U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable
Building Technologies Program

Building AMERICA
U.S. Department of Energy
Research Leading to Zero Energy Homes

Affordable Housing

Toward Zero Energy

Betsy Pettit, AIA

Building Science Corporation

PR-0507: Toward Zero Energy

www.buildingscience.com

Why Zero Energy Homes?

- They allow our long term existence in otherwise un-inhabitable or uncomfortable environments

What makes an affordable home?

- Someone who makes the median income in the area can afford to
  - **Purchase**
  - **Operate**
  - **Maintain**
- Long Term Durability

Maintain shelter to current high standards in hostile environments without stored energy consumption?

– No oil, gas, or ‘net” off-site electricity use?
- Aggressive conservation methods
- More site generated energy

Site Energy Consumption =
Site Energy Collection

Insuring Affordability

- Comfort of occupants
- Indoor air quality
- Energy efficiency
- Durability

Comfort

- Leak-free homes with high r-value enclosures

- Deliver heated and cooled air in consistent manner to living space

Indoor Air Quality

- Control water entry
- Control interior pollution
  - Source control
    - Combustion appliances
    - Interior finishes
    - Things brought into the house
- Provide air change

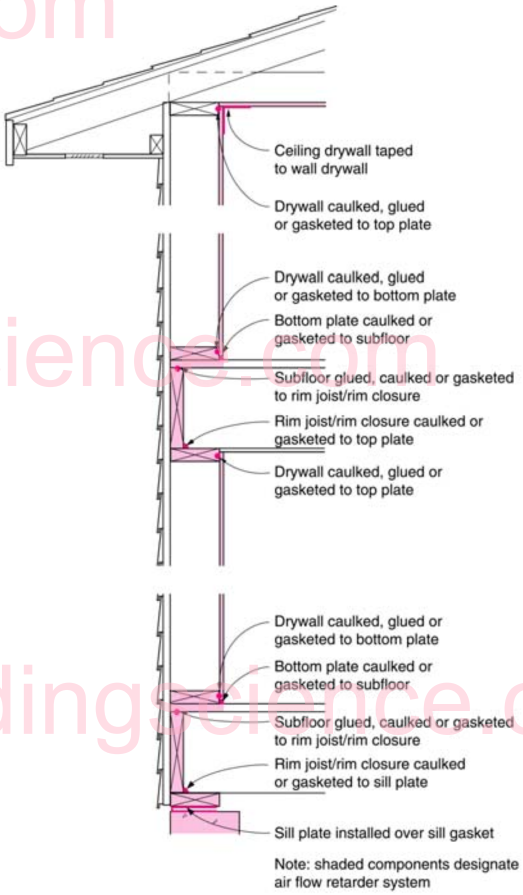
Energy Efficiency

Leakfree Construction

- Reducing the air leakage into and out of the building enclosure is critical for energy conservation and building durability

Airtight drywall

- Drywall typically provides the primary air barrier from inside to outside of the enclosure



Interior Air Flow Retarder Using Drywall and Framing

Energy Efficiency

Thermally Efficient Assemblies

- Structure only where needed
- Insulating sheathing
- Blown insulations that fill the entire void

Energy Efficiency

Control of electric load

- Energy Star Lights
- Energy Star Appliances

ENERGY STAR

Plug Loads

Common Large plug loads:

Items with internal heaters

- Cookers
- Hair dryers

Items with large-ish motors

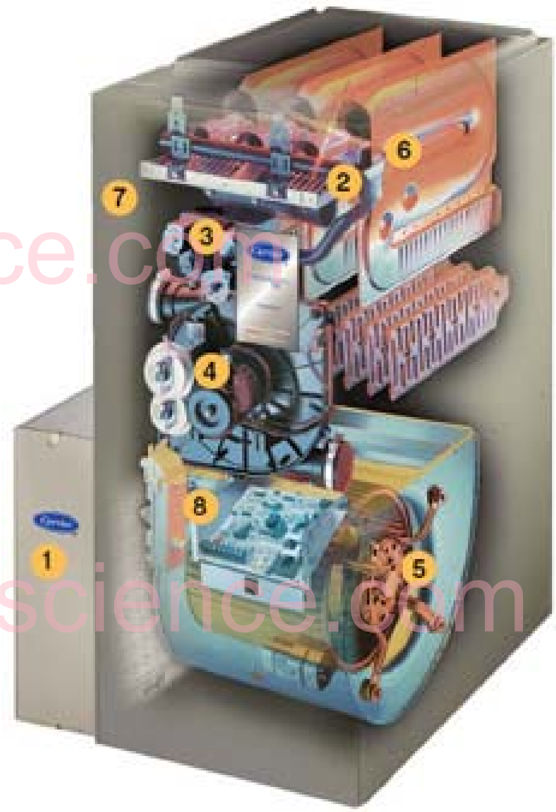
- Dehumidifiers
- Vacuums

Duty Cycle is important!!!!

Energy Efficiency
Heating/Cooling - Gas/Electric

Condensing furnaces yield efficiencies over 90% AFUE

- Typically sealed combustion
- Ducted system facilitates installation of ventilation system
- Get ECM motors
- Use High SEER AC units



Energy Efficiency Heating/Cooling - Electric

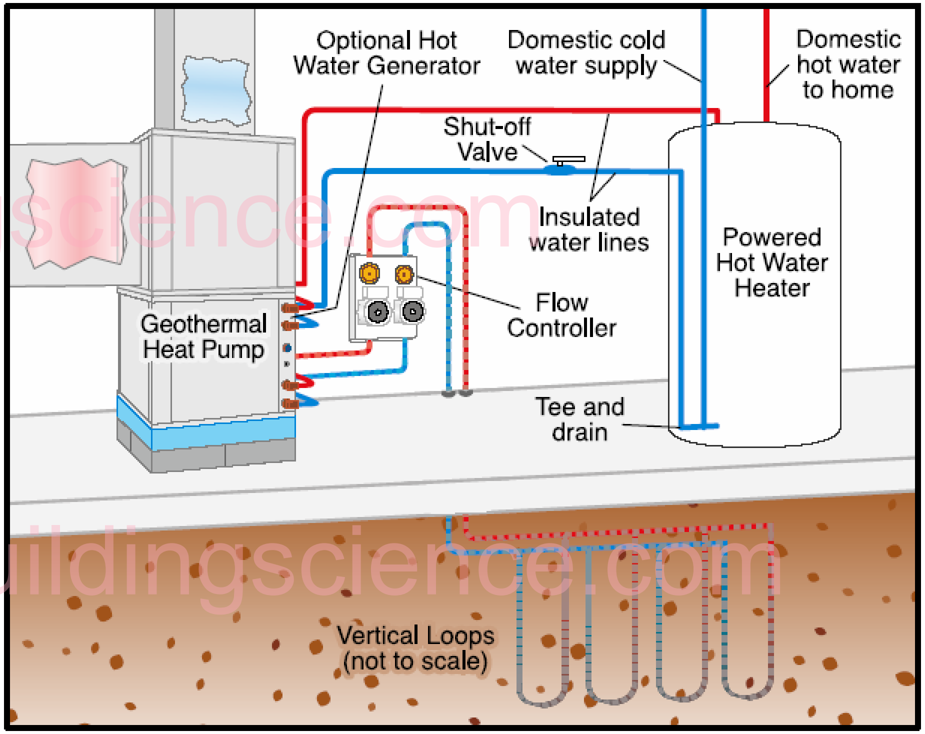
High efficiency air source heat pump (ASHP)

- Available up to 18 SEER & ~9 HSPF
- Simple & cheap installation (relatively speaking)
- No combustion risks

Energy Efficiency Heating/Cooling - Electric

High efficiency ground source heat pump (GSHP)

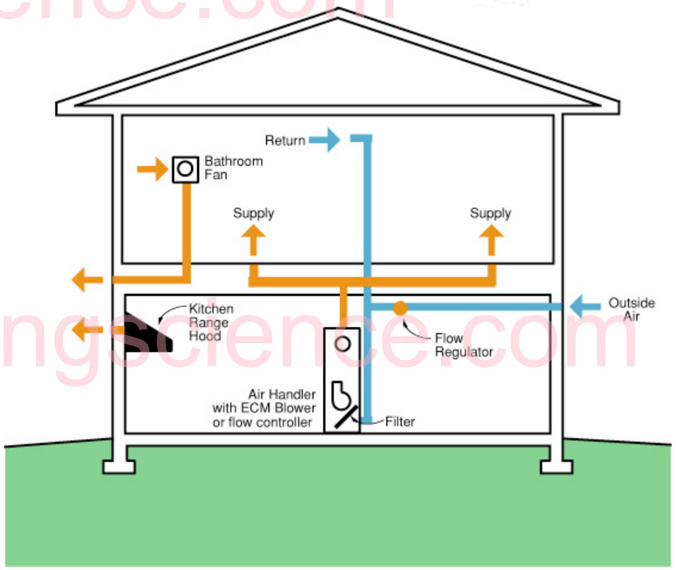
- Moves heat to & from the ground, instead of burning stuff
- Year 'round heating and cooling at high efficiency
- No combustion risks
- Option of de-superheater hot water system



Energy Efficiency - Ventilation

Plan for ventilation:

- Air tight houses need controlled air change
- ERV's can deliver savings, but watch out for their electricity consumption
- Central Fan integrated system among the simplest



Energy Efficiency - Hot Water, Gas

Sealed combustion gas, located in insulated space

- Efficiency of standard tanks reaches only ~62%
- Hard to justify in a ZEH, since solar collection system would more than pay for an upgrade

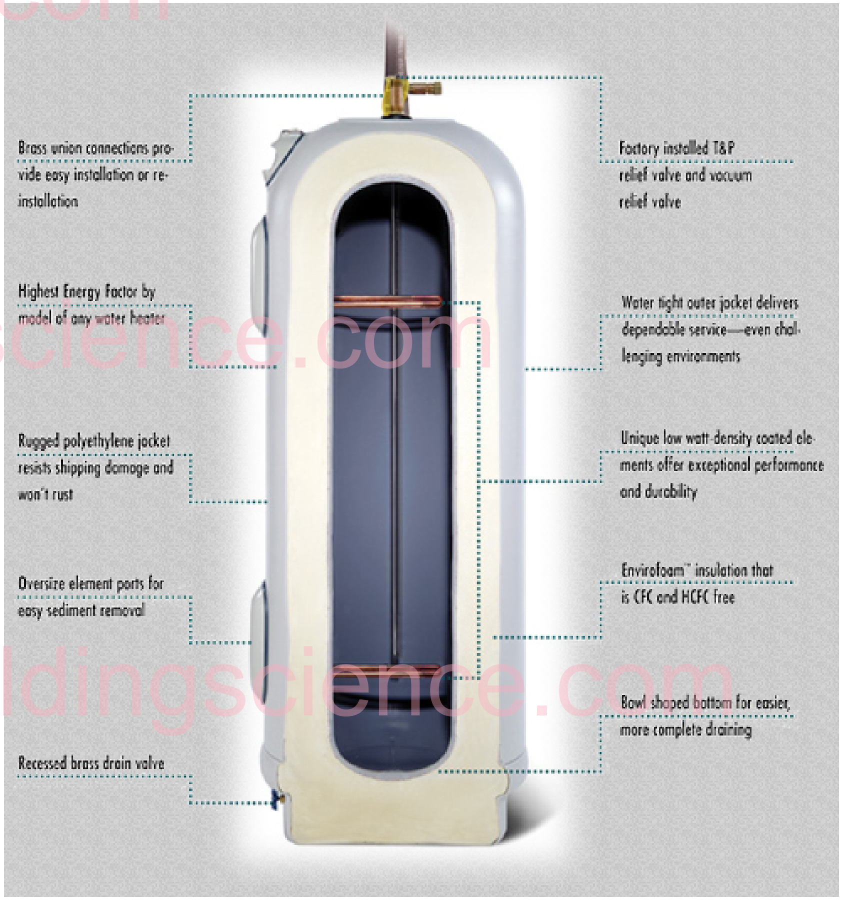
Energy Efficiency
Hot Water - Gas, Tankless

- Tankless hot water heater eliminates standby losses
- Efficiencies in ~83% range – a ~30% increase in hot water efficiency over gas tanks
- Locate hot water heater central to fixtures to create short piping runs
- Put piping in walls, not ground

