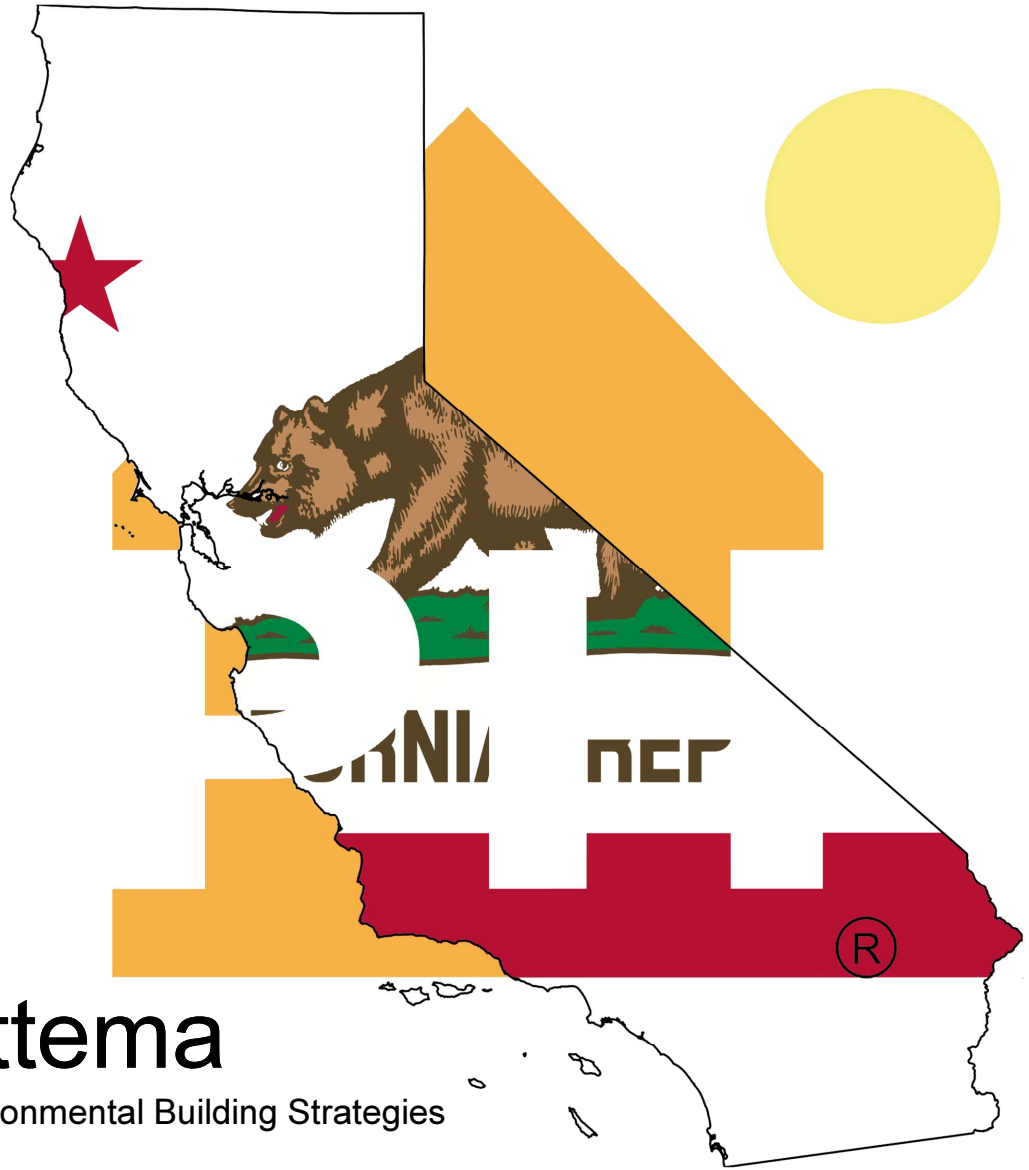
The Economic Viability of a Single-Story, Single Family Passive House in California



Jeremy Attema

Project Coordinator, Environmental Building Strategies

The Study:
CA 2013 Code vs. Passive House

I. Analysis of California Code-Minimum Construction in PH Energy Model (PHPP 8.4) by Climate Zone.

II. Step by Step Analysis of Cost Effective Upgrades to Reach Passive House Performance.

III. Perform Life Cycle Cost Analysis comparing Title 24 building to a Passive House Building.

Representative Building: “Prototype” One Story House

Figure A-1: One Story Prototype Front View

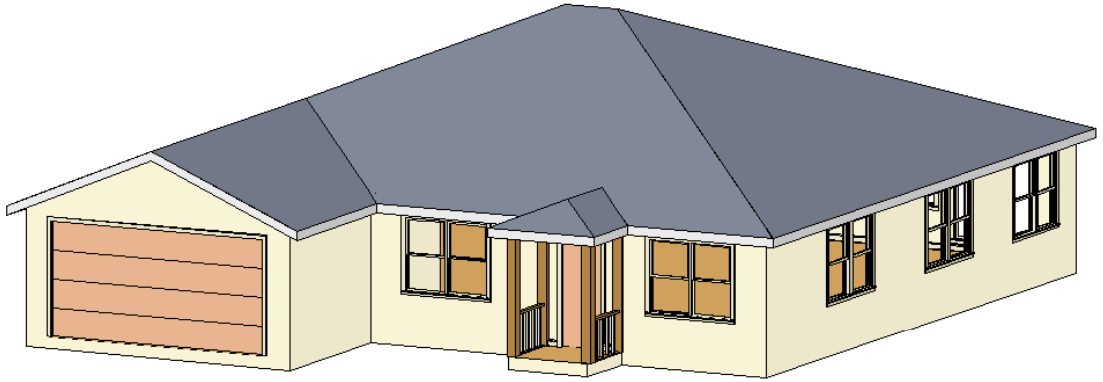
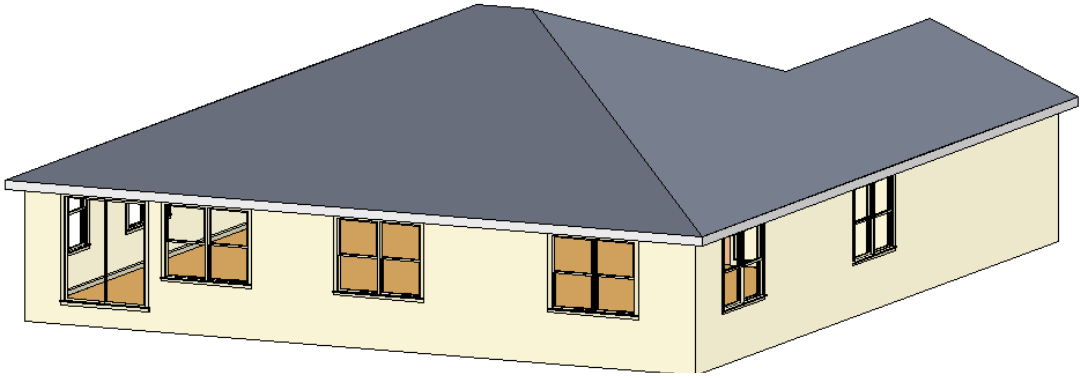


Figure A-2: One Story Prototype Back View

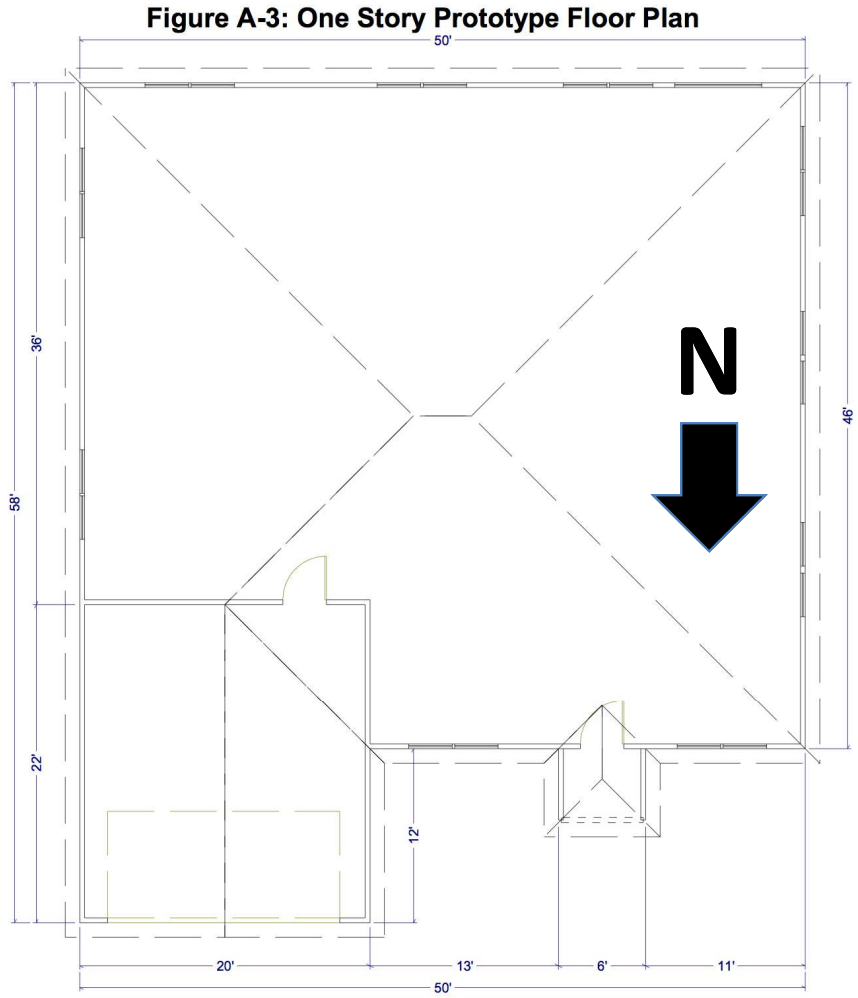


Source: 2013 Residential Alternative Calculation Method Reference Manual CEC-400-2013-003-SD-REV

