Passive House in California

BayREN December Forum

San Rafael, CA, December 10, 2015

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www.essentialhabitat.com

What is Passive House?

- **Rigorous, Voluntary Energy Efficiency Standard**
- **Formalized by European Scientists ~1990**
- **Based on Super-Insulated, Passive Solar & “Low-Energy” Buildings**
- **30,000+ Worldwide: Residential, Commercial, Institutional Buildings**

The Passive House Standard is a rigorous building performance standard. Consultants, projects or building components that have obtained the right to carry the logo have committed themselves to design excellence and the Passive House energy performance criteria.

World’s 1st Passive House
Kranichstein Passive House
Darmstadt, Germany (1990)

1st Passive House in US
Smith House
Urbana, Illinois (2003)

1st Passive House in CA
Tahan Residence
Berkeley, California (2007)

1st Certified Passive House in CA
1st Certified PH Retrofit in US
O’Neill Residence
Sonoma, California (2010)

Passive House in Marin County

The Blue$_1$ House (PH Retrofit)
Community Land Trust of West Marin (CLAM)
Point Reyes Station (2009)

Blue$_2$ (Affordable Rental Housing)
Community Land Trust of West Marin (CLAM)
Point Reyes Station (2010)

James Residence (Staged Retrofit)
Larkspur, CA (2010)

Green Gulch Farm Zen Center (6 Unit Dormitory)
Muir Beach (2011) 1st Certified Multi-Unit PH in US

Passive House in California Code

- Marin County Building Code (2013)
  - Passive House recognized in Marin County Green Building Requirements
- San Francisco Planning Code (2014)
  - Priority processing for Passive House projects

1st Multi-Family PH in California

Sol-Lux Alpha, 4 Net-Zero Condominiums, San Francisco, CA (Under Construction)

How Does Passive House Work?

- Ventilation System is Main System
- Size Building Loads to Fresh Air Supply
- Invest in the Shell, Save on the Equipment

<u>Minimize Losses</u>

<u>Maximize Gains</u>

1. Super-Insulation
2. Air-Tightness
3. Heat Recovery Ventilation
4. Controlled Solar Gains
5. Efficient Equipment, Appliances & Lighting

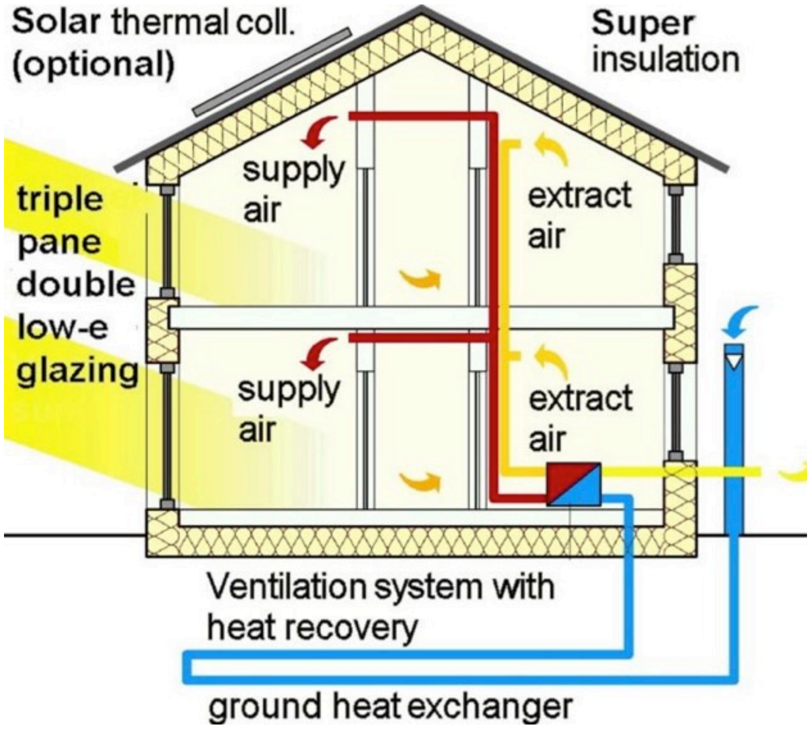
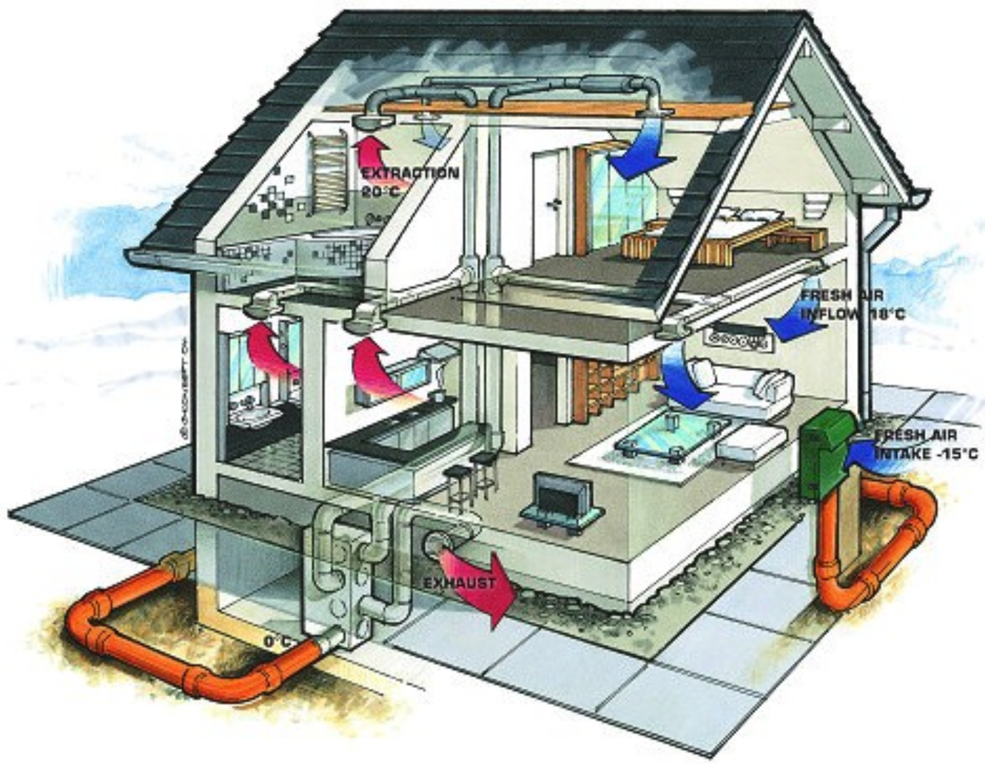


Image Source: Passivhaus Institut (PHI)

Centralized Ventilation

for "Heat Recycling" & Superior IAQ



- Centralized Ventilation
- Air Extracted from "Wet" Rooms
- Air Supplied to Living & Sleeping Rooms
- Balanced & Continuous
- Use Windows in Nice Weather

Image Source: www.greenbuildingstore.co.uk/mvhr.php

Passive House HRVs Recover 8-15x Their Electrical Use (PHI)

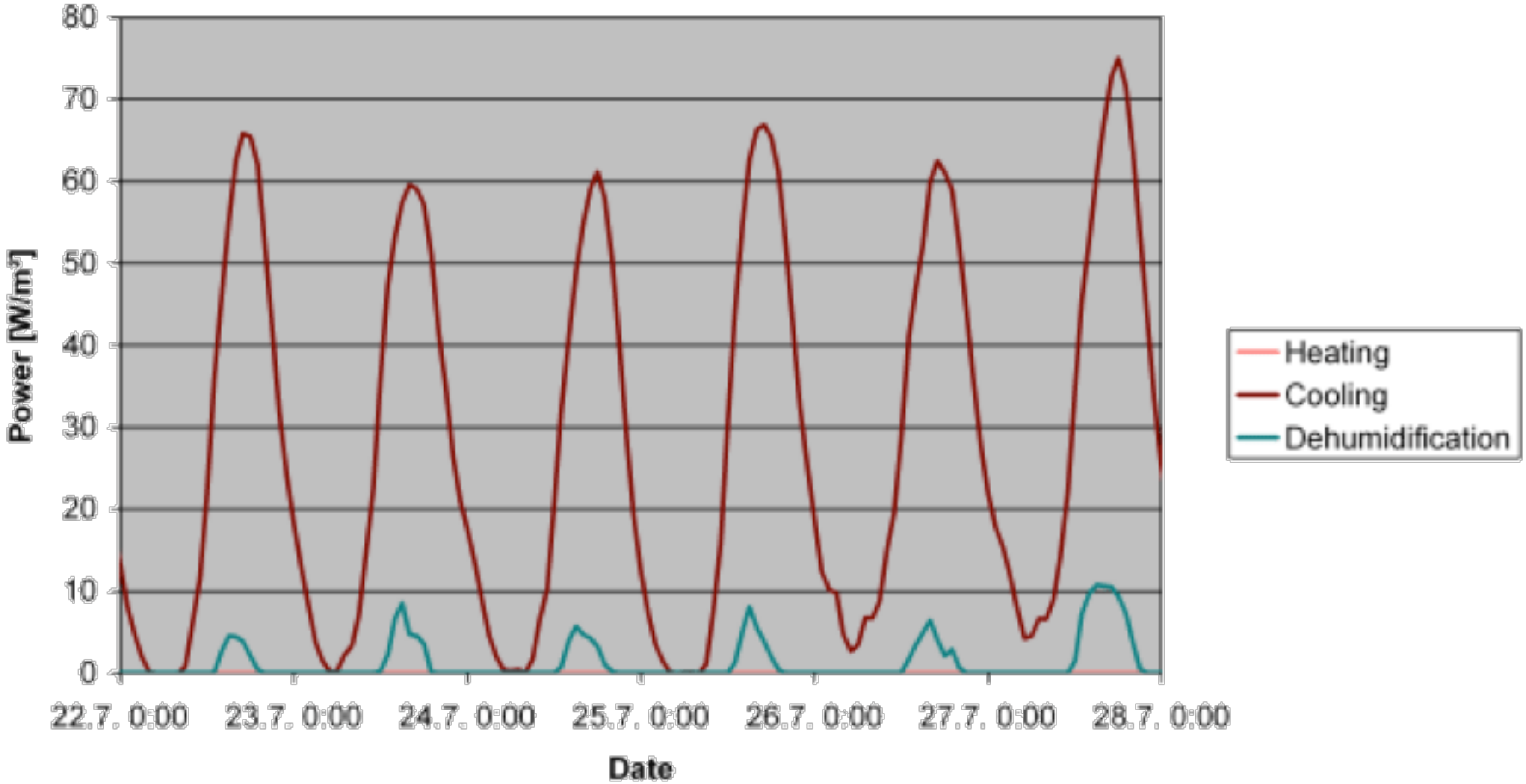
Passive House Ventilation (0.3 ACH) Exceeds ASHRAE 62.2 Levels

What About Cooling?

Source: Passive Houses in Mediterranean Climates, PHI

What About Cooling?

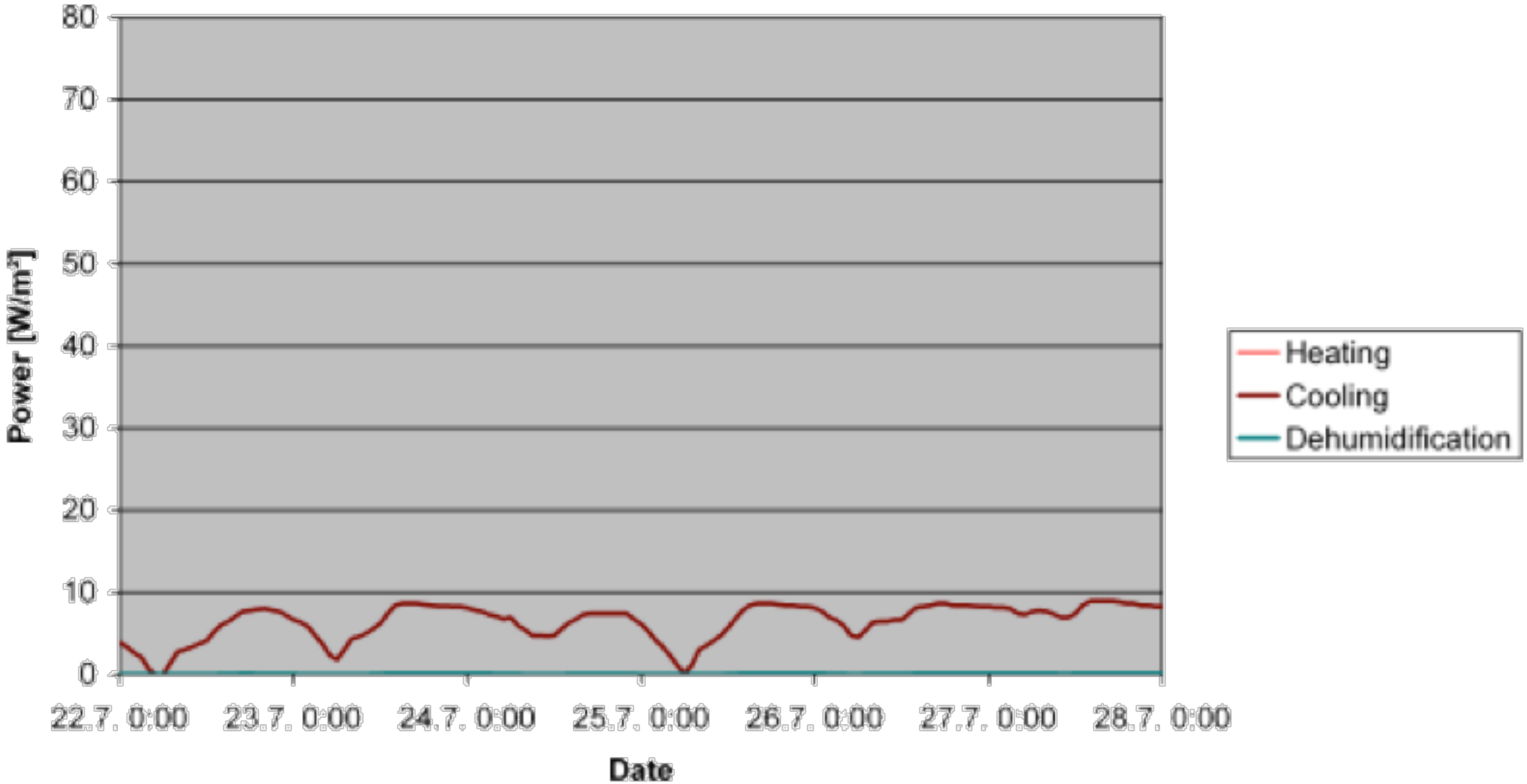
Peak Loads: Seville, Spain, Standard Construction



Source: Passive Houses in Mediterranean Climates, PHI

What About Cooling?

Peak Loads: Seville, Spain, Passive House



Source: Passive Houses in Mediterranean Climates, PHI

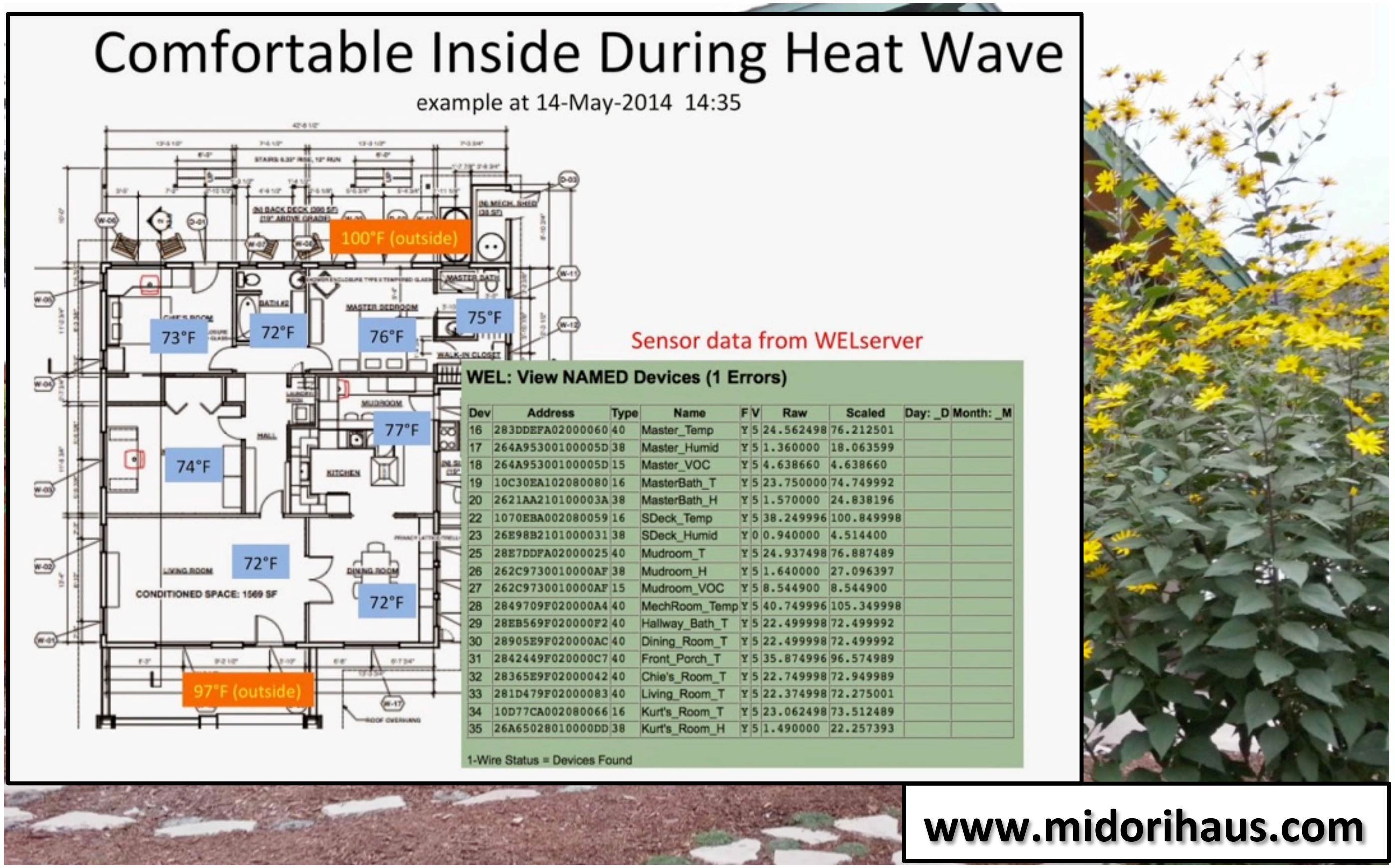
Proof in Practice

A Passive House in a Heat Wave

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

Proof in Practice

A Passive House in a Heat Wave



Dev	Address	Type	Name	F	V	Raw	Scaled	Day: _D	Month: _M
16	283DDEFA02000060	40	Master_Temp	Y	5	24.562498	76.212501		
17	264A95300100005D	38	Master_Humid	Y	5	1.360000	18.063599		
18	264A95300100005D	15	Master_VOC	Y	5	4.638660	4.638660		
19	10C30EA102080080	16	MasterBath_T	Y	5	23.750000	74.749992		
20	2621AA210100003A	38	MasterBath_H	Y	5	1.570000	24.838196		
22	1070EBA002080059	16	SDeck_Temp	Y	5	38.249996	100.849998		
23	26E98B2101000031	38	SDeck_Humid	Y	0	0.940000	4.514400		
25	28E7DDFA02000025	40	Mudroom_T	Y	5	24.937498	76.887489		
26	262C9730010000AF	38	Mudroom_H	Y	5	1.640000	27.096397		
27	262C9730010000AF	15	Mudroom_VOC	Y	5	8.544900	8.544900		
28	2849709F020000A4	40	MechRoom_Temp	Y	5	40.749996	105.349998		
29	28EB569F020000F2	40	Hallway_Bath_T	Y	5	22.499998	72.499992		
30	28905E9F020000AC	40	Dining_Room_T	Y	5	22.499998	72.499992		
31	2842449F020000C7	40	Front_Porch_T	Y	5	35.874996	96.574989		
32	28365E9F02000042	40	Chie's_Room_T	Y	5	22.749998	72.949989		
33	281D479F02000083	40	Living_Room_T	Y	5	22.374998	72.275001		
34	10D77CA002080066	16	Kurt's_Room_T	Y	5	23.062498	73.512489		
35	26A65028010000DD	38	Kurt's_Room_H	Y	5	1.490000	22.257393		

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

The "Classic" Passive House Standard

Measured

1. Maximum Air Leakage: 0.6 ACH_{50}

Modeled

2. Max. Heating or Cooling Demand

   15 kWh/m²/yr (4.75 kBtu/ft²/yr)

   OR Max. Heating Load

   10 W/m² (3.17 Btu/hr./ft²)

3. Max. Primary Energy Demand*

   120 kWh/m²/yr (38.1 kBtu/ft²/yr)

Shell Performance
Comfort,
Good IAQ,
Durability,
Open Building

Source
Energy

***Before PV** ← Efficiency vs. "Net" Zero Energy

Passive House Planning Package (PHPP)

for Predictable Performance

Passive House Planning

SPECIFIC ANNUAL HEAT REQUIREMENT

Climate:	Frankfurt (Region 12)	Interior Temperature:	20.0 °C
Building:	End-of-Terrace Passive House Kranichstein	Building Type/Use:	Terrace House / Dwellin
Location:	Darmstadt-Kranichstein	Treated Floor Area (TFA):	156.0 m²
		Standard Occupancy:	4.0 Pers.