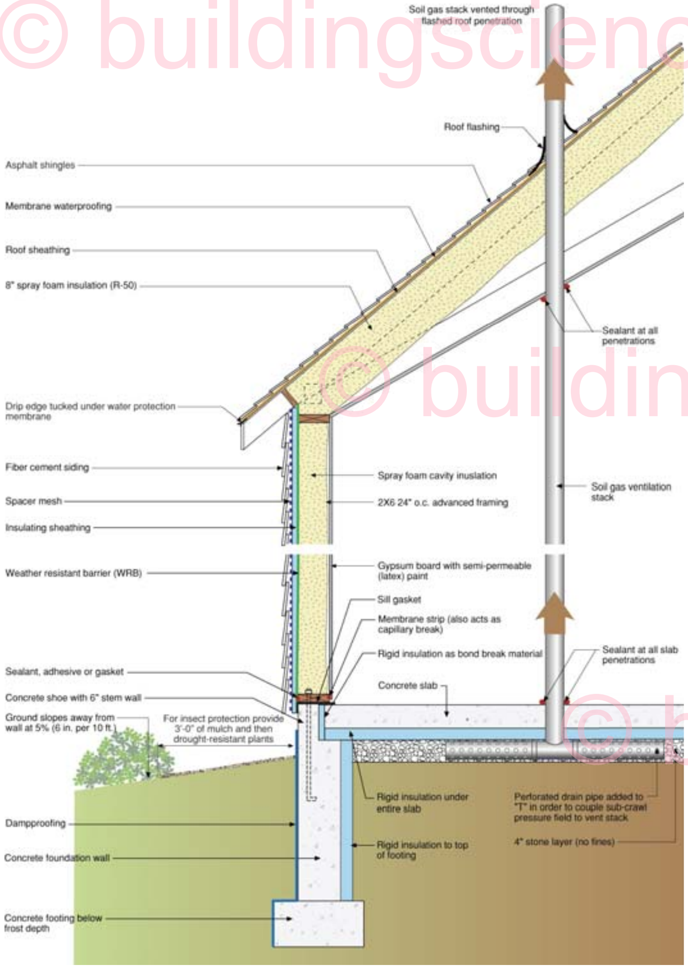
Energy Efficiency - Hot Water, Electric

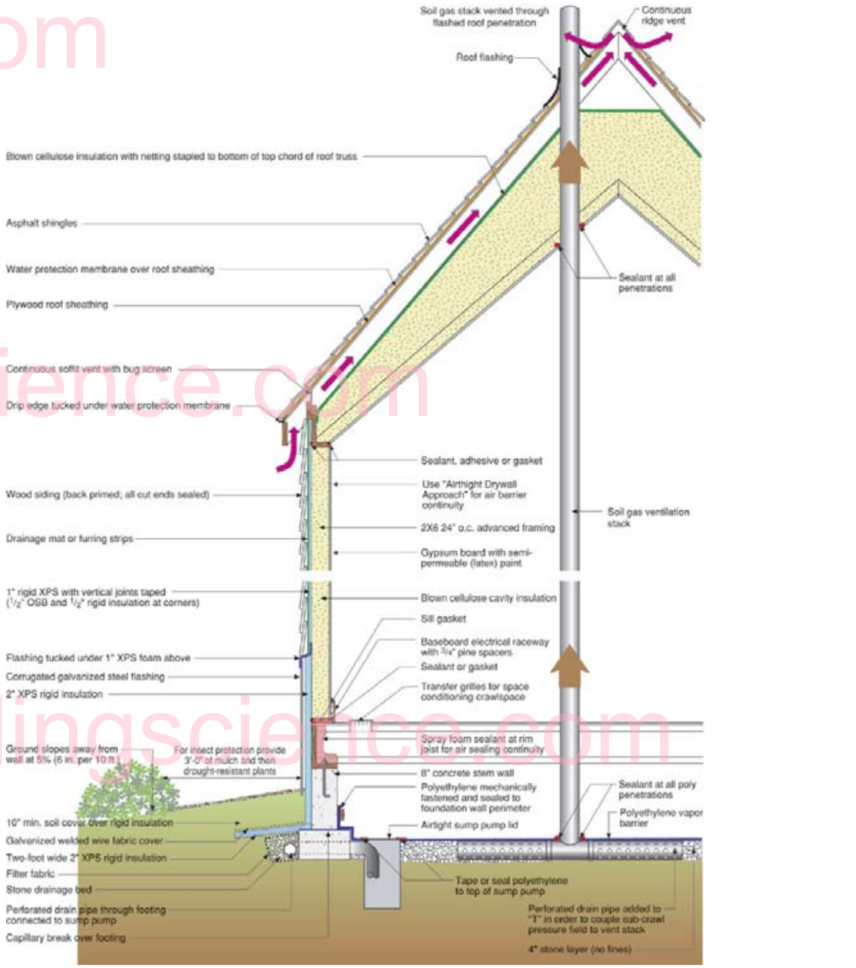
Electric resistance

- High efficiencies available, up to 94%
- However, it's more expensive than gas
- Simple installation
- No combustion risks

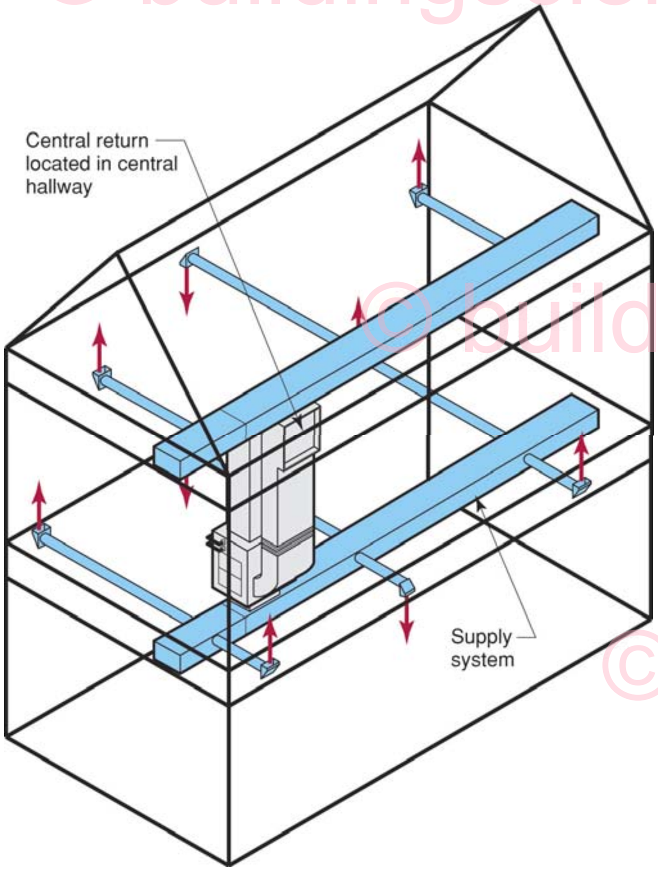


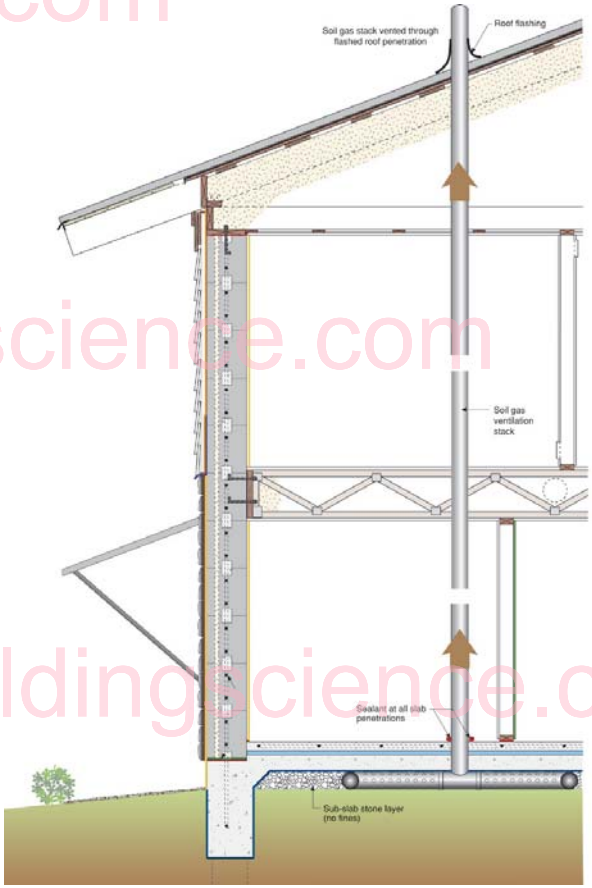
Integration





Integration





Integration

- Foundations
- Walls
- Roofs

How much can we conserve from our current levels?

Building enclosure savings:	20%
Mechanical Savings:	25%
Lights/Appliances/Plug:	10%
Conservation savings:	55%
Left to offset by site generation:	45%
Total savings:	100%

Solar Energy Collection

- Only after loads have been reduced and mechanicals downsized should solar collection equipment be considered

- Solar hot water better payback – should be considered first

- Solar PV system last piece of the whole

Solar Technologies

Solar hot water (SHW):

- Consider appropriate location for system components (ideally, south roof for panels, insulated or protected interior space for tank)

- Consider how system interacts with back-up heating source (electric tank, or gas boiler)
- Consider control strategy (PV panel, differential control, or thermosiphon)

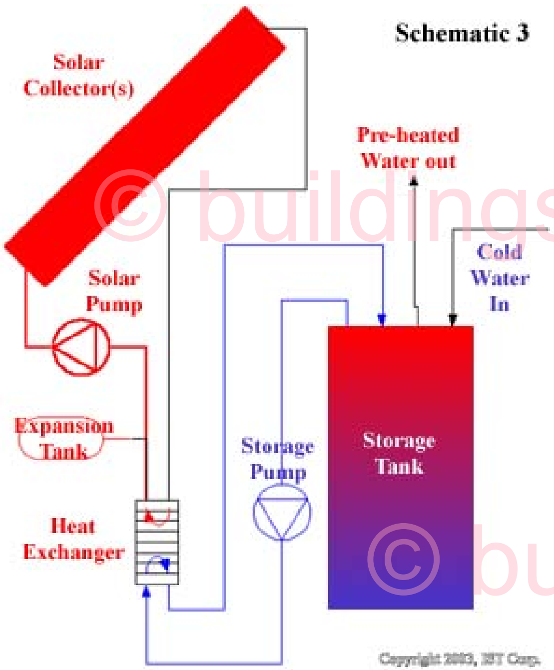
Site Generated Energy - Hot Water

SHW System - Not Simple!