Slide originally from “PH for ALL of CA V2” by Graham Irwin. 2014

Representative Building: "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



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

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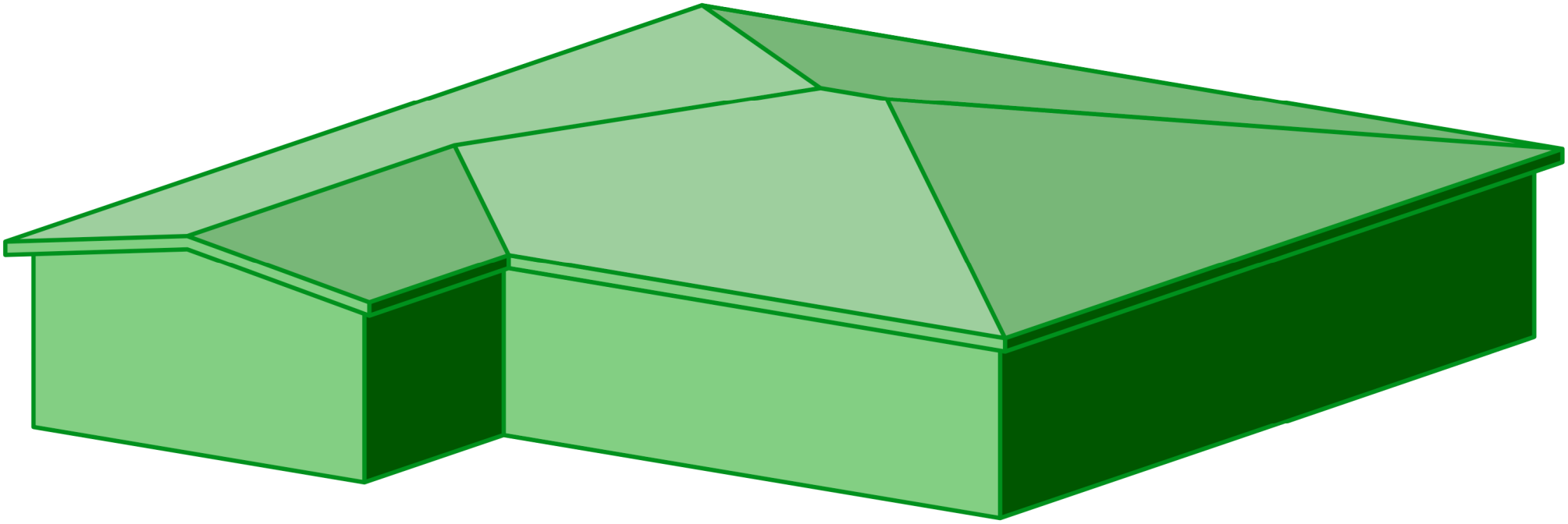
I. Title 24 Energy Modeling:
1. “Proposed” (Actual) Design



- No Landscape Shading – “Corbusian Plane”
- 12” Roof Overhang
- Glazing = 5% Exterior/“Conditioned Floor Area” (CFA) in Each Direction (108 ft^2)

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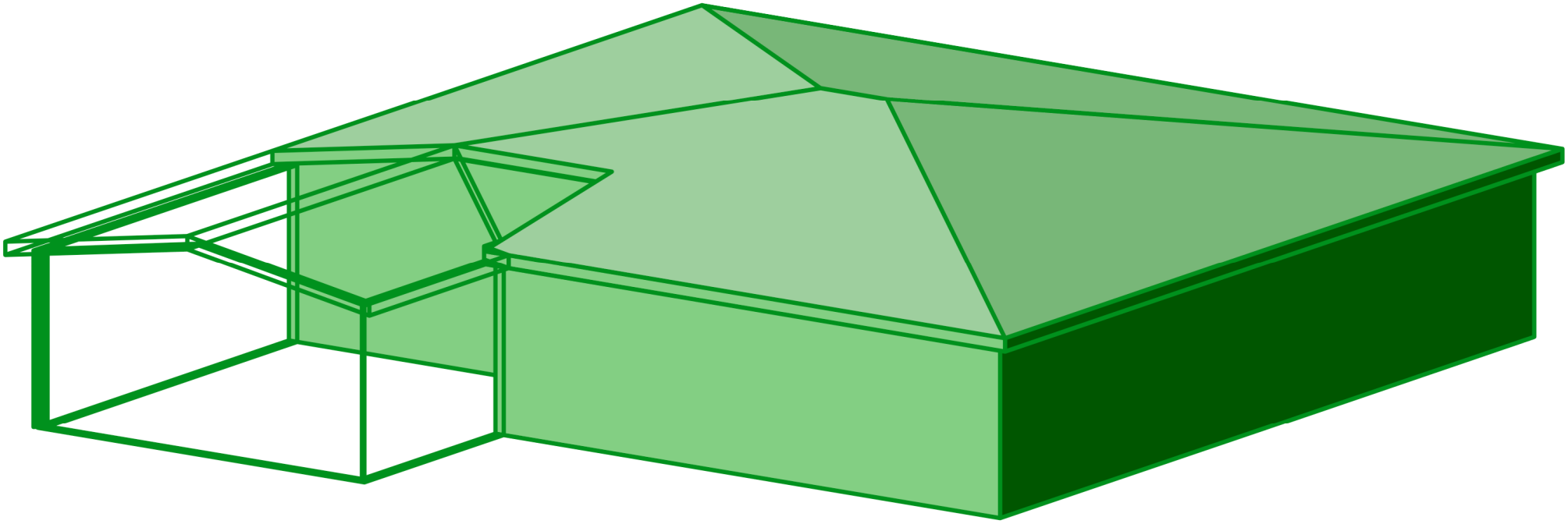
2. Study Adjustment – No Garage: Demising Walls Set As Ambient



- Conditions Heavily Dependent on Garage Door Operation = Unpredictable
- Deletion Likely to Make Winter Compliance More Difficult = Conservative
- Cooling Conditions w/ Cool Roof = Garage (Probably) Insignificant

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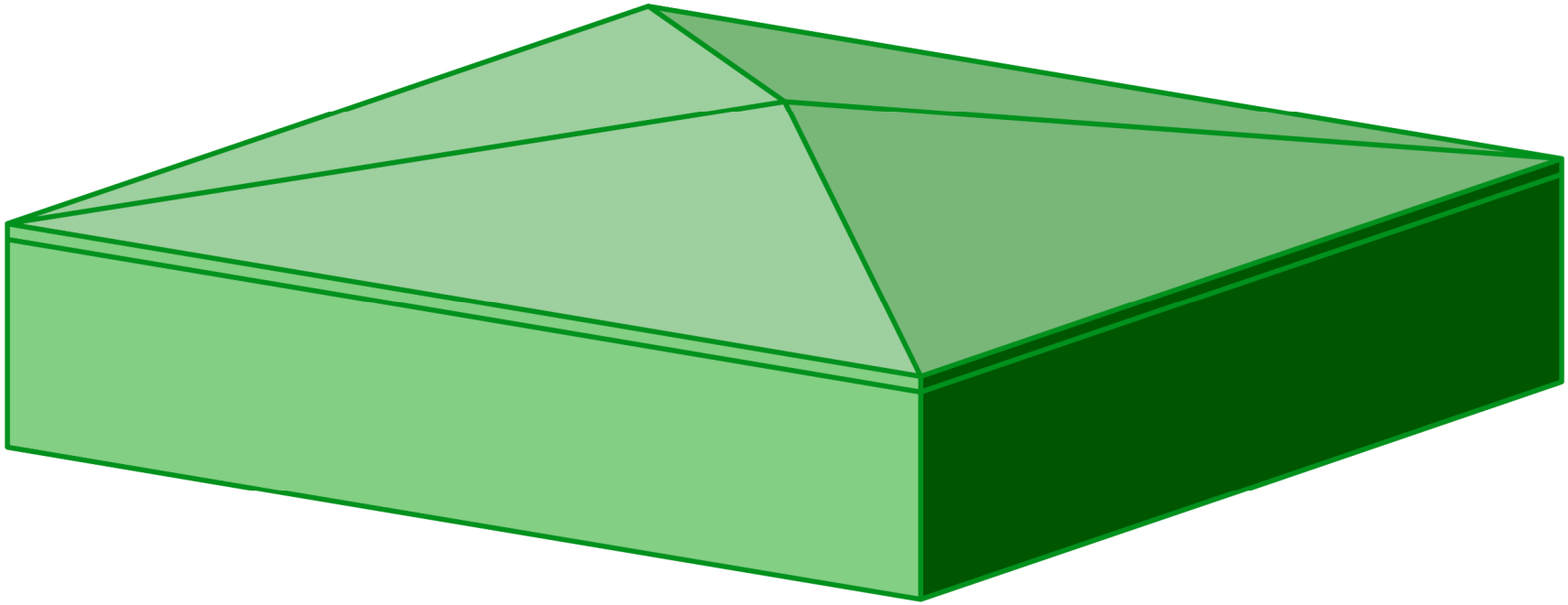
3. “Standard” Design:
= Energy Budget for Compliance



