10 DEEP RETROFIT CASE STUDIES

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Defining Deep Energy Retrofit (DER)

Upgrading/remodeling existing homes to reduce energy consumption by 75%

- Need before and after energy bills (half our homes did not)
- No changes in occupancy, size or use (e.g., home offices)

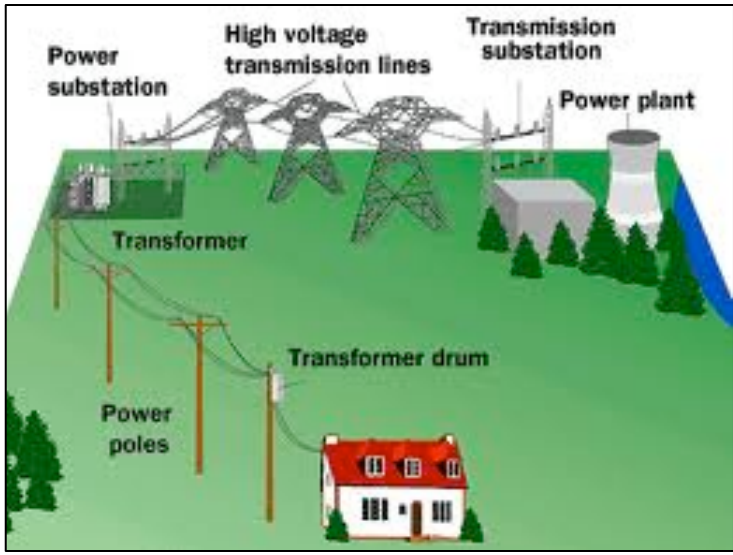
OR

Using less than a threshold value of energy

- E.g., Affordable Comfort Thousand Home Challenge option B:
  - energy use for a household includes number of occupants, house size and local climate

Assessing Performance of DER

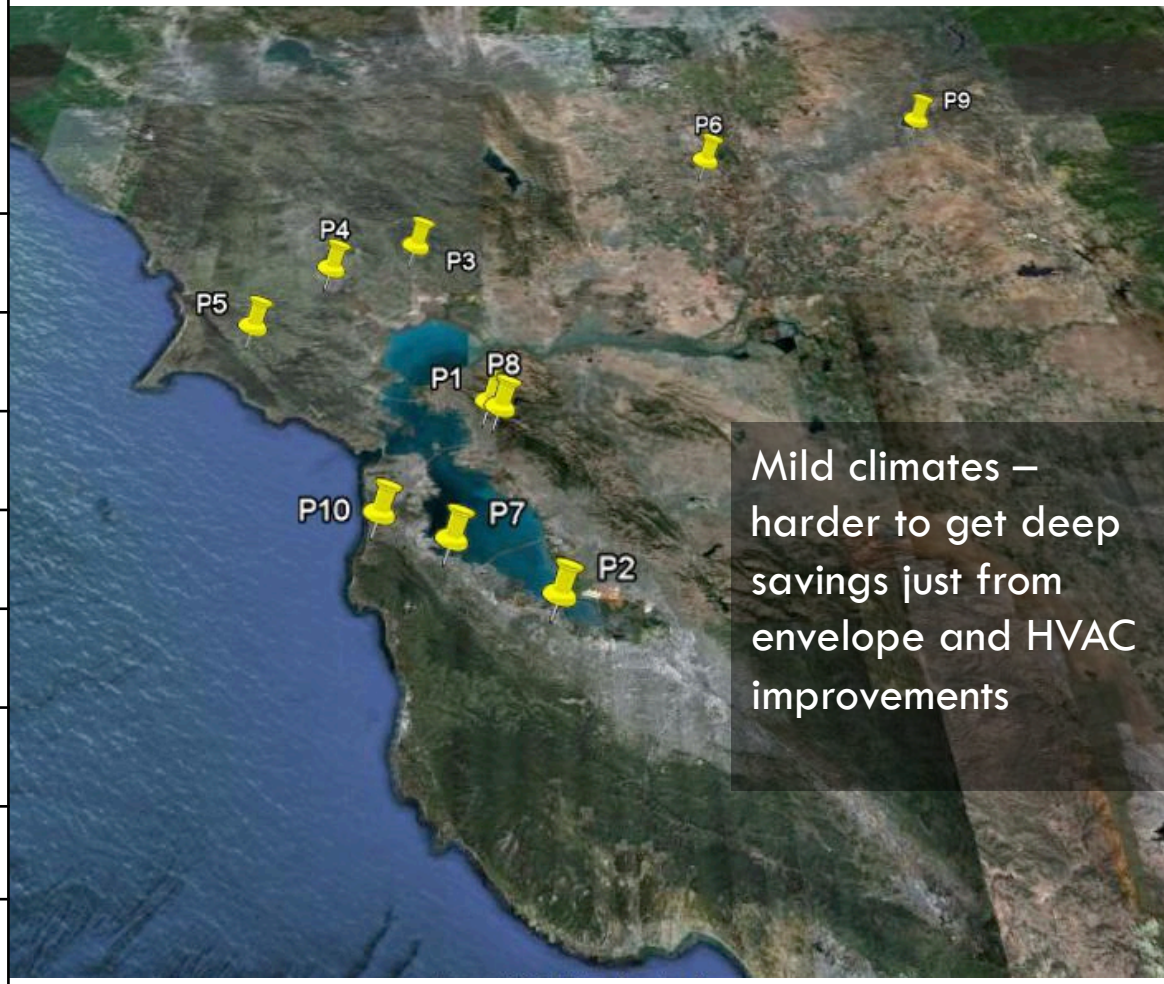
- **Site energy performance is the primary metric used in DES. Other metrics maybe more appropriate when considering global or societal benefits.**
- **The metric used in project planning and assessment has a major impact on the measures implemented and the results achieved.**
- Three ways to look at energy:
  - ***Site energy*** (billed energy use)
  - ***Source energy*** (accounts for hidden losses, conservation of resources and societal benefit)
  - ***Carbon dioxide equivalent emissions*** (environmental impact)
- Three ways to normalize:
  - House (closest to energy bill)
  - Person (societal)
  - Square Foot (perversely encourages higher consumption – not recommended)



http://science.howstuffworks.com/environmental/energy/power.htm

Project Summaries & Location

Project ID	Floor Area Pre / Post (sq ft)	Number of Occupants Pre / Post	HERS Index (Post)
P1	960 / 1630	2 / 4	72
P2	2780 / 2780	NA / 2	55
P3	1937 / 2357	NA / 1	25
P4	1540 / 2510	2 / 2	36
P5	800 / 905	NA / 3	86
P7	3136 / 3288	2 / 2	76
P9	3114 / 3114	NA / 4	72
P10	1503 / 1706	2 / 2	25

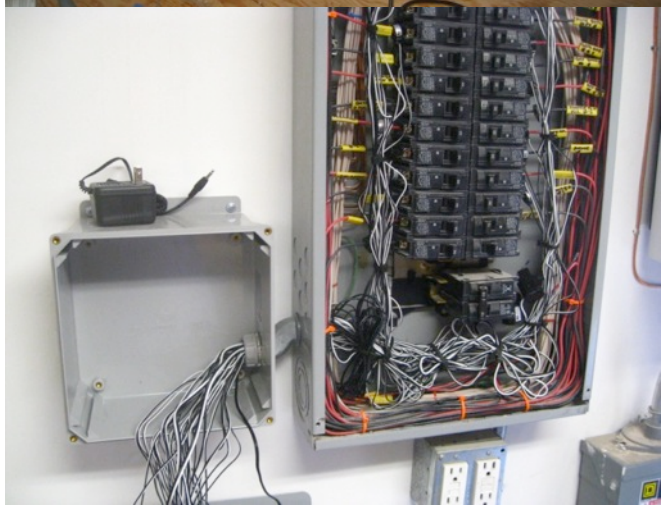


Four Approaches

1. Passive or NZE Home (P1, 3)
   - Extensive rebuilding
2. Old home – New Home (P2, 4, 5, 6, 7, 8, 10)
   - Bring home up to current energy code
3. Newer home – fixing construction failings (P9)
   - Bring home up to current energy code
4. Energy Aware Occupants (P4, 7, 9)
   - Good envelope + HVAC = big influence of occupant behavior/awareness