	Building Element	Temperature Zone	Area m²		U-Value W/(m²K)		Temp. factor f_t		G_t kKh/a		kWh/a	per m² Treated Floor Area
1.	Exterior Wall - Ambient	A	184.3	*	0.138	*	1.00	*	81.1	=	2055	
2.	Exterior Wall - Ground	B		*		*	0.57	*		=		
3.	Roof/Ceiling - Exterior	D	83.4	*	0.108	*	1.00	*	81.1	=	727	
4.	Floor Slab	B	80.9	*	0.131	*	0.57	*	81.1	=	493	
8.	Windows	A	43.5	*	0.777	*	1.00	*	81.1	=	2739	
9.	Exterior Door	A		*		*	1.00	*		=		
10.	Exterior Thermal Bridge	A	116.9	*	-0.030	*	1.00	*	81.1	=	-282	
11.	Perimeter Thermal Bridge	P		*		*	0.57	*		=		
12.	Ground Thermal Bridge (1	B	11.4	*	0.061	*	0.57	*	81.1	=	32	
	Total of all building envelope areas		392.1									kWh/(m²a)
	Transmission Heat Losses Q_T									Total	5764	36.9

			A_{TFA} m²		Room Height m		m³	
Ventilation System:	Effective Air Volume V_{RAX}		156.0	*	2.50	=	390.0	
Actual Efficiency of Heat Recovery	η_{eff}	81%						
Efficiency of Subsoil Heat Exchanger	η_{SHX}	33%						
		$n_{V,system}$ 1/h	Φ_{HR}		$n_{V,Res}$ 1/h		1/h	
	Energetically Effective Air Exchange n_V	0.300	(1 - 0.87	) +	0.019	=	0.058	

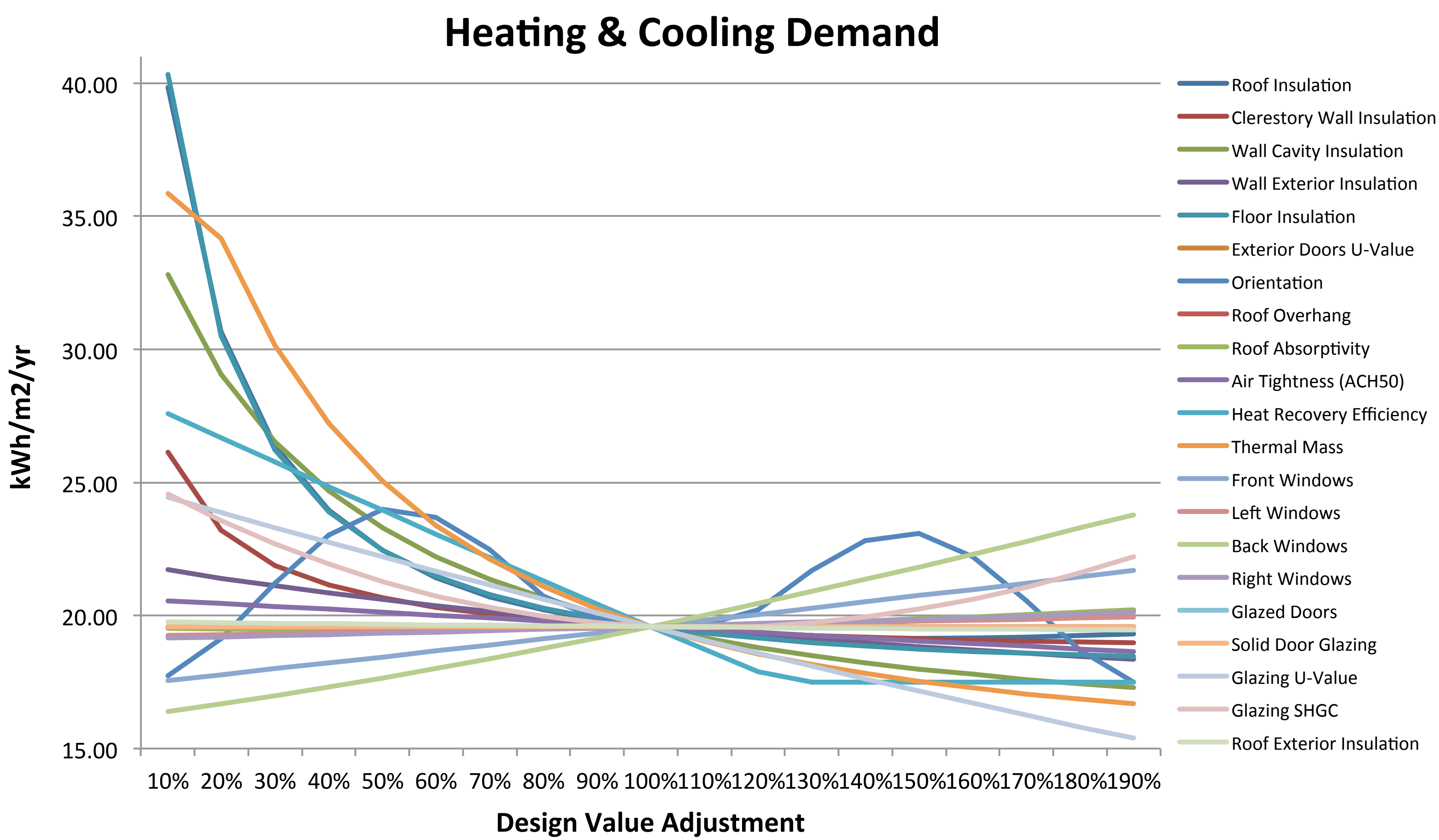
	V_V m³		n_V 1/h		c_{Air} Wh/(m³K)		G_t kKh/a		kWh/a	kWh/(m²a)
Ventilation Heat Losses Q_V	390	*	0.058	*	0.33	*	81.1	=	606	3.9

		Q_T kWh/a		Q_V kWh/a		Reduction Factor Night/Weekend Saving		kWh/a	kWh/(m²a)
Total Heat Losses Q_L	(	5764	+	606	)	1.0	=	6369	40.8

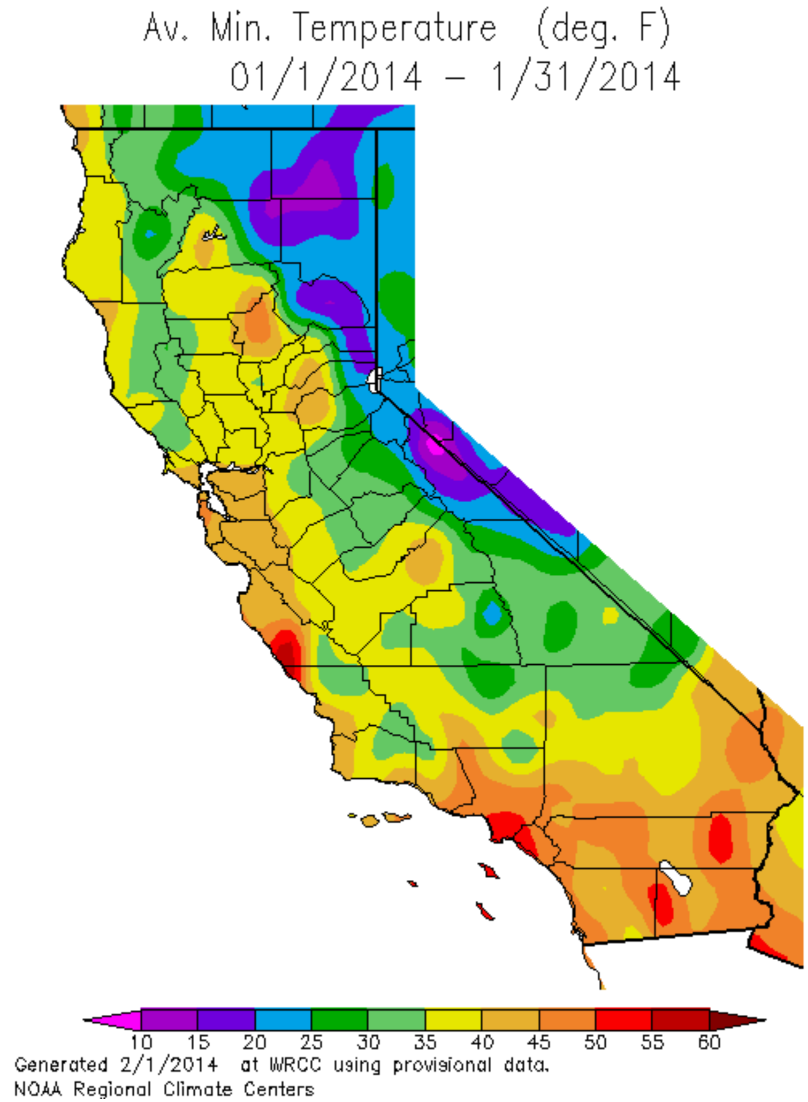
	Orientation of the Area	Reduction Factor see Windows		g-Value (perp. radiation)		Area m²		Global Radiation Heating Period kWh/(m²a)		kWh/a	
1.	East	0.40	*	0.00	*	0.00	*	256	=	0	
2.	South	0.44	*	0.50	*	30.42	*	406	=	2701	
3.	West	0.41	*	0.50	*	2.00	*	259	=	105	
4.	North	0.45	*	0.50	*	11.04	*	161	=	397	
5.	Horizontal	0.40	*	0.00	*	0.00	*	396	=	0	kWh/(m²a)
	Gross Solar Heat Gains Q_S								Total	3203	20.5

- Climate Zone
- Building Form & Orientation
- Building Assembly R Values
- Thermal Mass
- Heat Losses to Ground
- Thermal Bridges
- Air Tightness
- Window U Values, SHGC & Installation
- Shading
- Solar Heat Gains
- Internal Heat Gains
- Internal Heat Recovery
- Heating & Cooling Loads
- Summer Conditions
- Mechanical & Natural Ventilation
- DHW & Solar Thermal
- District Heating
- Plug Loads, Appliances, Lighting
- Source Energy
- CO_2 Emissions
- Occupancy Patterns & Schedules

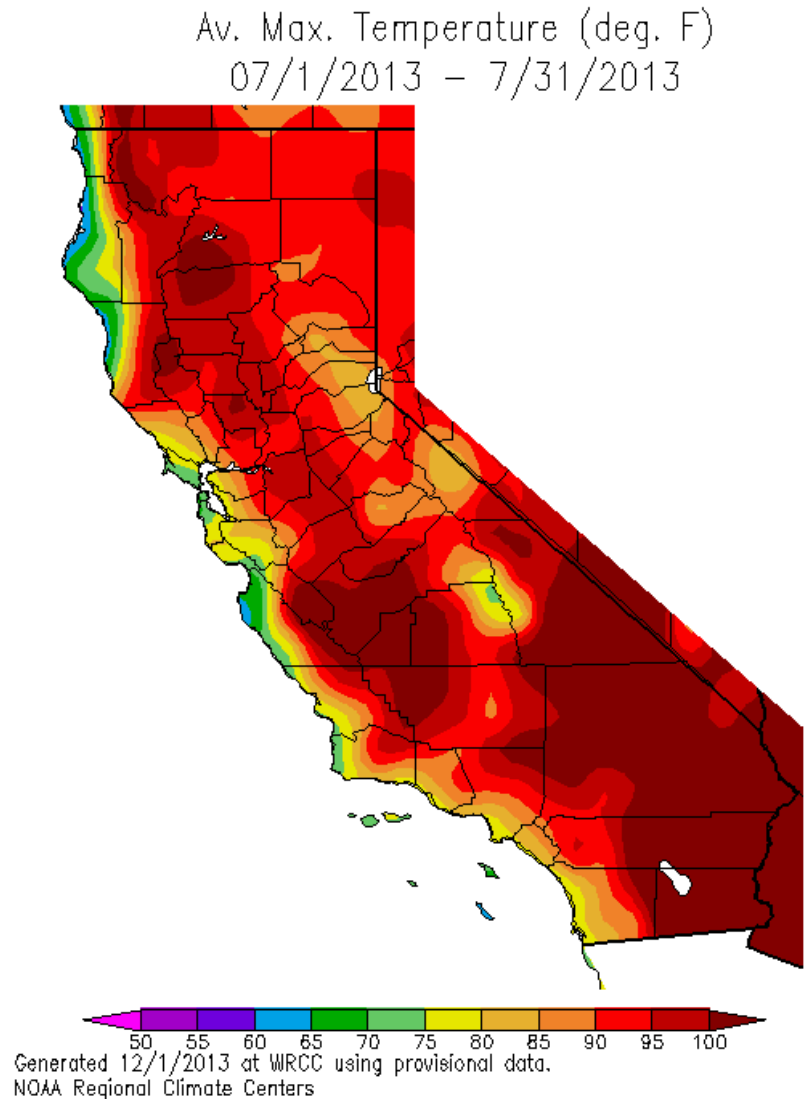
Passive House Planning Package (PHPP)
and Cost-Optimization



Perspective: Our California Projects



Perspective: Our California Projects



Questions About Wider Adoption

1. How Well Does Passive House Work in other California Climates? (Milder Has More Houses, Harsher Offers More Savings)
2. How Does Passive House Compare with 2013 Title 24 (CA Energy Code)?
3. What is Generally Required in Other California Climates?
4. What are the Most Effective Improvements?

Study: CA Code → Passive House

2013 California Code vs. Passive House

1. Analysis of California Code-Minimum Construction in Passive House Planning Package (PHPP 8.4) by Climate Zone.
2. Step by Step Analysis of Cost Effective Upgrades to Reach Passive House Performance.

Study: CA Code → Passive House

T24 "Prototype" One Story House

Figure A-1: One Story Prototype Front View

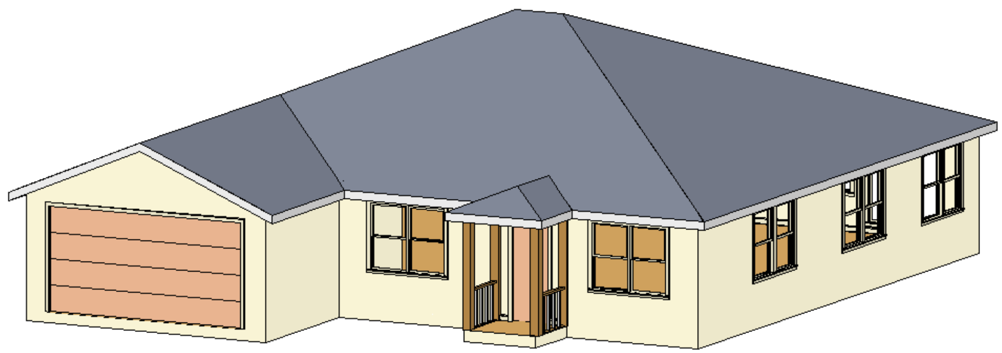
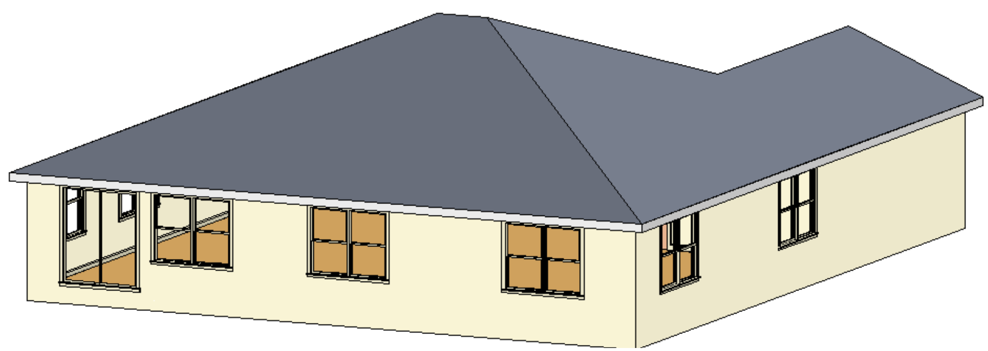


Figure A-2: One Story Prototype Back View



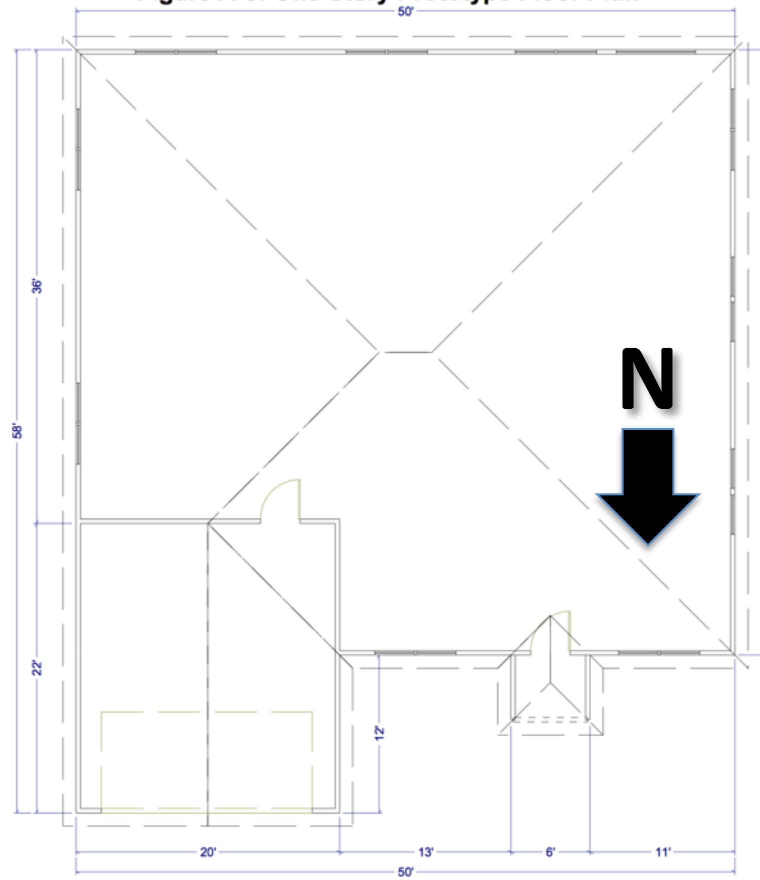
Source: 2013 Residential Alternative Calculation Method Reference Manual CEC-400-2013-003-SD-REV

Study: CA Code → Passive House

T24 "Prototype" One Story House

- Conditioned Floor Area: 2100 ft^2
- Ceiling Height: 9 ft
- Conditioned Volume: 18,900 ft^3
- Slab Area: 2100 ft^2
- Slab Perimeter: 162 ft
- Ceiling Area: 2100 ft^2
- Glazing: 5% "Conditioned Floor Area" (CFA) in Each Direction (108 ft^2)
- 12" Overhangs

