# The Ecologists' House

## Case Study of a Zero Net Energy House in Duluth

Duluth Energy Design Conference 22 February 2017

Photo credit: Ethan Perry

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# Learning Objectives

1. Define "zero net energy”, and how such a goal might be approached.

2. Explore the design approach taken and design decisions made on this project, including the use of energy modeling.

3. Begin to see what it takes to build a house like this.

4. Learn how the building is actually performing.

5. Look into the details of the energy use and production in the home.

6. Gain an understanding about "how much more" it cost and what it saves, in more than just dollars.

7. What can we learn from this project, about our ability to achieve resilient design and zero net energy operation in our climate?

# What is “zero net energy”?

Imported energy (used on site) is less than or equal to exported energy (produced on site), on an annual basis.

Not typically an “off grid” home.

In an all electric building, the math is easier: kWh purchased from the grid must be equal to kWh sent to the grid.

When fossil fuels (i.e. propane or natural gas) are imported to the site, in order to achieve zero net energy, the exported energy (i.e. kWh produced) must also offset the energy value of the imported fossil fuel.

# Paths to zero net energy

## "Just Add Renewables"

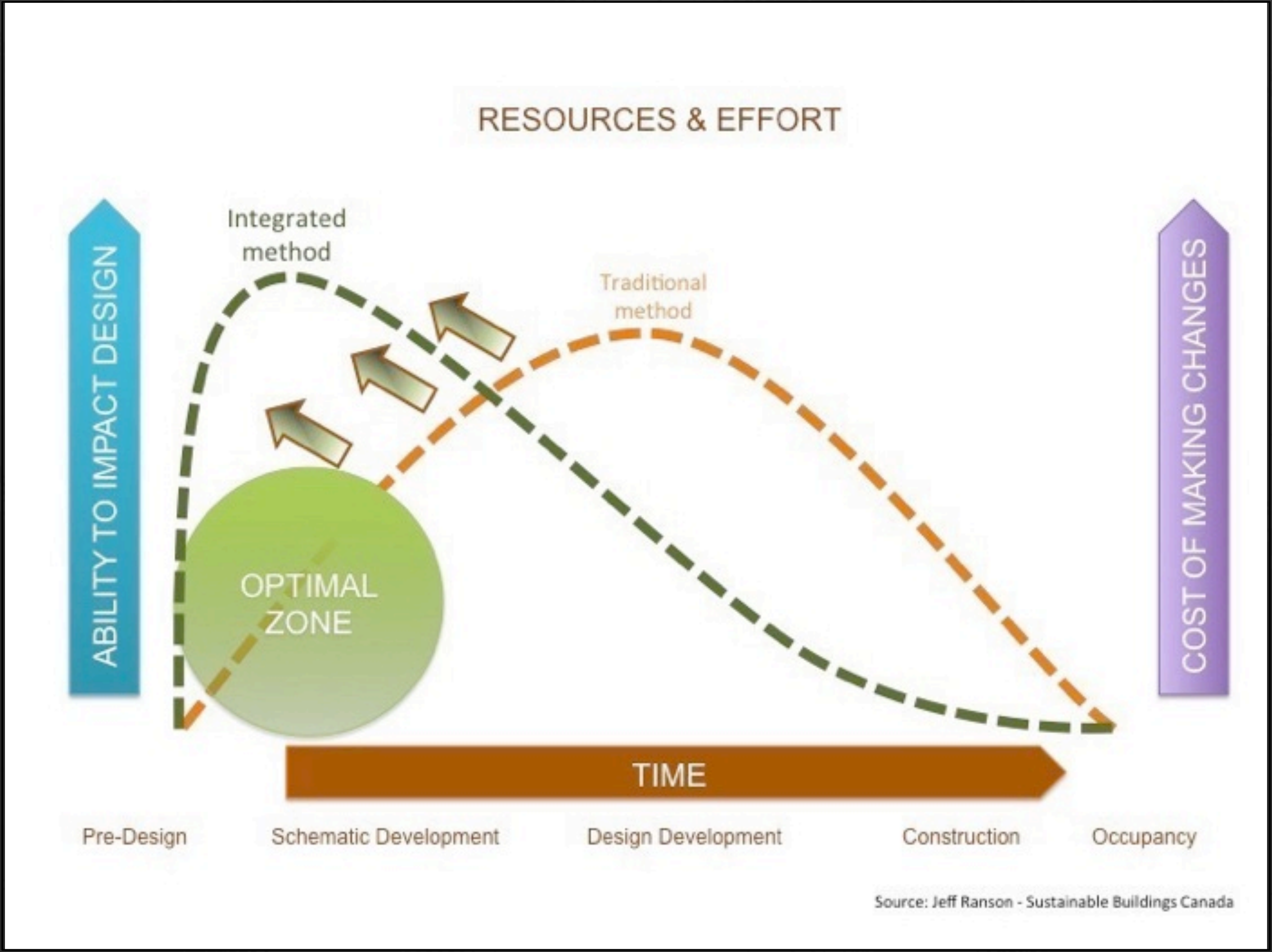
Enclosure not necessarily optimized
Large renewable system(s)
Almost any house could be net zero