Monitoring

- Monitor all significant end uses at the electrical panel & gas appliance, avoiding any intrusion on living space
- Provide real-time feedback to occupants – web-based: “Check-it”
- Real-time access to data to facilitate detection of faults, communication failures, changes in load profile, etc.
- Wireless communication- no clutter in the home
- One minute resolution that allows precise characterization of load profiles



	P1	P2	P3	P4	P5	$P6_N$	$P6_S$	P7	P8	P9	P10
Building Enclosure											
Super Insulated (100% > T-24)			X			X	X				
Highly Insulated (50% > T-24)	X				X						
Insulated (Meets T-24)		X		X				X	X	X	X
All Triple Pane Glazing			X								
All Double Pane Glazing	X	X		X	X	X	X			X	X
Passive House Standard <0.6 ACH_{50}			X								
R-2000 Standard <1.5 ACH_{50}	X		X								
Energy Star V. 3 <5 ACH_{50}	X		X		X					X	
HVAC											
Heat/Energy Recovery Ventilation	X	X	X		X						
Electric Resistance Heating	X				X						
Heatpump Heating and Cooling		X	X								
A/C with Evaporative Cooling										X	
Solar Thermal Combisystem			X						X		X
Night Ventilation Cooling				X		X	X			X	
DHW											
Electric Resistance					X						
Heatpump		X									
On Demand Condensing Natural Gas	X			X				X			
Tank Natural Gas										X	
Solar Thermal w/ Condensing N. Gas Backup			X			X	X		X		X
User Behavior											
Baseload Below 225 Watts	X			X	X	X	?	X		X	X
Baseload Above 225 Watts		X	X						X		
Renewable Energy											
PV		X	X	X		X	X		X		X
Solar Thermal			X			X	X		X		X

P1 Project Description

1904 Craftsman Bungalow

Berkeley, CA

Pre: 960ft^2 ⟹ Post: 1,630ft^2

- Original home – no insulation, 1 natural gas floor heater on the 2nd level
- House raised, & the ground floor rebuilt to legal height
- Project guided by European *Passive House* principles
- 4 bedrooms, 2 baths, 4 occupants, home office

P1	Pre-Retrofit	Post-Retrofit
ENVELOPE		Code Compliant
Wall Insulation	None	1st floor: 5.5" cellulose - R19 2nd floor: 3.5" cellulose; 2" ext. XPS - R23
Attic/Roof Insulation	Some fiberglass	10" cellulose in attic floor- R38
Foundation Insulation	None	1" XPS slab perimeter - R5 3" Polyiso over slab with thermally broken wooden sleepers - R21
Windows	Single pane wood frame, double hung	2-pane, Low E, argon, wood frame – U-0.3, SHGC-0.35, VT- 0.54
Air Leakage		271 CFM_{50}, 0.0634 CFM_{50}/SA, 1.1 ACH_{50}
MECHANICAL		
Cooling	None	None
Heating	Gas floor furnace, ~60% efficient, on 2nd floor, no dist.	Electric resistance baseboard heaters in each room
DHW	40-gal gas tank in garage	Gas tankless, 0.84 EF. 11-199 kBtu/hr.
Ventilation	Natural	ERV SER 81-83%, exhausts: bath & kitchen, supplies: living room & bedrooms
Distribution	None	R6, foil faced flex duct for ERV
LIGHTS/APP/MEL	All incandescent lights, old appliances	100% CFL lights, new Energy Star appliances, small home office

Doesn't meet PH spec

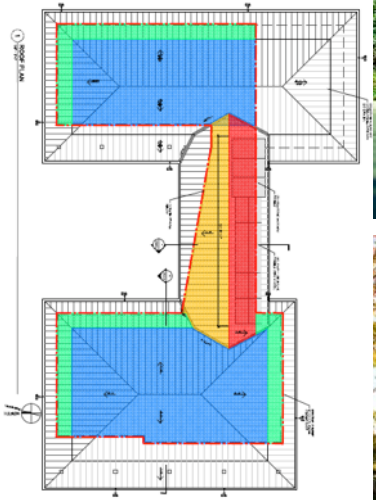
Cheap & easy – no existing FA

P3 Project Description

Check out the additional THC webinar hosted by PG&E about this project on 5/2

Two 1958 ranch-style homes connected by a covered breezeway

Pre: 1,933 ft^2 ⇨ Post: 2,342 ft^2



- The two structures were connected by forming a u-shaped home with a central courtyard
- 3 bedrooms, 2 baths, 1 occupant, home office

P3	Pre-Retrofit	Post-Retrofit
ENVELOPE		
Wall Insulation	None	1: 3.5" dense-pack fiberglass, 5" EPS - R38 2: 5.5" dense-pack fiberglass, 2.5" EPS - R33
Roof Insulation	Vented attic, R19 batt insulation	15" blown fiberglass, 2.5" EPS -R68
Foundation Insulation	None	Slab edge: 3.75" rockwool -R16 1: 4.5" EPS - R19 2: 1.5" EPS, .6" Aerogel - R12.5
Windows	U: 1.2 SHGC: 0.8	3 pane, wood frame U: 0.125, SHGC: 0.53
Air Leakage		151 CFM_{50}, 0.0186 CFM_{50}/SA, 0.48 ACH_{50}
MECHANICAL		
Heating & Cooling	Gas boiler, air handler with hydronic coil	Mini-split heat pump, solar hydronic coil on ERV
DHW	Gas tank, 0.58 EF	(3) 4'X6' solar thermal panels, 80-gallon insulated storage tank, gas tankless backup 0.82 EF
Ventilation	Kitchen & bath exhaust	ERV SER 81-83%, exhausts from bath & kitchen, supplies living room & bedrooms
Distribution	R4 ducts in attic	Ducted ERV, all within thermal envelope
LIGHTS/APP/MELs	All incandescent lights, old appliances	CFL & LED lights, new Energy Star appliances, 2nd refrigerator
RENEWABLES	None	2.15 kW PV, 3 solar thermal panels

Passive House = way beyond new house

Super tight

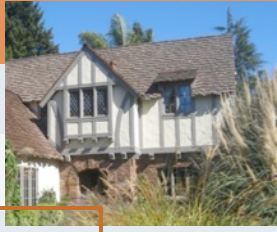
P2 Project Description

1936 English Tudor

Revival-Style Home
Palo Alto, CA

Pre: 2,780 ft^2 ⟶ Post: 2,780 ft^2

- Due to architectural significance, efforts made to maintain historical character throughout project
- 5 bedrooms, 3 baths, variable occupancy, home office



P2	Pre-Retrofit	Post-Retrofit
ENVELOPE		
Wall Insulation	None	3.5” cellulose - R13
Roof Insulation	None *Not quite code*	6.5” open cell spray foam - R23
Foundation Insulation	None	6.5” open cell spray foam - R23
Windows	Single pane, steel frame	2 pane, low E, argon - interior storm windows, values unknown
Air Leakage		2,260 CFM_{50}, 0.325 CFM_{50}/SA, 5.7 ACH_{50}
MECHANICAL		
Heating, Cooling, & DHW	Natural gas furnace, 40-gal gas tank DHW heater	3-ton air to water heat pump, EER 9-12, variable speed compressor *Very complex!*
Ventilation	Natural	2 air handlers, integrated HRVs -continuous ventilation, bath exhaust fans
Distribution	None	R6, foil faced flex duct in sealed & conditioned attic & basement
LIGHTS/APPLIANCES/MEL	All incandescent lights, old appliances	CFL, halogen & LED lights, new Energy Star appliances
RENEWABLES	None	4.3 kW PV