Figure A-3: One Story Prototype Floor Plan



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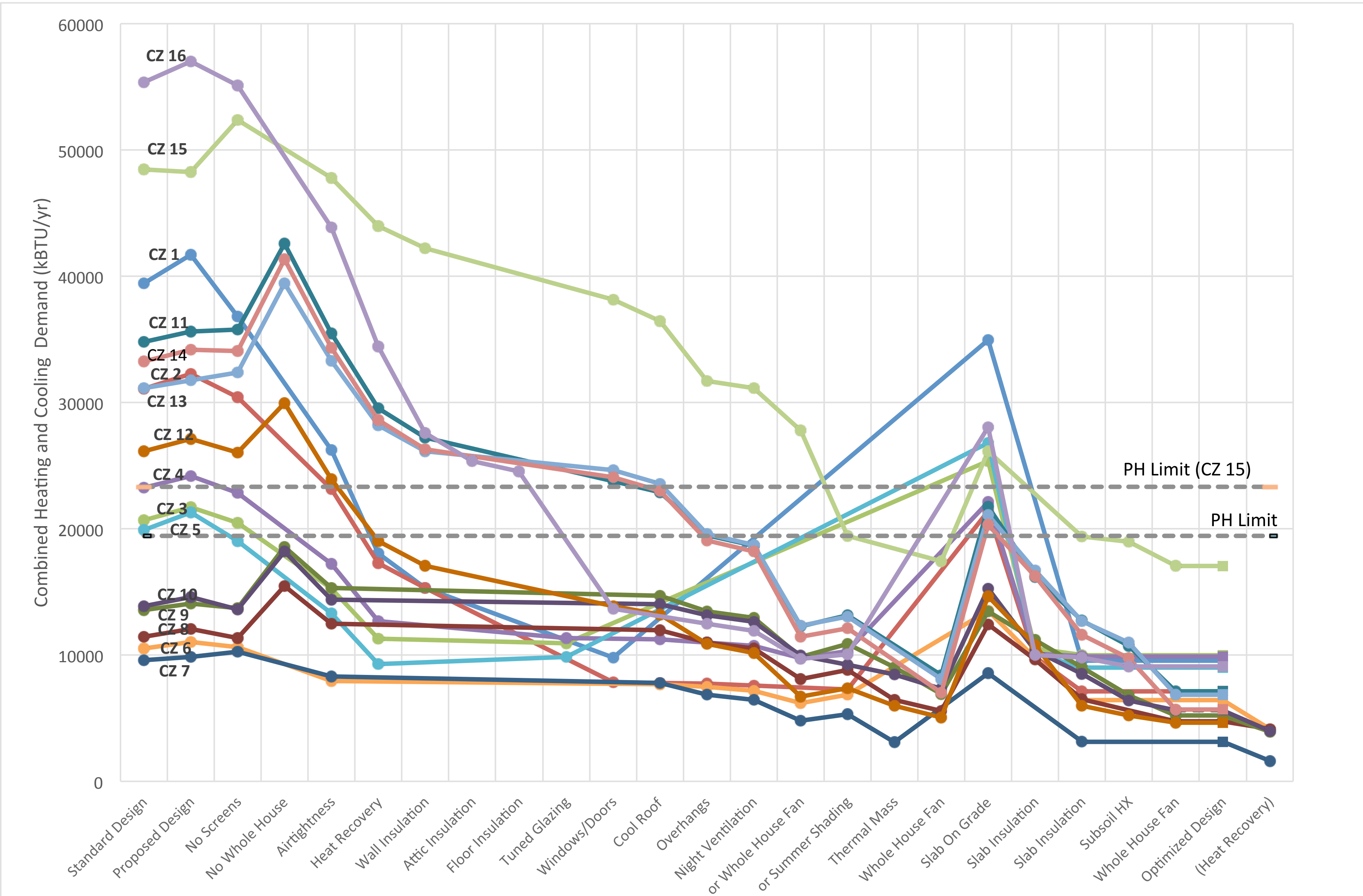
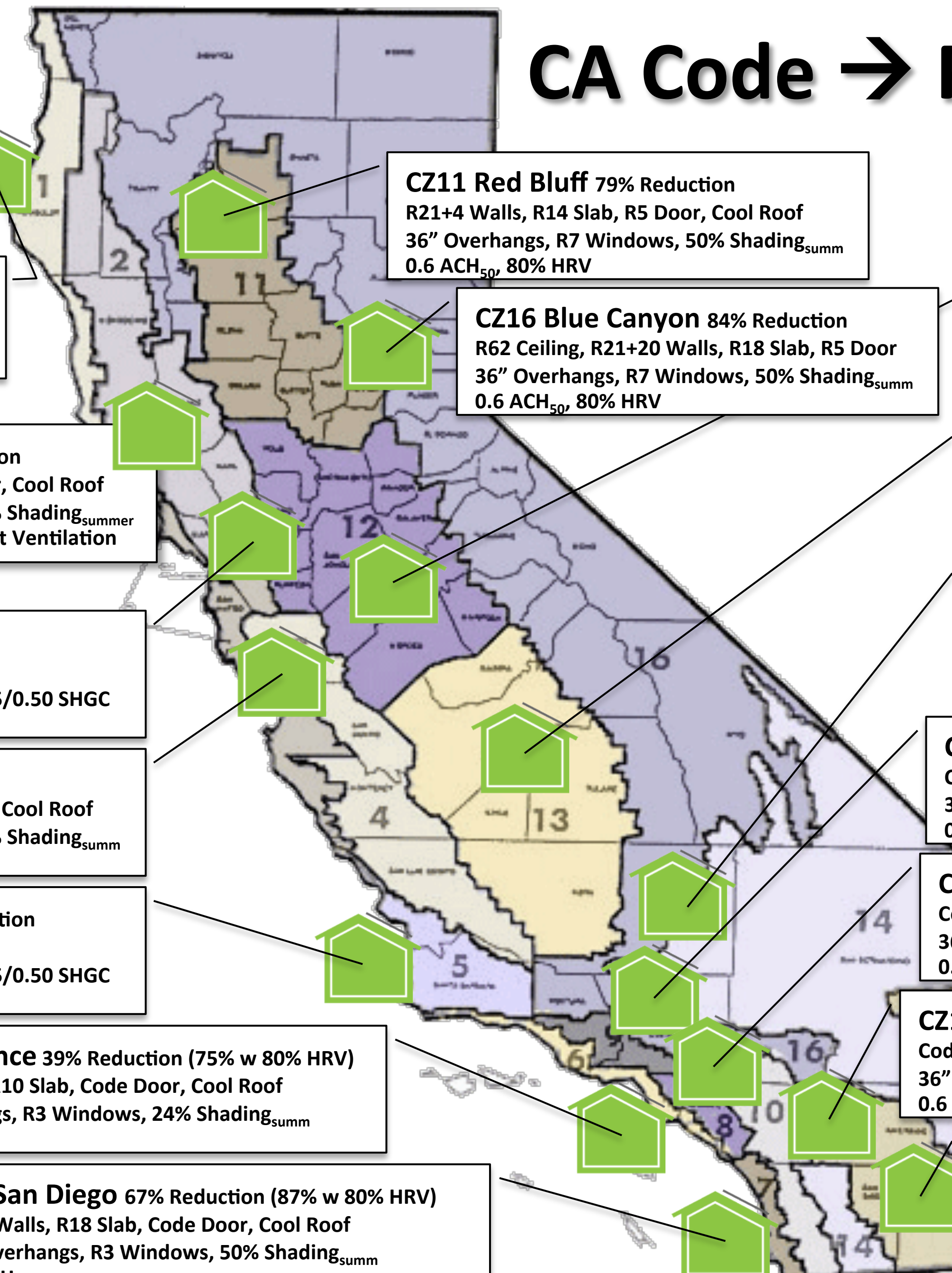
Study: CA Code → Passive House



ESSENTIAL HABITAT ARCHITECTURE

CA Code → Passive House



CZ1 Arcata 76% Reduction
R21+4 Walls, R14 Slab, R5 Door
12" Overhangs, R7 Windows
0.6 ACH$_{50}$, 80% HRV

CZ2 Santa Rosa 77% Reduction
R21+4 Walls, R14 Slab, Code Door, Cool Roof
30" Overhangs, R6 Windows, 24% Shading$_{summer}$
0.6 ACH$_{50}$, 80% HRV, 65 CFM Night Ventilation

CZ3 Oakland 52% Reduction
Code Walls, R13 Slab, R5 Door
12" Overhangs, R3 Windows, 0.25/0.50 SHGC
0.6 ACH$_{50}$, 80% HRV

CZ4 San Jose 57% Reduction
Code Walls, R13 Slab, Code Door, Cool Roof
30" Overhangs, R3 Windows, 24% Shading$_{summ}$
0.6 ACH$_{50}$, 80% HRV

CZ5 Santa Maria 55% Reduction
Code Walls, R12 Slab, Code Door
12" Overhangs, R3 Windows, 0.25/0.50 SHGC
0.6 ACH$_{50}$, 80% HRV

CZ6 Torrance 39% Reduction (75% w 80% HRV)
Code Walls, R10 Slab, Code Door, Cool Roof
30" Overhangs, R3 Windows, 24% Shading$_{summ}$
0.6 ACH$_{50}$

CZ7 San Diego 67% Reduction (87% w 80% HRV)
Code Walls, R18 Slab, Code Door, Cool Roof
36" Overhangs, R3 Windows, 50% Shading$_{summ}$
0.6 ACH$_{50}$

CZ11 Red Bluff 79% Reduction
R21+4 Walls, R14 Slab, R5 Door, Cool Roof
36" Overhangs, R7 Windows, 50% Shading$_{summ}$
0.6 ACH$_{50}$, 80% HRV

CZ16 Blue Canyon 84% Reduction
R62 Ceiling, R21+20 Walls, R18 Slab, R5 Door
36" Overhangs, R7 Windows, 50% Shading$_{summ}$
0.6 ACH$_{50}$, 80% HRV

CZ12 Sacramento 82% Reduction
R21+4 Walls, R19 Slab, R5 Door, Cool Roof
36" Overhangs, R7 Windows, 50% Shading$_{summ}$
0.6 ACH$_{50}$, 80% HRV

CZ13 Fresno 78% Reduction
R21+4 Walls, R13 Slab, R5 Door, Cool Roof
36" Overhangs, R7 Windows, 50% Shading$_{summ}$
0.6 ACH$_{50}$, 80% HRV

CZ14 Palmdale 83% Reduction
R21+4 Walls, R12 Slab, R5 Door, Cool Roof
36" Overhangs, R7 Windows, 50% Shading$_{summ}$
0.6 ACH$_{50}$, 80% HRV

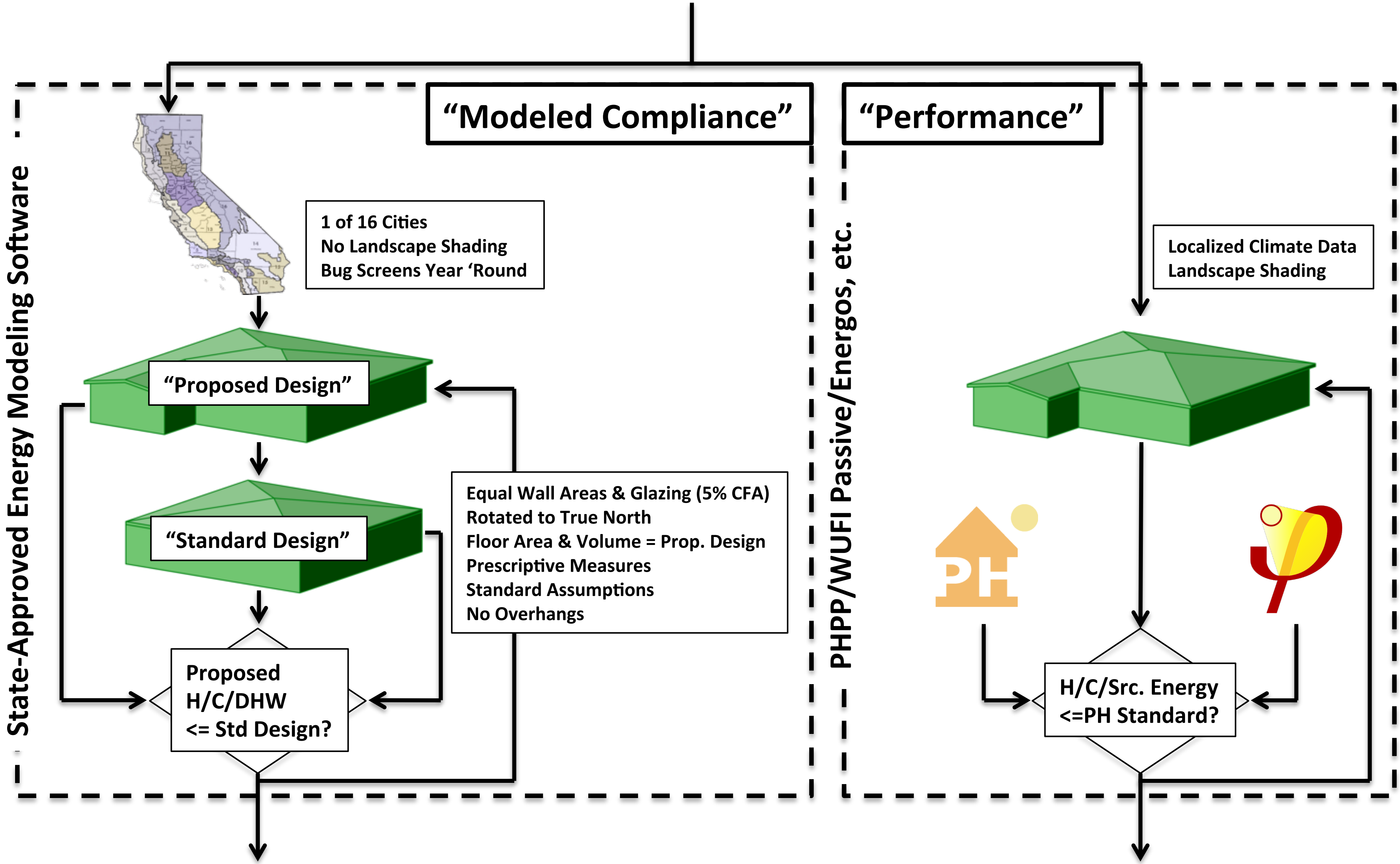
CZ9 Burbank 62% Reduction (82% w 80% HRV)
Code Walls, R19 Slab, Code Door, Cool Roof
36" Overhangs, R3 Windows, 50% Shading$_{summ}$
0.6 ACH$_{50}$

CZ8 Fullerton 64% Reduction (84% w 80% HRV)
Code Walls, R19 Slab, Code Door, Cool Roof
36" Overhangs, R3 Windows, 50% Shading$_{summ}$
0.6 ACH$_{50}$

CZ10 Riverside 59% Reduction (82% w 80% HRV)
Code Walls, R19 Slab, Code Door, Cool Roof
36" Overhangs, R3 Windows, 50% Shading$_{summ}$
0.6 ACH$_{50}$

CZ15 Palm Springs 65% Reduction
R21+4 Walls, R16 Slab, R5 Door, Cool Roof
36" Overhangs, R7 Windows, 90% Shading$_{summ}$
0.6 ACH$_{50}$, 80% HRV

Title 24 vs. PH Energy Modeling



Performance vs. Compliance

2012 GMC Yukon Denali 1500 (15 MPG)

2012 Honda Civic HF (33 MPG)

2012 Yukon Denali 1500 Hybrid (21 MPG)

2012 Honda Civic Hybrid (44 MPG)

40% (6 MPG) Improvement

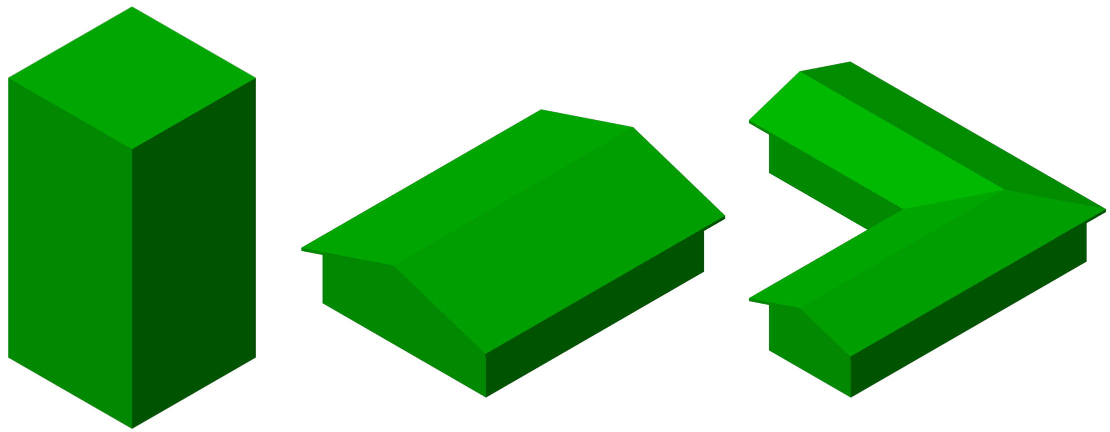
33% (11 MPG) Improvement

Reference: www.fueleconomy.gov, US DOE

Performance is an absolute standard, compliance is always relative.

Compliance Approach

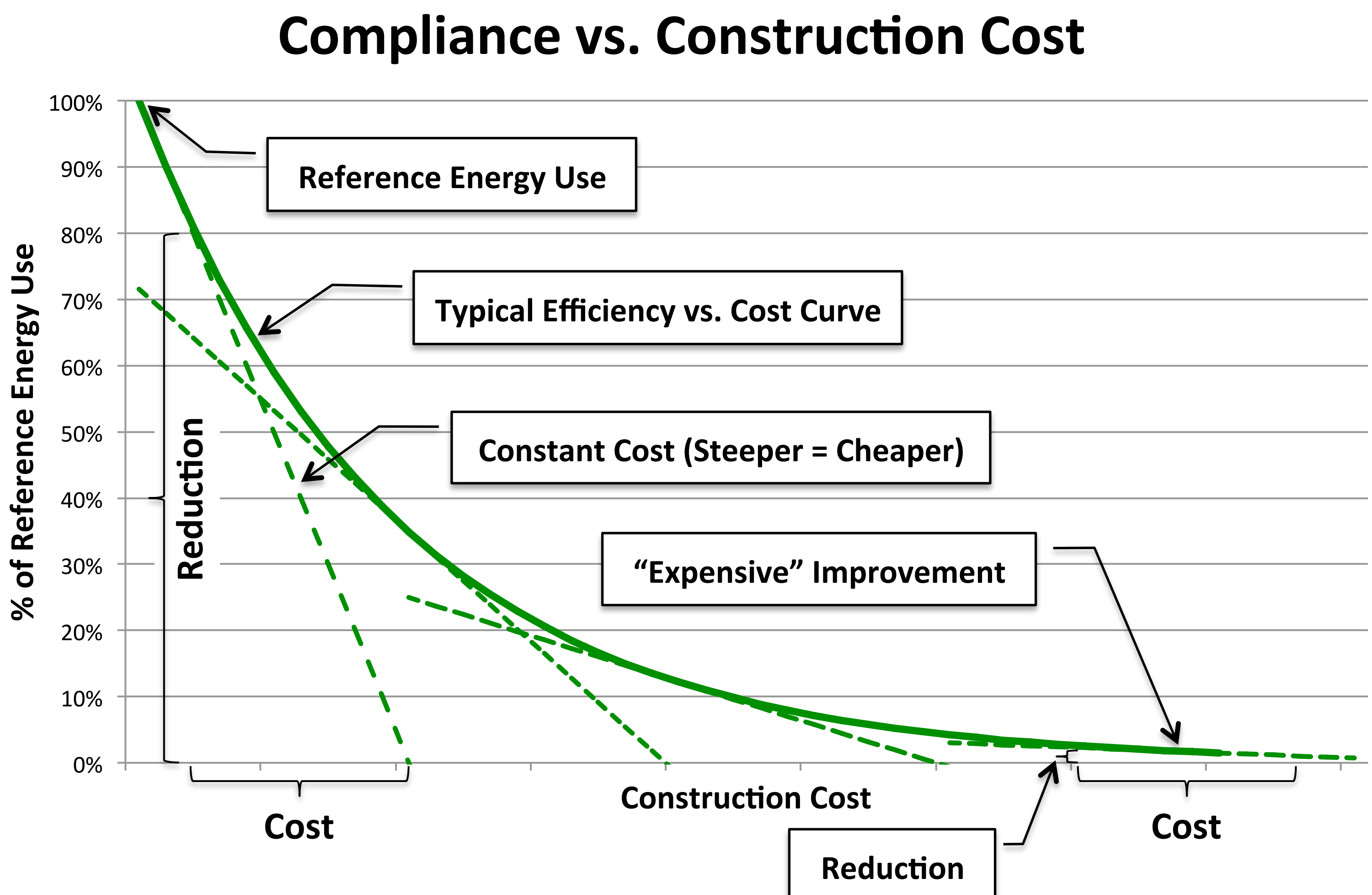
Compares the Building to Itself, Not to a Standard



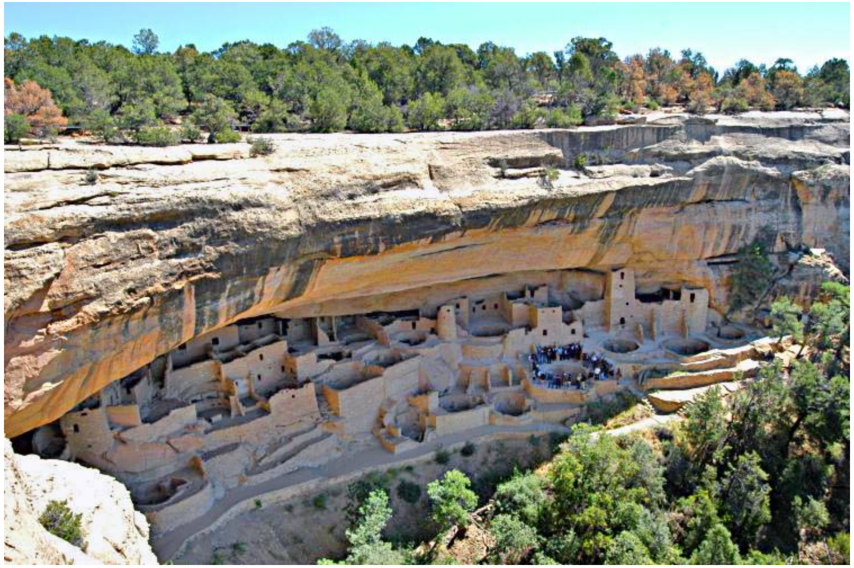
	Low Rise	Bungalow	'L' Shape
Surface/Floor Area	2.1:1	3.0:1	3.5:1
UA (R11 Shell)	384	544	567
UA (R17 Shell)	248	352	357
Improvement	35%	35%	35%
Total Heat Flow	x1.0	x1.4	x1.5

Compliance is "Sticky" to Baseline

Regardless of Reference Point



Orientation & Shading Matter



Cliff Dwelling, Mesa Verde, CO (Wikipedia)

Priene, Ancient Greece (Solarpedia)

…without purpose they wrought all things in confusion. They had neither knowledge of houses built of bricks and turned to face the sun nor yet of work in wood; but dwelt beneath the ground like swarming ants, in sunless caves - Aeschylus, PROMETHEUS BOUND