- Identical Floor Area & Volume = Proposed Design
- Equal Wall Area in Each Cardinal Direction: N, E, S, W
- Glazing = Prototype = 5% Exterior Floor Area (CFA) in Each Direction (108 ft^2)
- Overhangs Deleted

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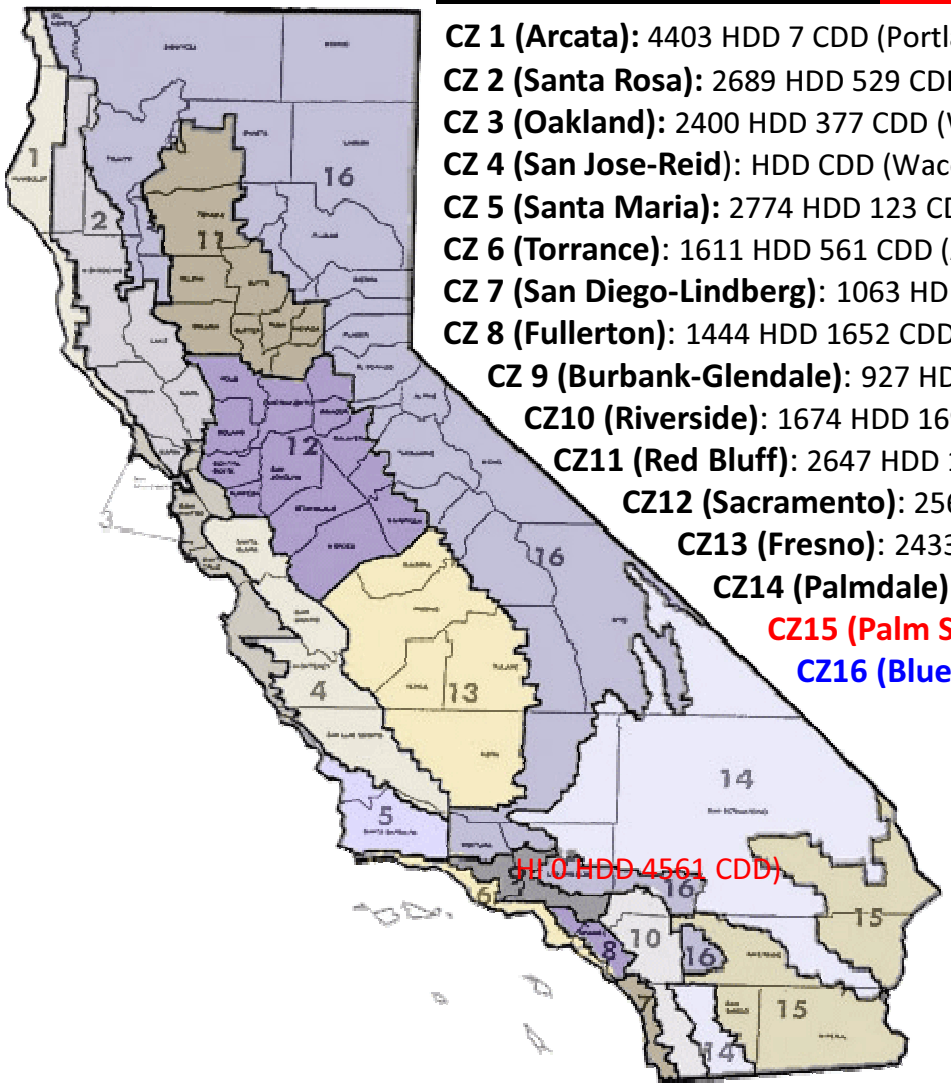
4. Set Location by Climate Zone: Locate Project in 1 of 16 Cities

16 Climate Zones (Desert to Subarctic)



CZ 1 (Arcata): 4403 HDD 7 CDD (Portland, OR 4400 HDD 390 CDD)
CZ 2 (Santa Rosa): 2689 HDD 529 CDD (Abilene, TX 2659 HDD 2386 CDD)
CZ 3 (Oakland): 2400 HDD 377 CDD (Wilmington, NC 2429 HDD 2017 CDD)
CZ 4 (San Jose-Reid): HDD CDD (Waco, TX 2164 HDD 2840 CDD)
CZ 5 (Santa Maria): 2774 HDD 123 CDD (Midland, TX 2716 HDD 2139 CDD)
CZ 6 (Torrance): 1611 HDD 561 CDD (Austin, TX 1648 HDD 2974 CDD)
CZ 7 (San Diego-Lindberg): 1063 HDD 866 CDD (Phoenix, AZ 1027 HDD 4364 CDD)
CZ 8 (Fullerton): 1444 HDD 1652 CDD (Norfolk, VA 3342 HDD 1630 CDD)
CZ 9 (Burbank-Glendale): 927 HDD 1506 CDD (Raleigh, NC 3465 HDD 1521 CDD)
CZ10 (Riverside): 1674 HDD 1697 CDD (Huntsville, AL 3262 HDD 1671 CDD)
CZ11 (Red Bluff): 2647 HDD 1926 CDD (Cape Hatteras, NC 2521 HDD 1737 CDD)
CZ12 (Sacramento): 2563 HDD 1426 CDD (Greenville, SC 3272 HDD 1526 CDD)
CZ13 (Fresno): 2433 HDD 1991 CDD (Wilmington, NC 2429 HDD 2017 CDD)
CZ14 (Palmdale): 2820 HDD 1764 CDD (Atlanta, GA 2827 HDD 1810 CDD)
CZ15 (Palm Springs-Intl): 1000 HDD 3895 CDD (Brownsville, TX 644 HDD 3874 CDD)
CZ16 (Blue Canyon): 5652 HDD 414 CDD (Salt Lake City, UT 5607 HDD 1089 CDD)

Statewide Extremes

Bodie, CA: 9770 HDD 4 CDD (Valdez, AK 9733 HDD 0 CDD)

Needles, CA: 1227 HDD 4545 CDD (Honolulu, HI 0 HDD 4561 CDD)

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5. T24 Requirements/Assumptions

CEC CLIMATE ZONE		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Roof Pit	**Reflectance**	NR (0.08 asphalt shingles, 0.10 other materials)									0.2						0.08/0.10
	Emissivity	NR (0.85)									0.75						0.85
Fenestration	**Max. U-Value**	U 0.32 (R 3.125)															
	Max. SHGC	0.66	0.25	0.66	0.25	0.66	0.25										
	Max. Area	20% of Conditioned Floor Area (exterior dimensions) equally distributed between N, E, S, W															
	Max. West	NR	5%	NR	5%	NR	5%										
	Shading	No overhangs or interior blinds (12" overhangs on proposed/prototype). Bug screens on windows (0.76 SHGC															
Entry Door (s)		Facing North, U 0.50 (R2), 3'0"x6'8", 2 doors: exterior & garage															
Air Leakage		4.4 ACH50 Single Family & Townhomes, 6.2 ACH50 Other															
Ventilation (CFM)		0.01Afloor + 7.5(Nbr + 1) = 53 CFM = 0.25 ACH (assuming 3 bedrooms)															
Night Flushing		NR							2CFM/ft2CFA x 25%(Whole House Fan)							NR	
Natural Ventalation		Min. Temperature 68F, 5% of Fenestration Area, Height Difference: 2 ft (1 story), 8 ft (2*3 stories), 6AM-Mid-night															

References: 2013 CEC Standards Table 150.1-A (Package A Prescriptive Requirements), 2013 Residential ACM Reference Manual CEC-400-2013-003-CMF

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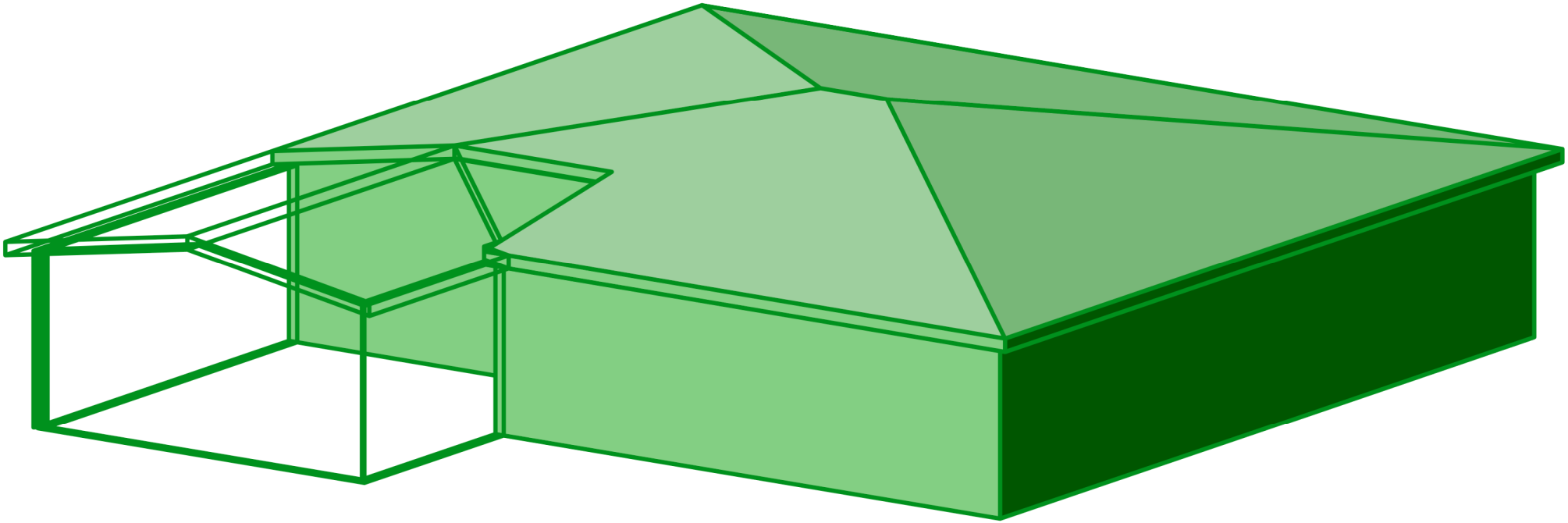
II. Passive House Optimization: 1. “Baseline” Design