P4 Project Description

1000 Home Challenge

1940's Bungalow
Petaluma, CA

Pre: 1,540 ft^2 ⟶ Post: 2,510 ft^2

3-phase retrofit

1 - 1998 prior to moving in

2 - 2004 added renewable energy

3 - 2010 a structural/seismic retrofit

- Phase 4 - Planning to reach net-zero carbon
- 1st home to officially meet THC in CA!
- 2 bedrooms, 2 baths, 2 occupants, home office

P4	Pre-Retrofit	Post-Retrofit
ENVELOPE		
Wall Insulation	None	1: 5.5” dense pack cellulose - R19 2: 3.5” dense pack cellulose - R13
Roof Insulation	None	12” loose fill cellulose - R-43
Foundation Insulation	None	Stem wall: 1.5” XPS - R7 exterior
Windows	1- pane aluminum frame	2-pane, Low E, argon filled, fiberglass frame U: 0.32
Air Leakage		1,983 CFM_{50}, 0.322 CFM_{50}/SA, 5.4 ACH_{50}
MECHANICAL		
Heating & cooling	Gas furnace, 40% eff	Condensing gas furnace, variable speed fan, 2-stage gas valve, 96.1 AFUE, 200 ft^2 of SolarWall with 500 CFM supply fan
DHW	Gas tank, 0.58 EF	Condensing gas tankless, .80 EF, demand recirc pump
Ventilation	Kitchen exhaust, vented to inside	Bath & kitchen exhaust, natural vent stack; SolarWall 500 CFM fresh air supply fan
Distribution	Sheet metal ducts	Manual central dampers added to ducts, supply leakage: 61CFM; return leakage: 99 CFM
LIGHTS/APPLIANCES /MELs	All incandescent lights, old appliances	CFL & LED lights, top 10% Energy Star appliances
RENEWABLES	None	2.5 kW PV

P5 Retrofit Description

1920's 2-bedroom house

Pt. Reyes Station, CA

Pre: 800 ft^2 ⟹ Post: 905 ft^2

- Community Land Trust Association of West Marin (CLAM) bought the property & funded the retrofit to rent to "very low-income households"
- 2 bedrooms, 1 bath, 3 occupants

P5	Pre-Retrofit	Post-Retrofit
ENVELOPE		
Wall Insulation	3.5” fiberglass batts	3.5” cellulose, 1” ext XPS - R18
Attic/Roof Insulation	Some fiberglass batts	16” loose fill cellulose - R57
Foundation Insulation	R-19 fiberglass batts	Sealed crawl space, 11.5” blown cellulose in floor framing - R41
Windows	Single pane aluminum frame	2-pane, Low E, argon filled, fiberglass frame. Unknown values
Air Leakage		292 CFM_{50}, 0.097 CFM_{50}/SA, 2.4 ACH_{50}
MECHANICAL		
Heating	Wood fireplace	Electric wall radiators
DHW		40-gal. electric tank; EF 0.88
Ventilation		Bath & kitchen exhaust, point source ERV
LIGHTS/APPLIANCES/MEL		Mostly CFL, very low MELs

P6 Retrofit Description

1932 / 1934 Ranches
Davis, CA
North – 1462 ft²
South – 1496 ft²

•Two existing homes were moved to a nearby site.
•2x stud wall homes with solar thermal are occupied by members of local co-housing association.
•North-5 bedroom, 1 bathroom, 5 occupants
•South-3 bedroom, 1 bathroom, 3 occupants

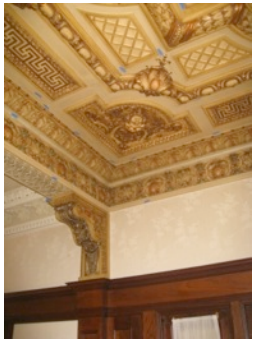
P6	Pre-Retrofit	Post-Retrofit
ENVELOPE		
Wall Insulation	None	7” cellulose – R25
Roof Insulation	Some fiberglass batts	13” loose fill cellulose – R44
Foundation Insulation	None	Sealed crawlspaces, 2” rigid XPS interior stem wall, 6” low density spray foam at rim joist
Windows	Single pane aluminum frame	North - 2 pane, Low E, argon filled, fiberglass frame U: 0.33 SHGC: 0.18 South – Refabbed existing windows with 2nd pane
Air Leakage		North - 991 CFM50, 5.1 ACH50 South – 1114 CFM 50, 5.6 ACH50
MECHANICAL		
Heating and cooling		Direct vent, gas fireplace
DHW		North – Solar thermal preheat, condensing gas tankless South—Integrated storage solar thermal preheat, condensing gas tankless
Ventilation		Bath and kitchen exhaust, Whole house fan
Distribution		none
LIGHTS/APPLIANCES/MEL		Mostly CFL
RENEWABLES		PV to be installed 2012

P7 Project Description

1910 Craftsman San Mateo, CA

Pre: 3136ft^2 ⟶ Post: 3288ft^2

- House within a house concept, using kitchen and rear zone as primary living space in winter. Insulated entire home, maintaining architecturally significant interiors, increased comfort and hope to achieve 1000 home challenge with future PV installation.
- 3 bedroom, 2.5 bath, 2 Occupants



P7	Pre-Retrofit	Post-Retrofit
ENVELOPE		
Wall Insulation	None	Rear Zone: 5.5" BIB, 1" polyiso – R23 Upstairs: 3.5" blown fiberglass – R13 Downstairs: None
Roof Insulation	Some fiberglass batts	5.5" BIB, 2" polyiso – R36 Rear Zone Ceiling: 7.5" BIB – R30
Foundation Insulation	None	2" Polyiso under floor joists – R12.9
Windows	Single pane aluminum frame	Rear Zone: 2 pane, Low E, argon filled, fiberglass frame - U: 0.28 SHGC: 0.27 Rest of House: Old, leaky double hung wood frame, single pane
Overall UA value		
Air Leakage	8432 CFM50	5336 CFM50, 10.8 ACH50 ***Mostly not sealed***
MECHANICAL		
Heating and cooling	119kBtu/hr gas furnace AFUE 75-80%	(2) 26-40kBtu/hr gas furnaces, three stage variable speed blower, 95% AFUE
DHW	Tankless gas heater & 40 gal	Condensing Gas Tankless with 2 gal??? integrated storage tank

P8 Project Description

1915 Craftsman Bungalow
Oakland, CA

Pre: 1440ft^2 ⟹ Post: 1440ft^2

- Super Green Retrofit– LEED Platinum rated, greywater, rainwater, sustainable materials and landscaping, low flow fixtures + energy efficiency
- 3 bedroom, 1.5 bath, 4 Occupants

P8	Pre-Retrofit	Post-Retrofit
ENVELOPE		
Wall Insulation	None	3.5” blown cellulose – R13
Roof Insulation	Some fiberglass batts	4” closed cell spray foam – R 28
Foundation Insulation	None	Fiberglass batts – R19
Windows	Single pane wood frame	Most windows replaced with 2 Pane, Low E, Argon, fiberglass frame – U: 0.33 SHGC: 0.3
Overall UA value		
Air Leakage		2397 CFM50, 9.3 ACH50 ***Too leaky?***
MECHANICAL		
Heating and DHW	Old gas furnace with 2 floor grills, gas tank DHW	3 panel solar thermal Combi system with 96% efficient condensing gas boiler, 120 gal storage tank, hydronic baseboard radiators, zone controlled
Ventilation	None	Bath and kitchen exhaust
Distribution	Sheet metal	Insulated Pex
LIGHTS/APPLIANCES/MEL	Old, inefficient	New, highest efficiency, CFL & LED lighting, 2nd Refrigerator in garage
RENEWABLES	None	2.7 kW PV