Air Sealing Matters

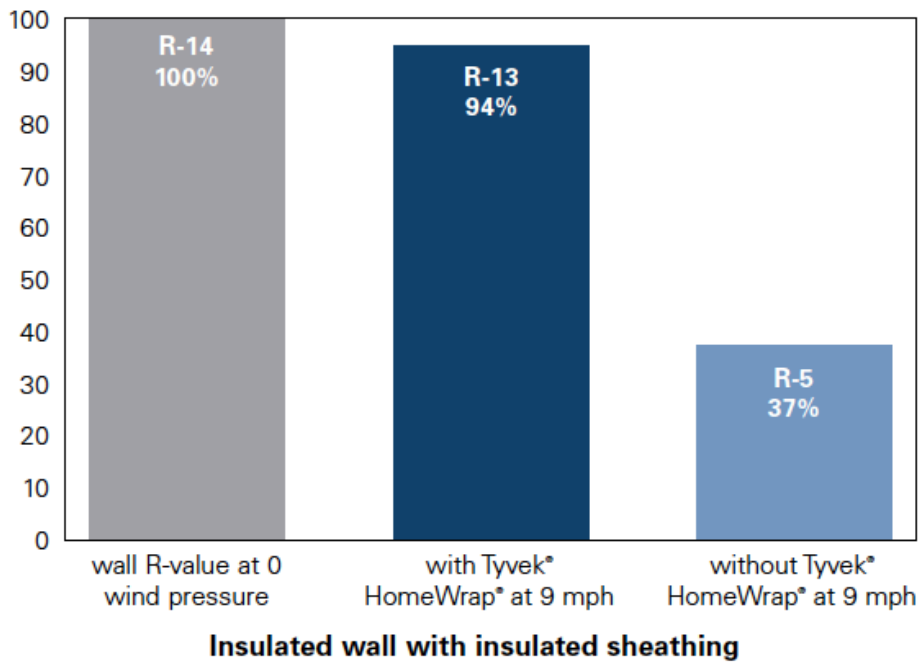
for Health

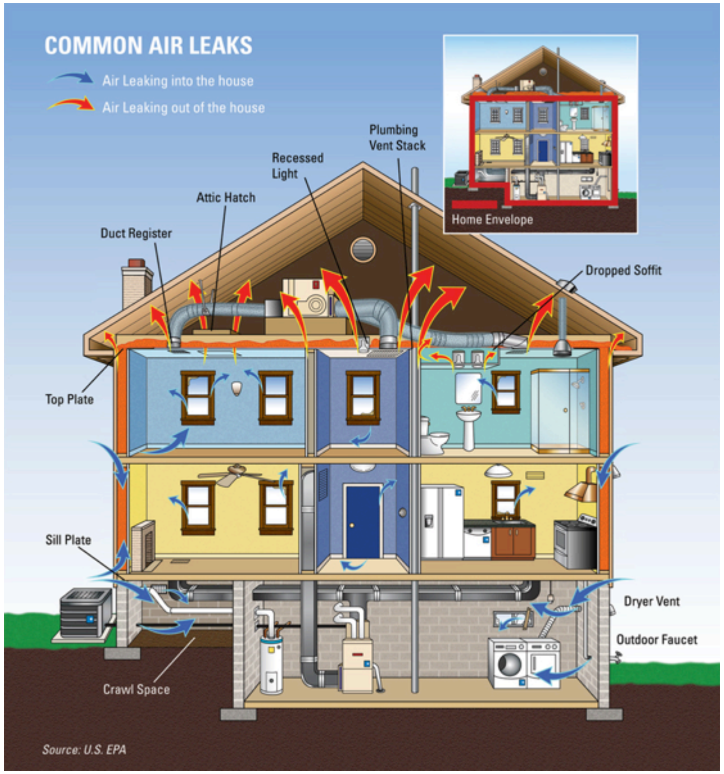
Source: Terry Nordbye, The Practical House

A Washington State University Extension Energy Program (WSU-EEP) study found that up to 40% of the air in the test homes originated in the crawl space.

Air Sealing Matters

for Comfort

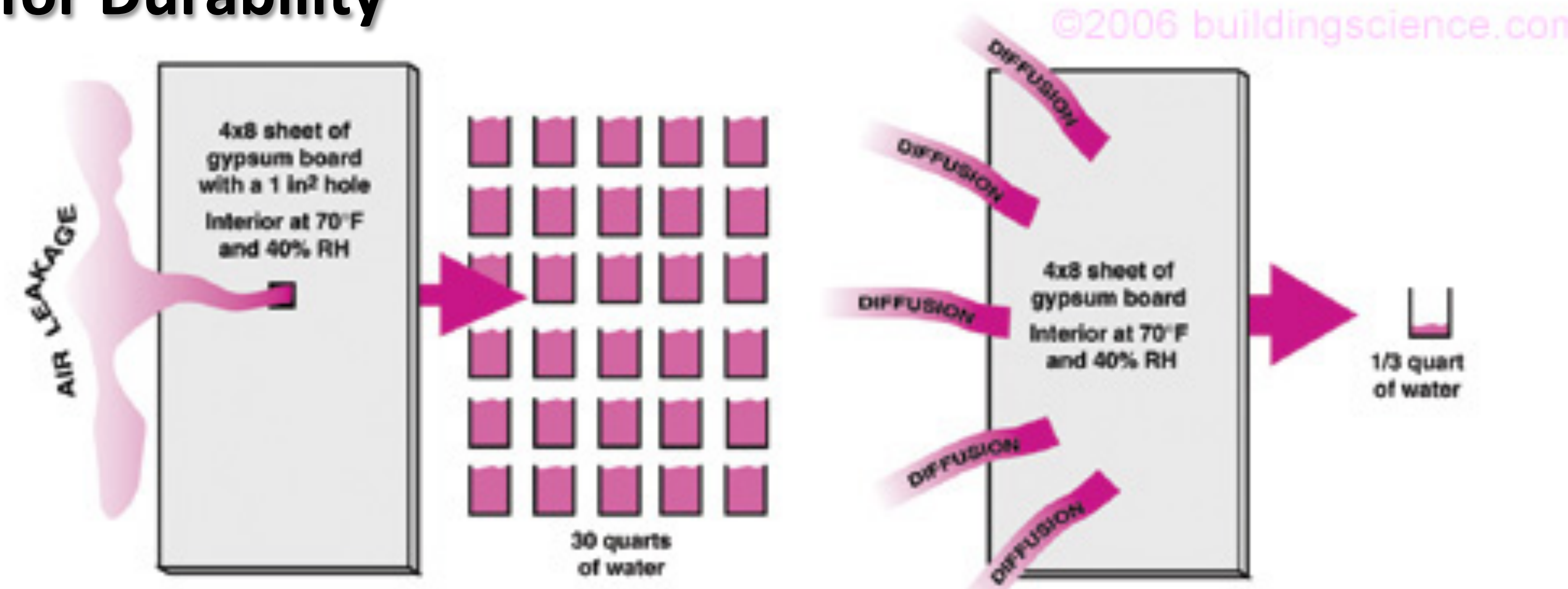




9 mph Wind = -30% R Value (Dupont, 2007)

Air Sealing Matters

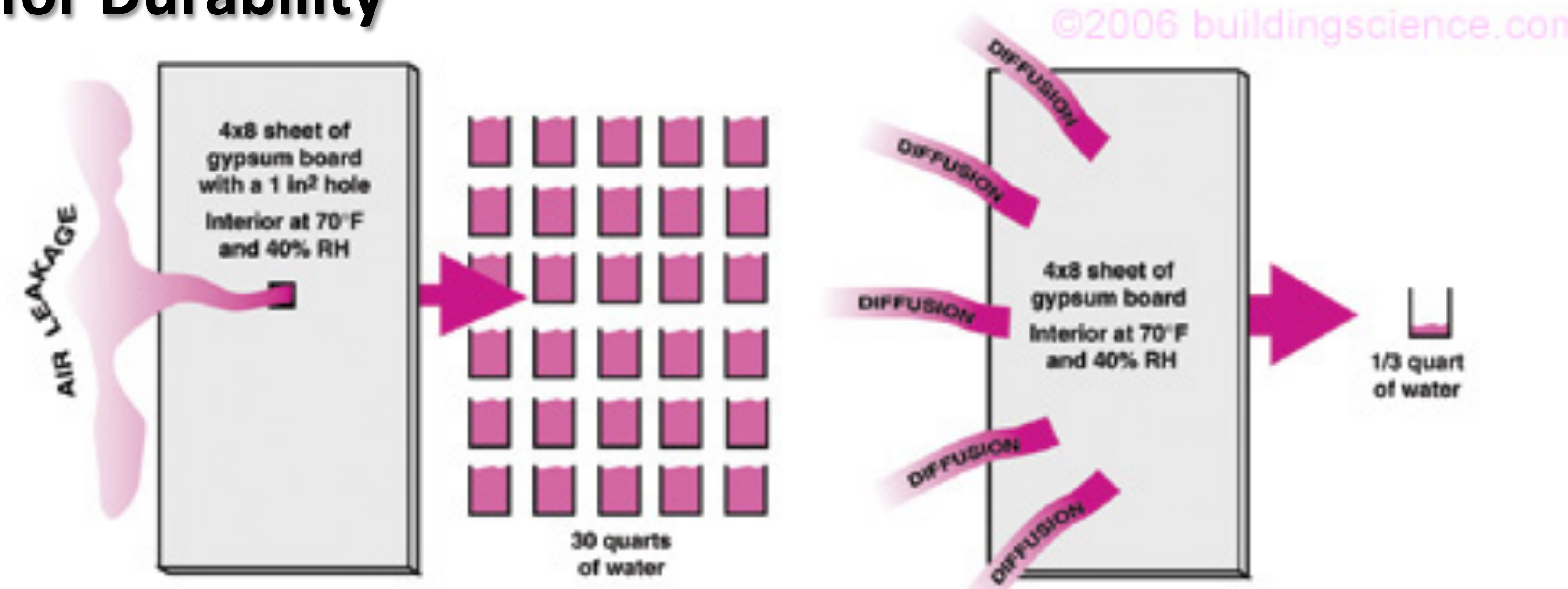
for Durability



- Air movement accounts for 98%+ of water vapor movement in building cavities
- Canadian Study (One Heating Season, Indoors @ 70ºF, 40% RH)
  - Diffusion: 4’x8’ sheet of drywall = 1/3 quart of water
  - Infiltration: 1 in^2 hole = 30 quarts of water
  - 90:1 ratio!!!

In Quickly (Air Leakage) - Out Slowly (Diffusion) = Accumulation

Air Sealing Matters
for Durability



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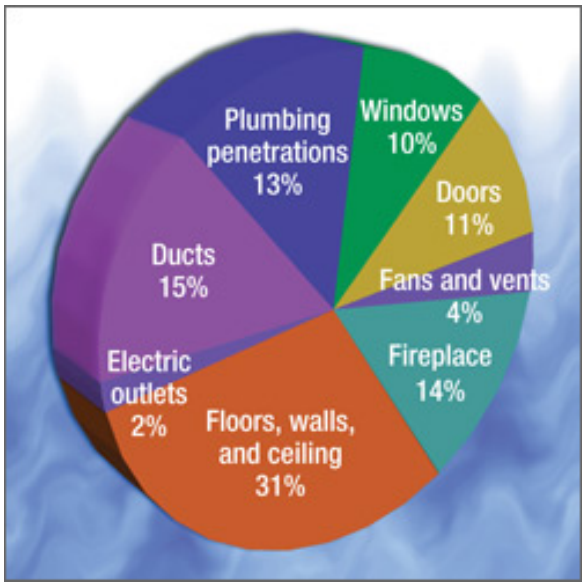
    - Infiltration: 1 in^2 hole = 30 quarts of water
    - 90:1 ratio!!!

"Walls don't need to breathe, but they do need to sweat!!!"

Air Sealing Matters
for Performance

- 30-50% of Space Conditioning Energy (DOE)
- 9 MPH Wind = -30% R-Value (DuPont, 2007)
- Average US House: 3 ft^2 of Holes
- Typical 2500 ft^2 Home: ½ Mile of Cracks



Investigation of the Impact of Commercial Building Envelope Airtightness on HVAC Energy Use (NISTIR 7238)
- NIST, US D.O.C.

Passive House: 60-70% Savings, <u>BEFORE PV</u>

Table 6 Energy cost savings for office building

City	Gas Savings		Electrical Savings		Total Savings
Bismarck	$1,854	42%	$1,340	26%	$3,195
Minneapolis	$1,872	43%	$1,811	33%	$3,683
St. Louis	$1,460	57%	$1,555	28%	$3,016
Phoenix	$124	77%	$620	9%	$745
Miami	$0	0%	$769	10%	$769

Table 8 Energy cost savings for retail building

City	Gas Savings		Electrical Savings		Total Savings
Bismarck	$1,835	26%	$33	2%	$1,869
Minneapolis	$1,908	28%	$364	18%	$2,272
St. Louis	$1,450	38%	$298	9%	$1,748
Phoenix	$176	64%	$992	14%	$1,169
Miami	$6	98%	$1,224	14%	$1,231

Table 10 Energy cost savings for apartment building

City	Gas Savings		Electrical Savings		Total Savings
Bismarck	$2,187	40%	-$116	-9%	$2,071
Minneapolis	$2,421	43%	-$165	-14%	$2,256
St. Louis	$1,794	57%	-$232	-12%	$1,562
Phoenix	$133	65%	$0	0%	$133
Miami	$31	63%	$380	9%	$411

Air Sealing Matters
for Predictable Performance

- ACH_{NAT} Very Unpredictable
- "**Infiltration: Just ACH_{50} Divided by 20?**"

  \- Alan Meier, Home Energy Magazine, January/February 1994
- "Translating blower door measurements into an average infiltration rate has bedeviled the retrofitter and researcher alike."
- N = C * H * S * L
  - C = climate factor
  - H = height factor
  - S = wind shielding factor
  - L = leakiness factor

LEAKAGE/INFILTRATION RATIO

Figure 1. Climate correction factor, "C," for calculating average infiltration rates in North America. Note that the climate correction factor depends on both average temperatures and windiness. It also includes possible air infiltration during the cooling season. For these reasons, locations in greatly dissimilar climates, such as Texas and Vermont, can have equal factors. Select the value nearest to the house's location and insert it in Equation 2. This map is based on data from 250 weather stations.

Source: PHI

Air Sealing Matters
for Predictable Performance

- ACH_{NAT} Very Unpredictable
- **“Infiltration: Just ACH_{50} Divided by 20?”**
  - Alan Meier, Home Energy Magazine, January/February 1994
- “Translating blower door measurements into an average infiltration rate has bedeviled the retrofitter and researcher alike.”
- N = C * H * S * L
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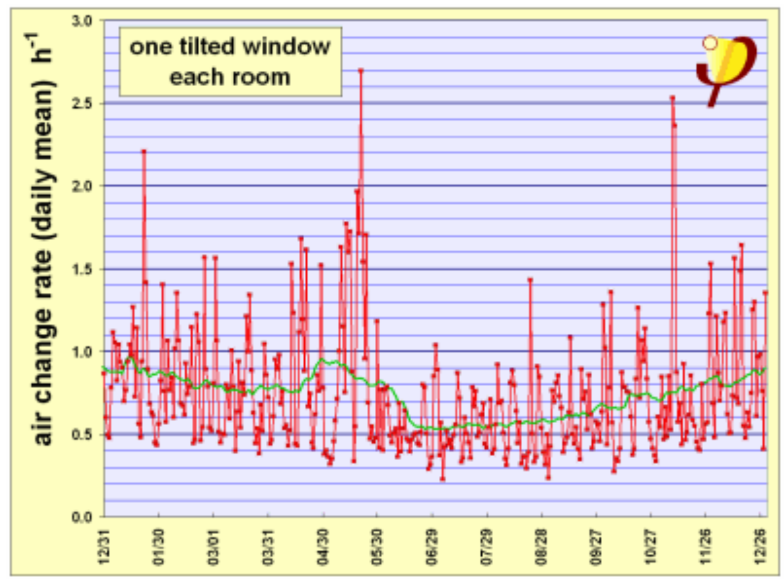
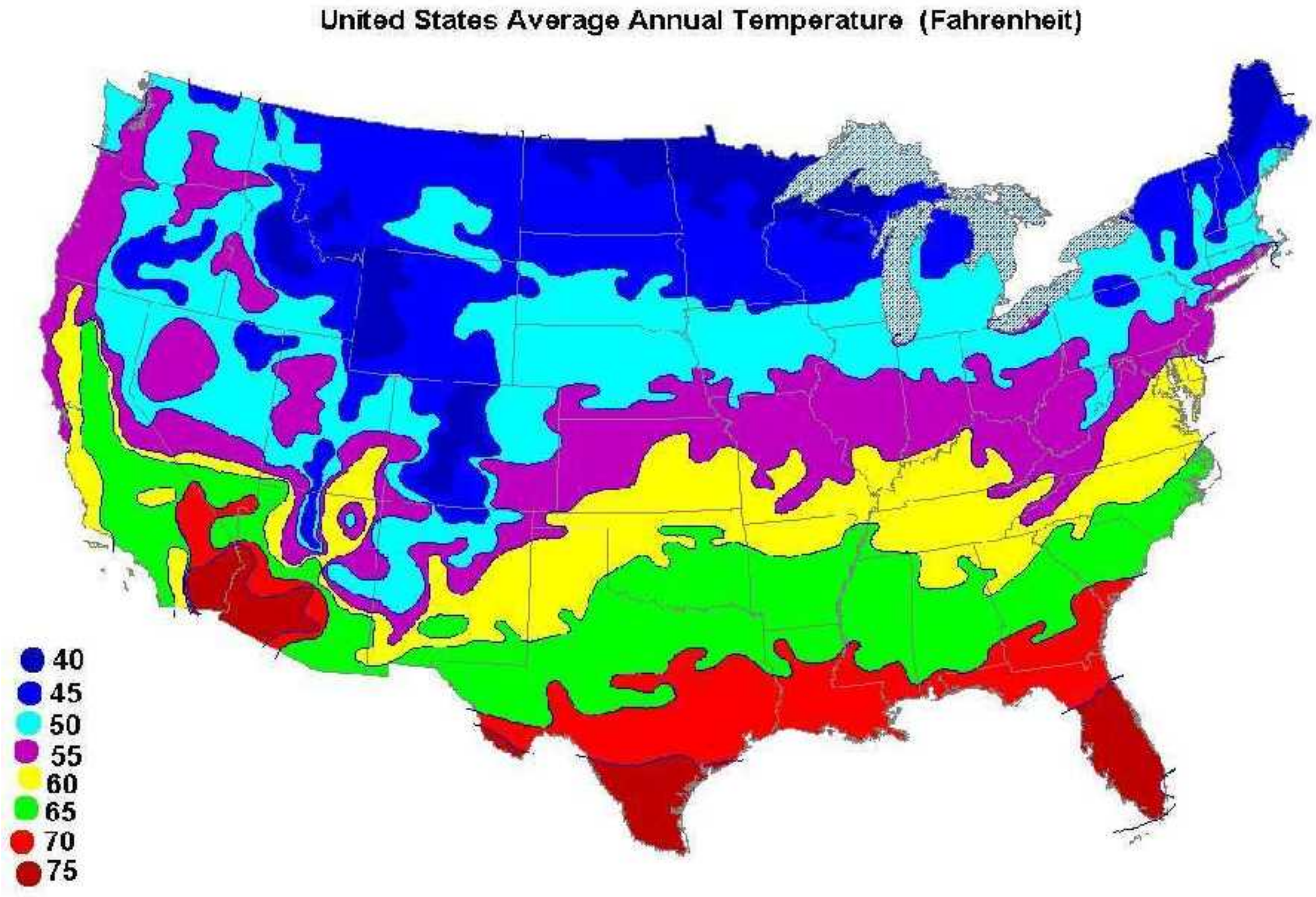


Source: PHI

Insulate Slabs!

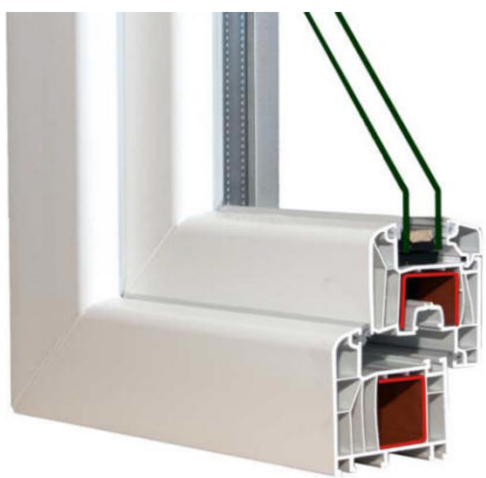


CA Ground Temp. – Fine in Summer, Winter's a Bummer!

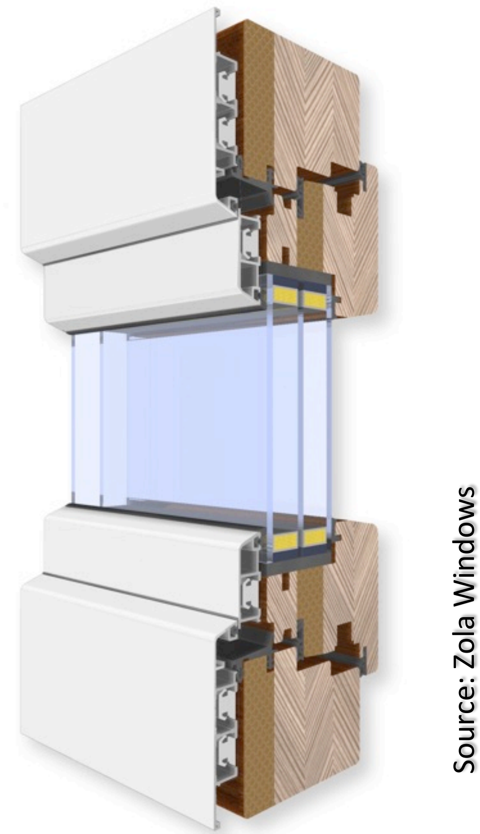
The Windows Matter

For Performance

Energy Star
Double Pane
U = 0.3 (R3)



vs.