- Prototype Design w/ No Garage
- 2:12 Roof Pitch w/ Steep Slope Requirements
- Year ‘Round Bug Screens (76% SHGC) Removed (Sometimes Used In Summer)
- Whole House Fan (Where Required by Code) Removed
- Baseline Optimized w/ Raised Floor, Re-Optimized w/ Slab on Grade
- No Code Measures Reduced, Many Measures Upgraded to Typical PH Values
- Night Ventilation Cooling: Whole House Fan as “Last Resort”

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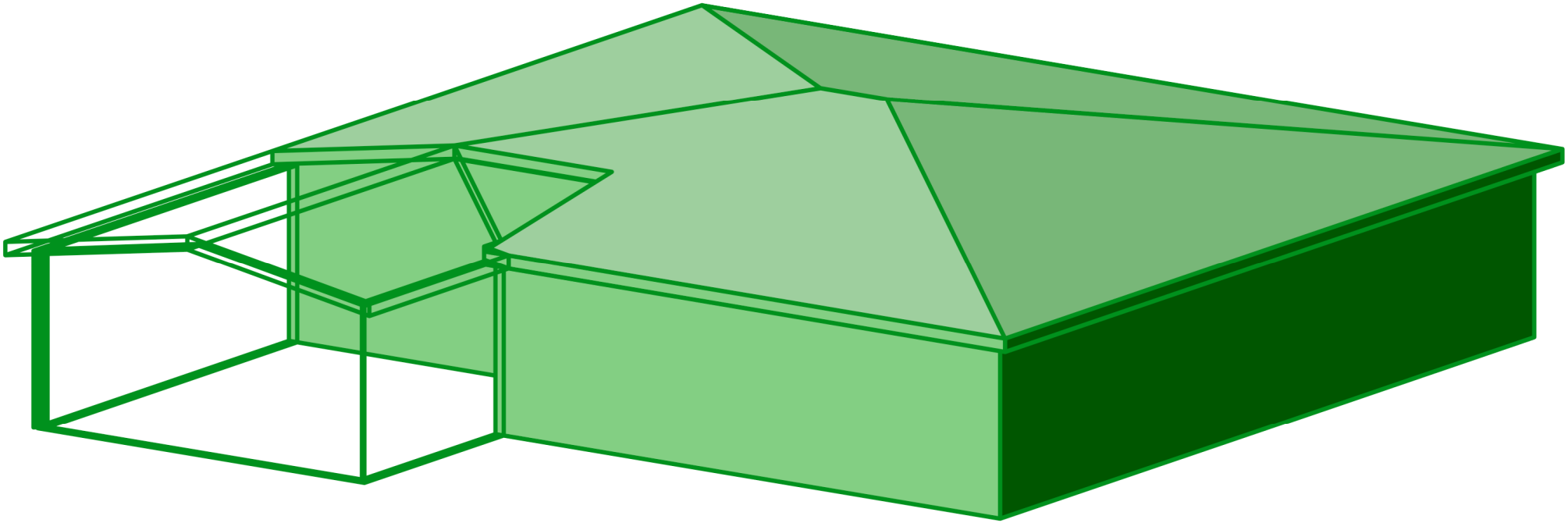
Baseline Design & Optimization: Assumptions & Limitations



- No Thermal Brides (Eaves/Windows/Slab Edge?)
- No Landscape Shading
- Shell Focus Only: (Assume Best-in-Class PH Mechanicals, Appliances, Lighting)
- No Architectural Changes (i.e. Glazing Distribution)
- PHPP vs. T24 (HERS x Seasonal Multipliers) Internal Heat Gains
- Excessive Daily Temperature Swing Exceeded Static Modeling In Some Cases

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2. Results, In Order of Focus

Environmental Impact

1. Heating & Cooling Demand (kBTU/ft^2/yr)
2. Combined Demand (kBTU/ft^2/yr)

Comfort & Equipment

1. Heating & Cooling Load (BTU/hr/ft^2)
2. Fresh Air Heating & Cooling Deficit (BTU/hr)
3. % Overheating Without A/C (Hours/yr >77ºF)

Result	Demand (kBTU/ft2/yr)	Load (BTU/hr)
Heating	4.75	3.17
Cooling	4.75 – 6.66*	3.17
Overheating without A/C	< 10%	

*Cooling Demand Climate-Adjusted by PHPP 8.5 for CZ15 (Palm Springs)

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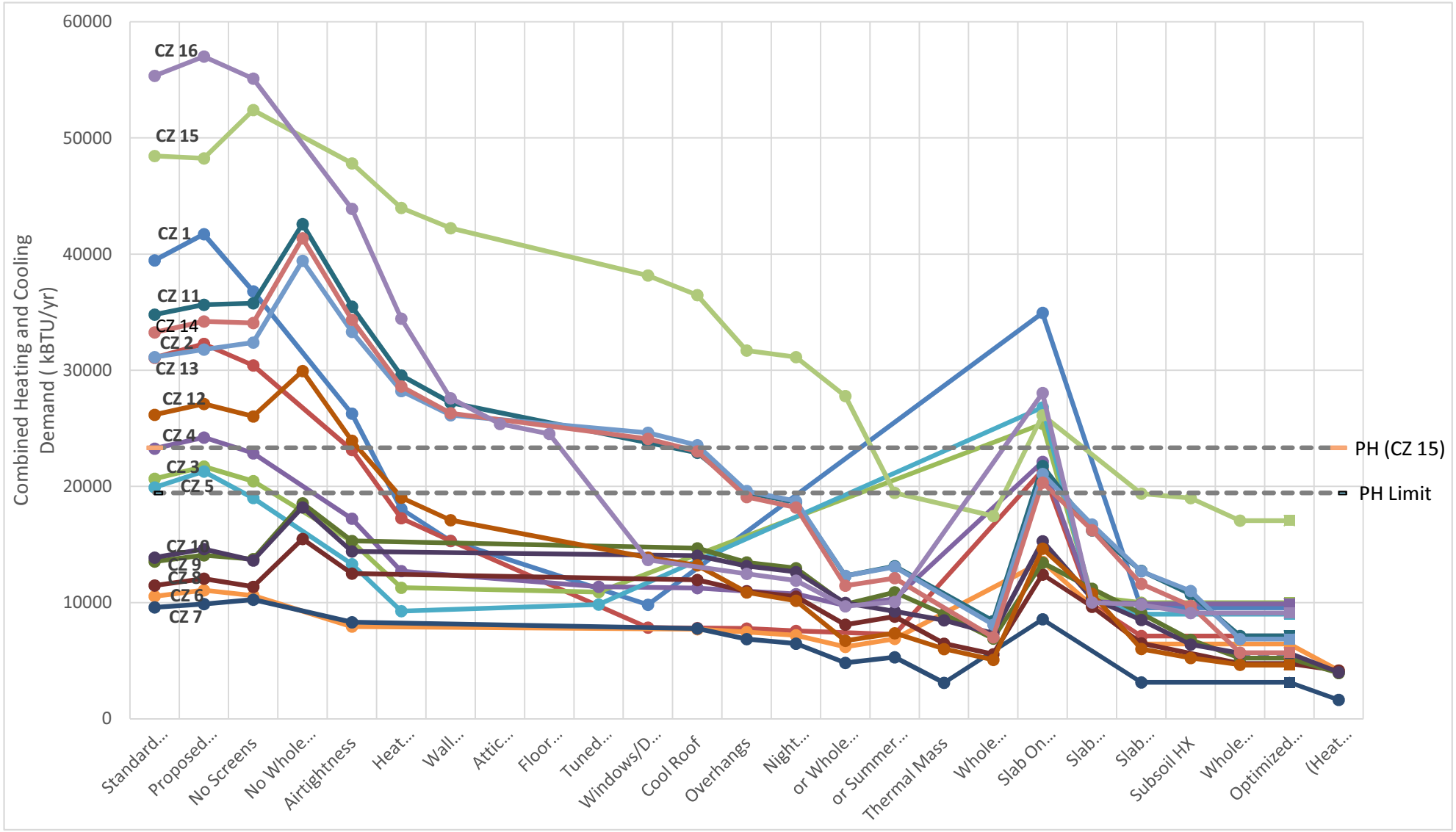
Combined Heating and Cooling Demand



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Example of Upgrades Required

Climate Zone 3
Scenario 3.3
PH Airtightness
0.6 ACH 50
0.3 ACH ventilation (65 CFM)
Scenario 3.4
80% heat recovery
Scenario 3.5
tuned glazing
N, E, W 0.25 SHGC, S 0.50 SHGC
Scenario 3.6
slab on grade
Scenario 3.7
2.75" (R11) under slab insulation
Scenario 3.8
3.25" (R13) under slab insulation