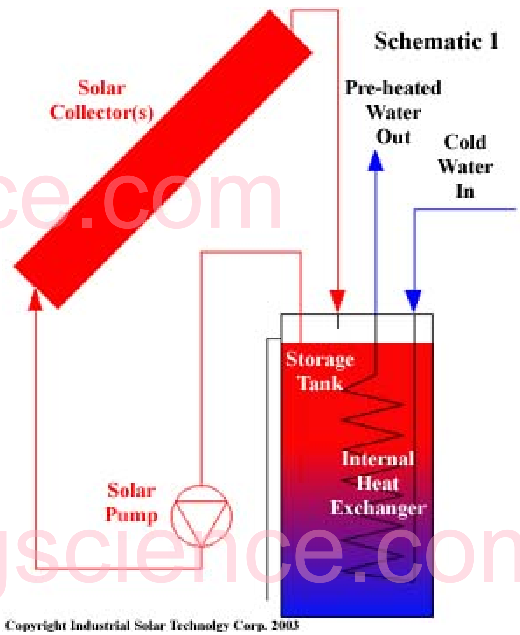
- SHW systems can get to quite high temperatures
  - **(180F at tank, over 200F between collector & tank)** under normal operation
- Stagnation is when the solar collector is in full sun, but heat is not being moved to the storage tank
  - Leads to very high collector temperatures, and therefore elevated pressures in an antifreeze system
  - Result of low hot water usage, or times of high solar gains
- Verify all piping components can handle temperatures and pressures developed in SHW system under stagnation

<u>All SHW systems must have a tempering valve</u>

Freeze protected Solar Hot Water System Options



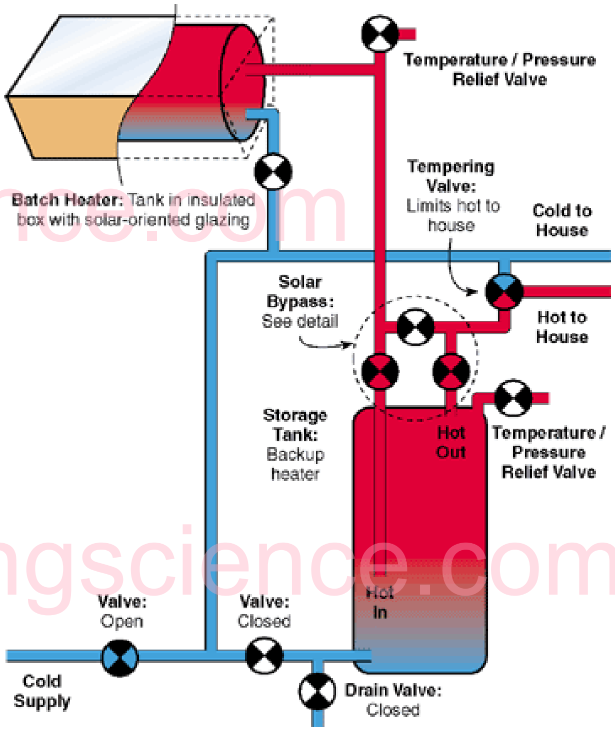
Anti-freeze loop



Drain Back

Freeze Tolerant Solar Hot Water System Options

- ICS (Integrated Collector Storage)
- Storage tank in the collector, water warms up when sun shines in
- Water can cool overnight
- Simplest type
- Hybrid systems



Site Generated Energy - Hot Water

Tank and piping

Panels on south roof

Solar Hot Water Savings

- Solar Hot water will contribute about 10% of the remaining total

- Hot water use can vary widely, where space conditioning is more climate dependent

- Other site generation for remaining 35%

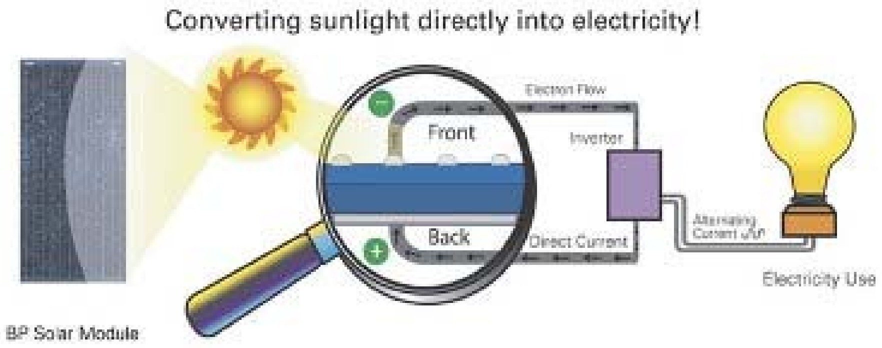
Site Generated Energy - Electricity

And the last step for the remaining 35%…PV panels

- Most costly component in getting to ZEH
  - Still, costs are half what they were 10 yrs ago
- Unfortunately, also one of the most visible
- Simple principle, no moving parts
- Generally low collection efficiency (less than ~15% of available solar energy)
- System loss reduces peak output by 10-20%
- Still the simplest, cheapest method for generating electricity from the sun directly

Photovoltaic effect: some theory

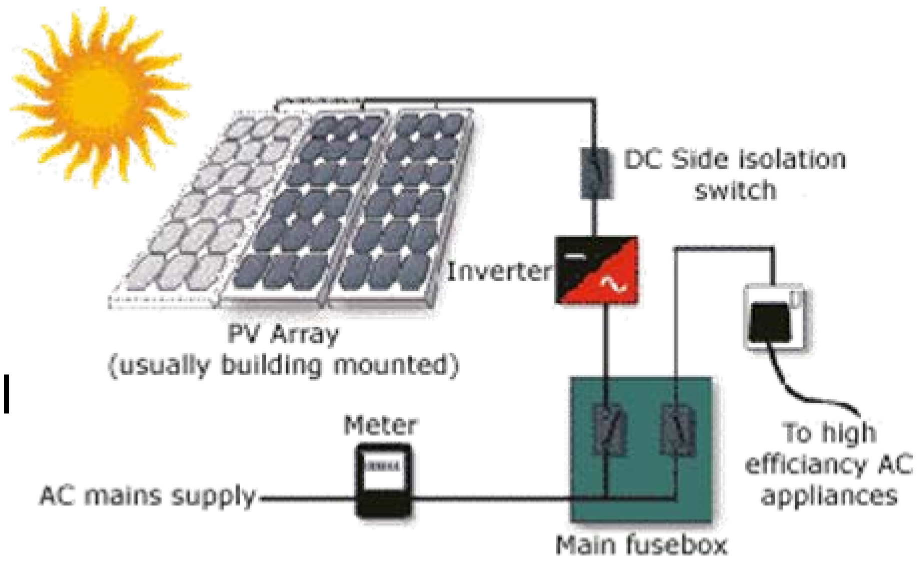
- Sun's rays (photons) strike semi-conductor PV panel
- Electrons are 'bumped up' to a higher energy state, leaving an electron hole and a high energy electron
- Electrons pass through house circuit on way back to electron hole



Ok, it's magic…but it works repeatably, and it looks cool…

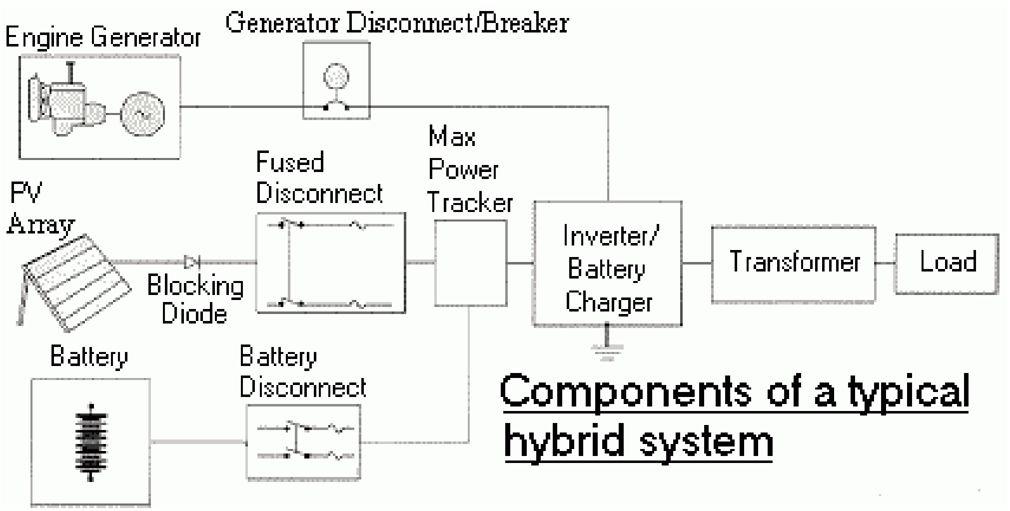
PV system layout: grid tied

- PV panels in sun
- DC wiring to disconnect
- DC disconnect
- Inverter
- AC wiring to main electric panel
- Utility meter & grid

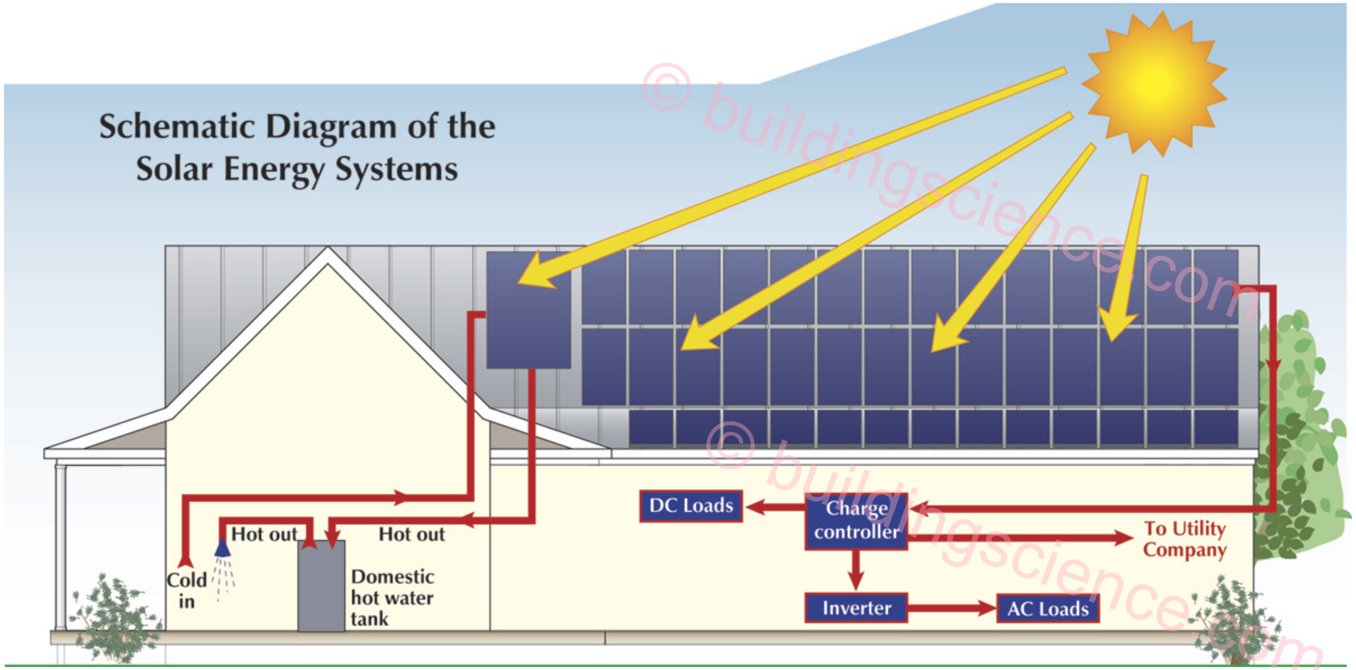


PV system layout: stand alone

- PV panels
- DC wiring to charge controller
- Charge controller
- Battery bank
- Backup generator, etc