Passive House
Triple Pane
U = 0.12 (R8)

The Windows Matter

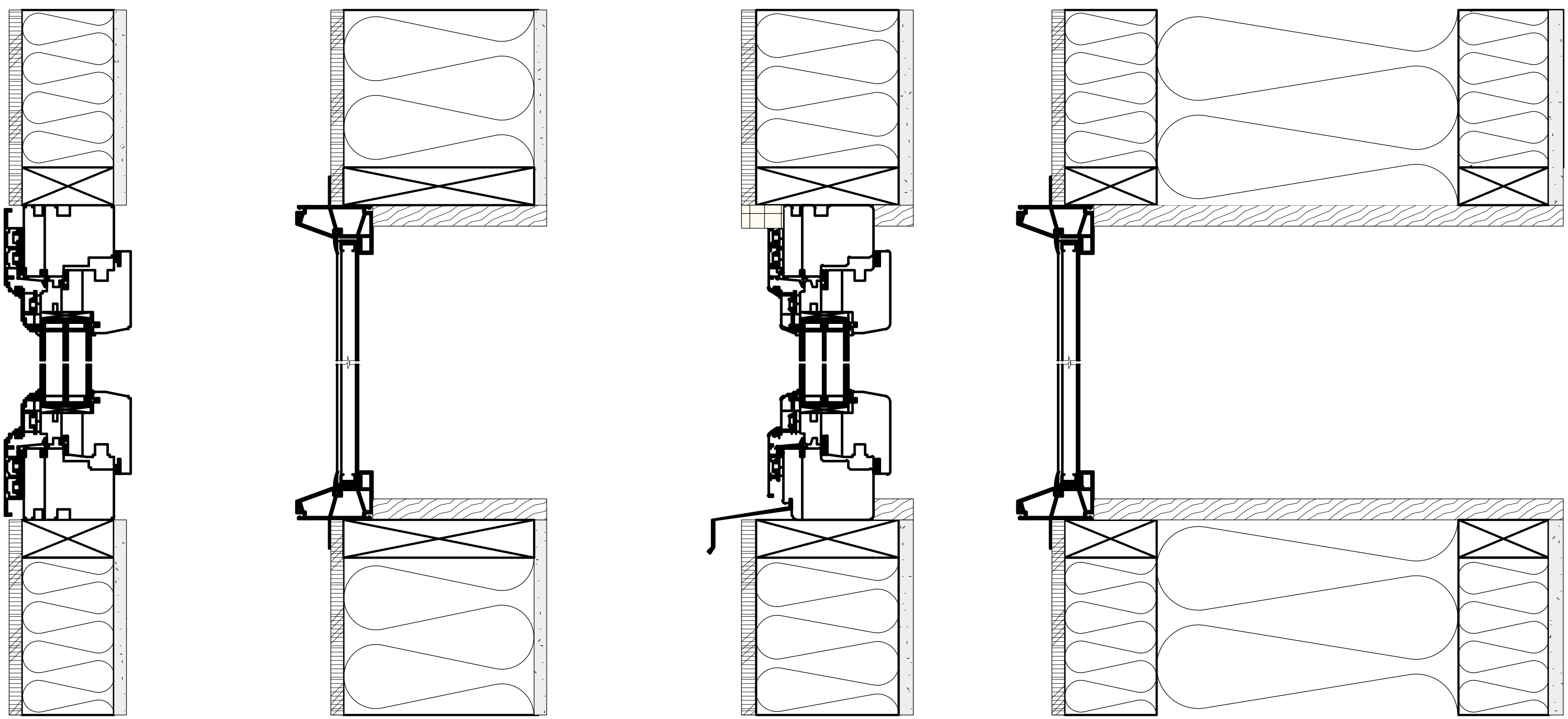
For Performance

2X4 Wall
20% Glazing

7.4” Cavity
20% Glazing

2X6 Wall
20% Glazing

19.4” Cavity
20% Glazing



R10 (R8 Window)

R10 (R3 Window)

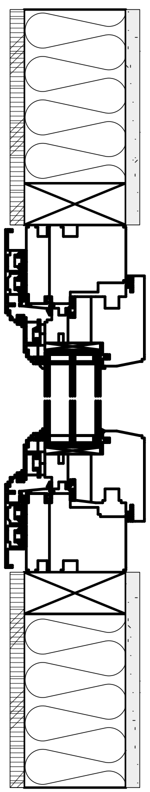
R14 (R8 Window)

R14 (19.4” Cavity)

The Windows Matter

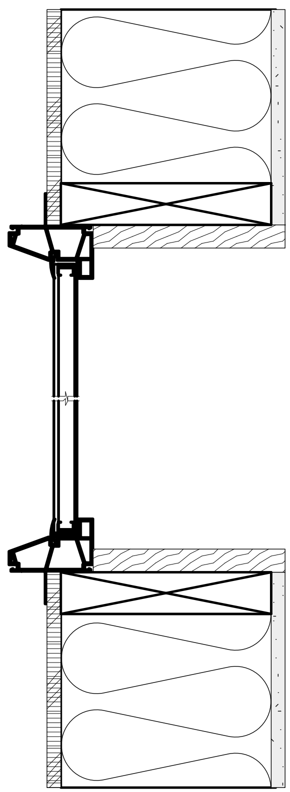
For Performance

2X4 Wall
20% Glazing



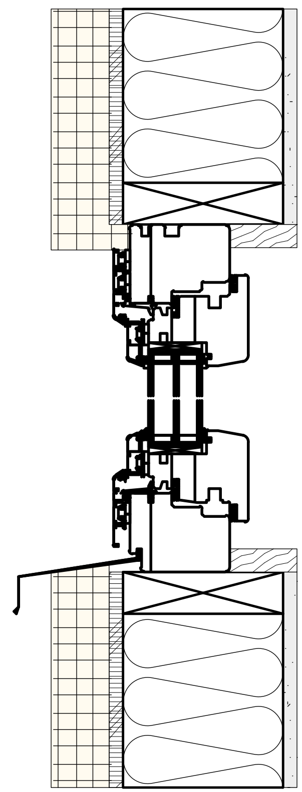
R10 (R8 Window)

7.4” Cavity
20% Glazing



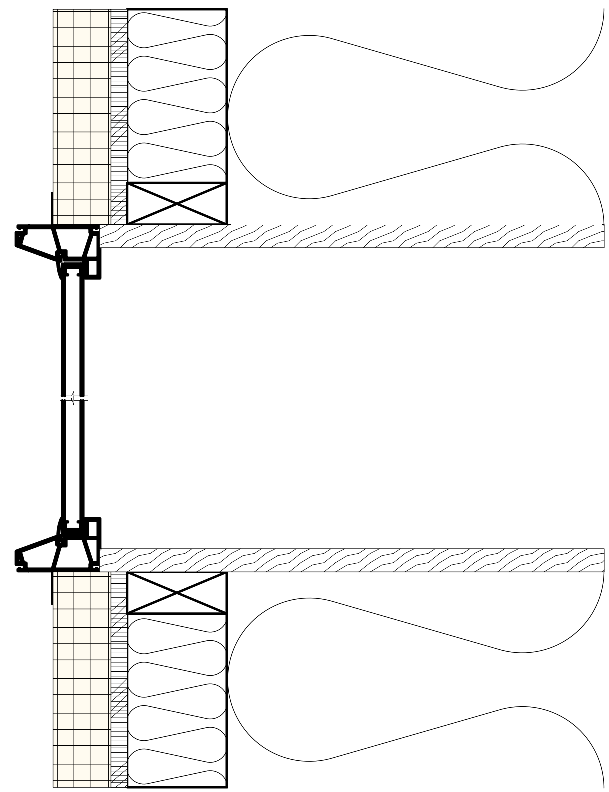
R10 (R3 Window)

2X6 Wall + R8
20% Glazing



R18 (R8 Window)

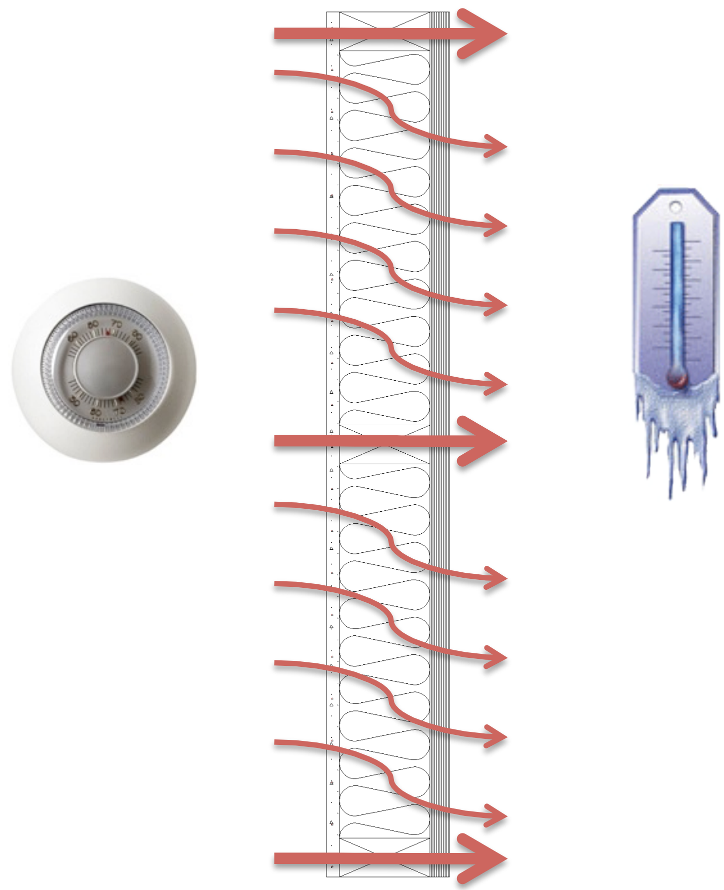
Infinite Cavity
20% Glazing



R17 (R3 Window)

The Details Matter
Thermal Bridges

Material	"R" Value
Aluminum	0.0006/in
Steel	0.04/in
Concrete	0.08/in
Glass (Single Pane)	~1
Glass (Double Pane)	2 to 4
Glass (Triple Pane)	3 to 11
Wood	1.25/in
Icynene Spray Foam	3.6/in
Fiberglass	3.14-4.30/in
Cellulose	3.70/in
EPS Foam	4.00/in
XPS Foam	5.00/in
CC Spray Foam	6.25/in
Poly-Iso (Foil Faced)	7.20/in



The Details Matter
Thermal Bridges

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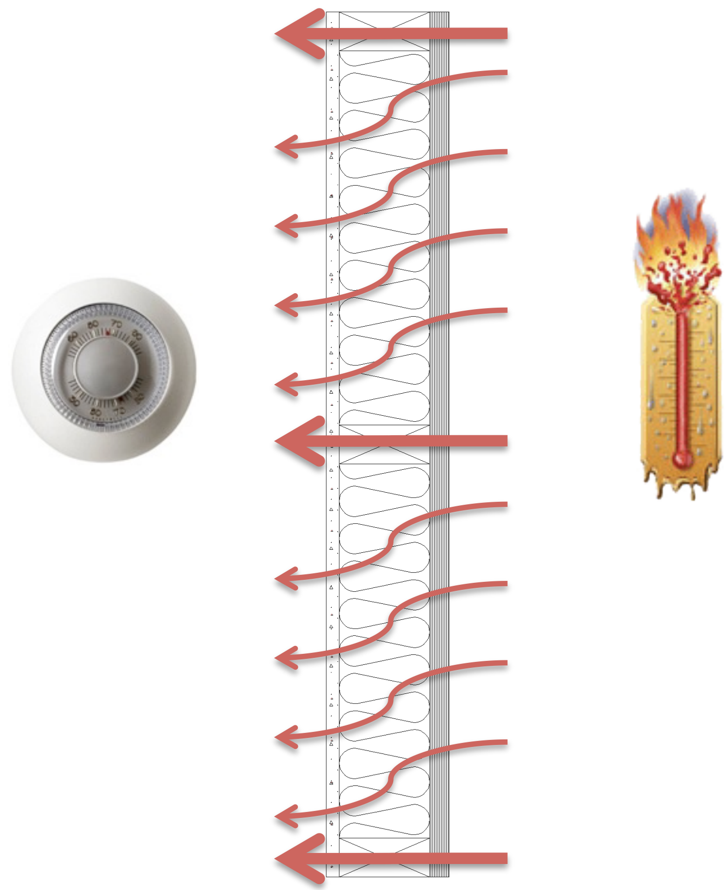
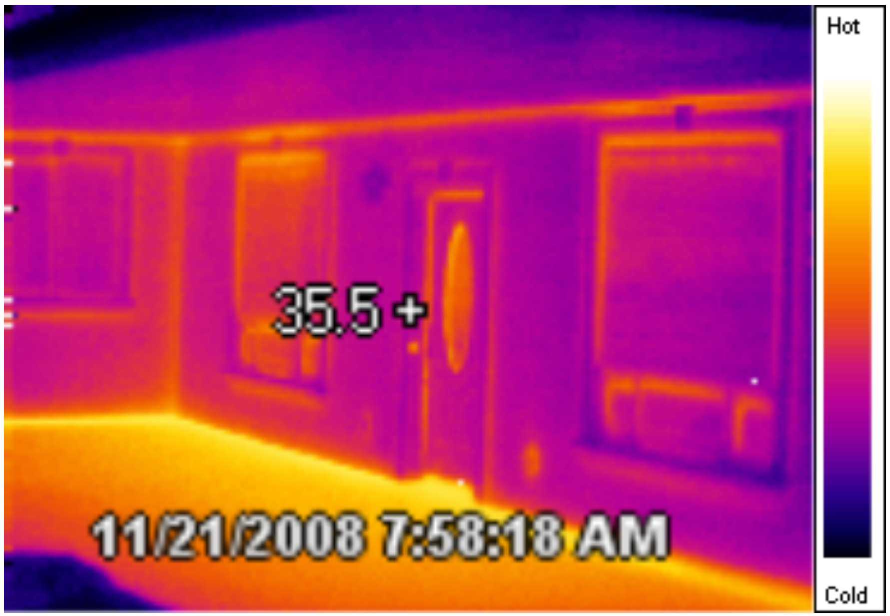
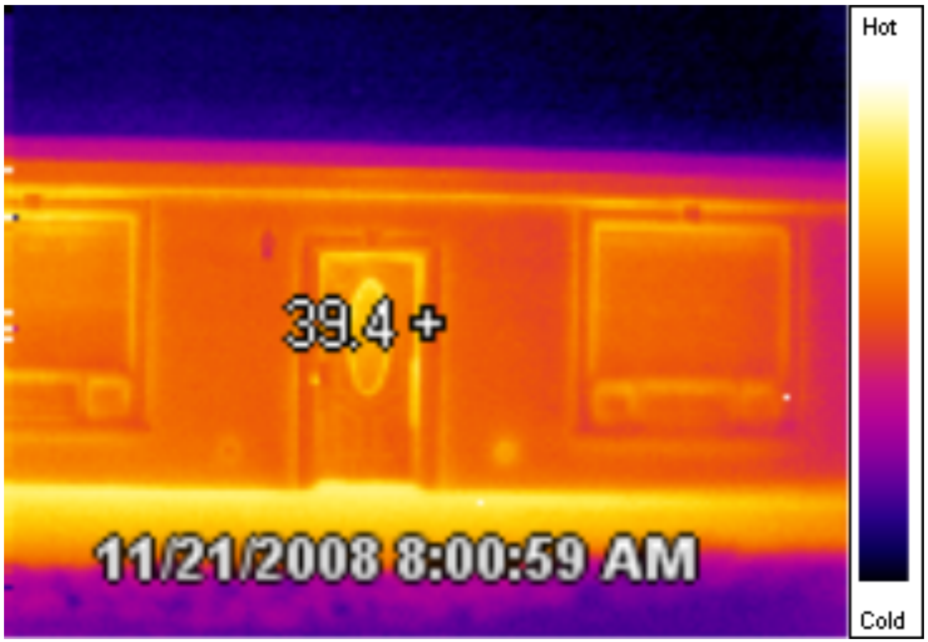