Climate Zone 16
Scenario 16.3
PH Airtightness
0.6 ACH 50
0.3 ACH ventilation (65 CFM)
Scenario 16.4
80% Heat Recovery Efficiency
Scenario 16.5
2x6 (R21) OVE/AWS wall framing (17% framing factor) +R20 (5" @ R4/in) ext
Scenario 16.6
24" (R62) attic insulation
Scenario 16.7
1" (R4) under floor insulation
Scenario 16.8
Window U Value 0.14 (R7) SHGC 0.35
Entry door U value 0.2 (R5)
Scenario 16.9
36" roof overhang
Scenario 16.10
65 CFM additional mechanical night ventilation cooling
Scenario 16.11
1067 CFM (CEC Whole House Fan CFA x 2 CFM/ft2 * 25%) additional mechanical night ventilation cooling

Scenario 16.12
Bug screens on windows in summer (50% SHGC)
Scenario 16.13
Slab on grade, R7 x 16" deep frost skirt
Scenario 16.14
4.25" (R17) under slab insulation
Scenario 16.15
4.5" (R18) under slab insulation
Scenario 16.16
60% efficient subsoil heat exchanger

PH Demand Reduction Over Code

CLIMATE ZONE & LOCATION	SPECIFIC DEMAND (KBTU/FT2/YR) - SINGLE FAMILY, 1 STORY, 2044 FT2 TFA						COMBINED DEMAND REDUCTION (KBTU/YR)
CZ03 Oakland	8.78	1.33	10.11	4.5	0.38	4.88	10,692
CZ04 San Jose-Reid	10.77	0.61	11.38	4.65	0.19	4.84	13,370
CZ05 Santa Maria	8.61	1.13	9.74	4.12	0.28	4.4	10,917
CZ06 Torrance	4.24	0.92	5.16	2.93	0.22	3.15	4,109
CZ07 San Diego	3.06	1.64	4.7	1.41	0.12	1.53	6,480
CZ08 Fullerton	4.79	0.82	5.61	2.01	0.02	2.03	7,319
CZ09 Burbank	5.15	1.48	6.63	2.41	0.14	2.55	8,341
CZ10 Riverside	5.96	0.83	6.79	2.73	0.03	2.76	8,239
CZ11 Red Bluff	13.32	3.7	17.02	2.5	0.99	3.49	2,7659
CZ12 Sacramento	12.15	0.65	12.8	2.24	0.03	2.27	21,526
CZ13 Fresno	10.83	4.4	15.23	2.03	1.33	3.36	24,266
CZ14 Palmdale	12.08	4.19	16.27	1.7	1.08	2.78	27,578
CZ15 Palm Springs-Intl	1.27	22.43	23.7	0.01	8.33	8.34	31,400
CZ16 Blue Canyon	25.95	1.13	27.08	4.3	0.15	4.45	46,262

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PH Load Reduction Over Code

CLIMATE ZONE & LOCATION	SPECIFIC LOAD (KBTU/FT2/YR) - SINGLE FAMILY, 1 STORY, 2044 FT2 TFA						LOAD (BTU/HR)	
CZ04 San Jose	6.43	-1.03	2.07%	2.8	-1.18	0.16%	5724	-2412
CZ05 Santa Maria	4.67	-2.05	0.68%	2.07	-2.52	0.00%	4232	-5152
CZ06 Torrance	4.49	-1.69	3.53%	2.75	-2.03	0.00%	5622	-4150
CZ07 San Diego	3.17	0.33	10.66%	1.52	-0.49	1.68%	3107	-1002
CZ08 Fullerton	4.04	0.99	9.93%	1.93	-0.31	0.16%	3945	-634
CZ09 Burbank	5.09	3.01	11.51%	2.5	1.48	3.92%	5111	3026
CZ10 Riverside	5.47	2.24	11.14%	2.61	0.66	1.28%	5336	1349
CZ11 Red Bluff	7.71	4.82	19.73%	2.39	2.43	13.70%	4886	4968
CZ12 Sacramento	7.71	3.11	9.79%	2.05	1.12	0.29%	4191	2290
CZ13 Fresno	8.88	3.84	22.11%	2.57	1.83	15.25%	5254	3741
CZ14 Palmdale	8.91	3.95	20.92%	2.07	1.81	14.26%	4232	3700
CZ15 Palm Springs	3.71	8.58	53.88%	0.22	4.48	39.47%	450	9158
CZ16 Blue Canyon	13.67	1.39	4.97%	3.37	0.27	0.21%	6889	552

Slide originally from “PH for ALL of CA V2” by Graham Irwin. 2014

What is life cycle costing and why is it relevant to green design?

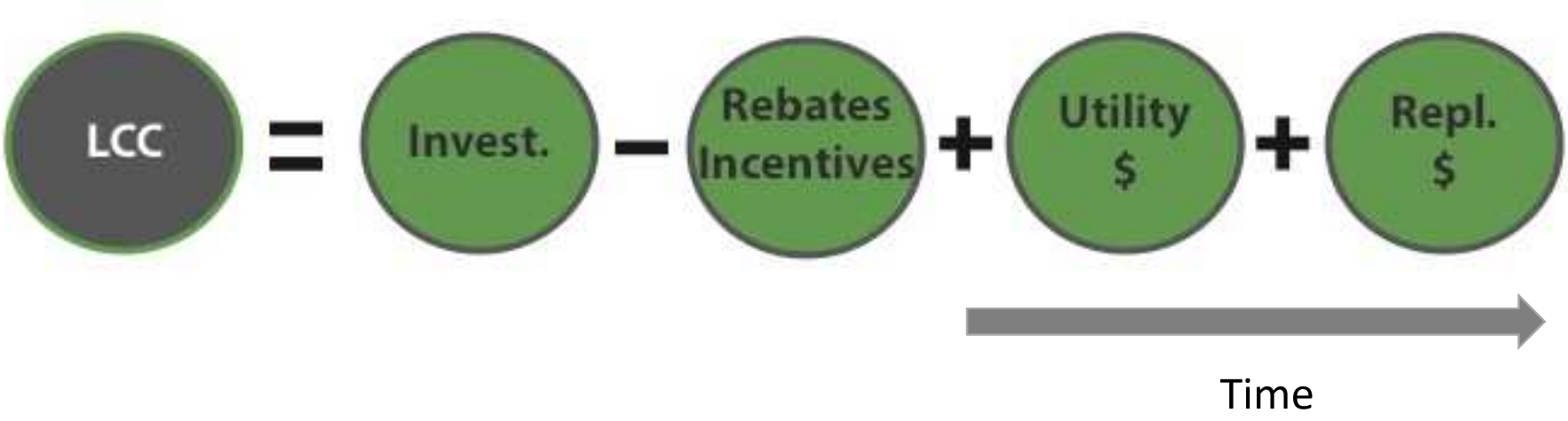
- Traditionally referred to as “cradle to grave” costs for a building/other project, including some or all of the following:
  - Initial Costs: Purchase, Acquisition, Construction Costs, Planning and Design, Engineering, R&D
  - Fuel Costs, Consumables
  - Operation, Maintenance, and Repair Costs
  - Replacement Costs
  - Residual Values—Resale or Salvage Values or Disposal Costs
  - Finance Charges—Loan Interest Payments
  - Non-Monetary Benefits or Costs
- Hugely complex analysis for large building projects

Life Cycle Cost Analysis

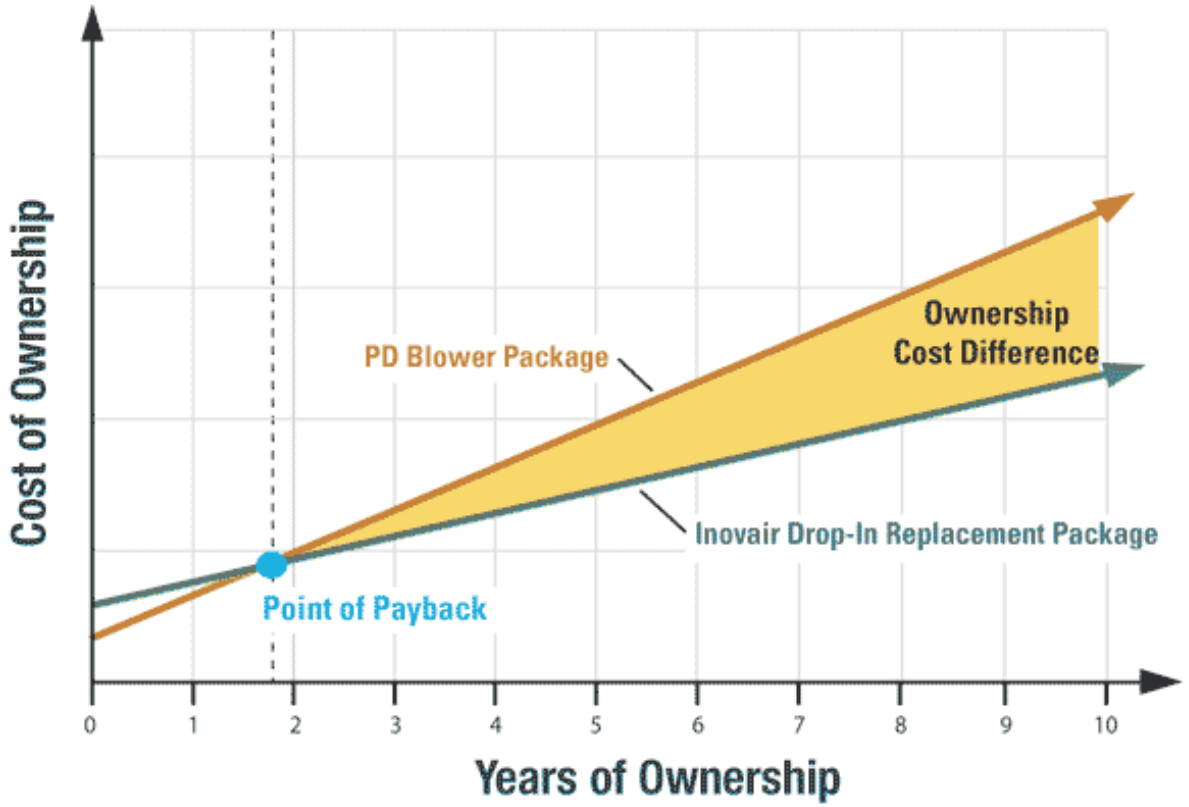
- What is it?
- What are the components?
  - Discount Rates, Energy Escalation Rates, Rebates, Operational costs, replacement costs, etc.
- Why is it Important?
- How do you value LCCA
  - NPV, IRR, MIRR, SIR

What is life cycle costing and why is it relevant to green design?