Image from fullspectrumsolar.com

## "Low Energy Design"

Super insulated enclosure
Balance of enclosure to systems
Small, efficient mechanical systems
Renewable energy system(s)

# Integrated Design Approach



# Where We Began: Goals

**Overall Project Goals**

1. Small, efficient, enduring, affordable.
2. A home that is happy and beautiful.
3. Flexibility of spaces to serve one or more function.

**Priorities**

1. Ecological focus to all aspects of project
2. Ability to heat with wood
3. Renewable energy system (solar PV)

**Building Performance Goals**

1. Use the concept of “appropriate technology”
2. Passive solar design

# Where We Began: Building Program

**Site Design**

1. plan for house to have view of pond
2. consider fire protection
3. allow for gardens, orchard, unheated outbuilding
4. slab on grade design
5. possible sleeping porch (attached or detached)

**Building Design/Character**

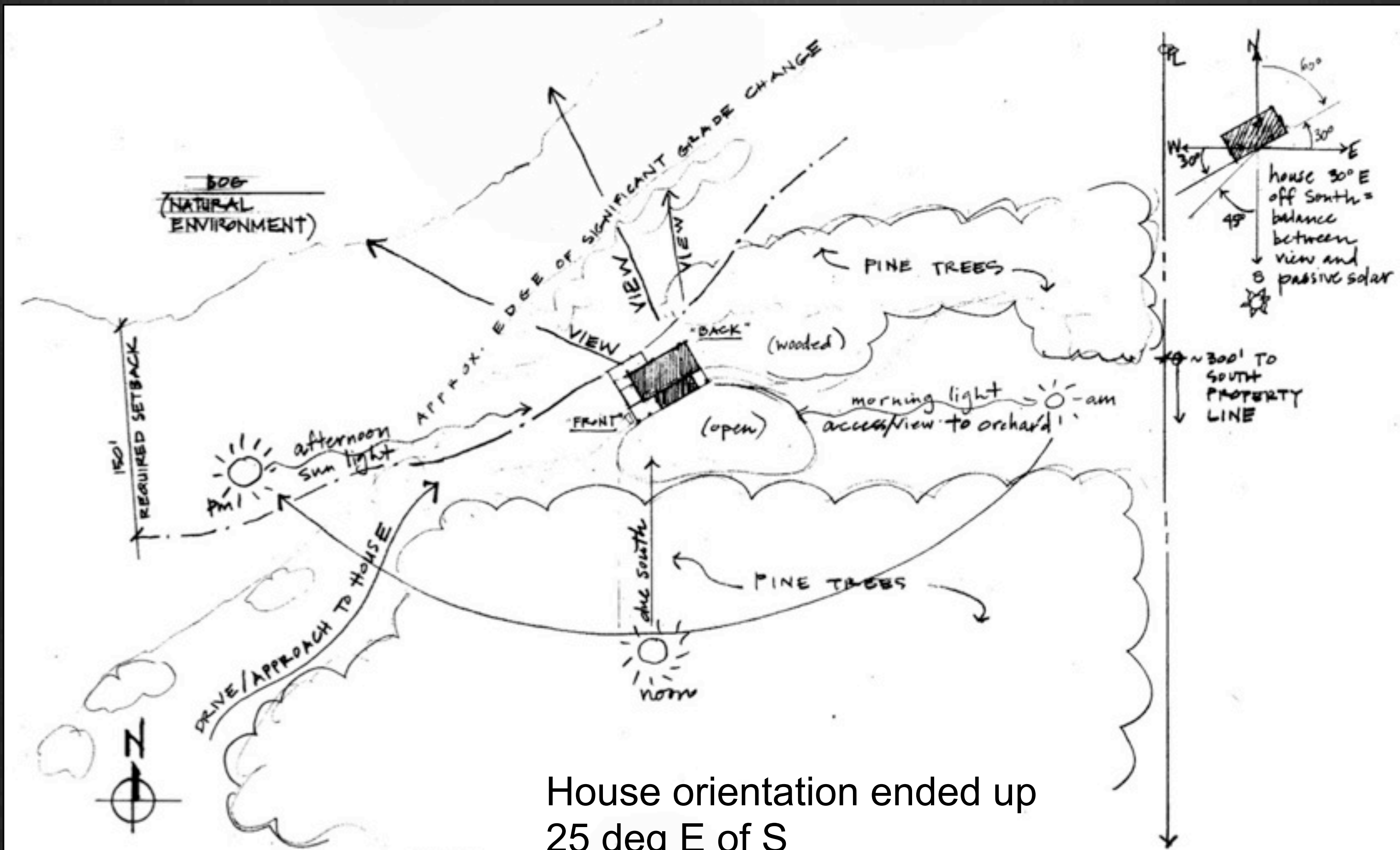
1. farm and/or east coast iconic
2. cottage/farmhouse aesthetic blended with European-modern spare
3. natural and organic
4. defined spaces within open plan
5. exterior space such as porch or verandah