The Details Matter
Thermal Bridges

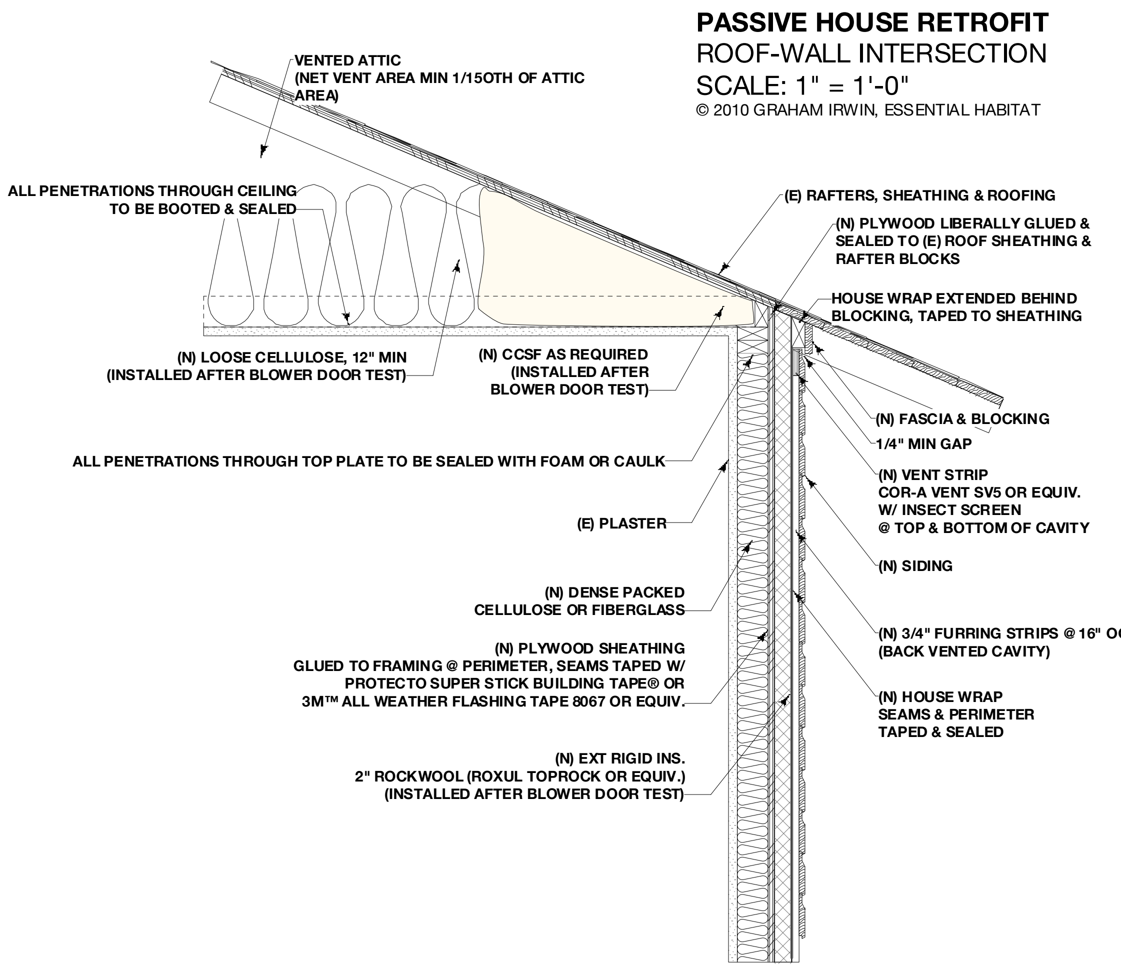




Images: Gavin Healy, Balance Point Home Performance

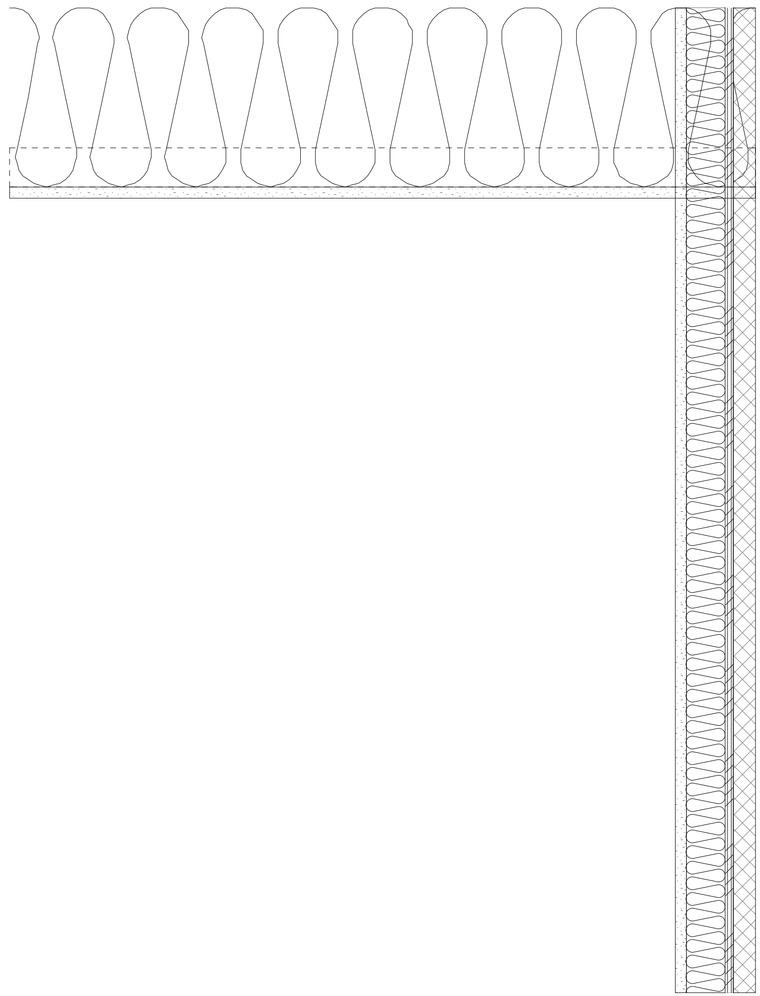
The Details Matter

Thermal Bridge Analysis of Intersections



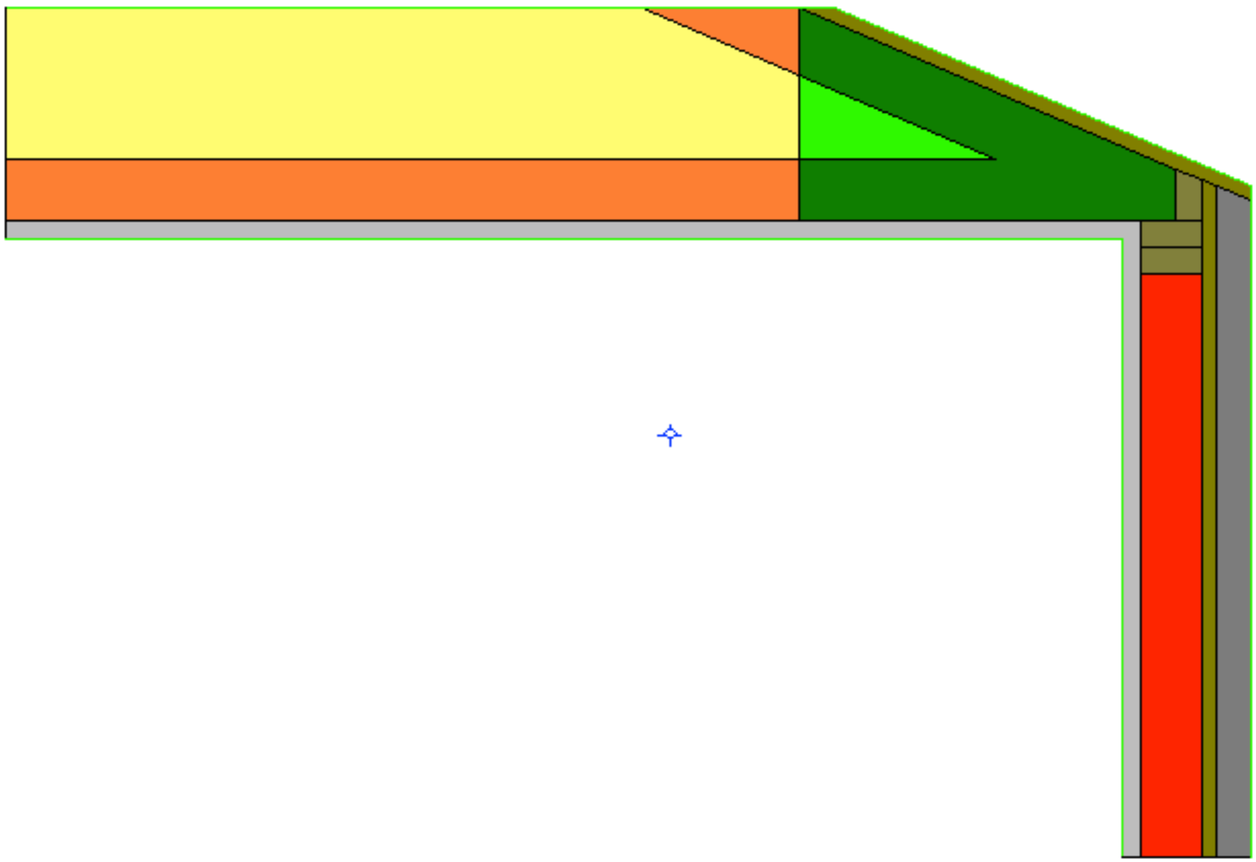
The Details Matter

Thermal Bridge Analysis of Intersections



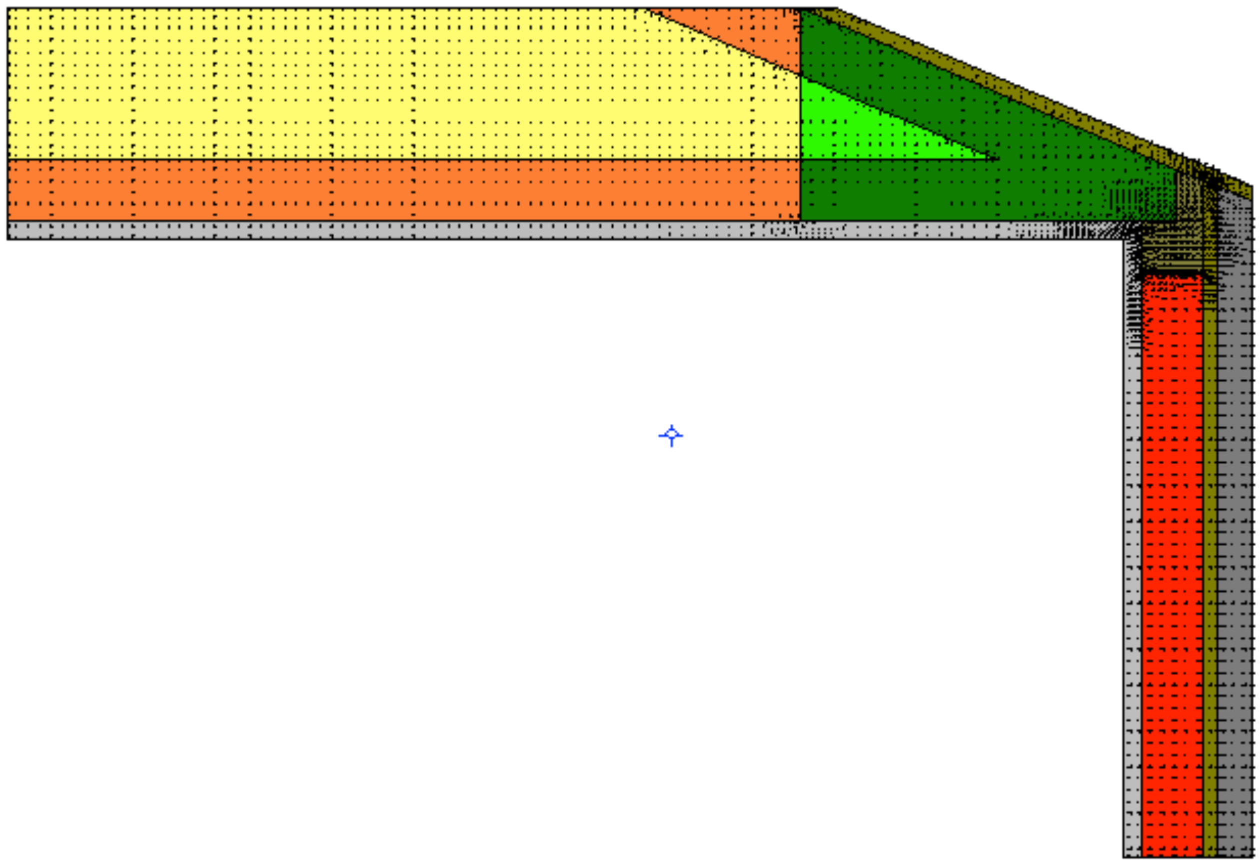
The Details Matter

Thermal Bridge Analysis of Intersections



The Details Matter

Thermal Bridge Analysis of Intersections



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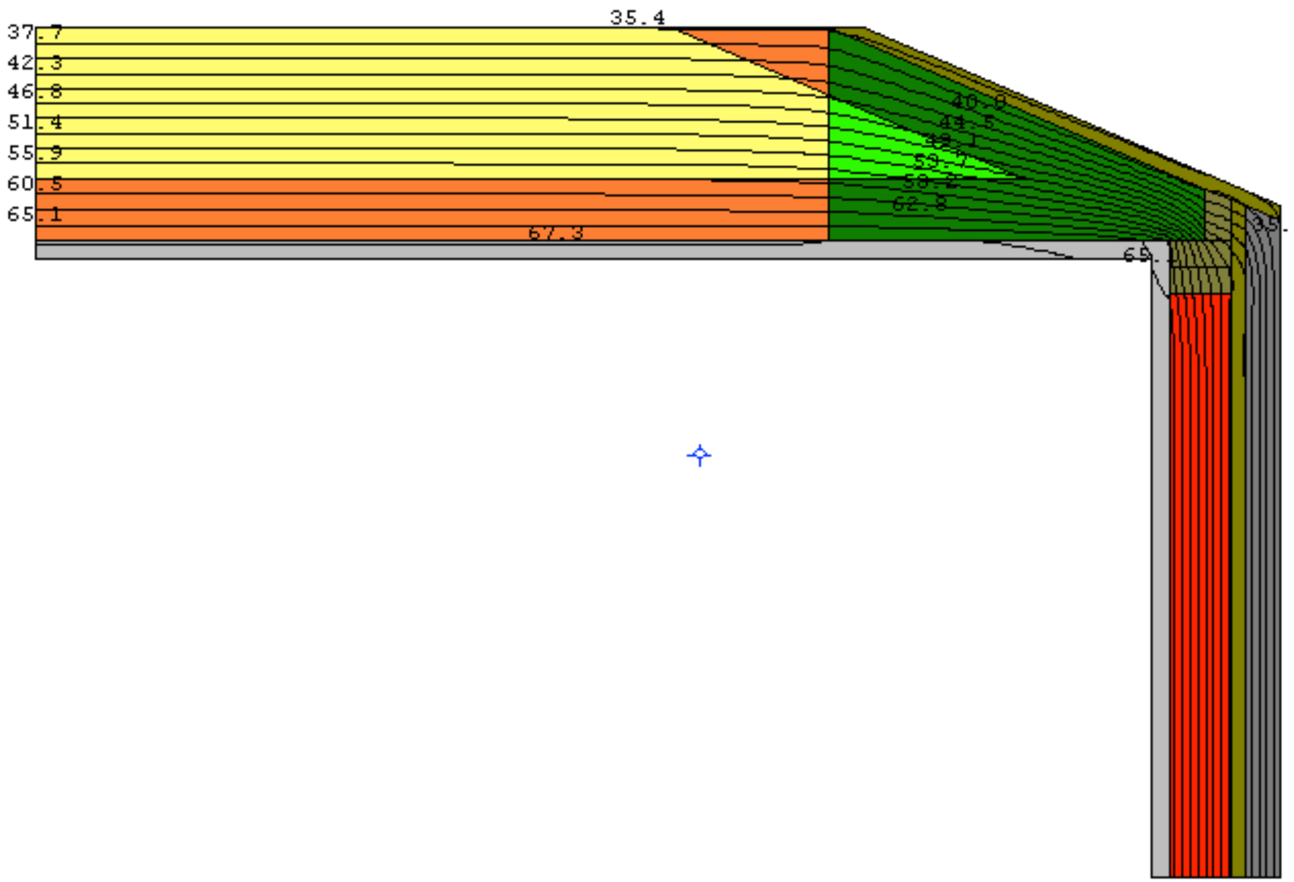
Thermal Bridge Analysis of Intersections



The Details Matter

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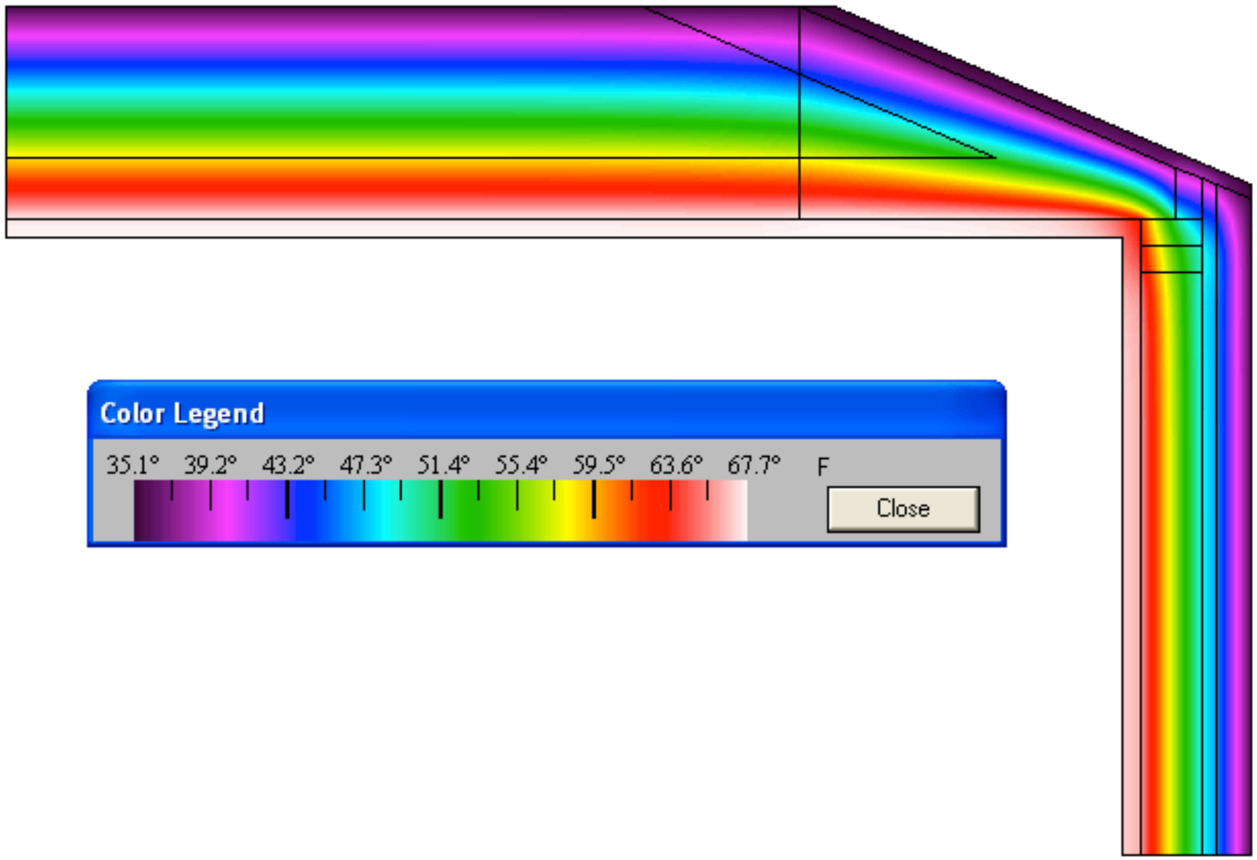
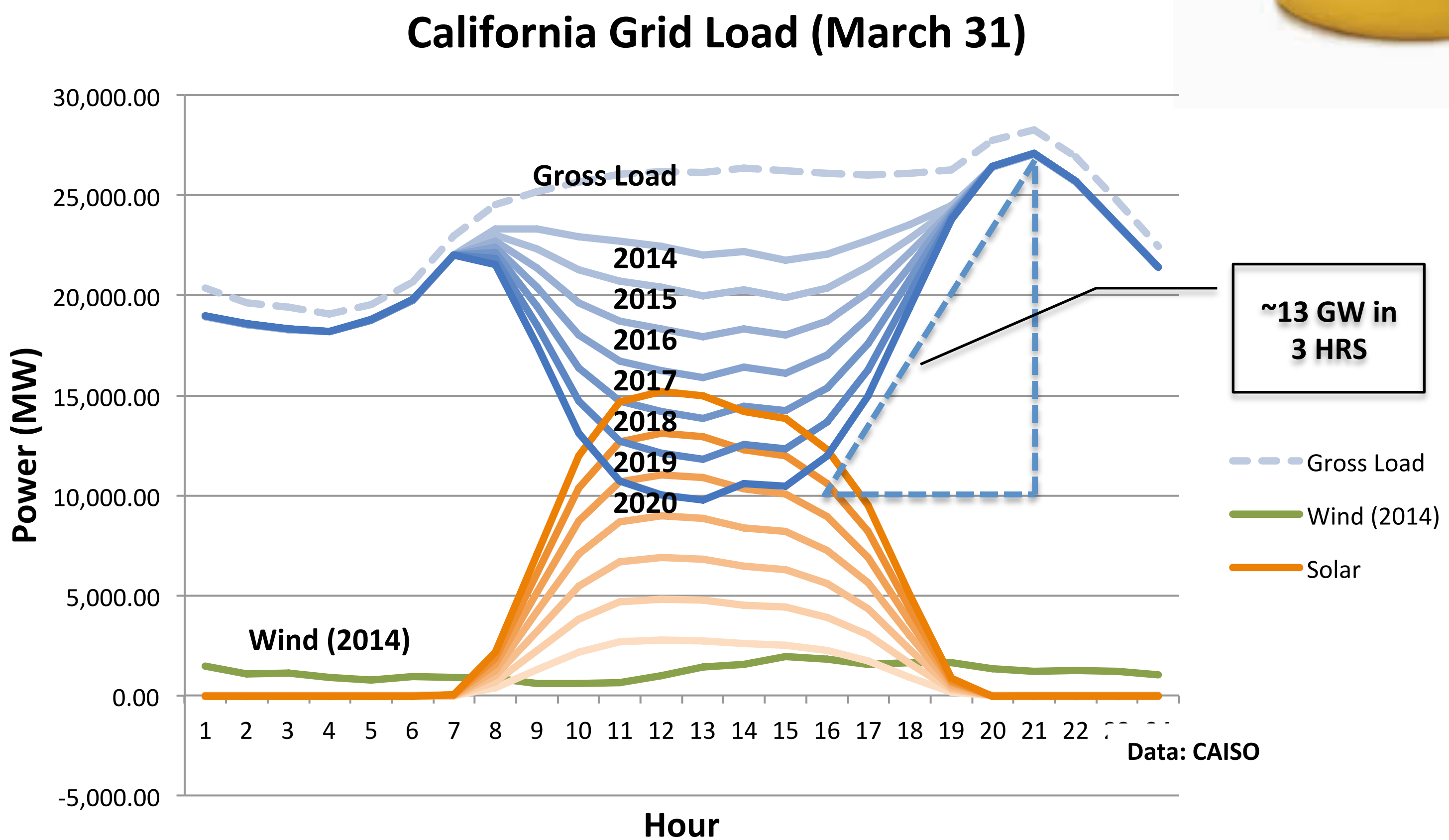


The "Duck Curve"

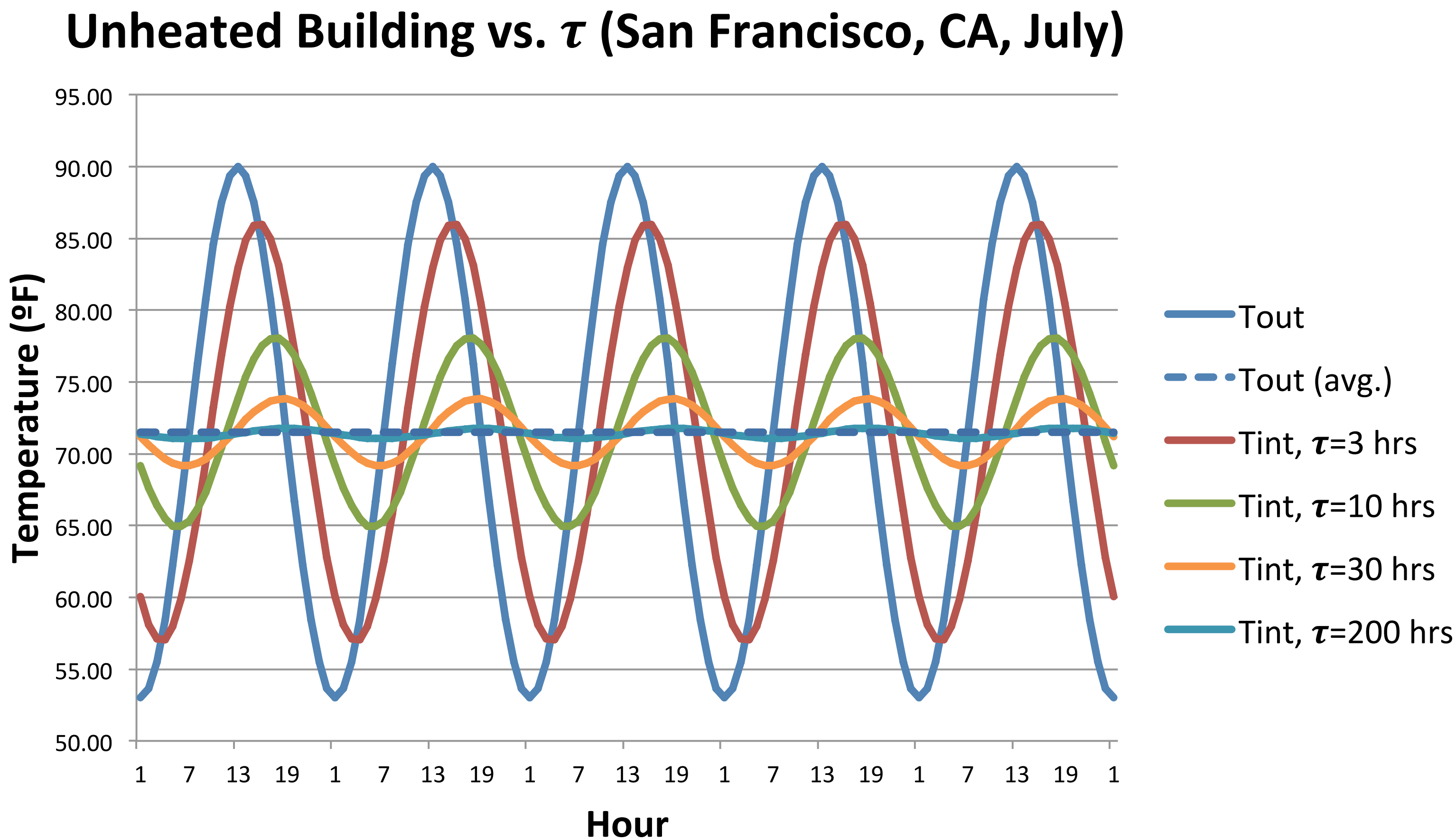
and the End of Net-Zero?