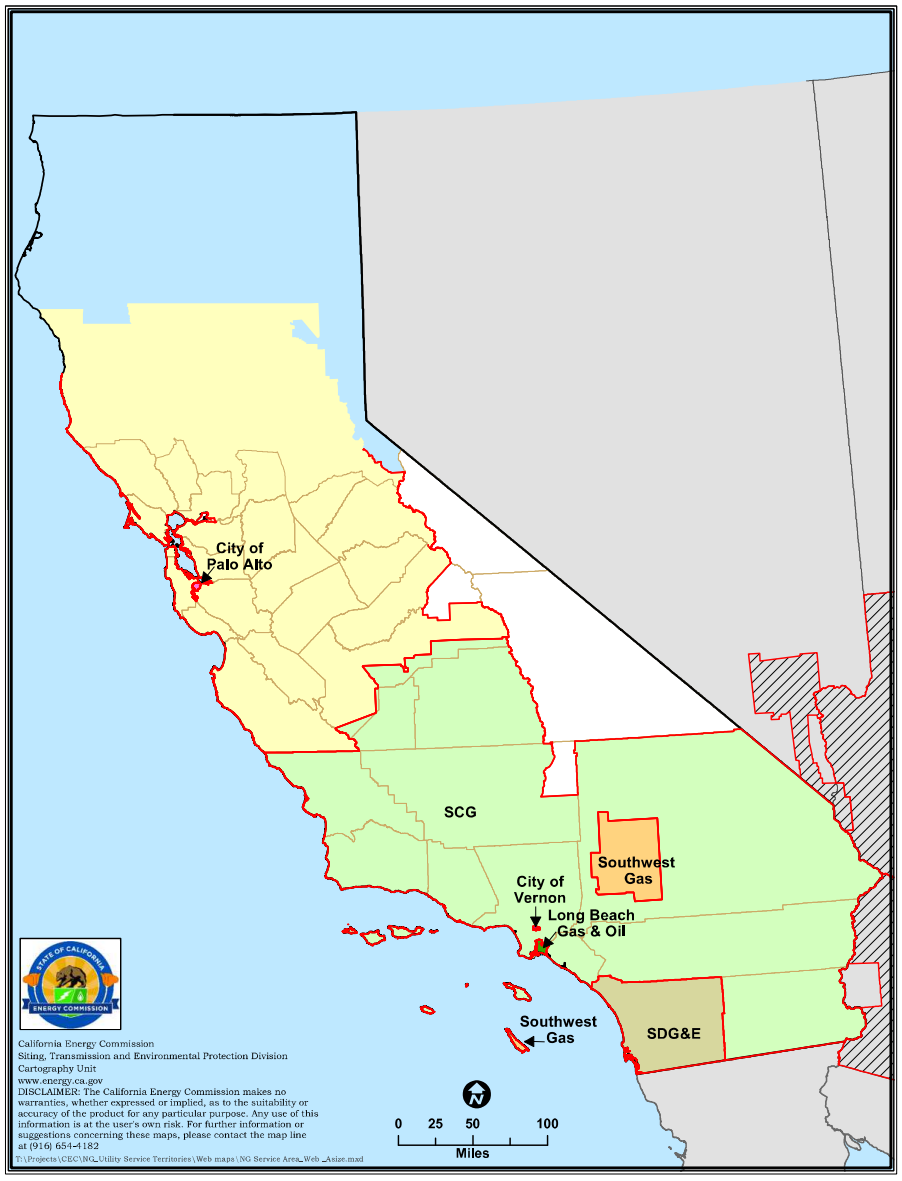
- LCCA justifies many of the high upfront costs as we prioritize more durable materials, pricy but efficient systems, and smart innovations.
  - Recouping our capital costs through savings in utility costs!



Put Simpler, LCCA Attempts to Prove The Following



Energy Districts



Energy Providers By CZ

Climate Zone	electric Utility Provider	natural Gas Utility Provider
1	Pacific Gas & Electric (PG&E)	Pacific Gas & Electric (PG&E)
2	PG&E	PG&E
3	PG&E	PG&E
4	PG&E	PG&E
5	PG&E	Southern California Gas (SCG)
6	Souther California Edison (SCE)	SCG
7	San Diego Gas & Electric (SDG&E)	San Diego Gas & Electric (SDG&E)
8	SCE	SCG

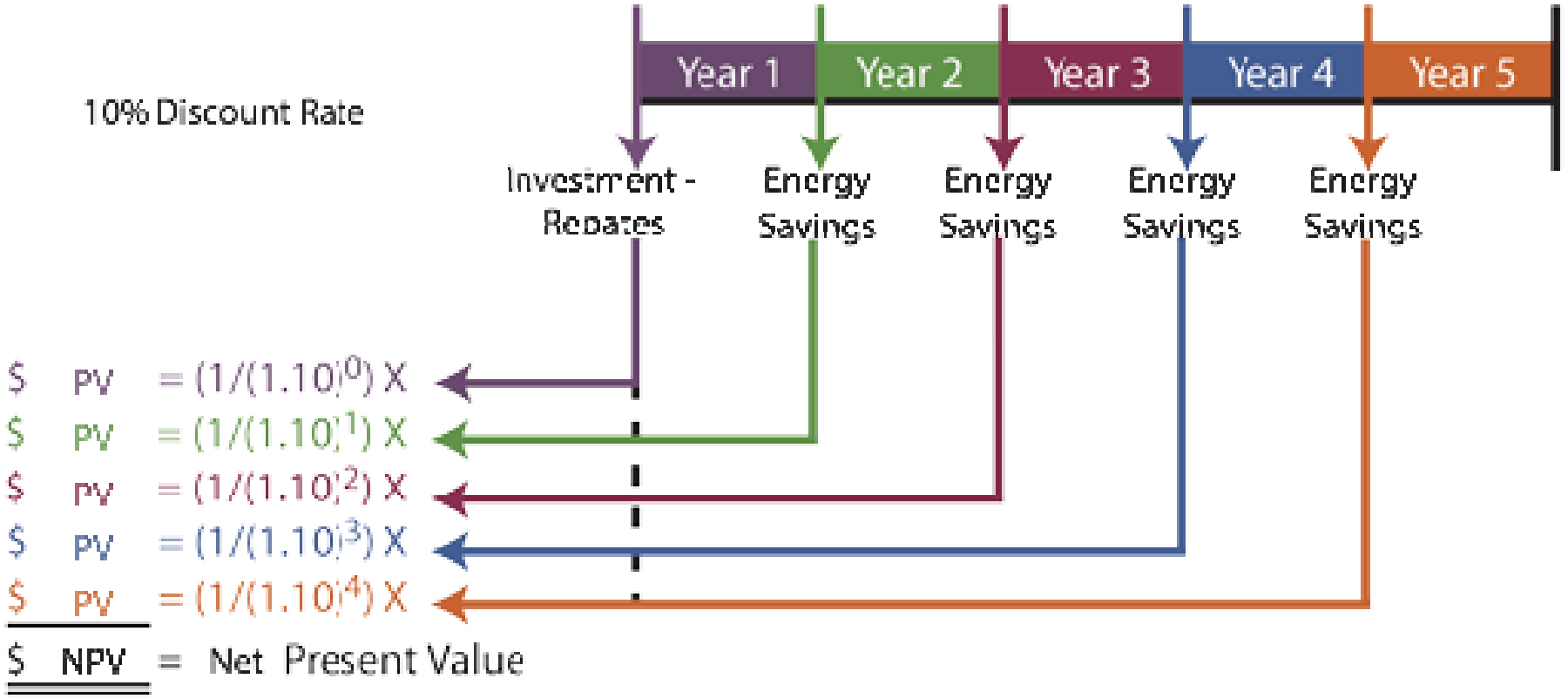
Climate Zone	electric Utility Provider	natural Gas Utility Provider
9	Burbank Water and Power	SCG
10	Riverside Municipal Utility	SCG
11	PG&E	PG&E
12	Sacramento Municipal Utility District (SMUD)	PG&E
13	PG&E	PG&E
14	Los Angeles Department of Water and Power (LADWP)	SCG
15	SCE	SCG
16	PG&E	PG&E