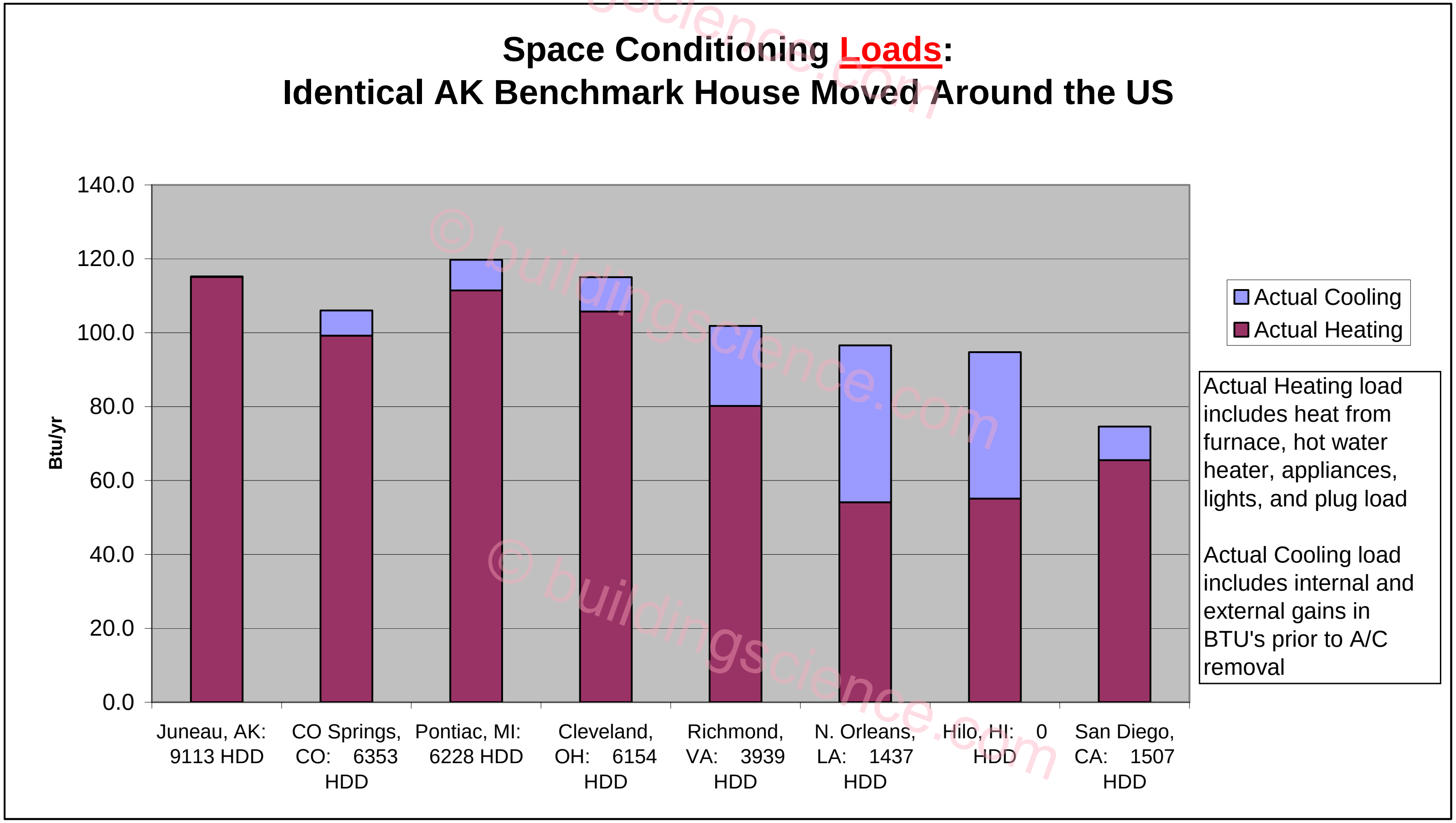


Site Generated Energy - Integration

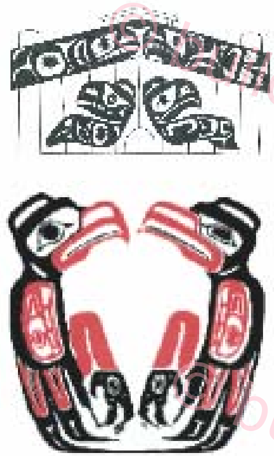


- **PV** - back-up batteries or grid connection
- **Solar water** - passive system drawn down with demand
- **Passive Solar Gain -** awnings to protect from overheating

Heating / Cooling Trade-off



Extreme Home -Very Cold, Haidaburg, AK

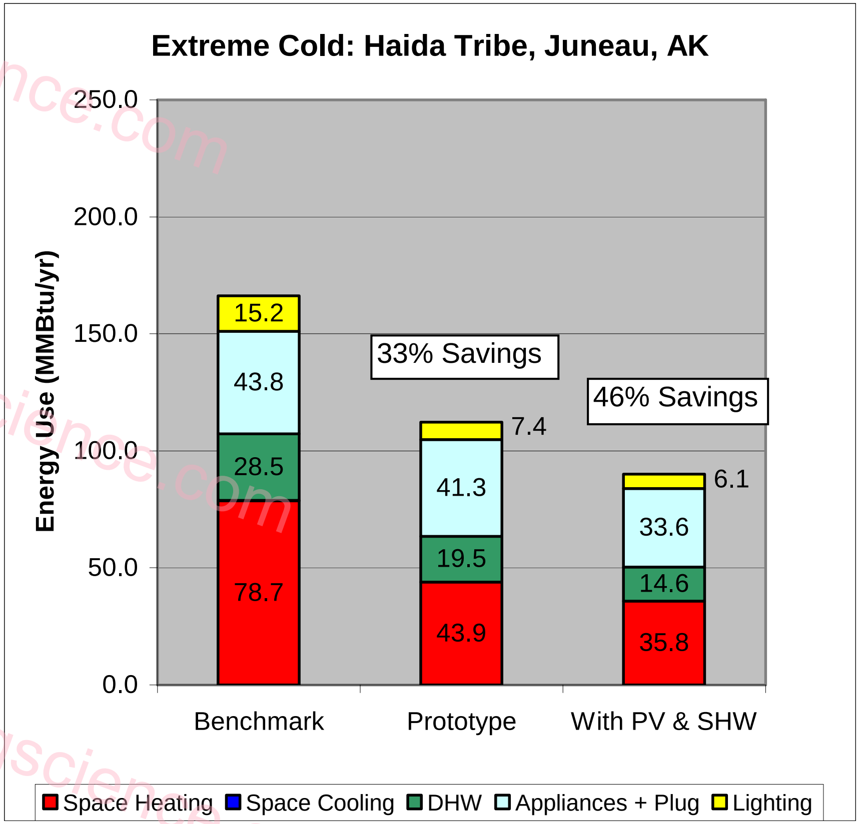


Extreme Cold: Haida Tribe, Juneau, AK

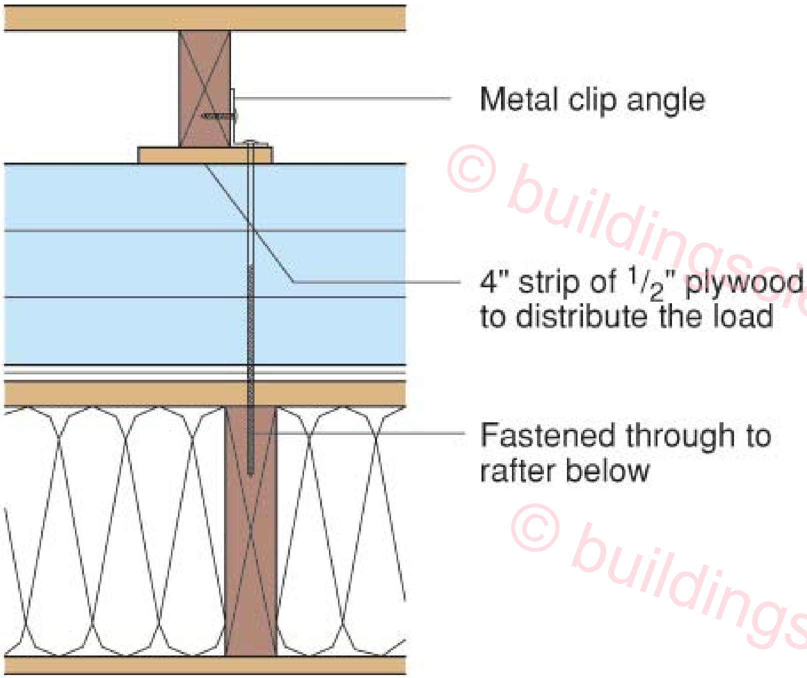
Heating Degree Days: 9113

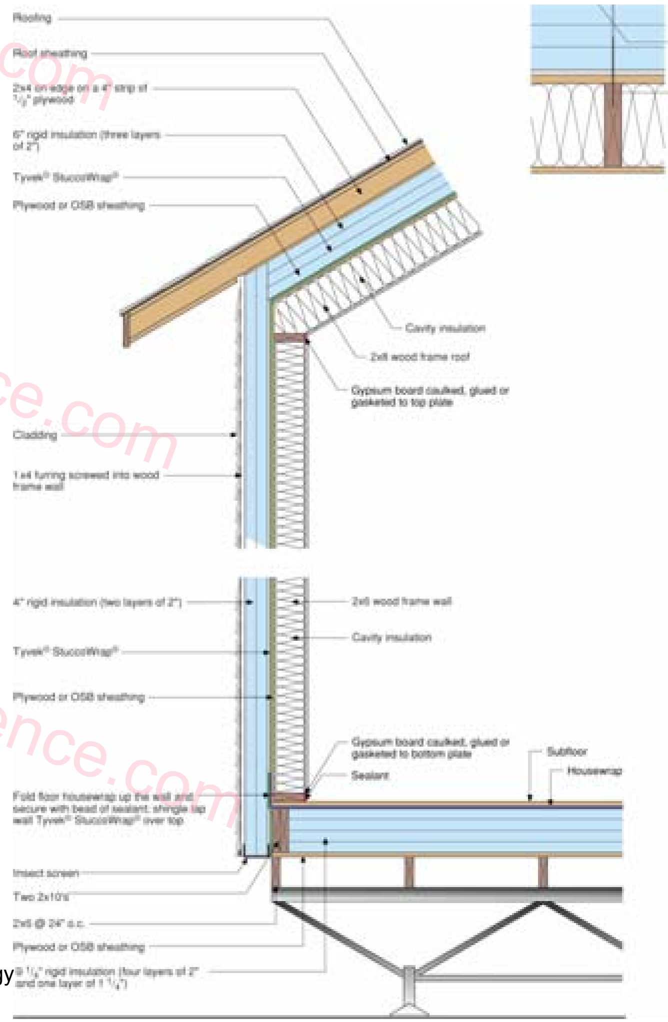
Project Highlights (1190 sf House)

Building Enclosure	R-28 rigid foam with interior frame R-42 cathedral ceiling Low E windows (U-0.33, SHGC-0.45) R-33 Floor insulation on pier foundation BSC BA Airtightness (2.5 ins/100 sf)
Mechanical	Combo System 85% AFUE Hot Water Heater Baseboard heaters ASHRAE 62.2 ventilation by HRV Flourescent lighting
Solar Site Collection	40 sf glycol SHW system (3% Savings) 2.0 kW Peak PV system (10% Savings)