Energy: 13 GW x 3 hrs / 2 = 19,500,000 kWh / 10 kWh / 70% = 2,790,000 Tesla 10 kW Powerwalls
Power: 13 GW / 2 kW = 6,500,000 Tesla 10 kW Powerwalls
California: 12% Renewable in 2014, 33% by 2030, 50% Renewable by 2050

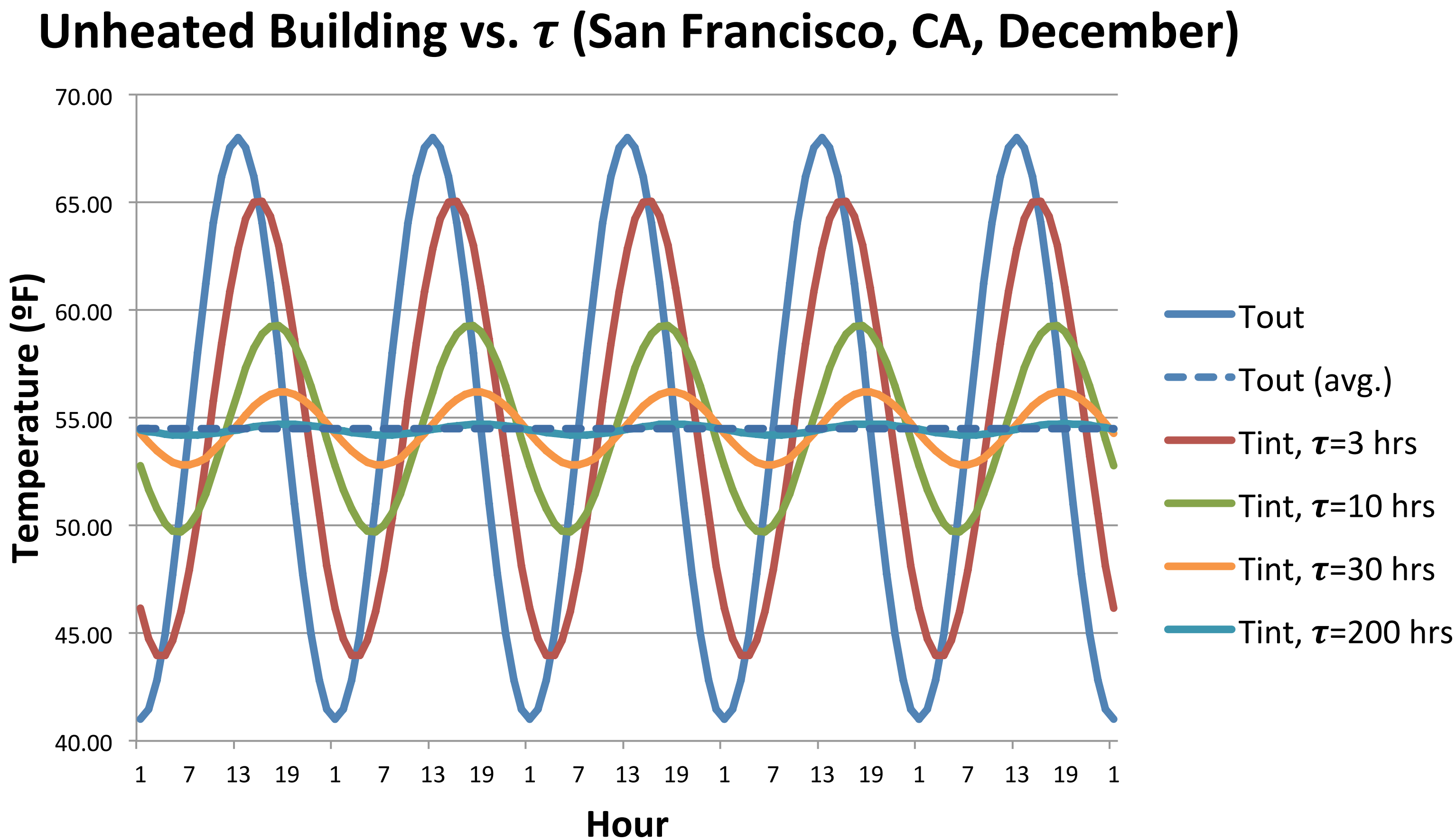
The Dao of Tau ☯

萄 of τ



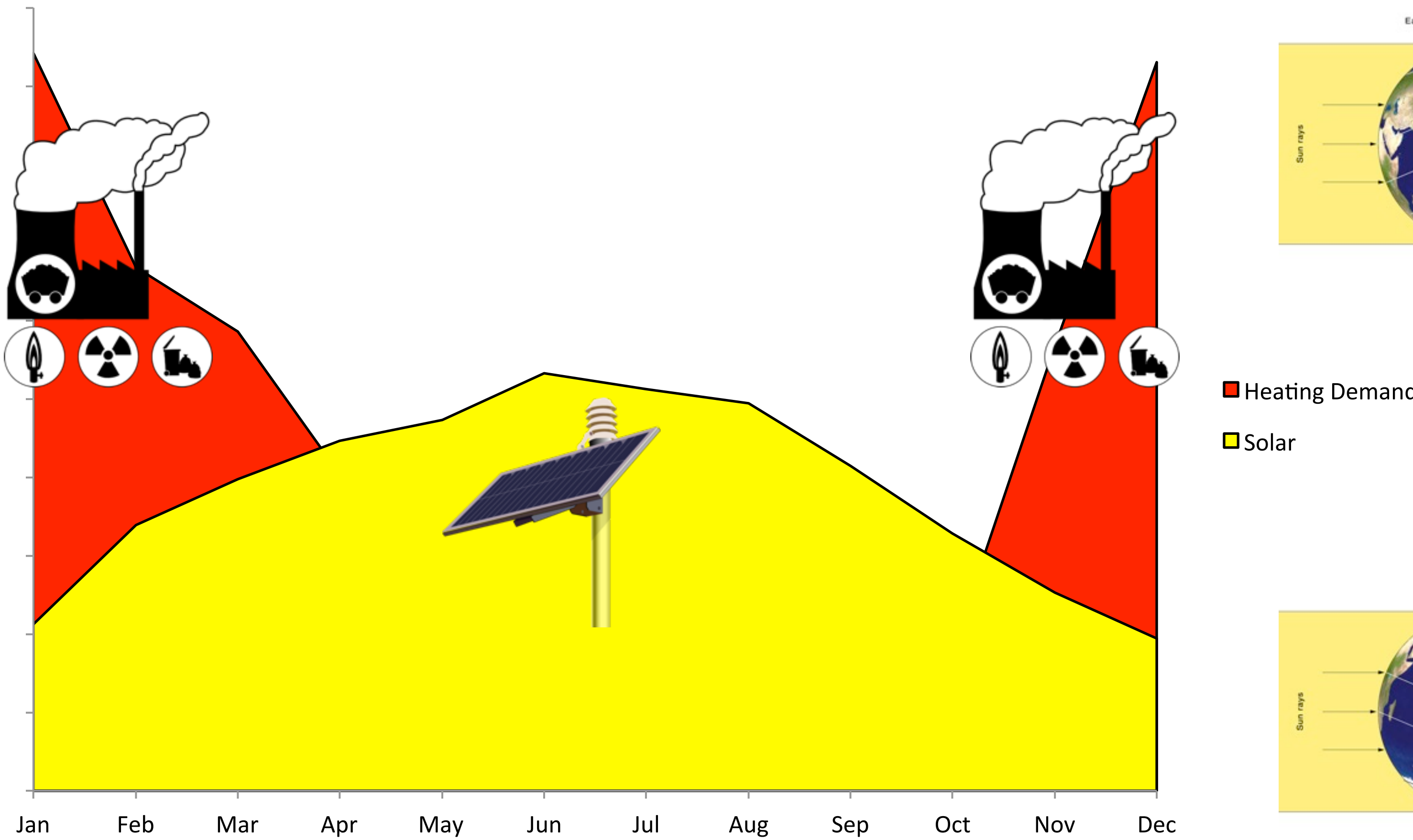
The Dao of Tau ☯

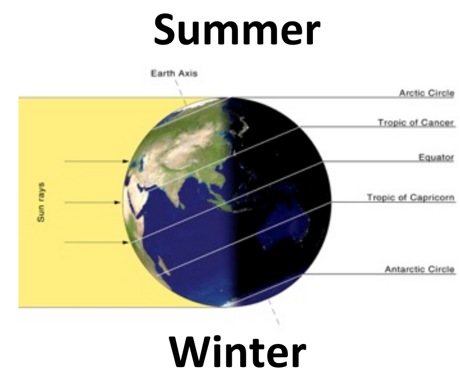
萄 of τ

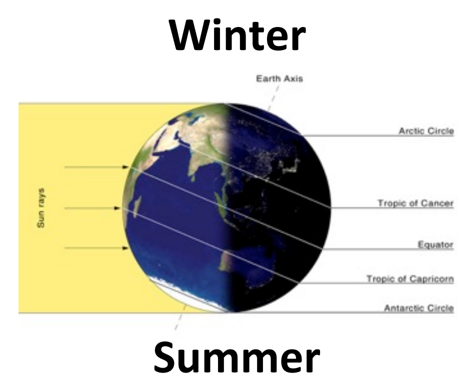


Net Zero Energy

Just Add Solar & Call It Done?







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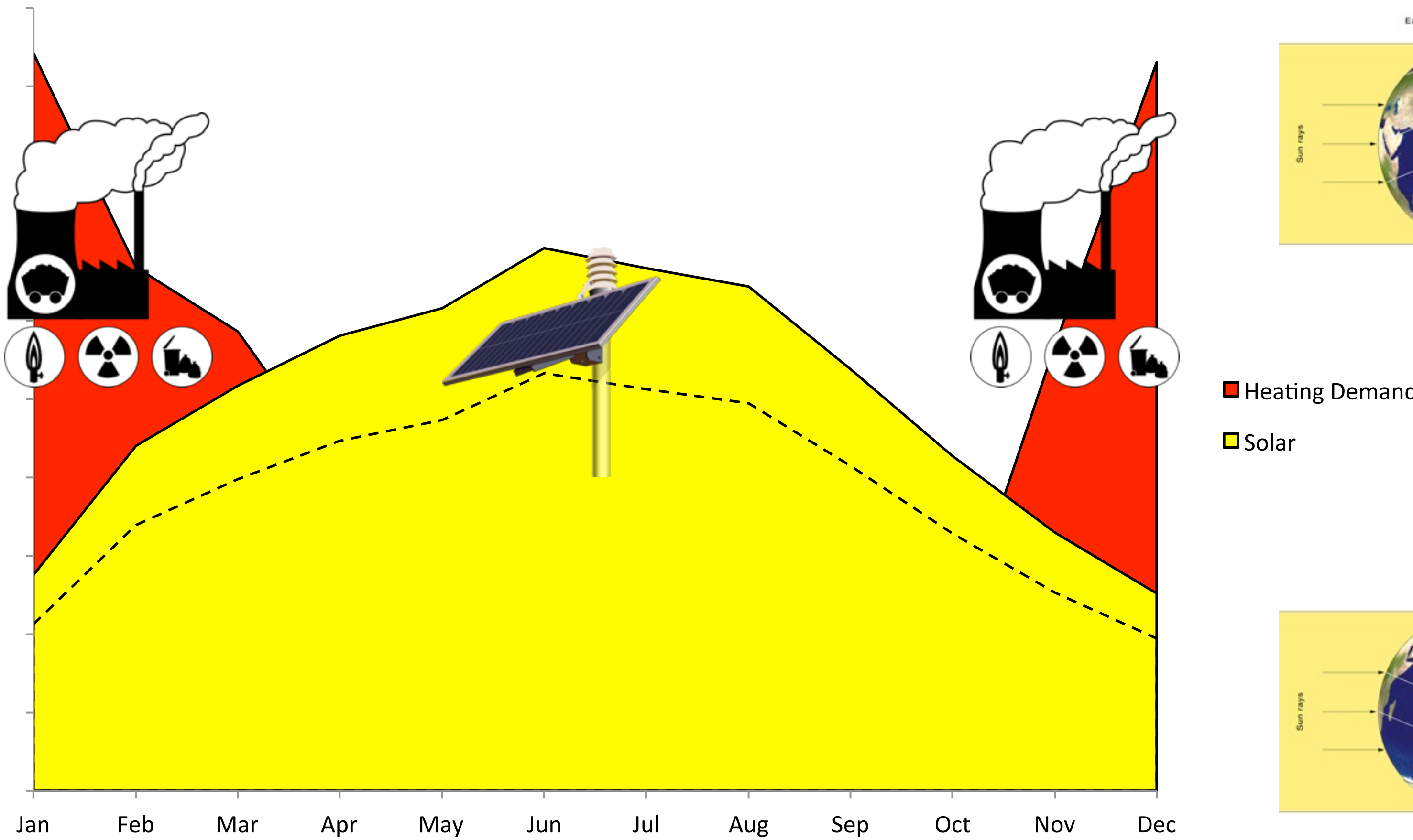
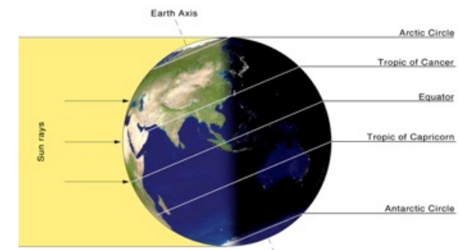
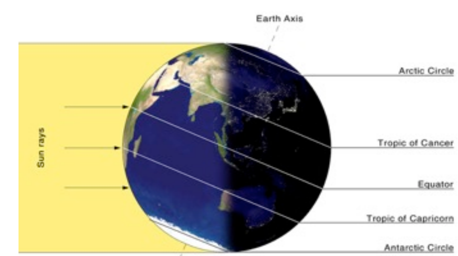


Summer



Winter

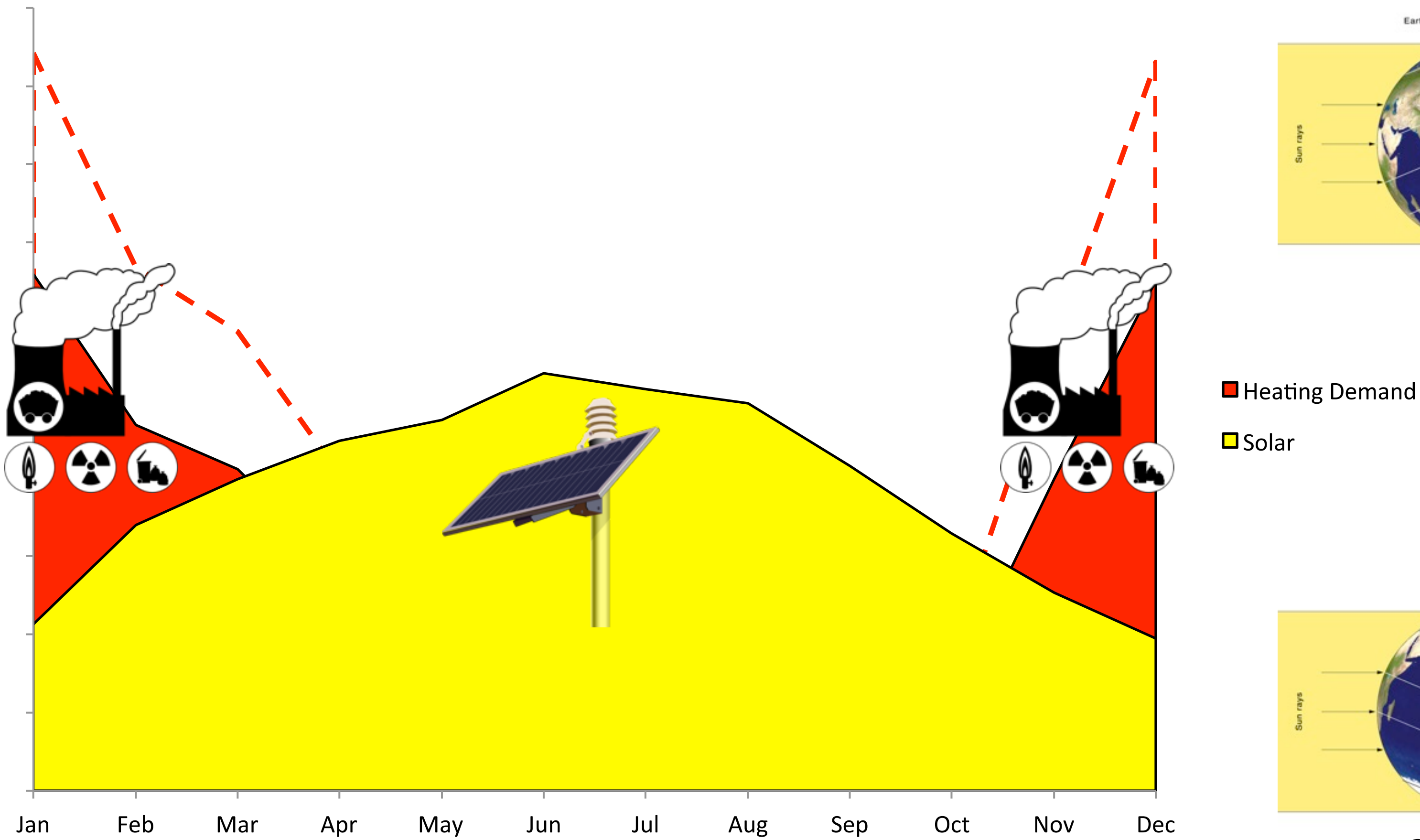
Winter

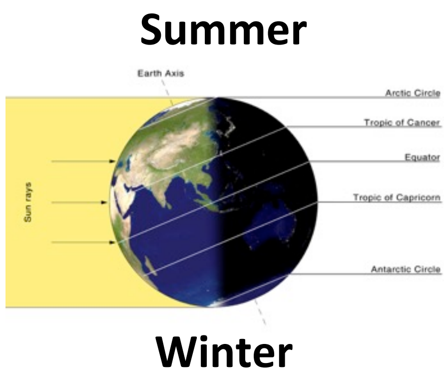


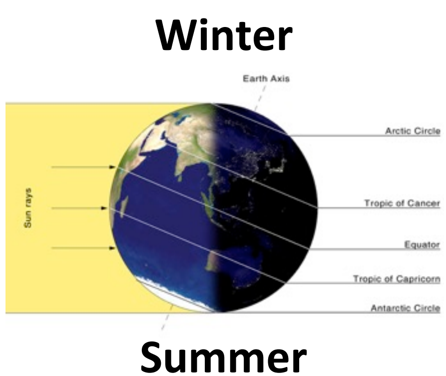
Summer

Net Zero Energy

Just Add Solar & Call It Done?