P10 Project Description

1000 Home Challenge

1938 Cottage

Pacifica, CA

Pre: 1,440 ft^2 ⟶ Post: 1,745 ft^2

- Family-built "Shamrock Shack" remodeled for retirement with goals of resource & energy efficiency, while maintaining original charm with modern comforts
- 2 bedrooms, 1.5 baths, 2 occupants

P10	Pre-Retrofit	Post-Retrofit
ENVELOPE		
Wall Insulation	None	3.5” LD spray foam - R13 5.5” LD spray foam in garden room - R19
Roof Insulation	None	7.5”- 9.5” LD spray foam - R25-R32 ***not quite code***
Foundation Insulation	None	4.5”- 6” LD spray foam - R16-R22
Windows	Single-pane wood frame	Most windows replaced with 2-pane, Low E, argon, alum. clad; U: 0.29-0.34 SHGC: 0.23-0.32
Air Leakage		1,455 CFM_{50}, 0.288 CFM_{50}/SA, 6.1 ACH_{50} ***Not tight enough?***
MECHANICAL		
Heating & DHW	Wood fireplace	Woodstove, 75% thermally efficient; 2-panel solar thermal combi system with 96% efficient condensing gas boiler, 120-gal storage tank, zone controlled underfloor hydronic
Ventilation	None	Bath & kitchen exhaust
Distribution	None	Insulated PEX
LIGHTS/APPLIANCES/ MEL	Old, dark, inefficient	Energy Star appliances, CFL, LED & halogen lighting, skylights, & solar light tubes
RENEWABLES	None	3.3 kW PV

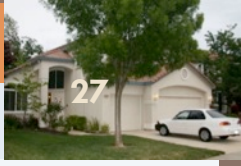
P9 Project Description

1998 Tract Home

Folsom, CA

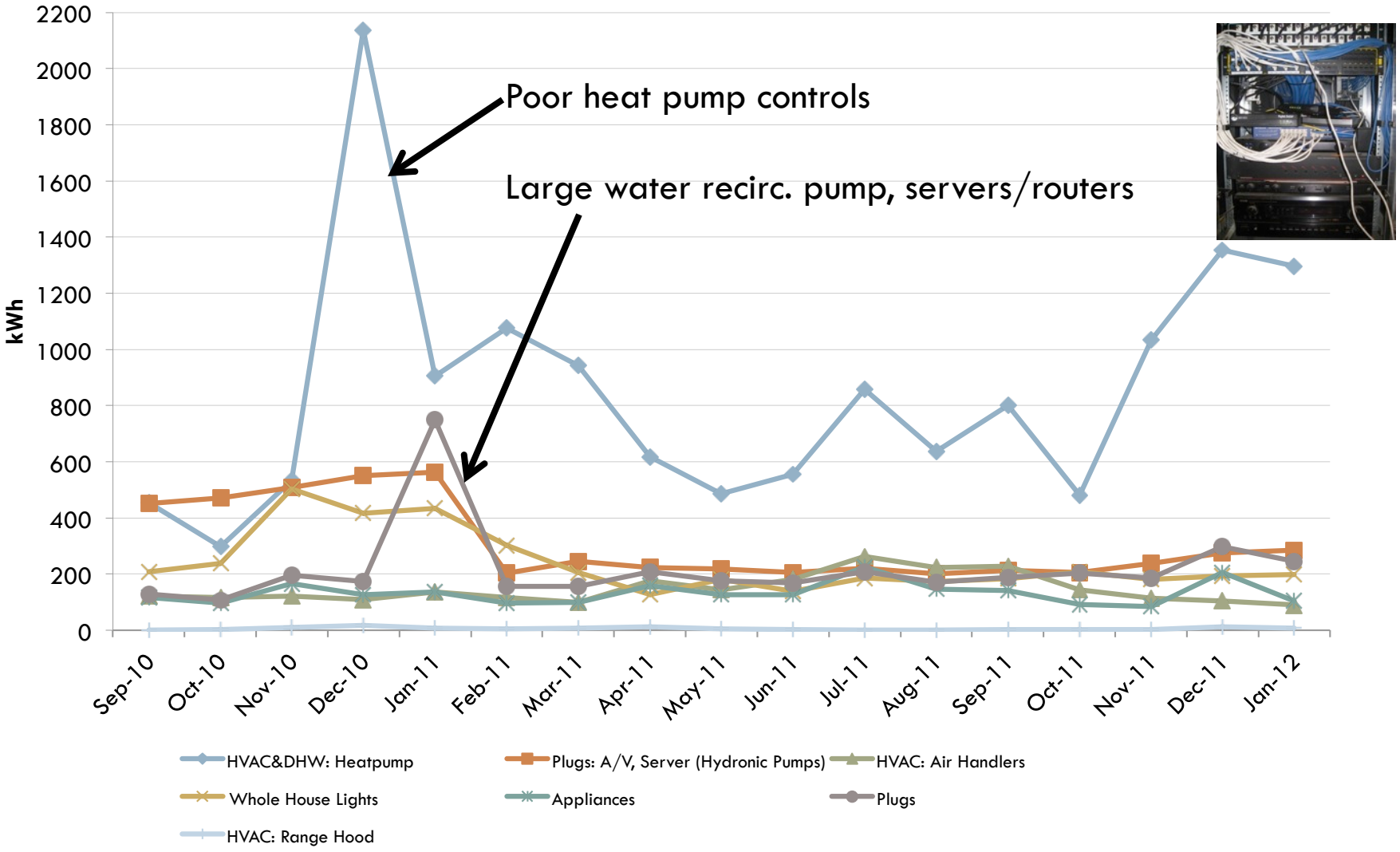
Pre: 2,850 ft^2 ⟹ Post: 2,850 ft^2

- SMUD Advantage home with a significant energy upgrade & a kitchen remodel
- Increased insulation, air sealed, lighting retrofit & an extensive HVAC overhaul
- 3 bedrooms, 2.5 baths, 4 occupants