Extreme Home -Extreme Details



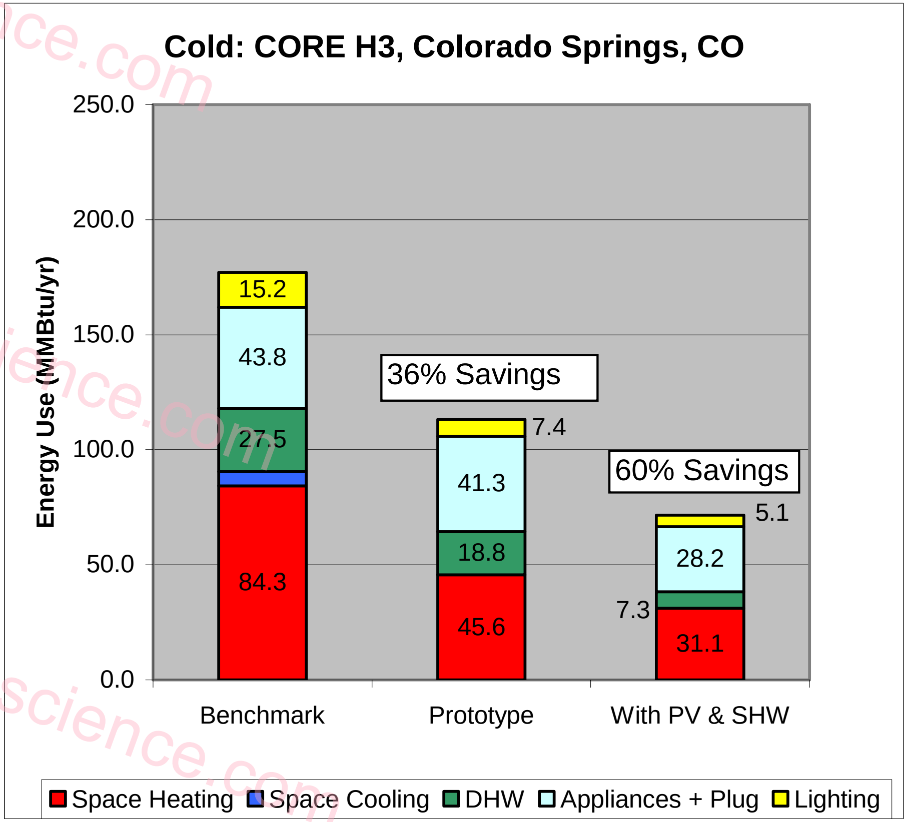


Very Cold - Colorado Springs, Colorado

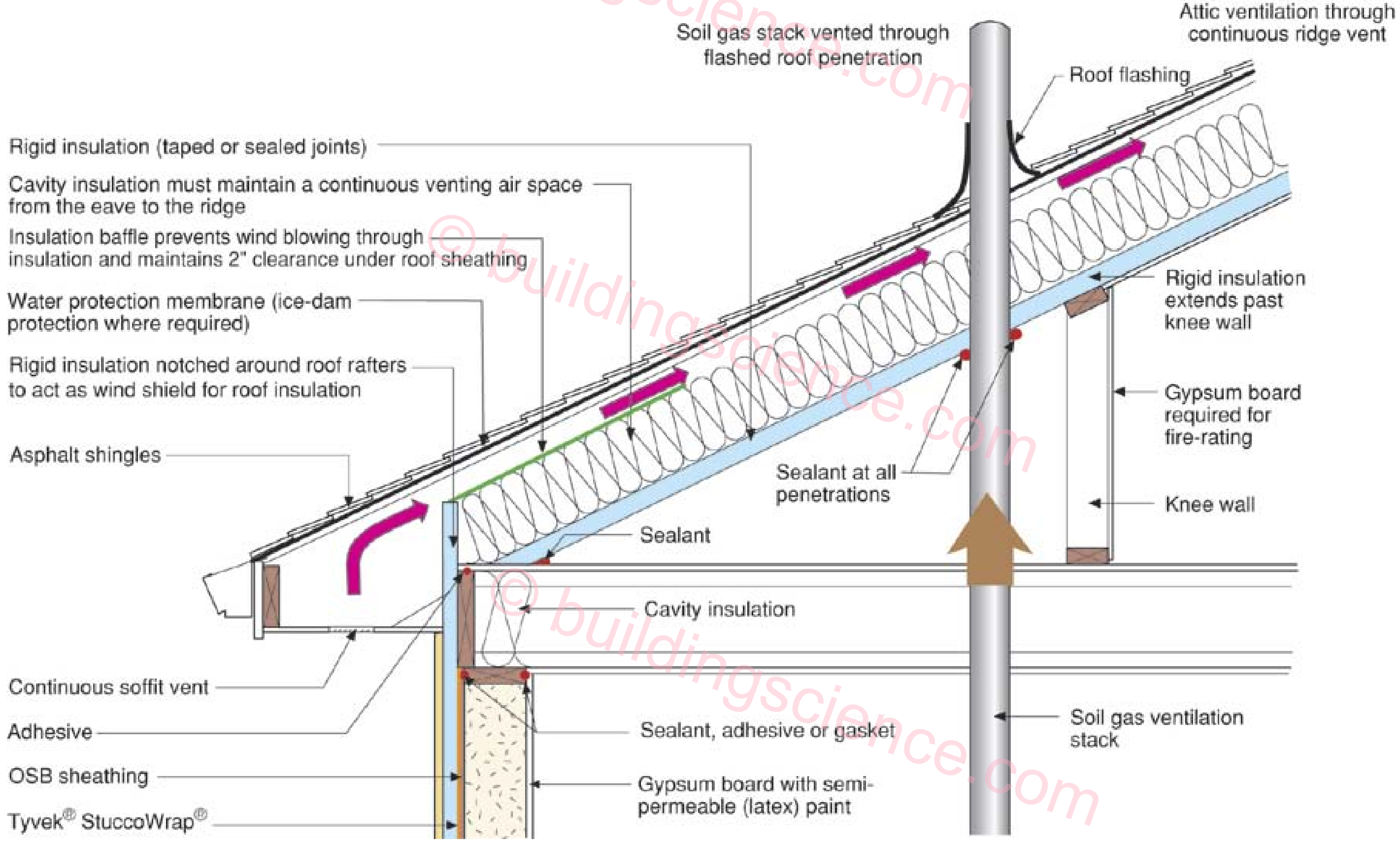
Cold: CORE H3, Colorado Springs, CO

Heating Degree Days: 6353
Project Highlights (1190 sf House)

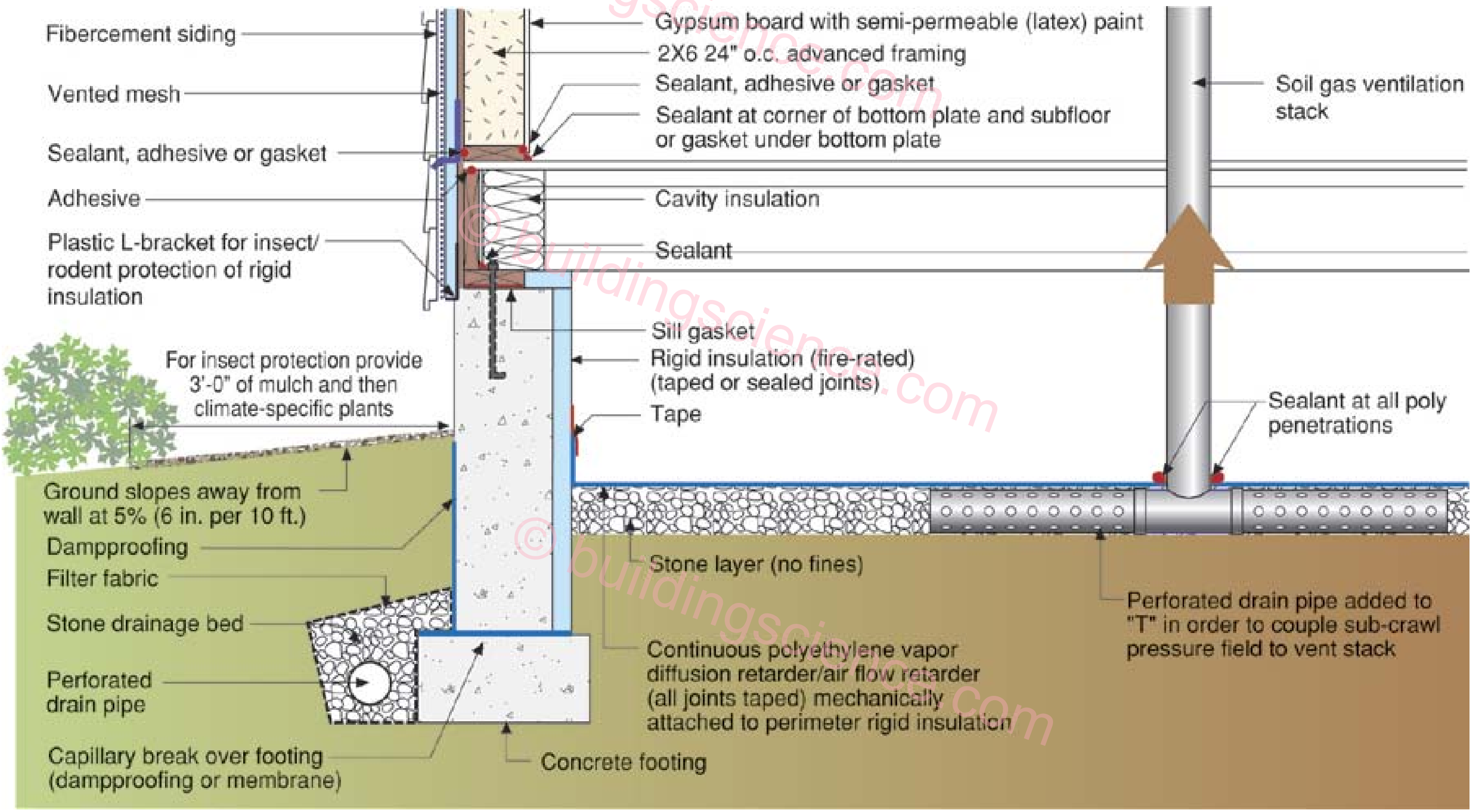
Building Enclosure	R-19 + R-5 Walls R-38 attic / R-35 Cathedral ceiling Low E windows (U-0.33, SHGC-0.28) R-23 walls on conditioned crawl BSC BA Airtightness (2.5 ins/100 sf)
Mechanical	92% AFUE Gas Furnace Ducts in conditioned space 0.82EF Tankless Hot Water Heater ASHRAE 62.2 ventilation by HRV Flourescent lighting
Solar Site Collection	64 sf glycol SHW system (7% Savings) 2.0 kW Peak PV system (17% Savings)