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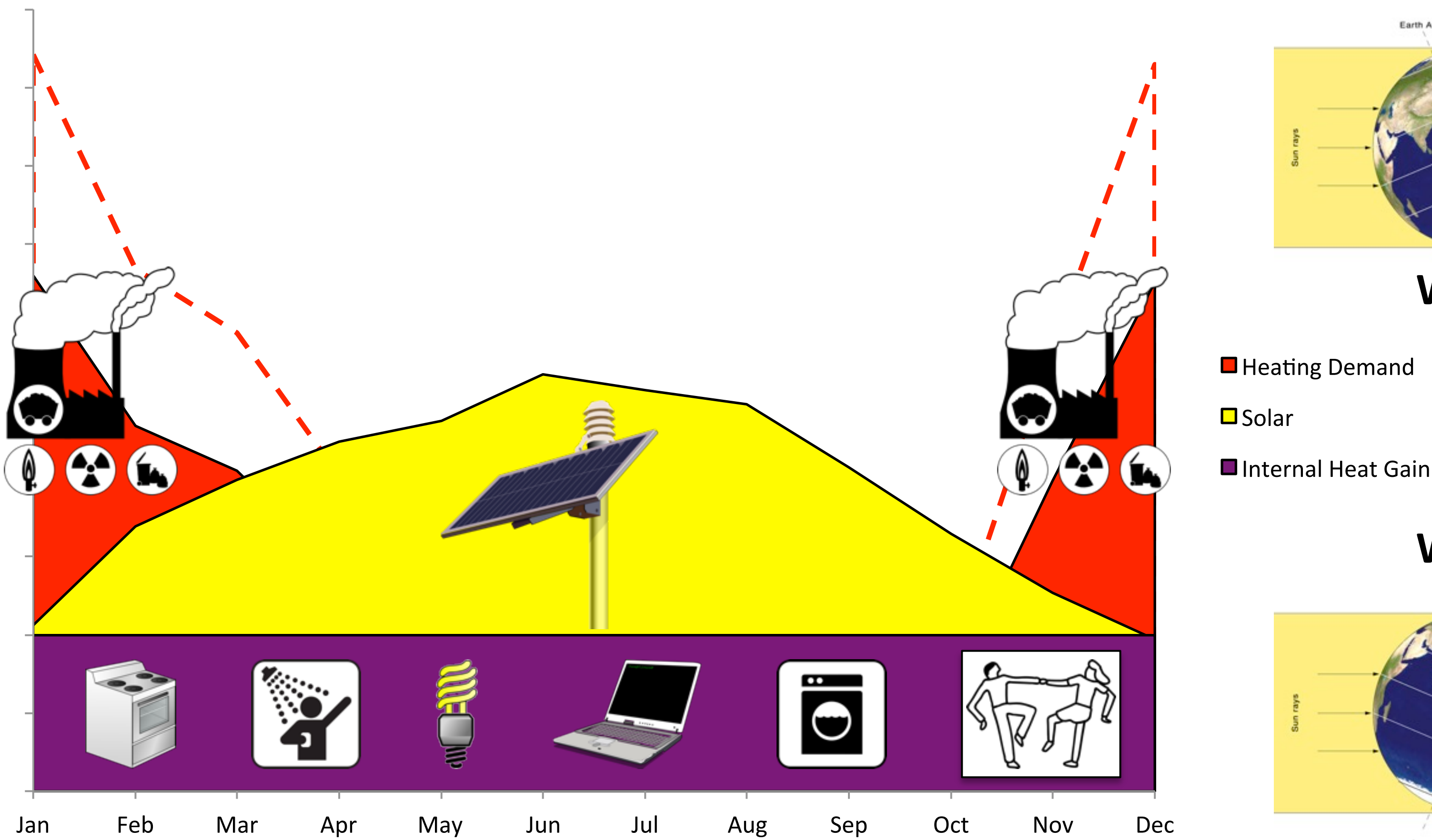

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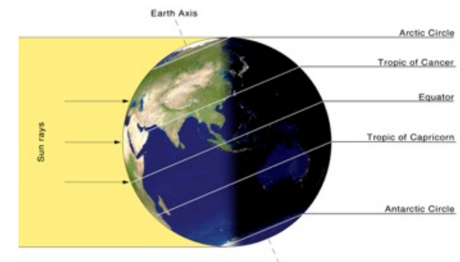

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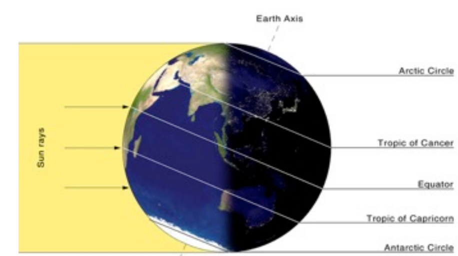
Winter



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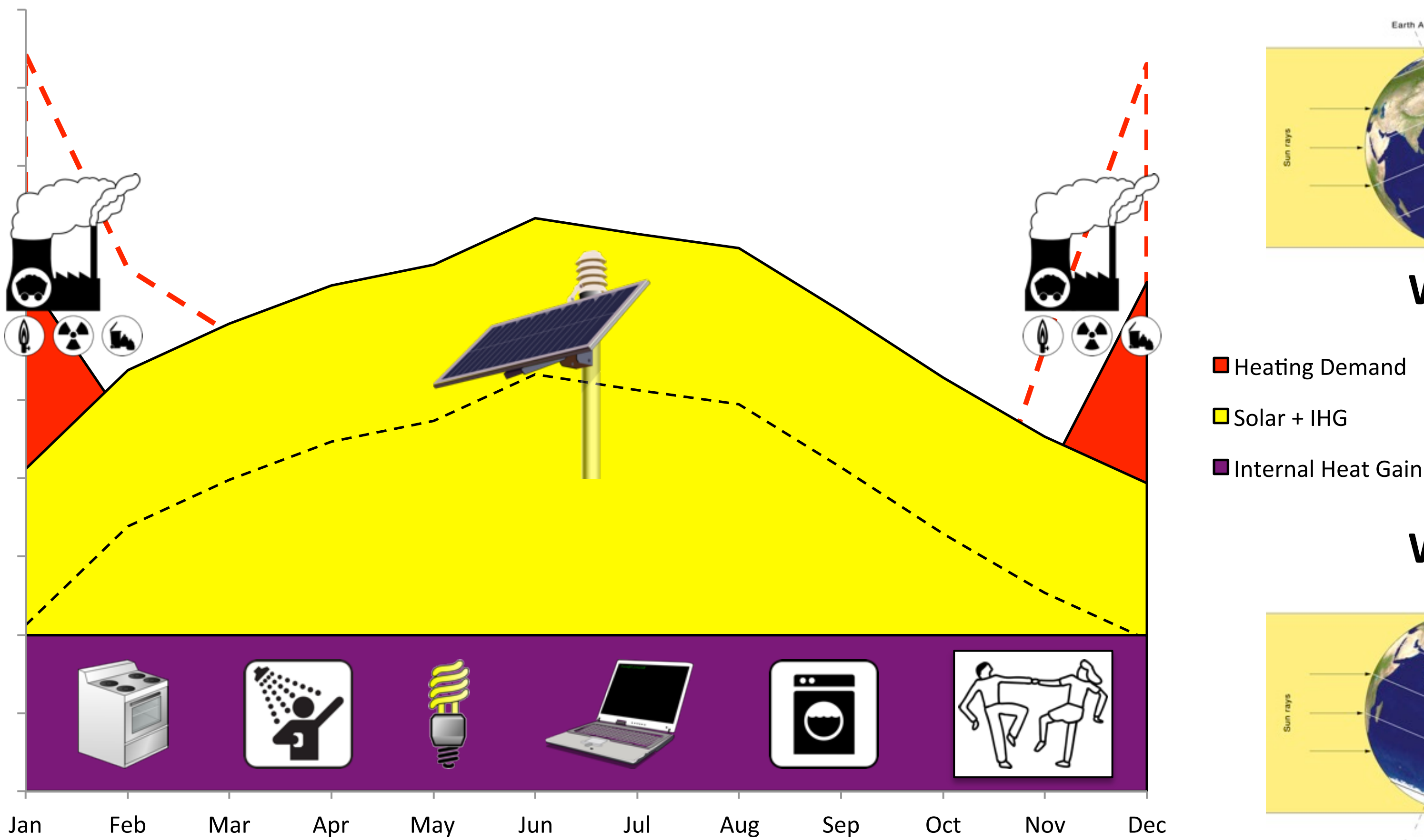
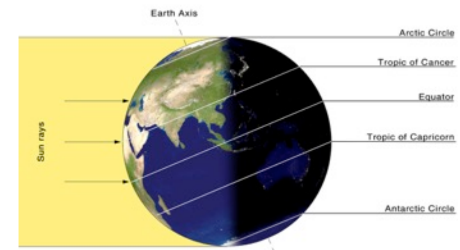
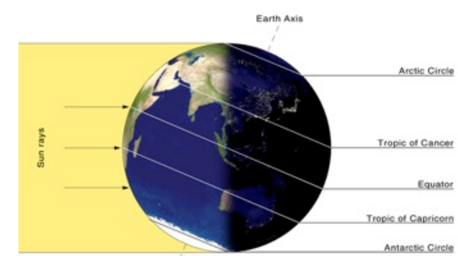


Summer



Winter

Winter



Summer

Proof in Practice

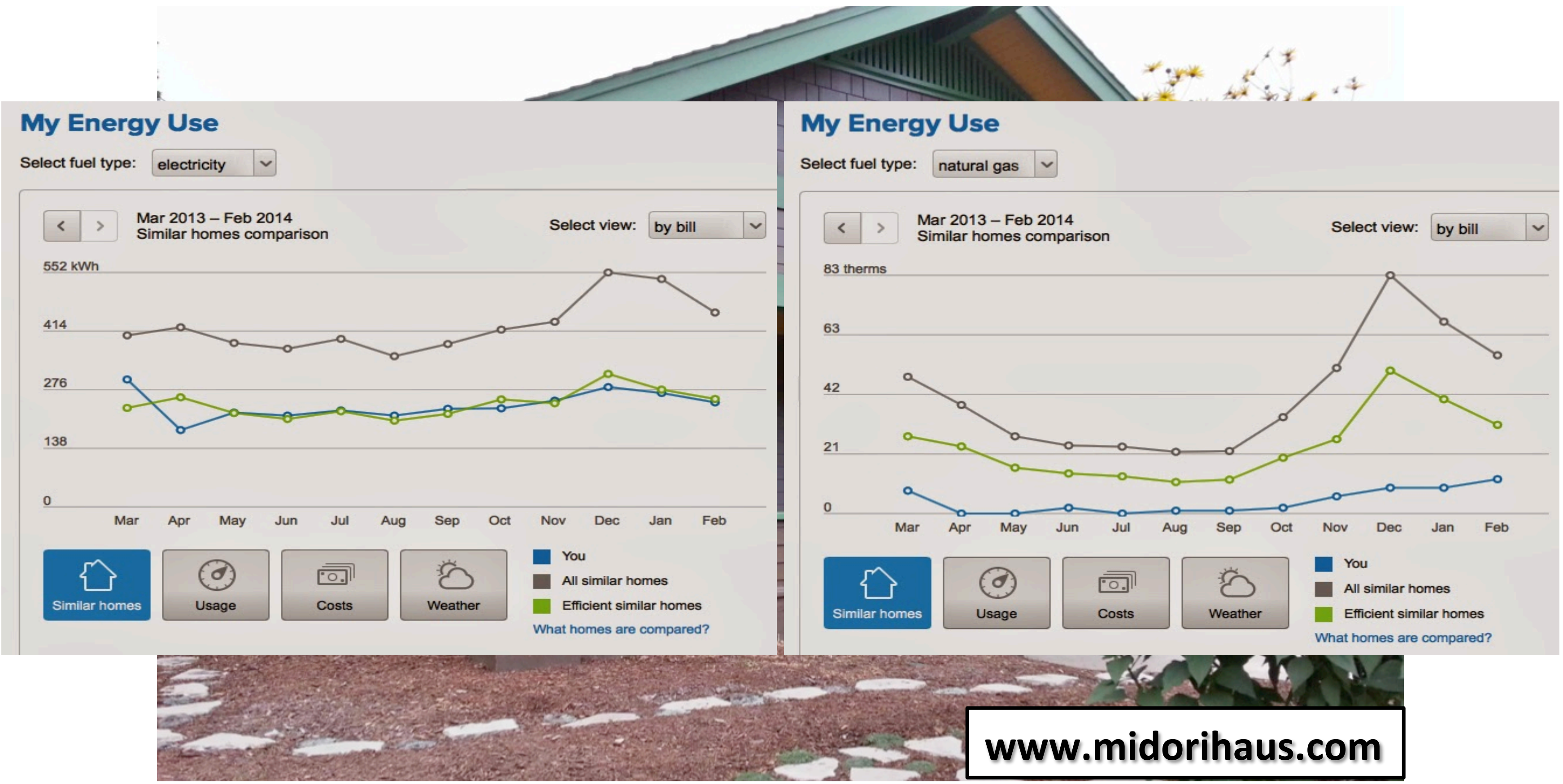
Passive House "Flattened" Seasonal Energy Use

2869 kWh Elec. + 50 Therms (1,465 kWh) Nat. Gas = 4,334 kWh (before PV!)

Before Retrofit 21,928 kWh/yr, Similar CA Home 19,596 kWh/yr

Proof in Practice

Passive House “Flattened” Seasonal Energy Use



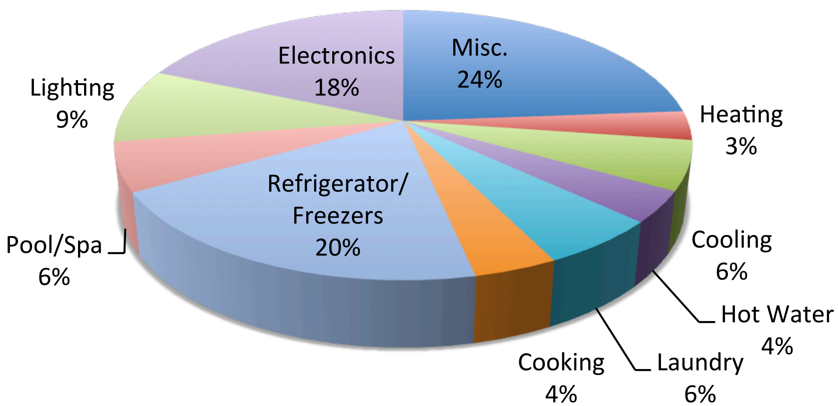
2869 kWh Elec. + 50 Therms (1,465 kWh) Nat. Gas = 4,334 kWh (before PV!)

Before Retrofit 21,928 kWh/yr, Similar CA Home 19,596 kWh/yr

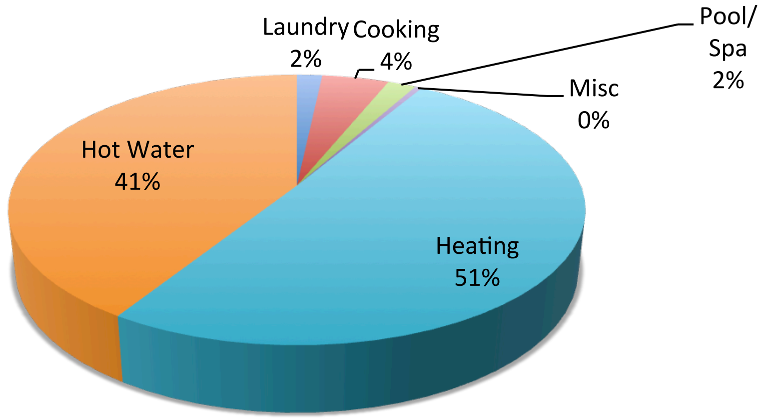
Where Does Our Energy Go?

Average PG&E Household (1584 ft^2)

PG&E Household Electricity Use



PG&E Household Natural Gas Use



Electricity: 6446 kWh/yr

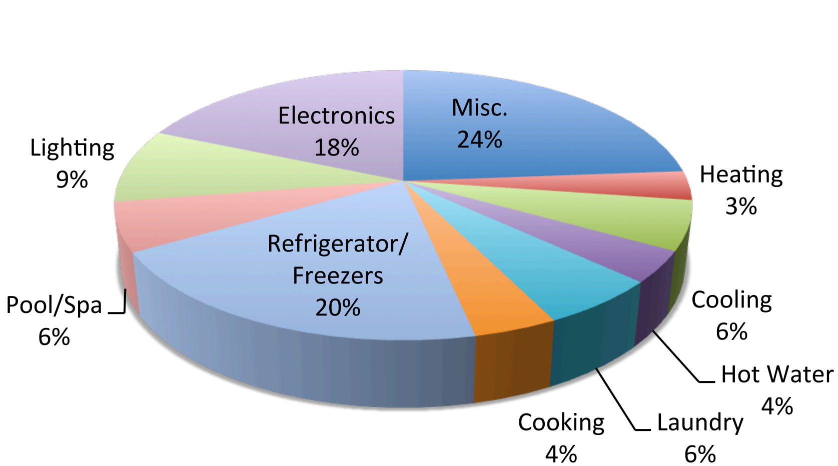
Natural Gas: 399 Therms/yr

Reference: 2009 Residential Appliance Saturation Survey (RASS), California Energy Commission (CEC)

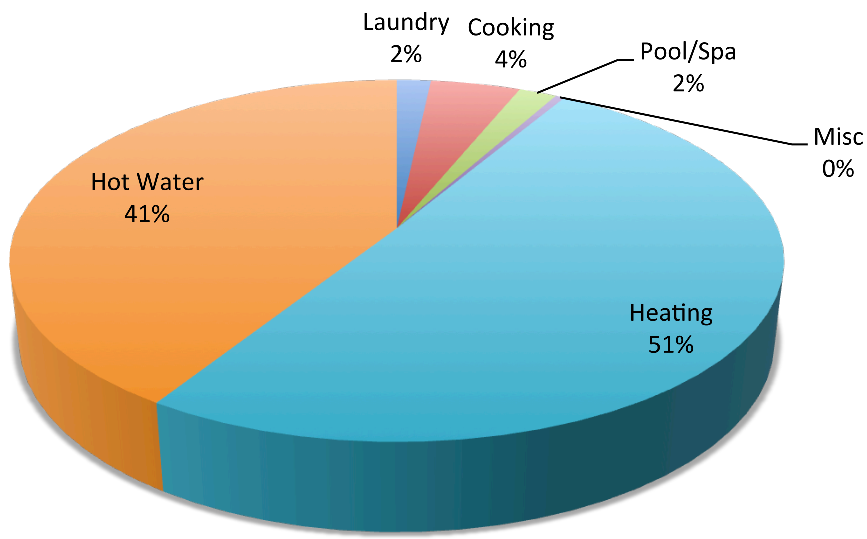
Where Does Our Energy Go?

Average PG&E Household (1584 ft^2)

PG&E Household Electricity Use



PG&E Household Natural Gas Use



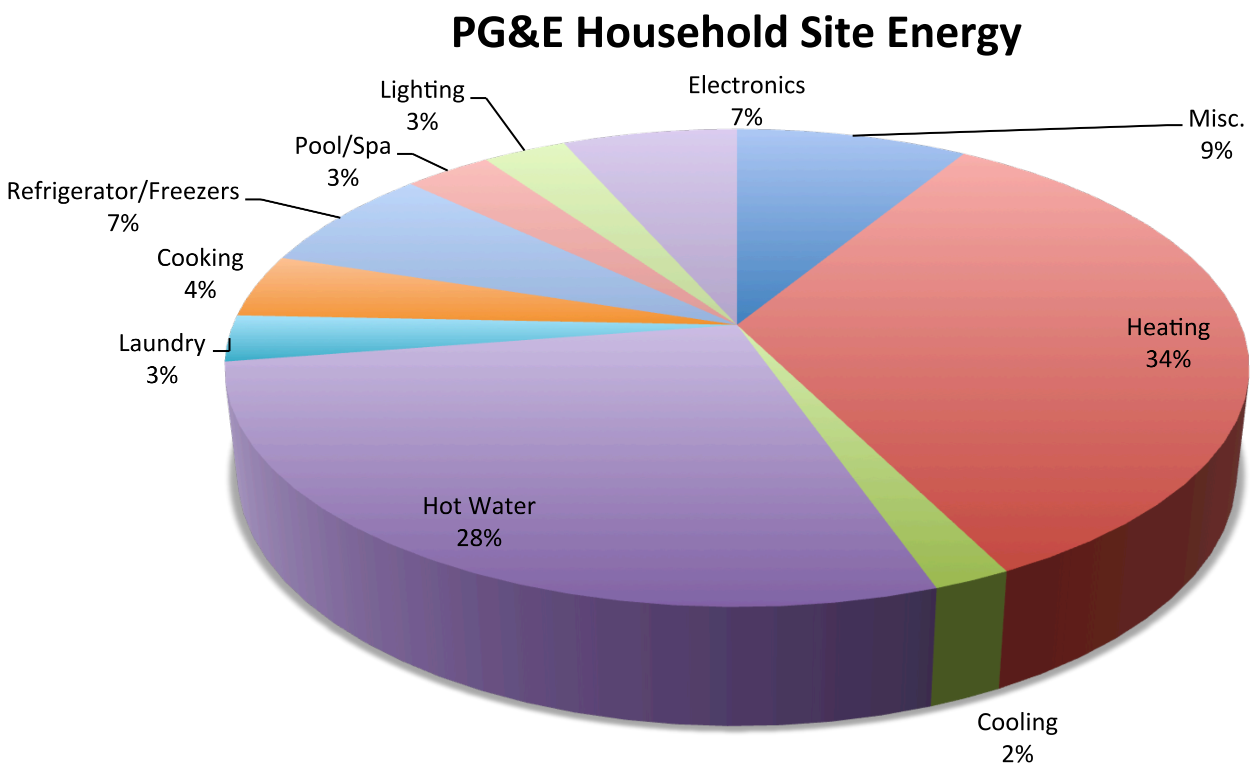
Electricity: 6446 kWh/yr

Natural Gas: 11,683 kWh/yr

Reference: 2009 Residential Appliance Saturation Survey (RASS), California Energy Commission (CEC)

Where Does Our Energy Go?

Average PG&E Household (1584 ft^2)



Site Energy: 18,263 kWh/yr
Electricity: 35%
Natural Gas: 65%

Reference: 2009 Residential Appliance Saturation Survey (RASS), California Energy Commission (CEC)

Thank You! Questions?

Graham Irwin

Principal, Essential Habitat Architecture

www.essentialhabitat.com