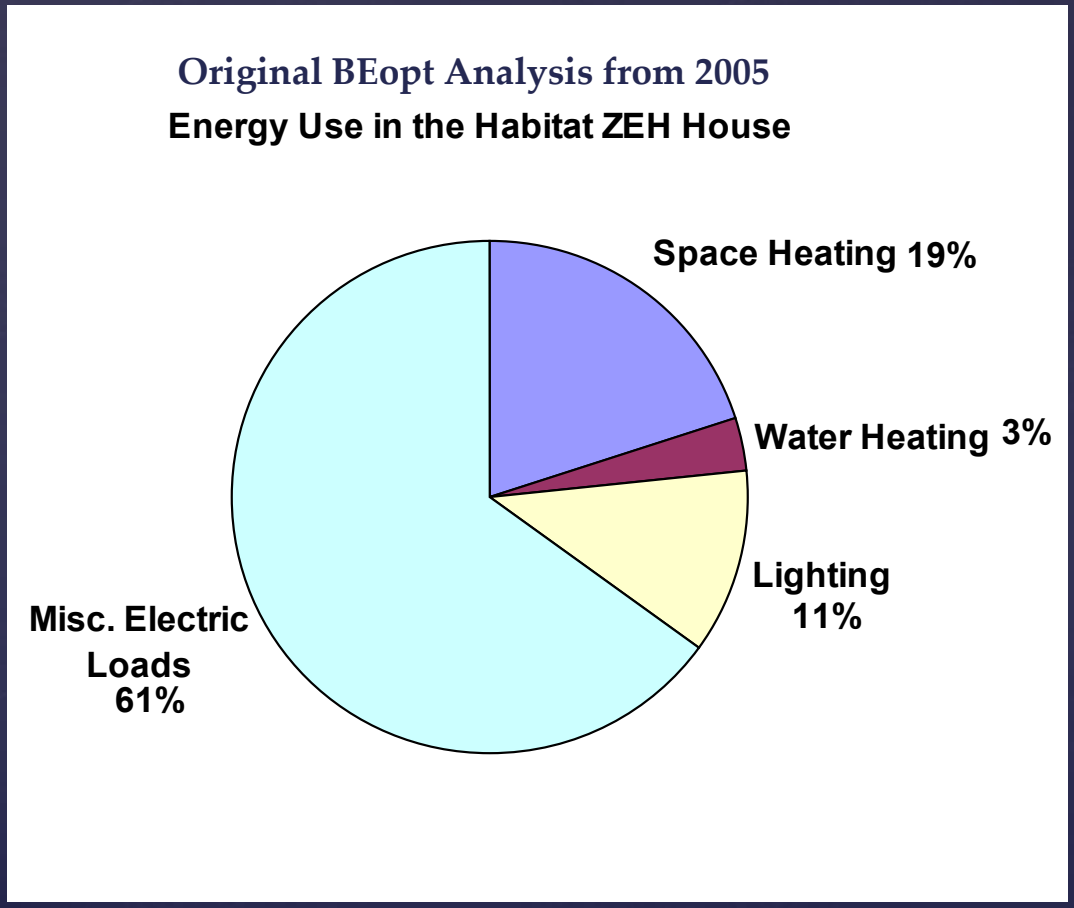
Energy Use in the Habitat ZEH House



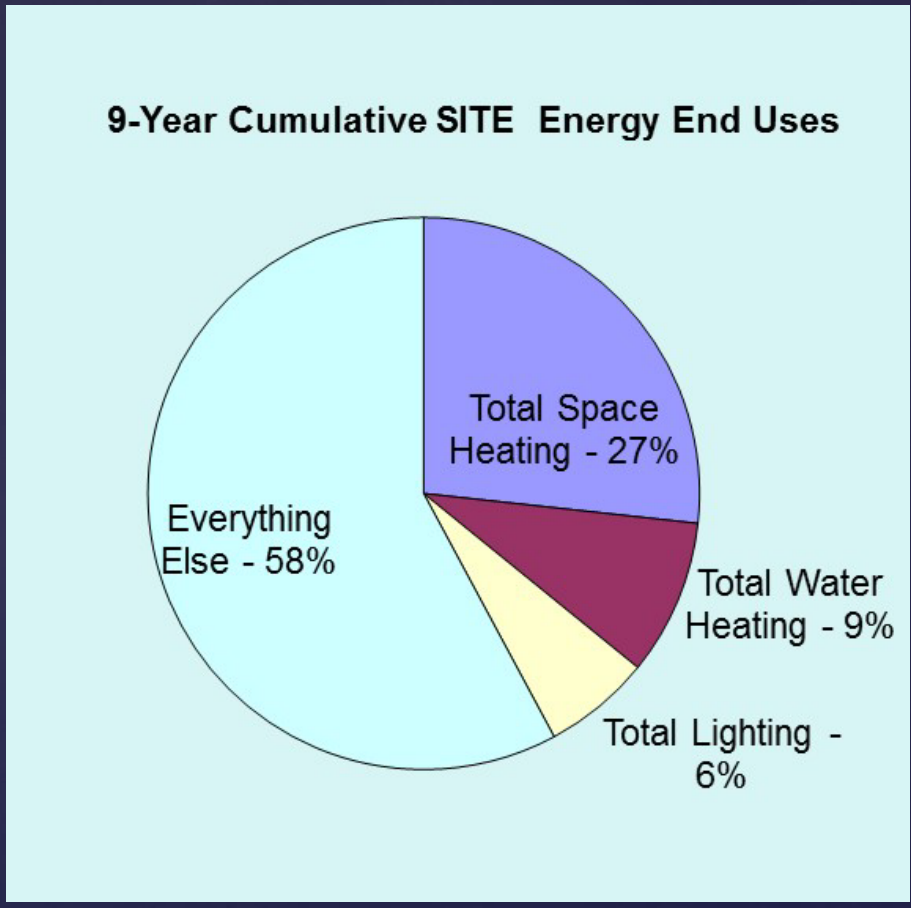
9-Year Cumulative SOURCE Energy End Uses



Predicted



Measured



Zero Energy History

1) Super-insulation
2) Passive Solar
3) Net Metering

Conclusions

1) x
2) x
3) x

One of the Largest Homebuilders

1,500 U.S. Affiliates
550 International Affiliates
in 90 Countries, and
3,000 Communities

1 Million Homes Worldwide
1 Home every 4 Minutes

Our Most Famous Volunteers

Jimmy and Rosalynn Carter

Among the first Ten Affiliates

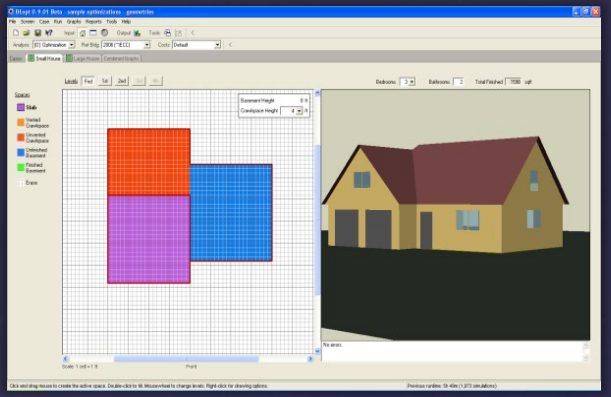
Habitat for Humanity of Metro Denver's Growth