Very Cold - Details



Very Cold - Details



Very Cold - Details

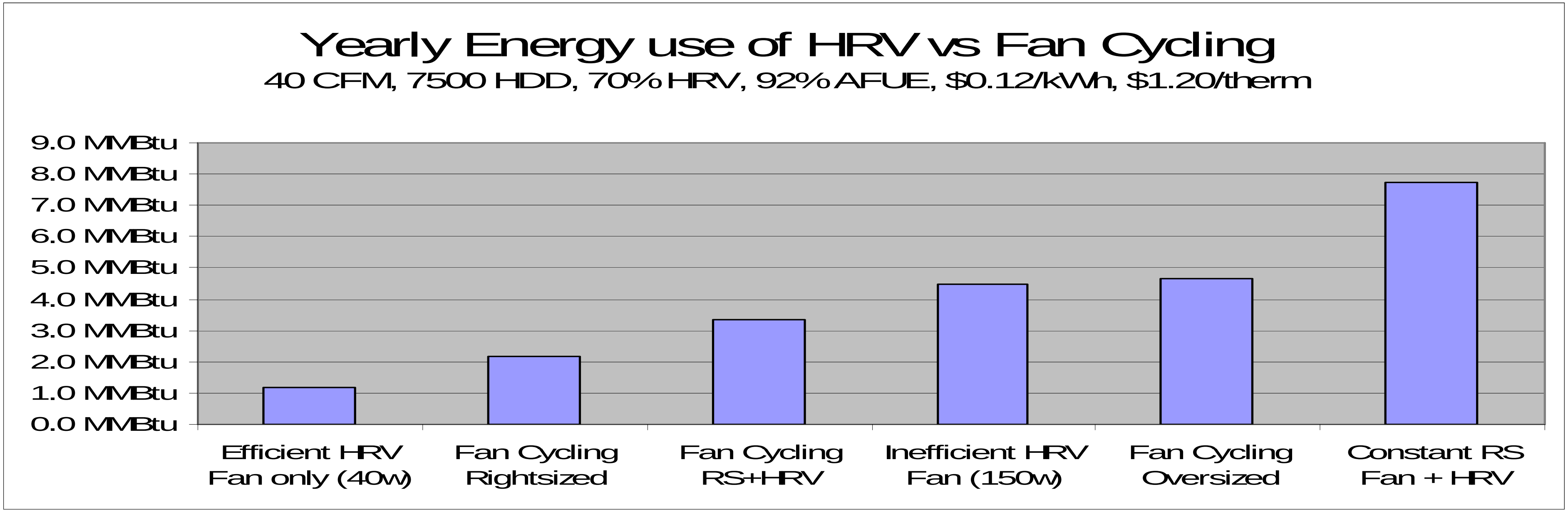
Very Cold - Details

HRV vs.Supply Ventilation

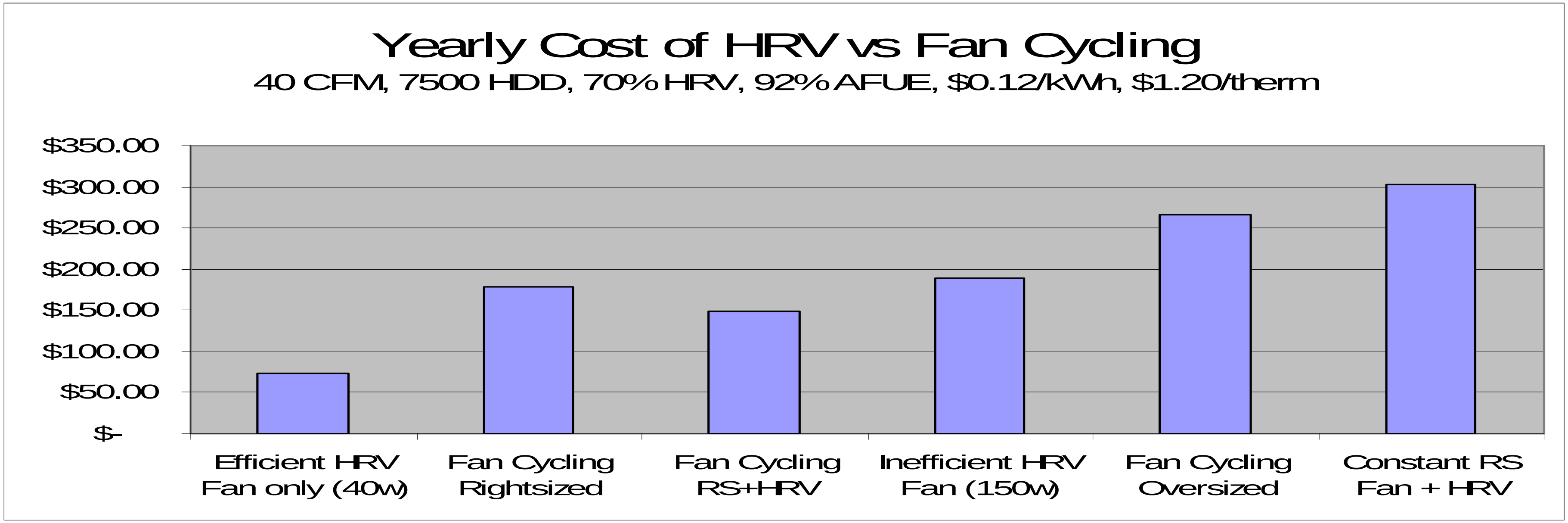
Yearly Energy Use: HRV vs Fan Cycling

Ventilation Air Heating		O. Airflow CFM	% Heat Recovery	Climate	Yearly Energy 92% AFUE	Cost @ $1.20/therm
Efficient HRV Fan only (40w)		40	70%	7500 HDD	25.6 therms	$ 30.71
Fan Cycling Rightsized		40	0	7500 HDD	85.3 therms	$ 102.37
Fan Cycling RS+HRV		40	70%	7500 HDD	25.6 therms	$ 30.71
Inefficient HRV Fan (150w)		40	70%	7500 HDD	25.6 therms	$ 30.71
Fan Cycling Oversized		40	0	7500 HDD	85.3 therms	$ 102.37
Constant RS Fan + HRV		40	70%	7500 HDD	25.6 therms	$ 30.71
Fan Energy	Duty Cycle	Unit watts	% Heating Calls	Continuous Watts	Yearly Energy Use	Cost @ $0.12/kWh
Efficient HRV Fan only (	100%	40		40	350 kWh	$ 42.05
Fan Cycling Rightsized	33%	250	13%	72	632 kWh	$ 75.83
Fan Cycling RS+HRV	33%	250	13%	112	982 kWh	$ 117.88
Inefficient HRV Fan (15(	100%	150		150	1314 kWh	$ 157.68
Fan Cycling Oversized	33%	500	6%	156	1363 kWh	$ 163.55
Constant RS Fan + HRV	100%	250	13%	259	2265 kWh	$ 271.85
					Yearly Energy	Yearly Cost
Efficient HRV Fan only (40w)					1.2 MMBtu	$ 72.76
Fan Cycling Rightsized					2.2 MMBtu	$ 178.20
Fan Cycling RS+HRV					3.4 MMBtu	$ 148.59
Inefficient HRV Fan (150w)					4.5 MMBtu	$ 188.39
Fan Cycling Oversized					4.7 MMBtu	$ 265.91
Constant RS Fan + HRV					7.7 MMBtu	$ 302.56

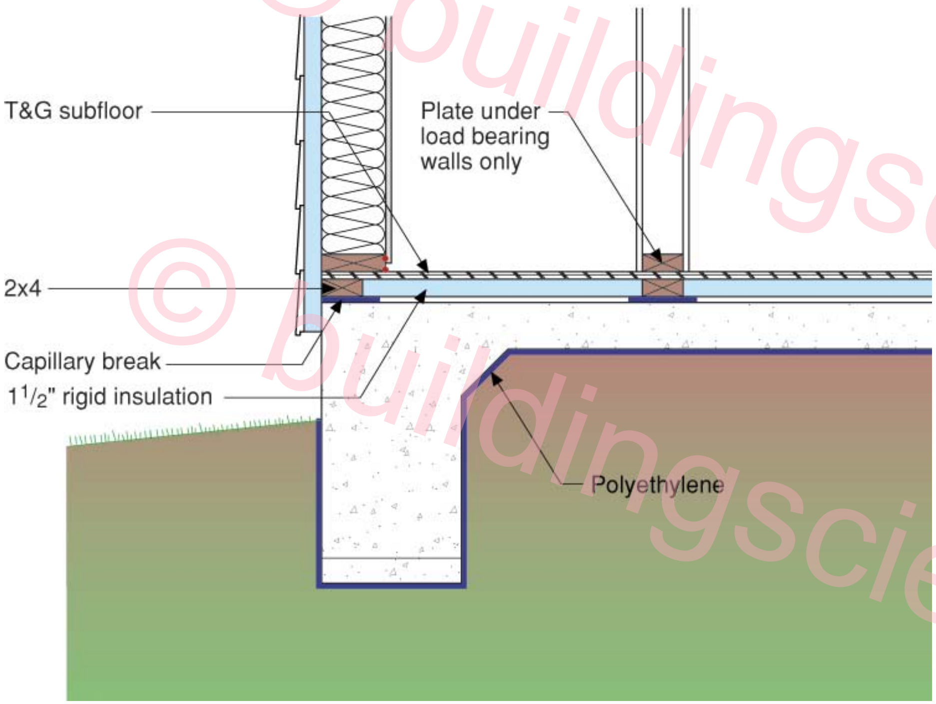
HRV vs. Supply Ventilation

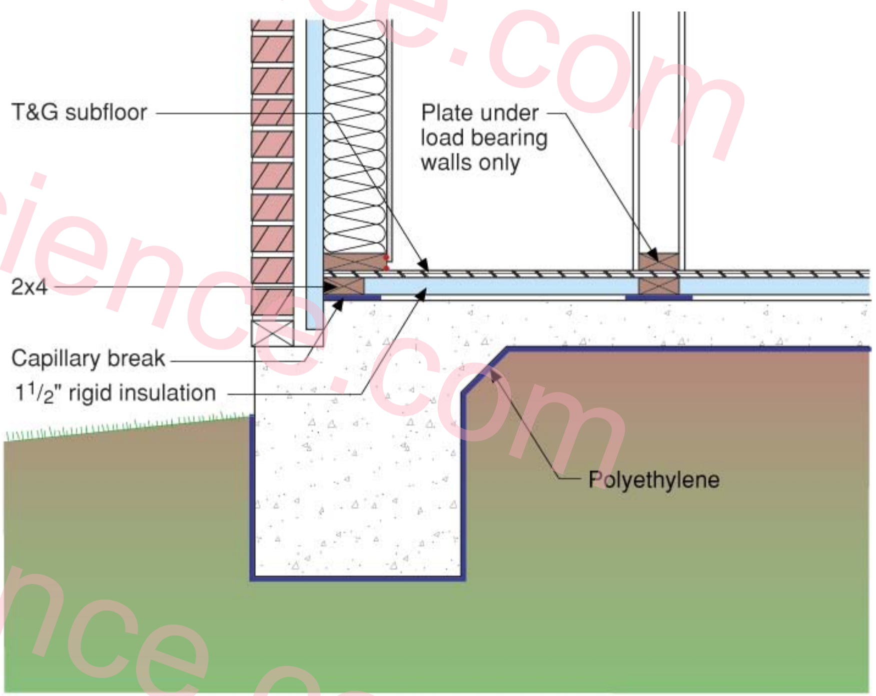


HRV vs. Supply Ventilation



Slab on Grade Options





Cold - Pontiac, Michigan

M STREET SITE ELEVATION

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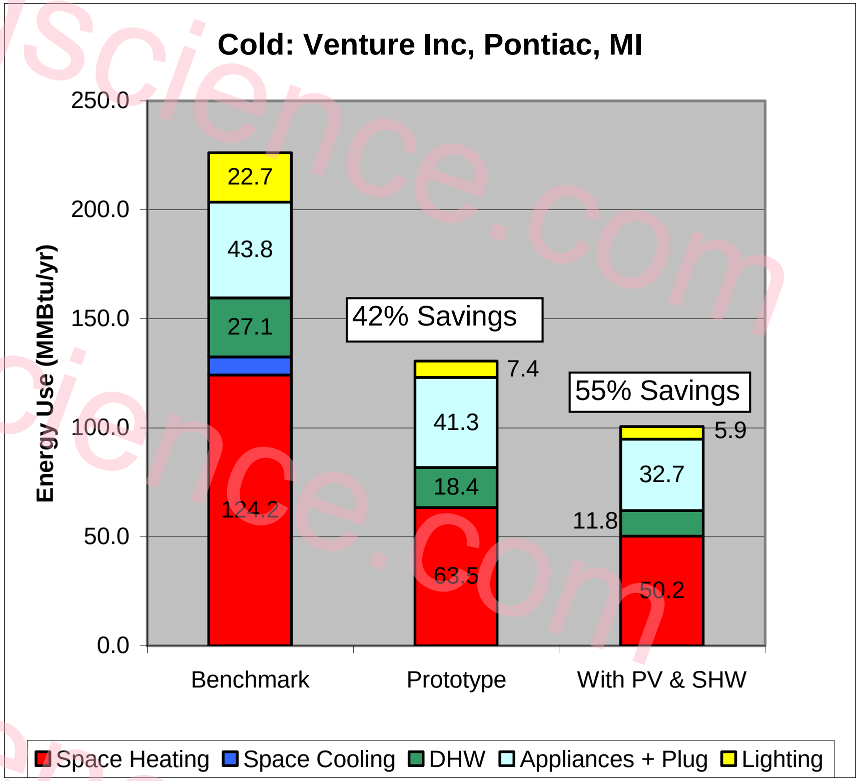
Cold: Venture Inc, Pontiac, MI

Heating Degree Days: 6228

Project Highlights (1190 sf House)

Building Enclosure	R-19 + R-5 Walls R-38 attic / R-35 Cathedral ceiling Low E windows (U-0.33, SHGC-0.28) R-23 walls on conditioned basement BSC BA Airtightness (2.5 ins/100 sf)
Mechanical	92% AFUE Gas Furnace Ducts in conditioned space 0.82EF Tankless Hot Water Heater ASHRAE 62.2 ventilation by FanCycler Flourescent lighting
Solar Site Collection	40 sf glycol SHW system (3% Savings) 2.0 kW Peak PV system (10% Savings)



Cold - Details

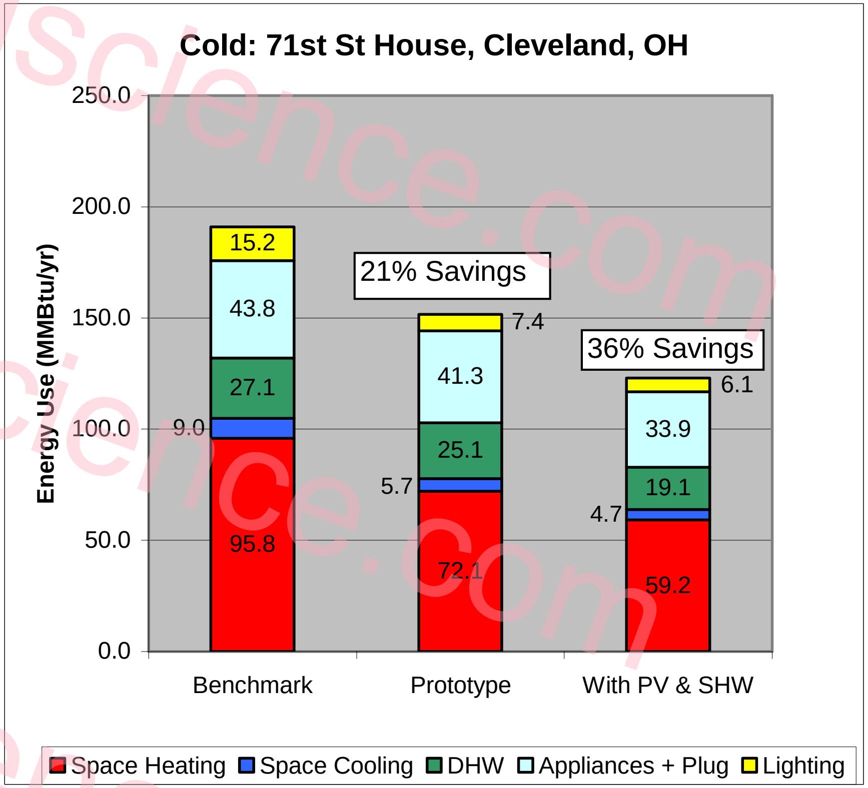
Cold - Cleveland, Ohio

Cold: 71st St House, Cleveland, OH

Heating Degree Days: 6154

Project Highlights (1190 sf House)