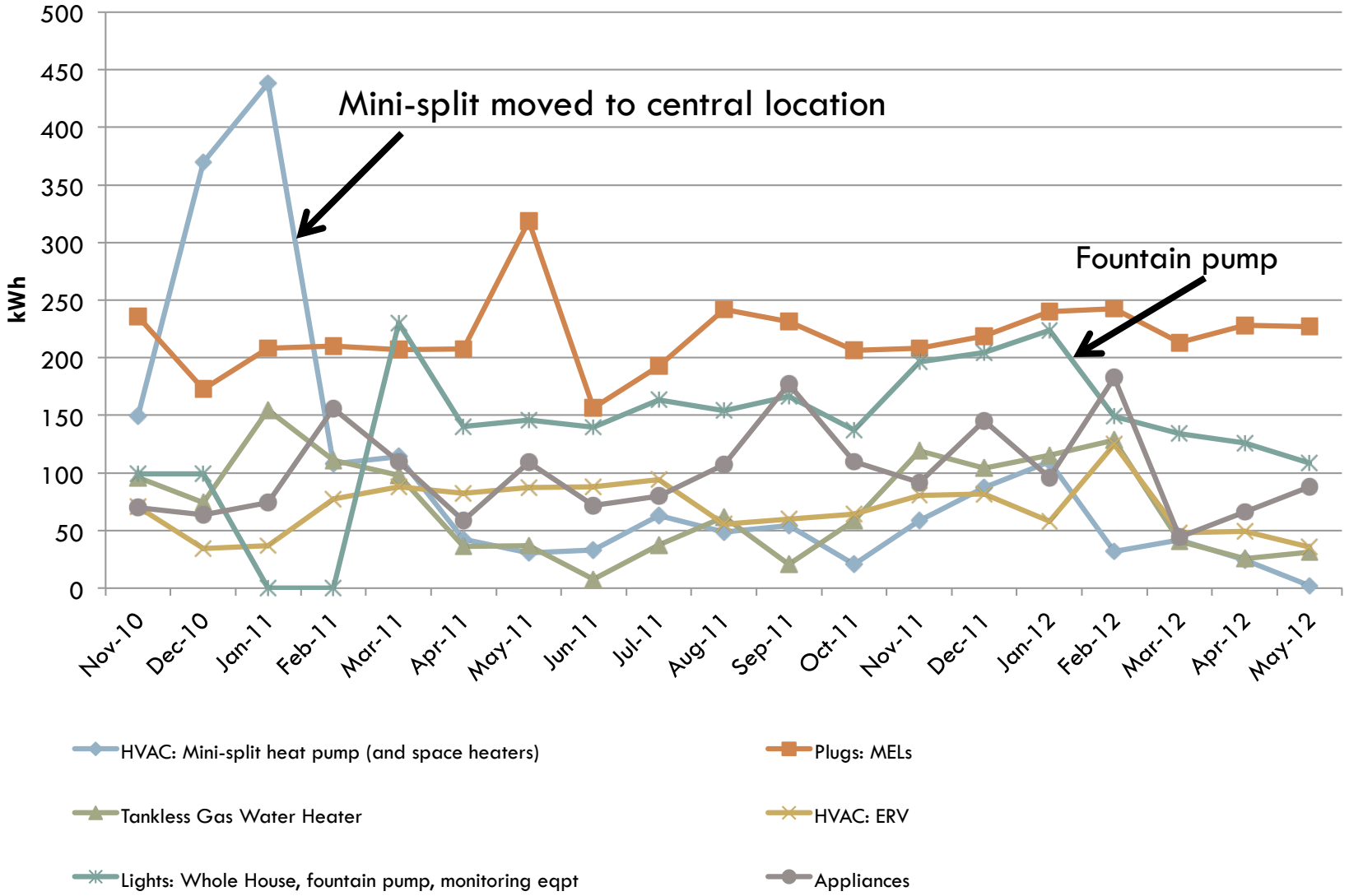


P9	Pre-Retrofit	Post-Retrofit
ENVELOPE		
Wall Insulation	Poorly installed Fiberglass batts -R13	Fiberglass batts - R13, improved installation & air sealed in Kitchen & stairs, insulated attic knee wall
Roof Insulation	Blown fiberglass	Increased to R40
Foundation Insulation	Uninsulated slab on grade	Garage ceiling R-19 batts did not fill joist space, filled with cellulose
Windows	Double pane vinyl frame, Low E	Added interior foam filled plantation shutters
Air Leakage	1,879 CFM_{50}	1,227 CFM_{50}, 0.183 CFM_{50}/SA, 2.44 ACH_{50}
MECHANICAL		
Heating	78 AFUE forced air furnace, 100 kBtu/hr	96 AFUE two-stage condensing furnace, disabled 2nd stage to limit capacity to 35 kBtu/hr
Cooling	Old 3.5 ton, 8 or 10 SEER	2-ton, 17 EER with evaporatively cooled condenser coil, charged refrigerant, replaced txv
DHW	40-gal. gas tank	40-gal. gas tank, insulated, recirc pump
Ventilation	Bath & kitchen exhaust	Night ventilation cooling integrated into 350W air handler. Bath exhaust, range hood
Distribution	R6 foil faced flex duct, unbalanced	Balancing dampers, repositioned ducts, buried in insulation, new return from master bed, jumper ducts, 2” MERV 8 filter, adjustable registers w/curved grills
LIGHTS/APPLIANCES /MELs	Incandescent	11 Watt LED recessed can fixtures, mix of CFL & LED everywhere else, new appliances exceed Energy Star by 10-15%, smart strips on all A/V & computers