Energy Prices and Escalation Rates

	PG&E	SCE	SDG&E	LADWP	BURBANK WATER AND POWER	RIVERSIDE MUNICIPALITY	SMUD
Electricity $ per kWh	$0.21	$0.15	$0.17	$0.15	$0.12	$0.10	$0.10
tion Rates							

	PG&E	SCG	SDG&E
Natural Gas $ per Therm	$1.14	$0.83	$1.20
30 Year Annual Growth Rate	2.5%	2.5%	2.5%

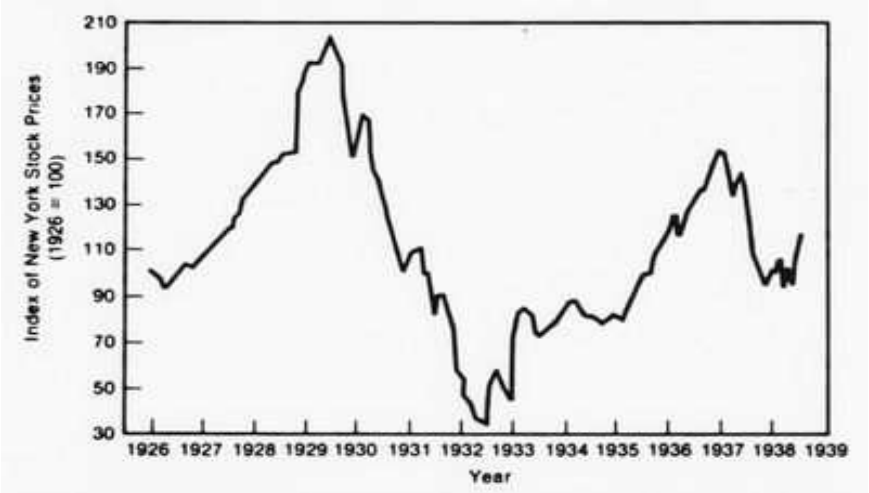
How? Net Present Value



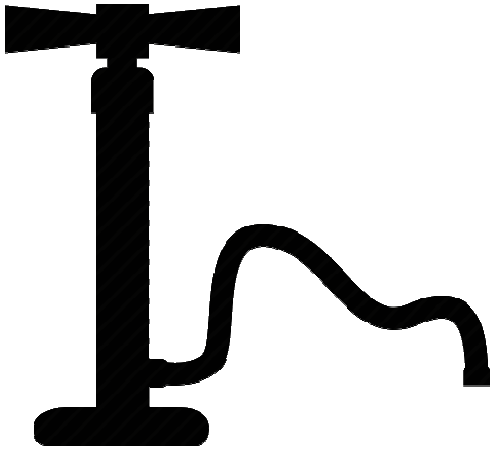
Why Discount Future Cash Flows?