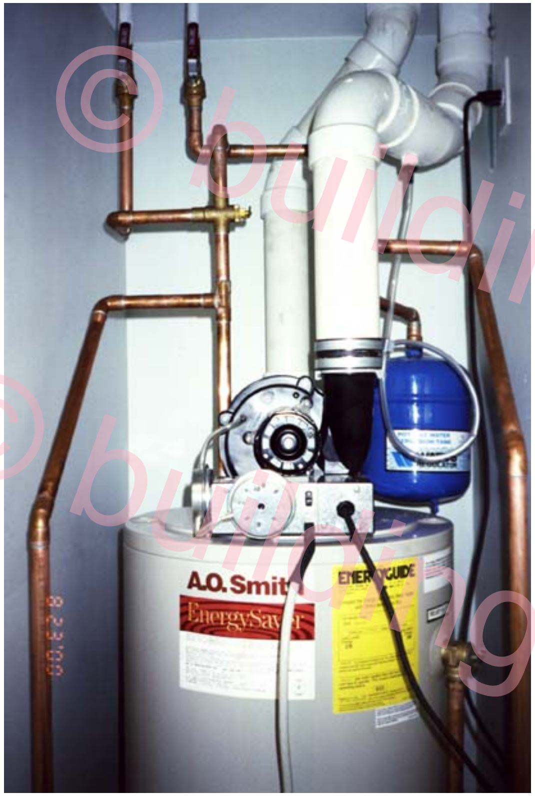
Building Enclosure	R-19 + R-5 Walls R-38 attic / R-35 Cathedral ceiling Low E windows (U-0.33, SHGC-0.45) R-8 walls on conditioned crawl BSC BA Airtightness (2.5 ins/100 sf)
Mechanical	0.75EF CA Combo System Heat 10 SEER Cooling System Ducts in conditioned space 0.59EF Tank Hot Water Heater ASHRAE 62.2 ventilation by FanCycler Flourescent lighting
Solar Site Collection	40 sf glycol SHW system (3% Savings) 2.0 kW Peak PV system (12% Savings)



Annual Energy Costs

Regional standard (2000)		Infill prototype (2000)	
heating	$613	heating	$262
cooling	$189	cooling	$144
hot water	$148	hot water	$135
total	$950 ($80 mo)	total	$541 ($45mo)
HERS rating	82	HERS rating	90

Cold - Details



Cold - Details

Cold - Details

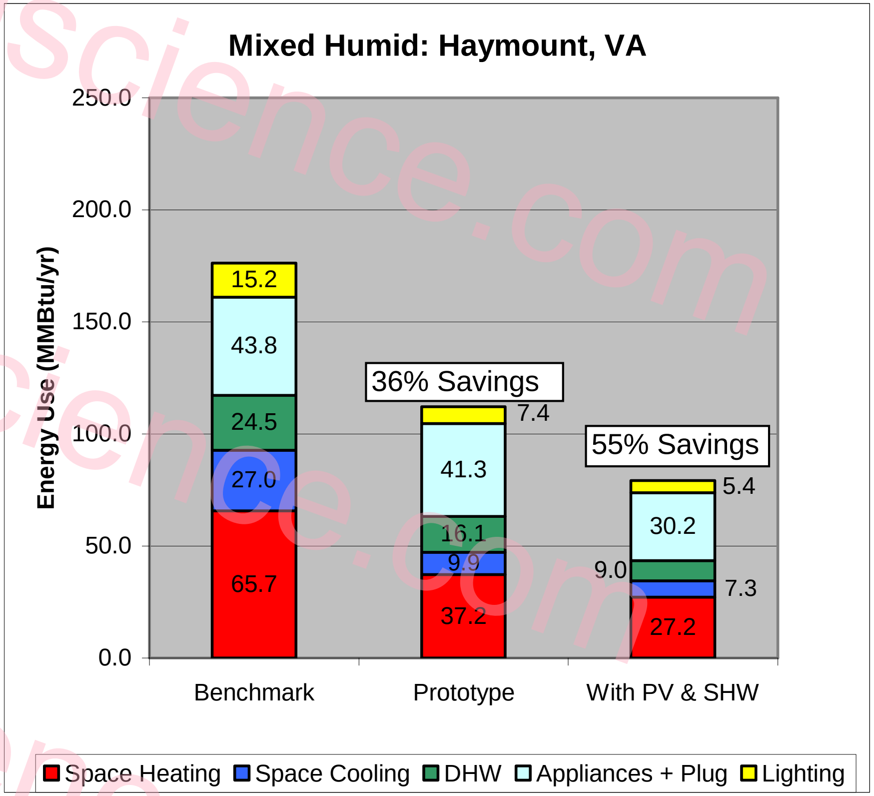
Mixed Humid, Fredricksburg, Virginia

Mixed Humid: Haymount, VA

Heating Degree Days: 3939

Project Highlights (1190 sf House)

Building Enclosure	R-19 + R-5 Walls R-38 attic / R-35 Cathedral ceiling Low E windows (U-0.33, SHGC-0.28) R-23 walls on conditioned crawl BSC BA Airtightness (2.5 ins/100 sf)
Mechanical	92% AFUE Gas Furnace 14 SEER Cooling System Ducts in conditioned space 0.82EF Tankless Hot Water Heater ASHRAE 62.2 ventilation by FanCycler Flourescent lighting
Solar Site Collection	40 sf glycol SHW system (4% Savings) 2.0 kW Peak PV system (15% Savings)



Mixed Humid, Fredricksburg, Virginia

Ideal Homes, OKC, OK

Specifications

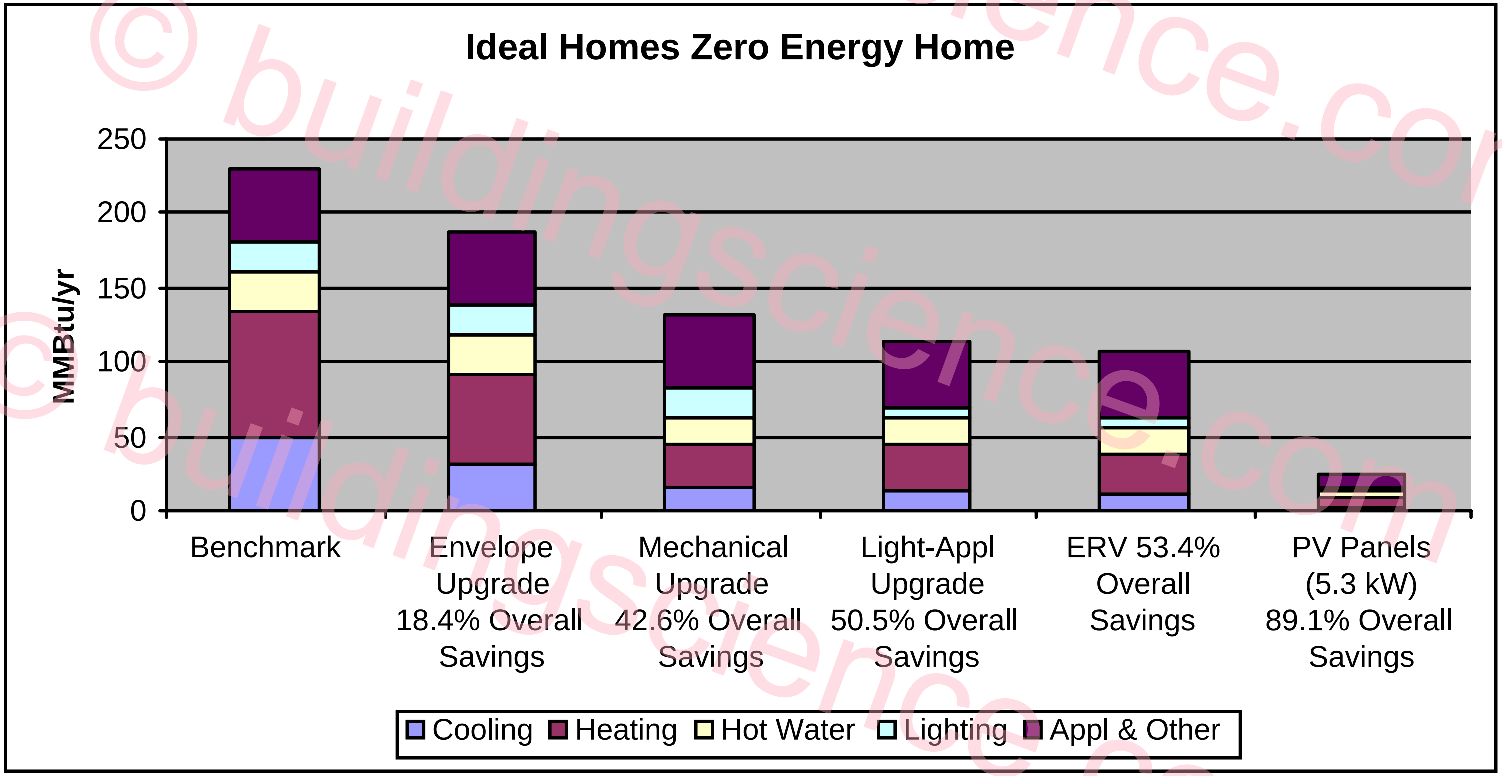
Building envelope

Ceiling	R-38 blown cellulose at ceiling
Walls	R-19 + R-3 insulating sheathing
Foundation	Slab, R-4 interior insulation
Windows	Double Glazed Vinyl Frame LowE2 U=0.39, SHGC=0.31
Infiltration	2.5 sq in leakage area per 100 sf envelope

Mechanical systems

Heat	4.3 COP Ground Source heat pump
Cooling	20 EER ground source heat pump
DHW	Rinnai Tankless HWH 0.82EF
AHU location	in conditioned space
Ducts	In vented attic, R-6 insulation
Duct Leakage	5% or less
Ventilation	ERV with 70% energy recovery 46 CFM continuous average flow
Lighting	90% compact fluorescent lighting
Appliances & Plug	Energy Star Appliances, 20% reduction in plug loads
PV System	5.3 kWp array & 5 kW Inverter

Mixed Humid - Details



Mixed Humid - Details

				Total Source Energy Savings (H/C/DHW/Lights/Appliances/Plug)					
Parametric Run ID	Description of change	Estimated Individual Cost	Estimated Cumulative Cost	Savings over BA BM	Change From Previous	Annual Energy Cost	Item Savings	Simple Payback (yr)	Payback of Change (yr)
0	Benchmark	n/a	n/a	n/a	n/a	$1,659	n/a	n/a	n/a
1	0 + Envelope Upgrade	$1,000	$1,000	18.4%	18.4%	$1,348	$311	3	3
2	1 + Mechanical Upgrade	$4,000	$5,000	42.6%	24.1%	$951	$397	7	10
3	2 + Light-Appl Upgrade	$1,000	$6,000	50.5%	7.9%	$818	$134	7	7
4	3 + ERV	$700	$6,700	53.4%	2.9%	$769	$48	8	15
5	4 + PV Panels (5.3 kW)	$31,000	$37,700	89.1%	35.8%	$168	$601	25	52

Table 1. Summary of End-Use Site-Energy

	Annual Site Energy		Annual Site Energy	
	BA Benchmark		Standard	
End-Use	kWh	therms	kWh	therms
Space Heating	8232	0	2617	0
Space Cooling	4740	0	1199	0
DHW	0	228	0	145
Lighting*	2085		693	
Appliances + Plug	4779	0	4368	0
Total Usage	19835	228	8877	145
Site Generation	0	0	8051	0
Net Energy Use	19835	228	826	145

Table 2. Summary of End-Use Source-Energy and Savings

		Est. Annual Source Energy	Source Energy Savings % of End-Use	Source Energy Savings % of Total
End-Use	BA Benchmark 106 BTU/yr	Standard 106 BTU/yr	Prototype 1 Savings	Prototype 1 Savings
Space Heating	84	27	**68%**	**25%**
Space Cooling	49	12	**75%**	**16%**
DHW	27	17	**36%**	**4%**
Lighting*	21	7	**67%**	**6%**
Appliances + Plug	49	45	**9%**	**2%**
Total Usage	230	108	**53%**	**53%**
Site Generation	0	-82		**36%**
Net Energy Use	230	26	**89%**	**89%**