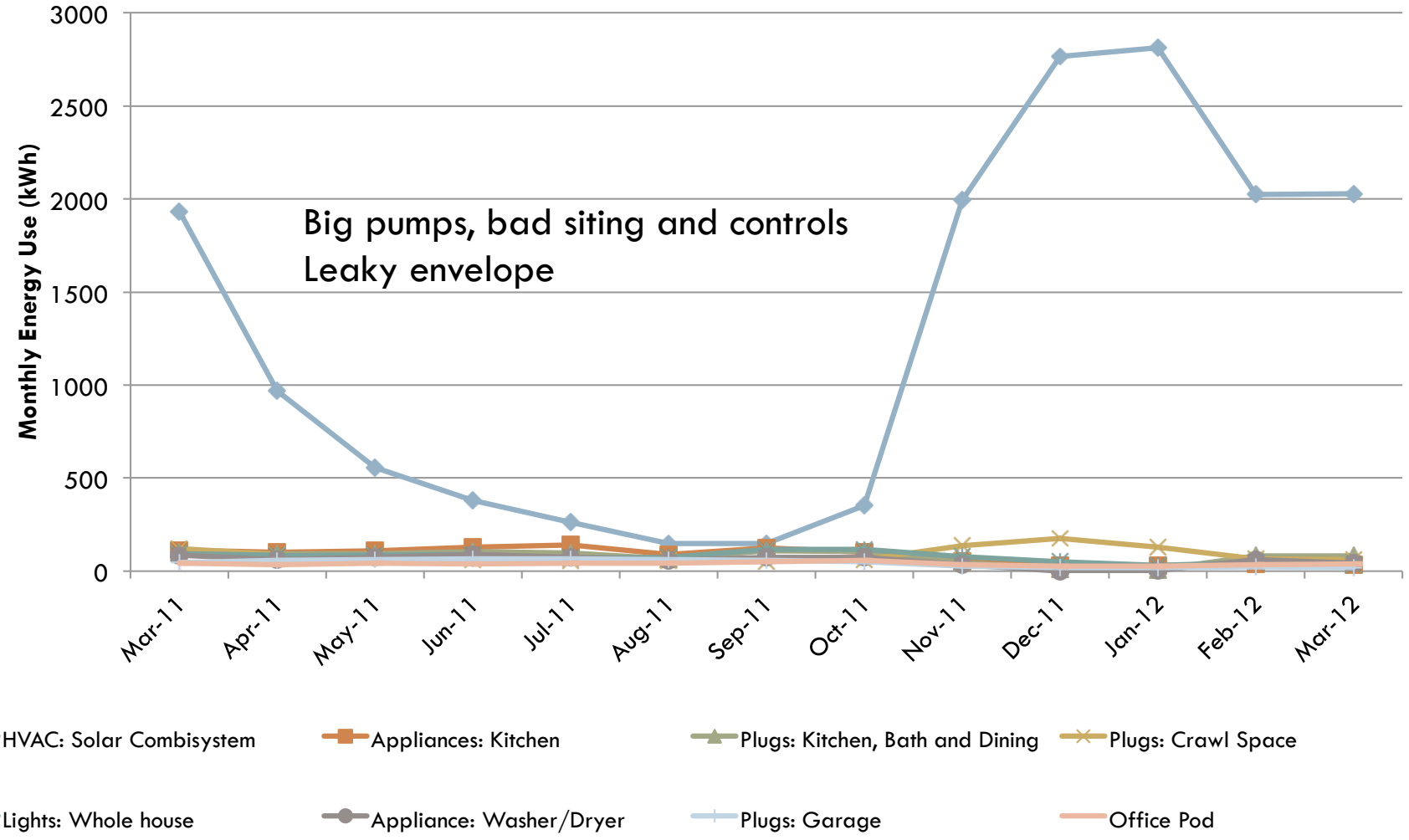
Fixing problems with complex systems



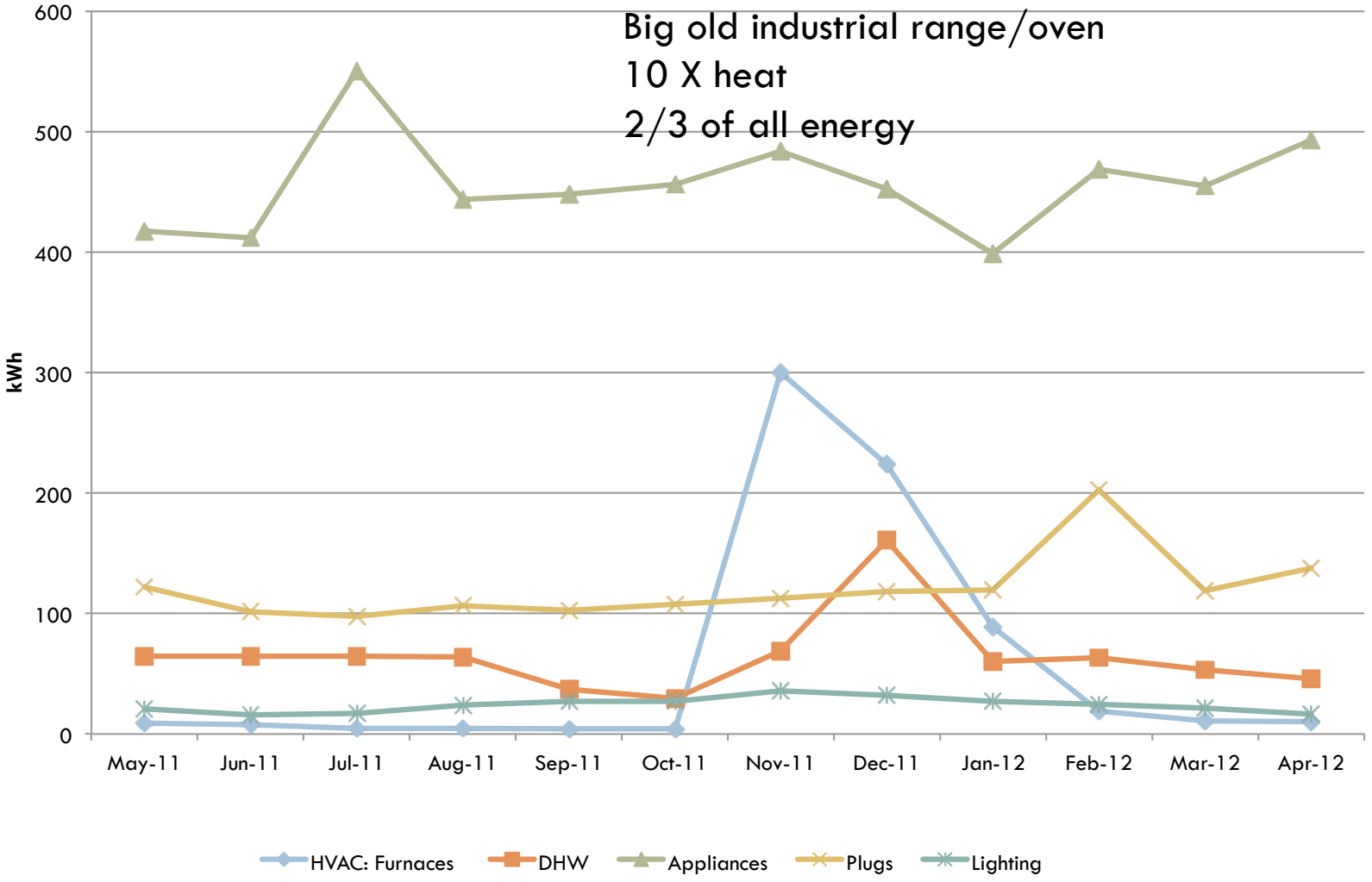
Fixing problems with complex systems & occupant education



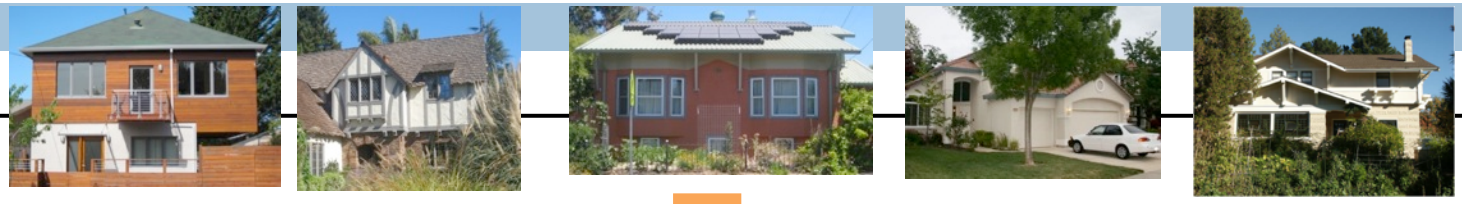
Not Fixing Problems with complex systems