Fox News

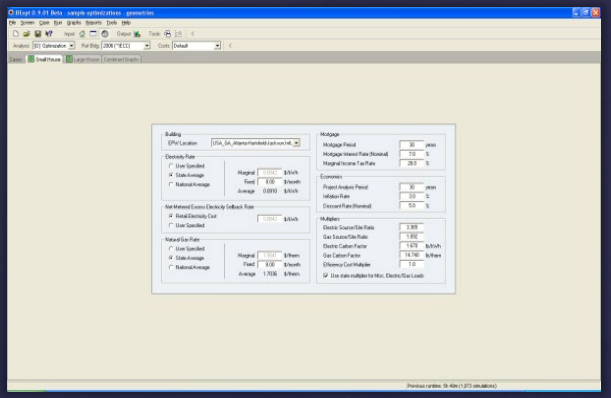
BEopt GUI

Input

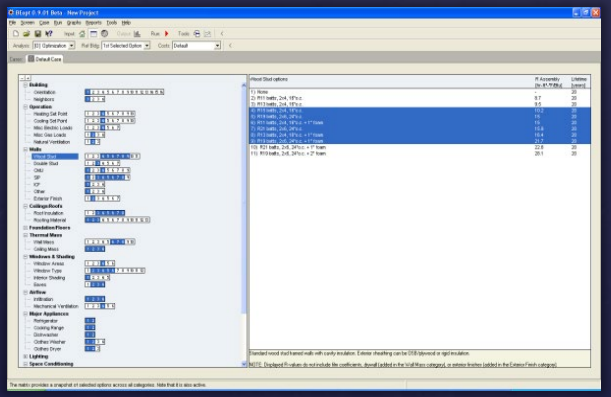
Geometry



Site

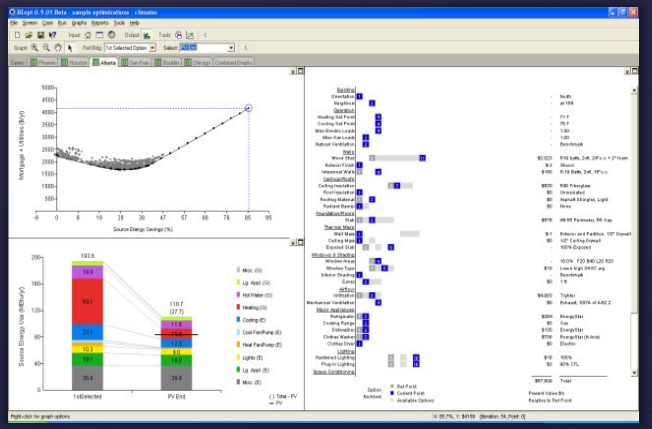


Options

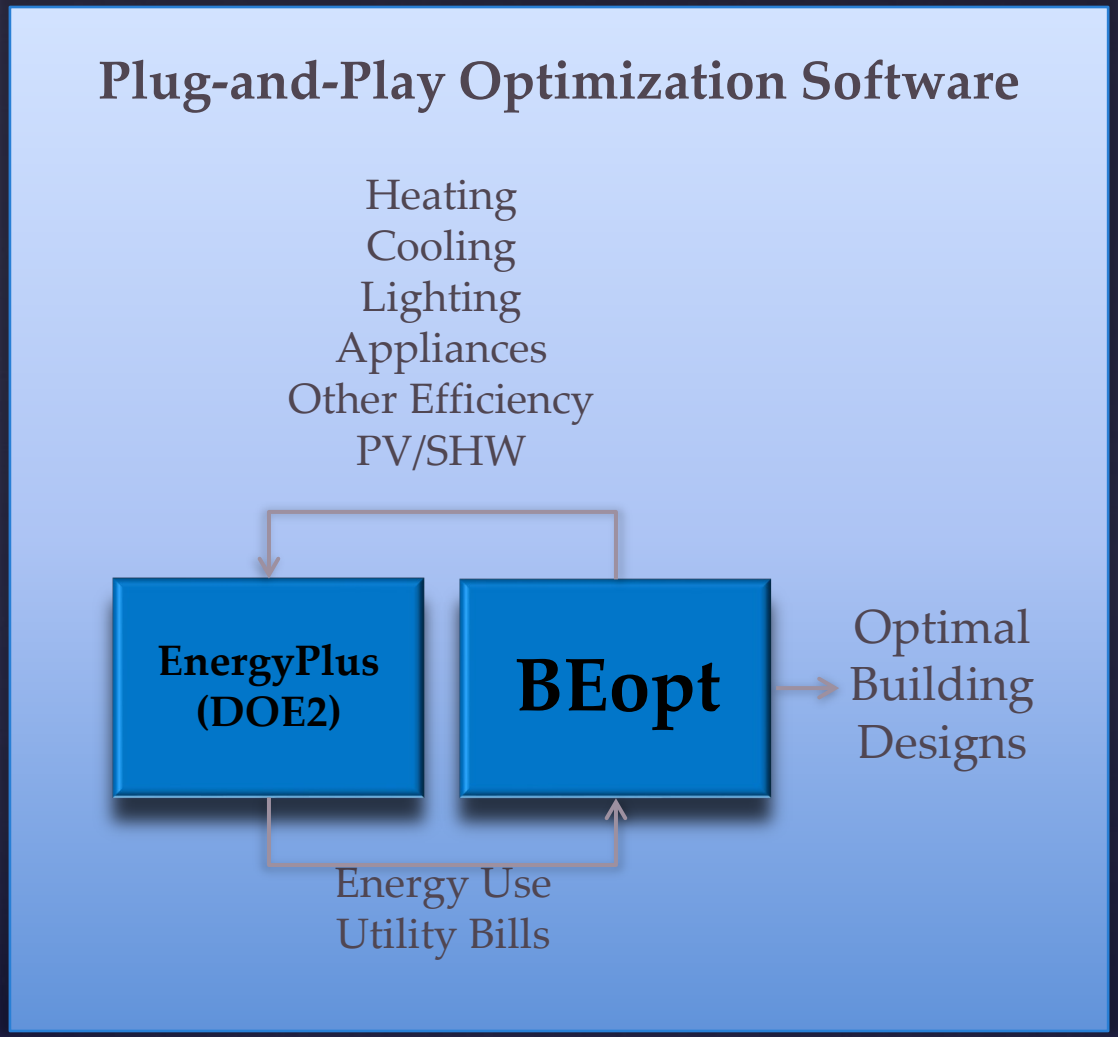


Run

Output



BEopt (Building Energy Optimization)



Features:

- Design, parametric, optimization
- New construction and retrofit
- Detailed cost database
- Rapid building drawing tool
- Detailed utility rates (tiered, time-of-use, real-time pricing)
- PV compensation (net-metering, feed-in tariffs)
- Utility cost effectiveness tests
- PV/efficiency incentives
- Demand response
- HPXML export
- Schedule wizard
- Output visualization
- Metrics: LCC, NPV, SPP, LCOE, CO2
- Batch simulations
- Library manager
- …

Data Acquisition

Table 4. Measurements and Components of the Data Acquisition System

Measurements	Component	Make	Model
Electrical Energy Measurements			
PV energy production Baseboard electric heaters Hard-wired lights Kitchen range Ventilation system Solar pump Space and water heating controls All other loads	Pulse output Watt-hour transducers	Continental Controls	Wattnode WNA-1P-240-P
NG Measurements			
Space heater Backup water heater	Diaphragm NG meters with pulse output	American Meters	AM250TC
Indoor and Water Temperatures			
Living room North bedroom Southeast bedroom Cold water supply Solar tank Solar—water to collectors Solar—water from collectors Solar—water to backup heater Hot water supply to house	Type T thermocouples	Omega	FF-T-20S-TWSH
Water Flow			
Hot water use	Water meter	Omega Engineering	FTB-6107-A-PS
Weather-Related Measurements			
Outdoor temperature and relative humidity	T&RH sensor with shield	Campbell Scientific	CS500-L and 4020
Solar radiation—horizontal	Pyranometer	Li-Cor, Inc.	LI-200SZ
Solar radiation—plane of collectors	Pyranometer	Li-Cor, Inc.	LI-200SZ
Data Logging Equipment			
	Logger	Campbell Scientific	CR-10
	Thermocouple multiplexer	Campbell Scientific	AM25T
	Switch closure multiplexer	Campbell Scientific	SDM-SW8A
Communications			
	Cell phone modem	Redwing	Airlink 100

Lori Vaclavik,
Executive Director
Habitat for Humanity
of Metro Denver

U.S. Secretary of Energy Samuel W. Bodman kicks Off Energizing America for Energy Security Tour


4100
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