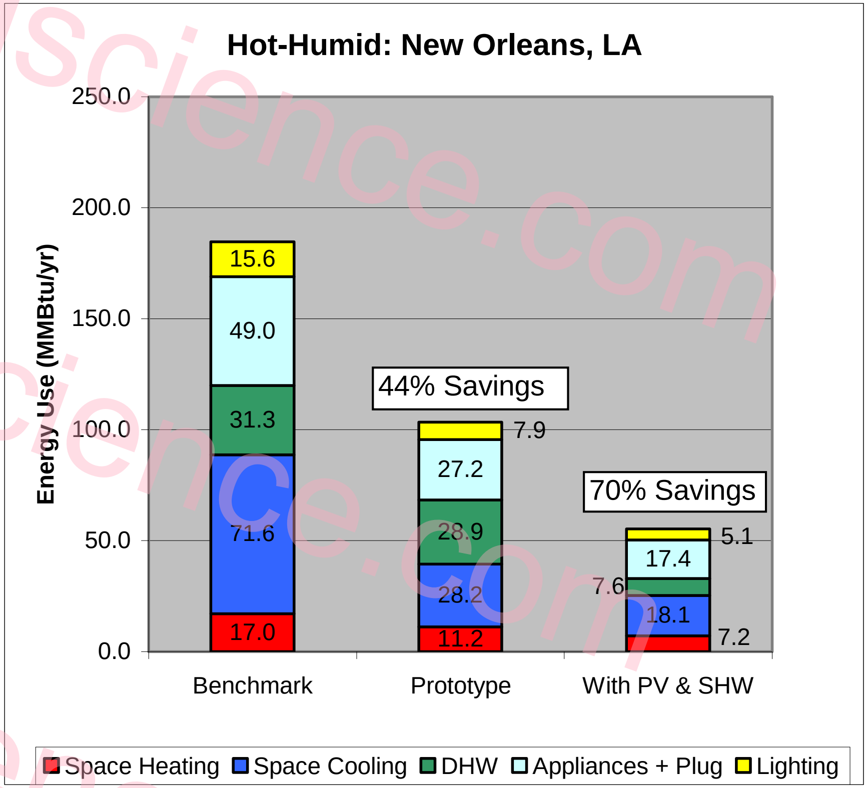
Extreme Home - Hot Humid, New Orleans, LA

Hot Humid: New Orleans, LA

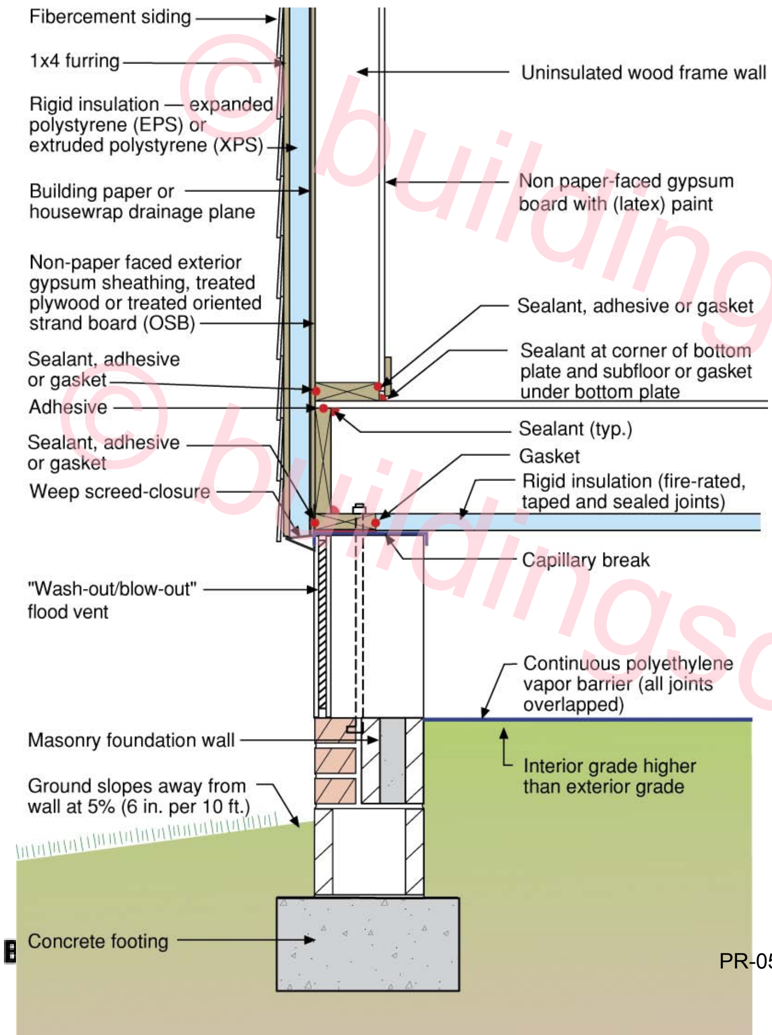
Heating Degree Days: 1437

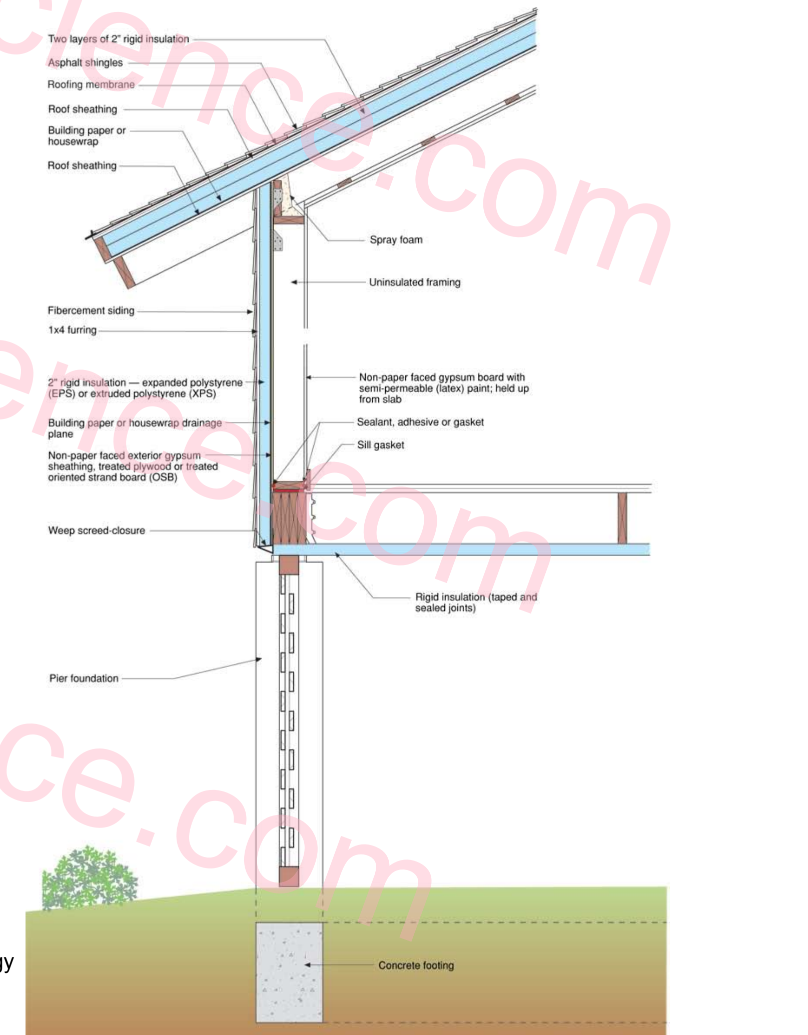
Project Highlights (1260 sf House)

Building Enclosure	R-10 Foam Sheathed walls R-20 Foam over roof deck Low E windows (U-0.33, SHGC-0.3) R-10 Foam under floor framing BSC BA Airtightness (2.5 ins/100 sf)
Mechanical	8.5 HSPF ASHP 14 SEER Cooling System Ducts in conditioned space 0.94EF Electric Hot water Tank ASHRAE 62.2 ventilation by FanCycler Flourescent lighting
Solar Site Collection	40 sf glycol SHW system (12% Savings) 2.0 kW Peak PV system (15% Savings)

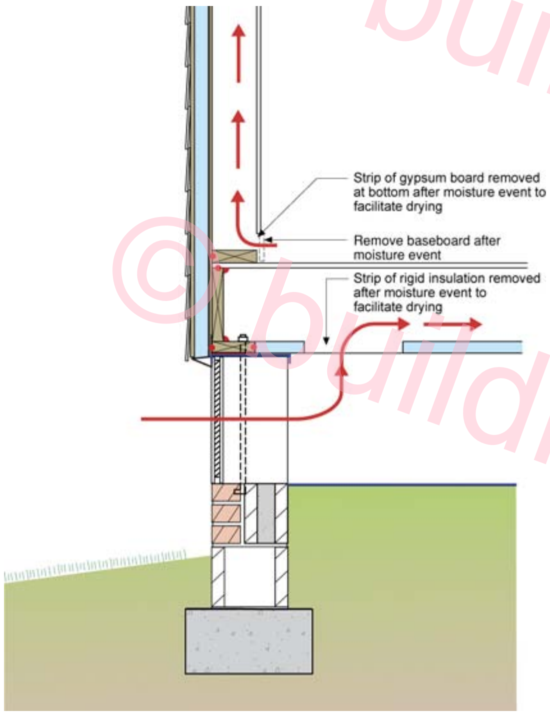


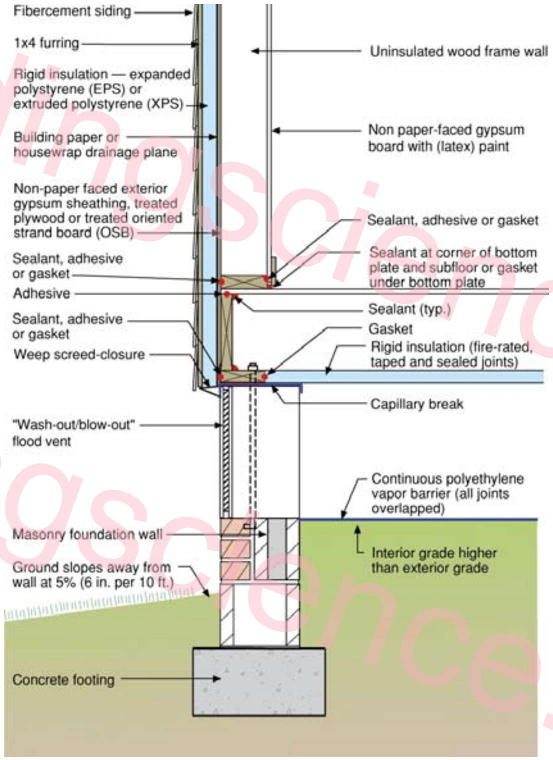
Extreme Home - Hot Humid - Details

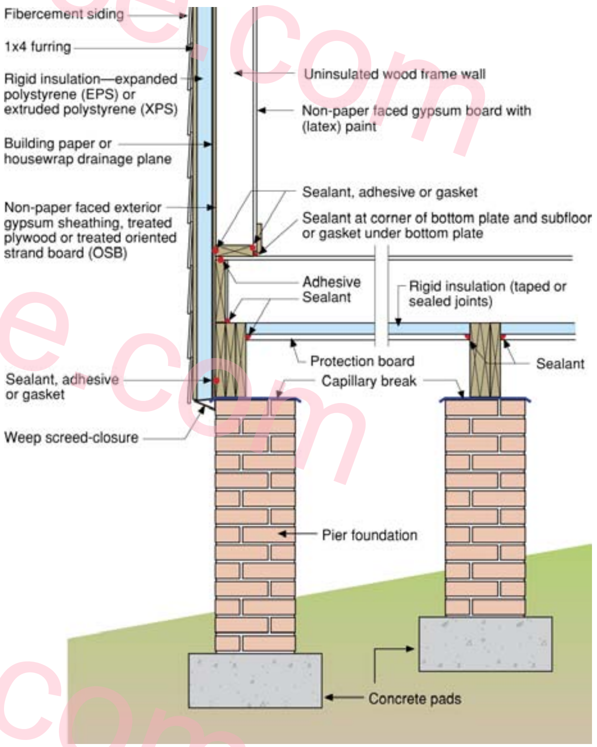




Extreme Home - Hot Humid - Details







Utility Savings across the US