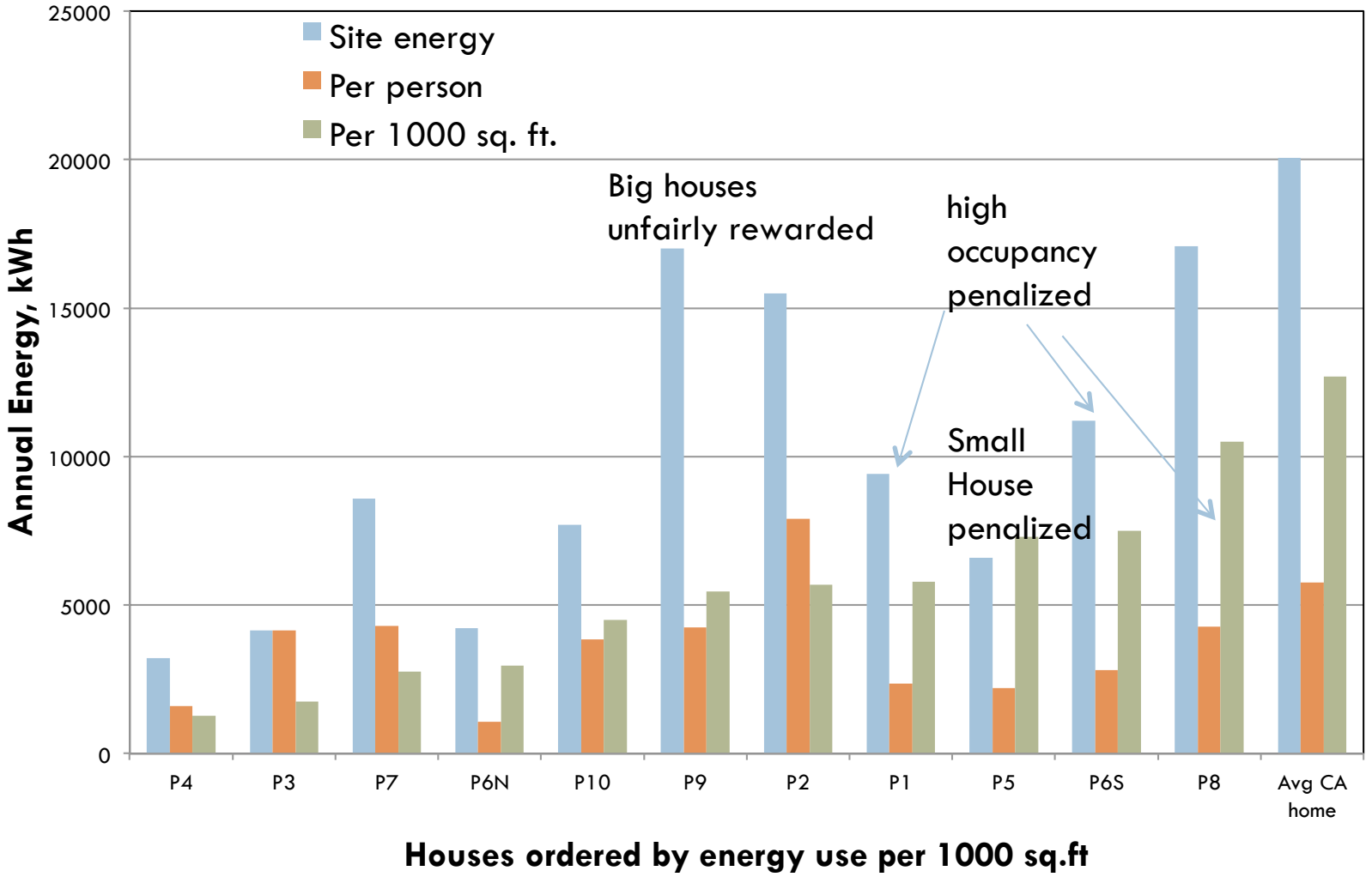
Not replacing old appliances



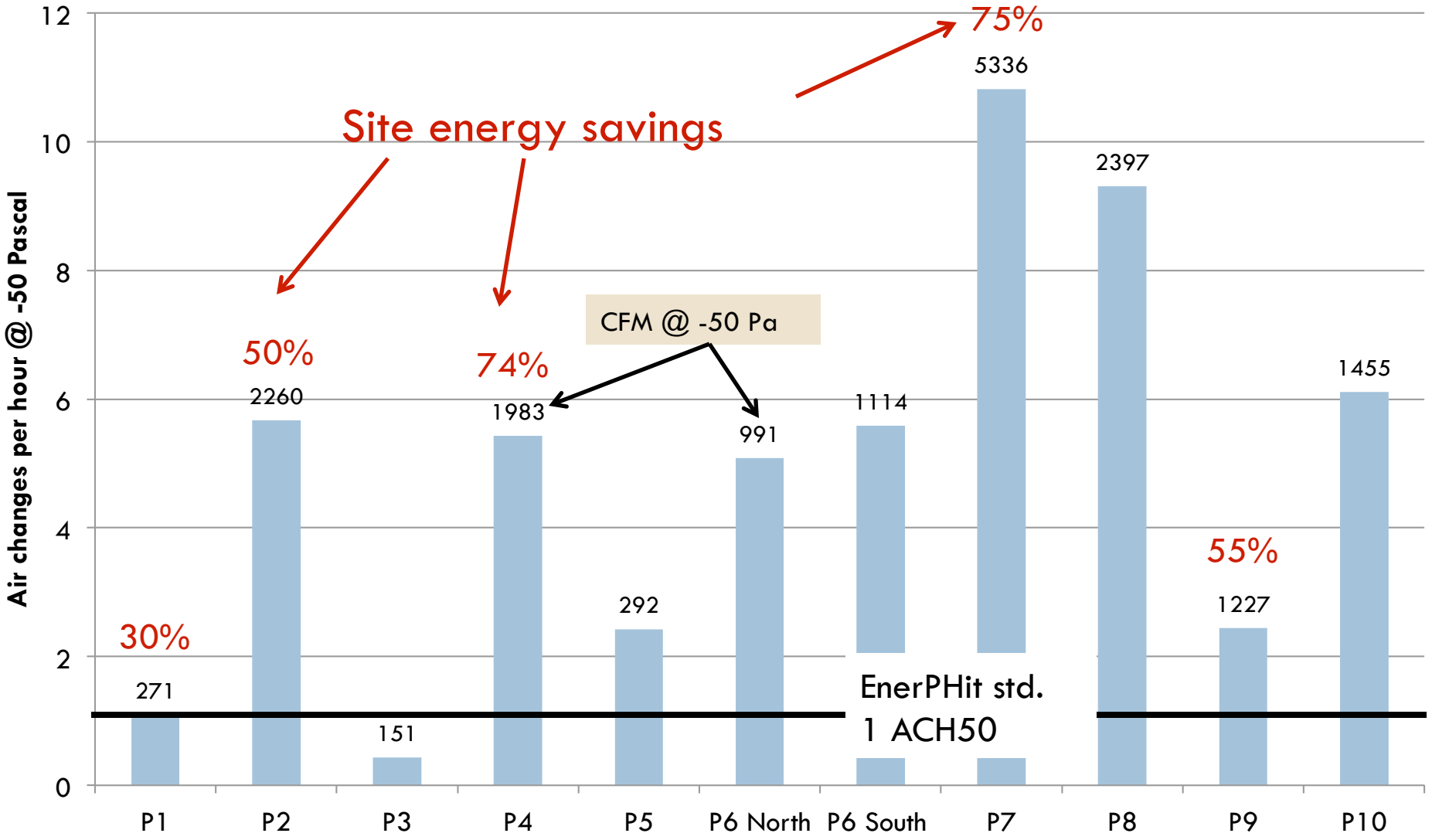
Energy Metric Selection



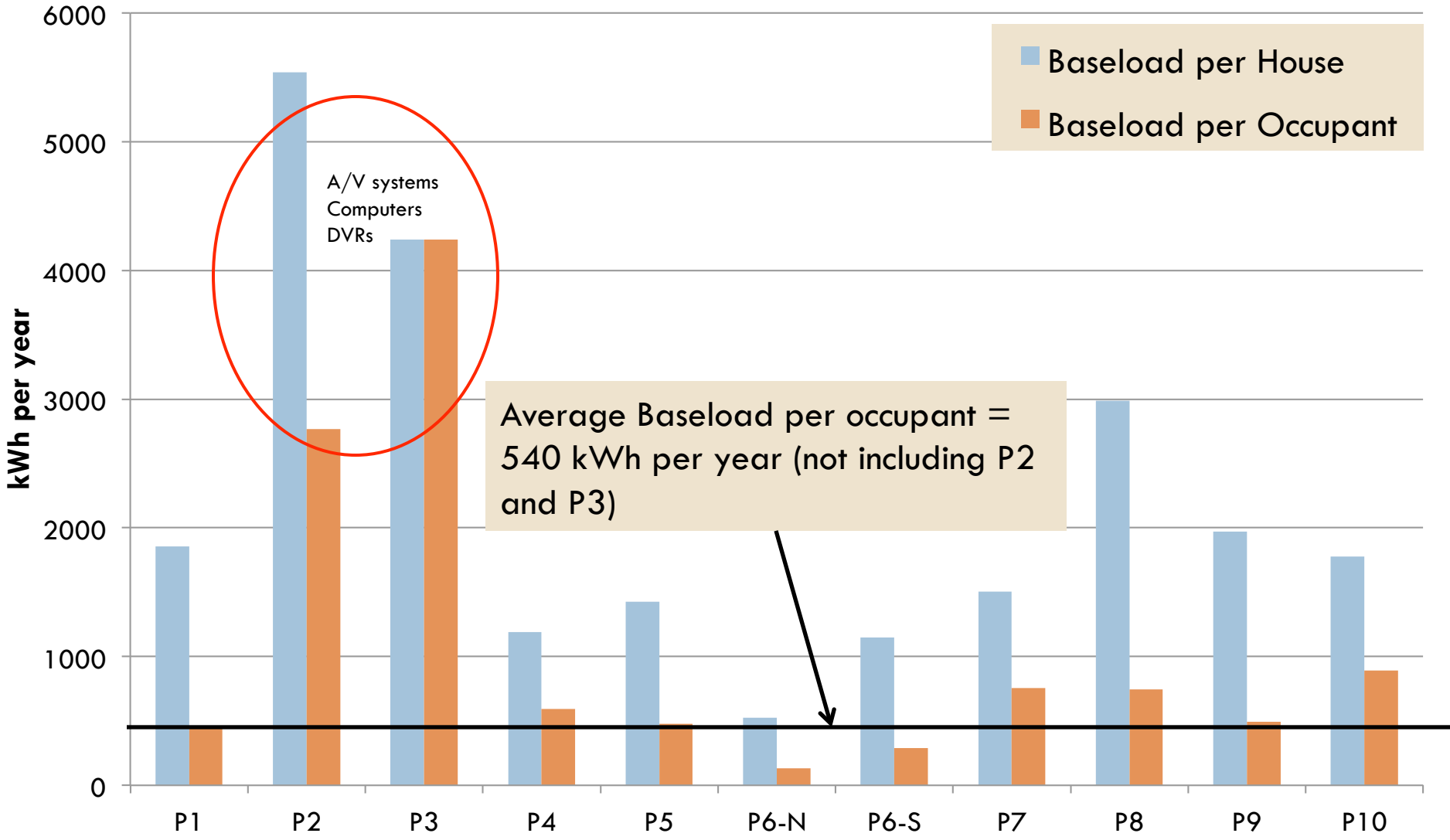
Normalization Metric Selection



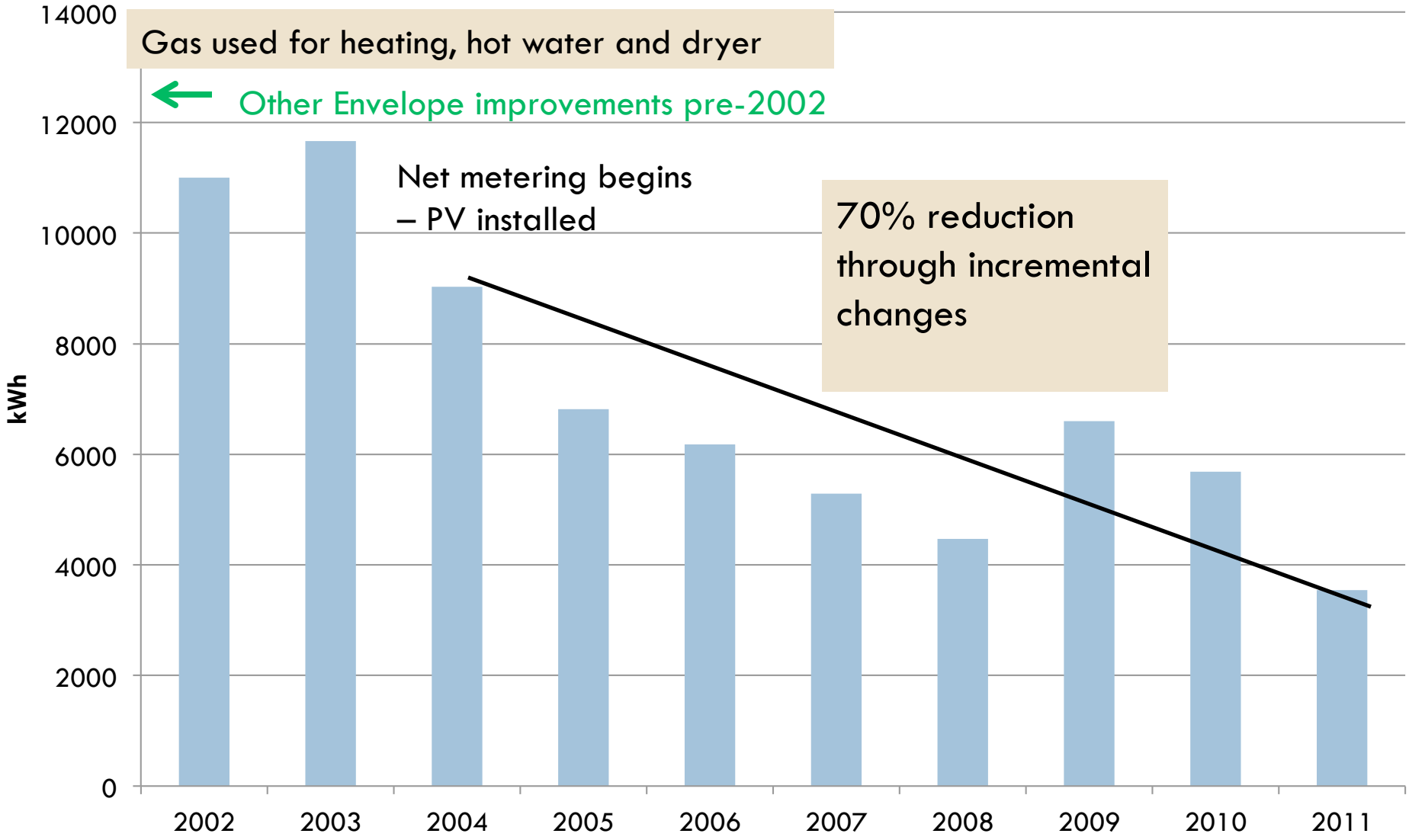
Airtightness of DEU



Average Baseload Comparison, Per House and Per Person



Staged Improvements



Cost – strongly target remodels

- Costs of DES are often quoted as $100K (***total remodel cost***)
- We assessed ***incremental costs*** from a baseline code compliant remodel, not total project costs
- ***Incremental costs*** of these DESs ranged from $10K -$57K
  - Only half houses in study: Unsubsidized PV, complex HVAC, HRV/ERV fully ducted systems, consultants (!)
- High cost, technologically novel or complex approaches not recommended – stick to readily available technology that is also easy and cheap to maintain, replace or repair in the future
- Remodeling Context
  - 20 million remodels each year
  - More than $150B
  - 1% of US households spend >$100k on remodels each year
  - Kitchen remodel costs $64K-$120K

Results & Guidance

- What's your objective?
  - Occupant = lower energy bills = site energy
  - Utilty/Govt. = societal good = source energy or CO2
  - Reduce energy use = per house or per person normalization NOT per square foot
- Keep it simple:
  - Complex/innovative systems led to high energy use and system failure
  - Complex/unusual systems lead to problems that are hard to fix (noone in yellow pages)