Opportunity

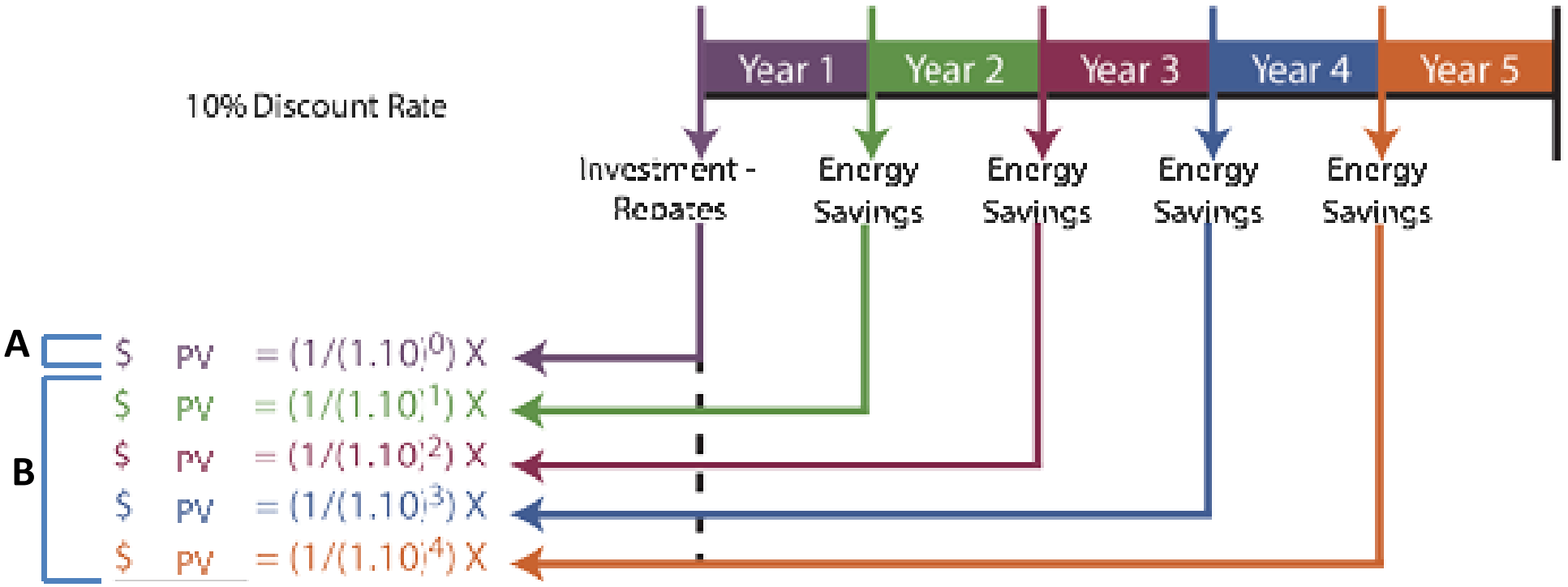
Risk



Inflation

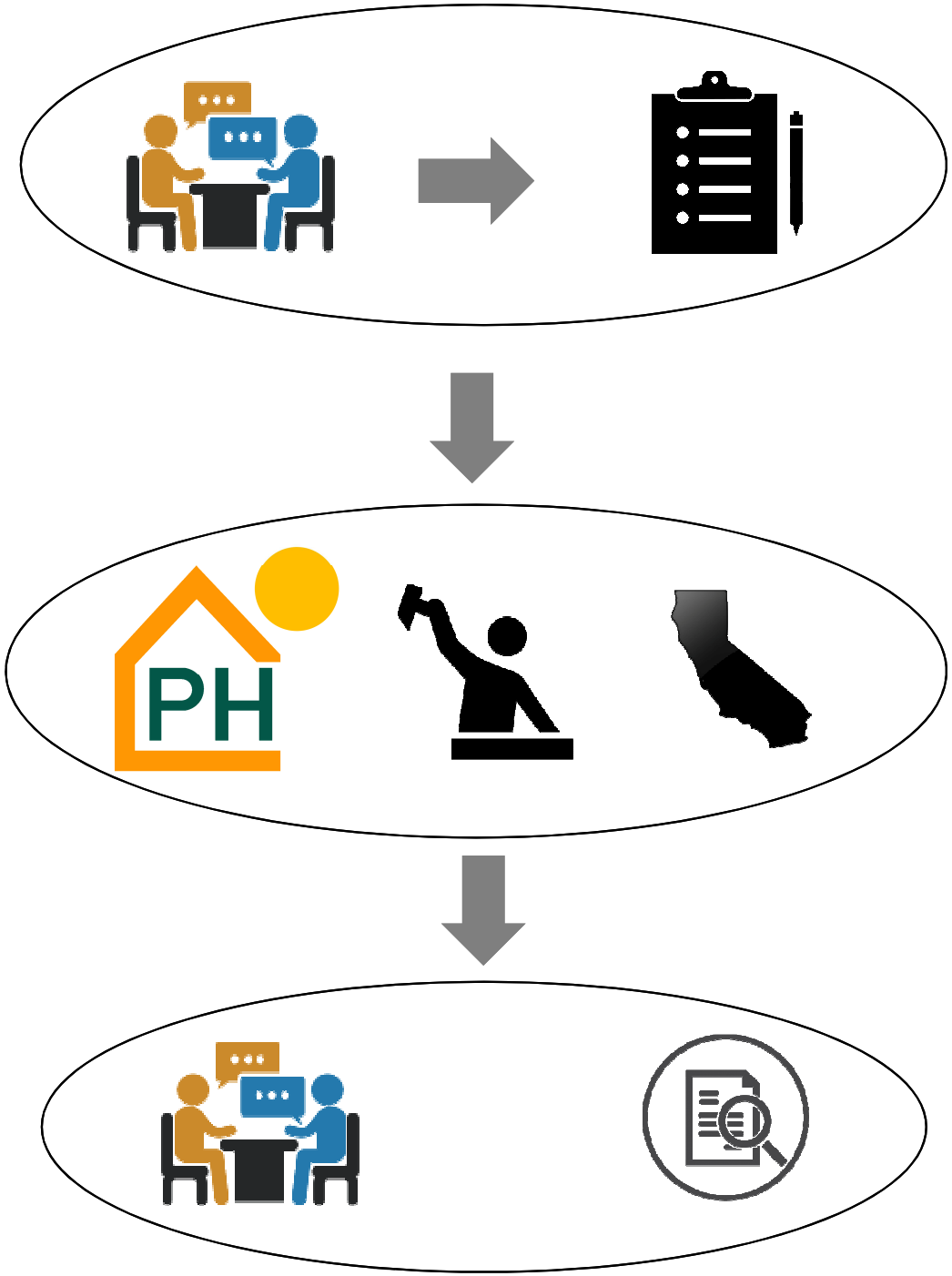


Savings to Investment Ratio



$$SIR = \frac{B}{A}$$

Cost Survey



Cost Survey Example

Figure A-1: One Story Prototype Front View

Figure A-2: One Story Prototype Back View

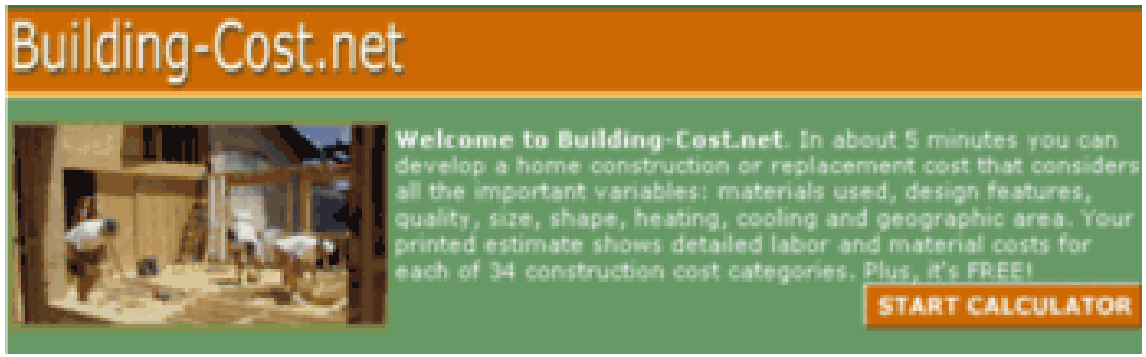
- Conditioned Floor Area: 2100 ft^2
- Ceiling Height: 9 ft
- Conditioned Volume: 18,900 ft^3
- Vented Crawl Space
- Ceiling Area: 2100 ft^2
- Total Window Area: 408 ft^2 => 102 ft^2 per side of home

Unless implicitly stated in the questions, you are to use your own recommended equipment or material used in previous Passive House Projects.

Q12. What is the estimated cost difference to upgrade the windows in this house (409 square feet total) from U Value 0.32 (R3) to U Value 0.14 (R7)?

Q13. What is the estimated cost difference, if any, to swap the south windows glazing from U 0.32 SHGC 0.25 to U 0.32 SHGC 0.50? (102 square feet of South facing window)

Considering Location Cost Differences



Cost Variance Factor

Climate Zone	Rep City	% Change fRom mean Cost
1	Arcata, CA	-9.35%
2	Santa Rosa, CA	0.06%
3	Oakland, CA	9.42%
4	San Jose, CA	8.81%
5	Santa Maria, CA	-0.68%
6	Torrance, CA	1.87%
7	San Diego, CA	1.52%
8	Fullerton, CA	4.64%
9	Burbank, CA	1.87%
10	Riverside, CA	-1.56%
11	Red Bluff, CA	-7.61%
12	Sacramento, CA	-0.81%
13	Fresno, CA	-6.83%
14	Palmdale, CA	-0.11%
15	Palm Springs, CA	-5.11%
16	Blue Canyon, CA	-0.36%

Electric H&C With Crawl Space

	ELECTRIC HEATING AND COOLING					
	CRAWL SPACE					
CZ 5	$(8,129)	$37	$(201)	$(8,598)	0.06	Never
CZ 6	$(4,447)	$17	$(135)	$(4,837)	-0.09	Never
CZ 7[a]	$(18,326)	$95	$196	$(16,075)	0.12	> 30 Years
CZ 8[ab]	$(18,643)	$52	$(8)	$(18,701)	0.05	Never
CZ 9[ac]	$(16,222)	$75	$69	$(14,957)	0.08	Never
CZ 10[acd]	$(14,841)	$73	$(29)	$(13,906)	0.06	Never
CZ 11[abd]	$(23,705)	$377	$751	$(14,923)	0.37	> 30 Years
CZ 12[acd]	$(38,610)	$317	$575	$(29,905)	0.19	> 30 Years
CZ 13[abd]	$(25,329)	$322	$700	$(17,542)	0.31	> 30 Years
CZ 14[abd]	$(27,831)	$279	$716	$(20,679)	0.26	> 30 Years
CZ 15[acd]	$(28,456)	$383	$1,604	$(15,630)	0.45	> 30 Years
CZ 16	$(30,524)	$598	$929	$(17,842)	0.42	> 30 Years

Note: [a] Baseline building requires cooling.
[b] CEC whole house fan option was selected.
[c] CEC whole house fan option was not selected.
[d] PH building requires cooling.

Electric H&C With Slab on Grade

	ELECTRIC HEATING AND COOLING					
	SLAB ON-GRADE					
CZ 5	$1,416	$35	$(192)	$1,022	NA	NA
CZ 6	$5,663	$45	$(11)	$6,246	NA	NA
CZ 7[a]	$(9,529)	$116	$281	$(6,596)	0.31	> 30 Years
CZ 8[ab]	$(12,566)	$69	$66	$(12,101)	0.11	Never
CZ 9[ac]	$(10,306)	$104	$216	$(7,929)	0.23	> 30 Years
CZ 10[acd]	$(9,124)	$103	$129	$(7,068)	0.23	> 30 Years
CZ 11[abd]	$(17,612)	$393	$815	$(8,303)	0.53	> 30 Years
CZ 12[acd]	$(32,841)	$322	$595	$(23,977)	0.23	> 30 Years
CZ 13[abd]	$(19,037)	$338	$759	$(10,761)	0.43	> 30 Years
CZ 14[abd]	$(20,929)	$290	$812	$(13,216)	0.37	> 30 Years
CZ 15[acd]	$(24,025)	$385	$1,615	$(11,116)	0.54	> 30 Years
CZ 16	$(22,812)	$605	$958	$(9,890)	0.57	> 30 Years

Note: [a] Baseline building requires cooling.
[b] CEC whole house fan option was selected.
[c] CEC whole house fan option was not selected.
[d] PH building requires cooling.

Natural Gas Heat With Crawl Space

NATURAL GAS HEATING ONLY						
CRAWL SPACE						
CZ 6	$(4,447)	$38	$79	$(3,543)	0.2	> 30 Years
CZ 7[a]	$(18,326)	$99	$296	$(15,564)	0.15	> 30 Years
CZ 8[ab]	$(18,643)	$72	$189	$(16,750)	0.1	> 30 Years
CZ 9[ab]	$(18,161)	$79	$250	$(15,902)	0.12	> 30 Years
CZ 10[abd]	$(16,709)	$76	$197	$(14,726)	0.12	> 30 Years
CZ 11[e]	NA	NA	NA	NA	NA	NA
CZ 12[abd]	$(38,610)	$304	$639	$(31,377)	0.19	> 30 Years
CZ 13[e]	NA	NA	NA	NA	NA	NA
CZ 14[e]	NA	NA	NA	NA	NA	NA
CZ 15[e]	NA	NA	NA	NA	NA	NA
CZ 16	$(30,324)	$647	$1,325	$(15,076)	0.5	> 30 Years

Note: [a] Baseline building requires cooling.
[b] CEC whole house fan option was selected.
[c] CEC whole house fan option was not selected.
[d] PH building requires cooling.
[e] Mechanical cooling required, heating only not an option in this climate zone.

Natural Gas Heat With Slab on Grade

	NATURAL GAS HEATING ONLY SLAB ON GRADE					
CZ 6	$5,663	$58	$119	$7,036	NA	NA
CZ 7a	$(9,529)	$109	$334	$(6,326)	0.34	> 30 Years
CZ 8ab	$(12,566)	$84	$214	$(10,388)	0.17	> 30 Years
CZ 9ab	$(12,245)	$104	$299	$(9,416)	0.23	> 30 Years
CZ 10abd	$(10,992)	$105	$256	$(8,337)	0.24	> 30 Years
CZ 11e	NA	NA	NA	NA	NA	NA
CZ 12abd	$(32,849)	$308	$649	$(25,505)	0.22	> 30 Years
CZ 13e	NA	NA	NA	NA	NA	NA
CZ 14e	NA	NA	NA	NA	NA	NA
CZ 15e	NA	NA	NA	NA	NA	NA
CZ 16	$(22,612)	$652	$1,335	$(7,252)	0.68	> 30 Years

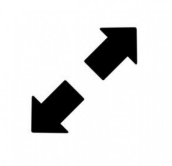
Note: [a] Baseline building requires cooling.
[b] CEC whole house fan option was selected.
[c] CEC whole house fan option was not selected.
[d] PH building requires cooling.
[e] Mechanical cooling required, heating only not an option in this climate zone.

Why the Results?

Lack of Local Access to Building Materials = Higher Costs

Lack of Understanding of PH Concept and Financial Assistance Strategies

California Building Codes Stringent than Others



Scalability: Small SF Area = Less Potential for Savings

Cheap Cost of Energy

Micro Study

- What makes more sense financially. Keeping the electric air conditioning unit in the baseline building or installing a whole house fan?
- Both achieve PH certifiable levels.
- Whole House Fan has lower energy demand.

Mutually Exclusive Strategies

OR

?

Mutually Exclusive Strategies

OR

Climate Zones 11, 13, and 14

Climate Zones 8, 9, 10, 12, and 15

Depends on the Climate!

- Applicable for climate zones 8-15 only where electric cooling was required.
- Assuming A/C unit is standard in Code minimum Home select climates.
- Justified by a higher SIR.

Thank You! Questions?

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