  - Going hydronic: combi-systems – had problems matching loads & pump energy – not well understood

Results & Guidance

- The DERs were generally successful:
  - Net-site energy reductions from 35.6% to 75.1%,
  - Net-source reductions from -6% to 90.9%
  - CO2e reductions from 24.6% to 73.5%
- Site energy reductions >60% did not guarantee source energy or carbon performance
  - Be careful about going all electric – causes problems in source energy/CO2
- Heating & DHW still make up the majority (>50%) of annual energy use in most projects
- Occupants surprised at where energy goes – "always on" baseload: second refrigerator and fountain pump in Passive House, computers, A/V, servers, routers
- Ventilation
  - HRV/ERV common - ERVs recirculate moisture – not recommended
  - Not enough kitchen/bath exhaust with HRV/ERV installations
  - Kitchen recirc fans – not acceptable

Results & Guidance

- Aim for compliance with current building energy codes
- Keep it simple: Deep savings achievable with ordinary equipment/ insulation
  - Complex/innovative systems led to high energy use and system failure
  - Complex/unusual systems lead to problems that are hard to fix (noone in yellow pages)
  - Going hydronic: combi-systems – had problems matching loads & pump energy – not well understood
- Always: air seal, insulate, fix windows, upgrade lighting and appliances
- Details, details, details: watch out for: second refrigerator and fountain pump in Passive House, computers, A/V, servers, routers
- Don't require PV or SHW – do them last