# Where We Began: Space Program

1. 3 Bedrooms (one space to sleep on first floor)
2. Office/work area (can be upstairs or downstairs)
3. Open spaces for living/dining/cooking
4. Pantry
5. Functional mudroom leading easily to outdoor activity
6. Laundry/utility/mechanical can be combined
7. Work bench adjacent or within utility space
8. 2 Bathrooms
9. Dedicated storage
10. Greenhouse (can be combined with entry/mud space)

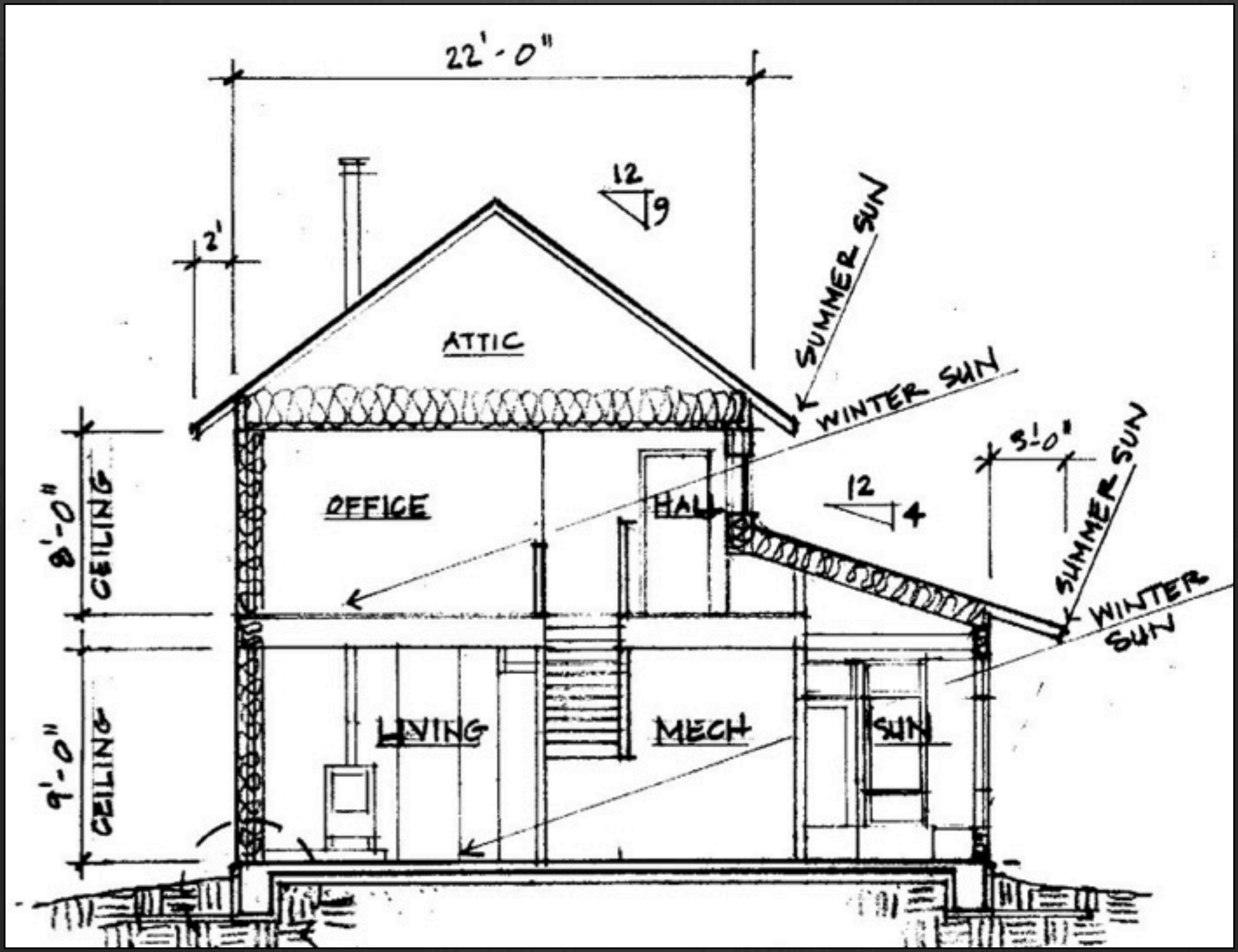
# The Site

# Analyzing the Site

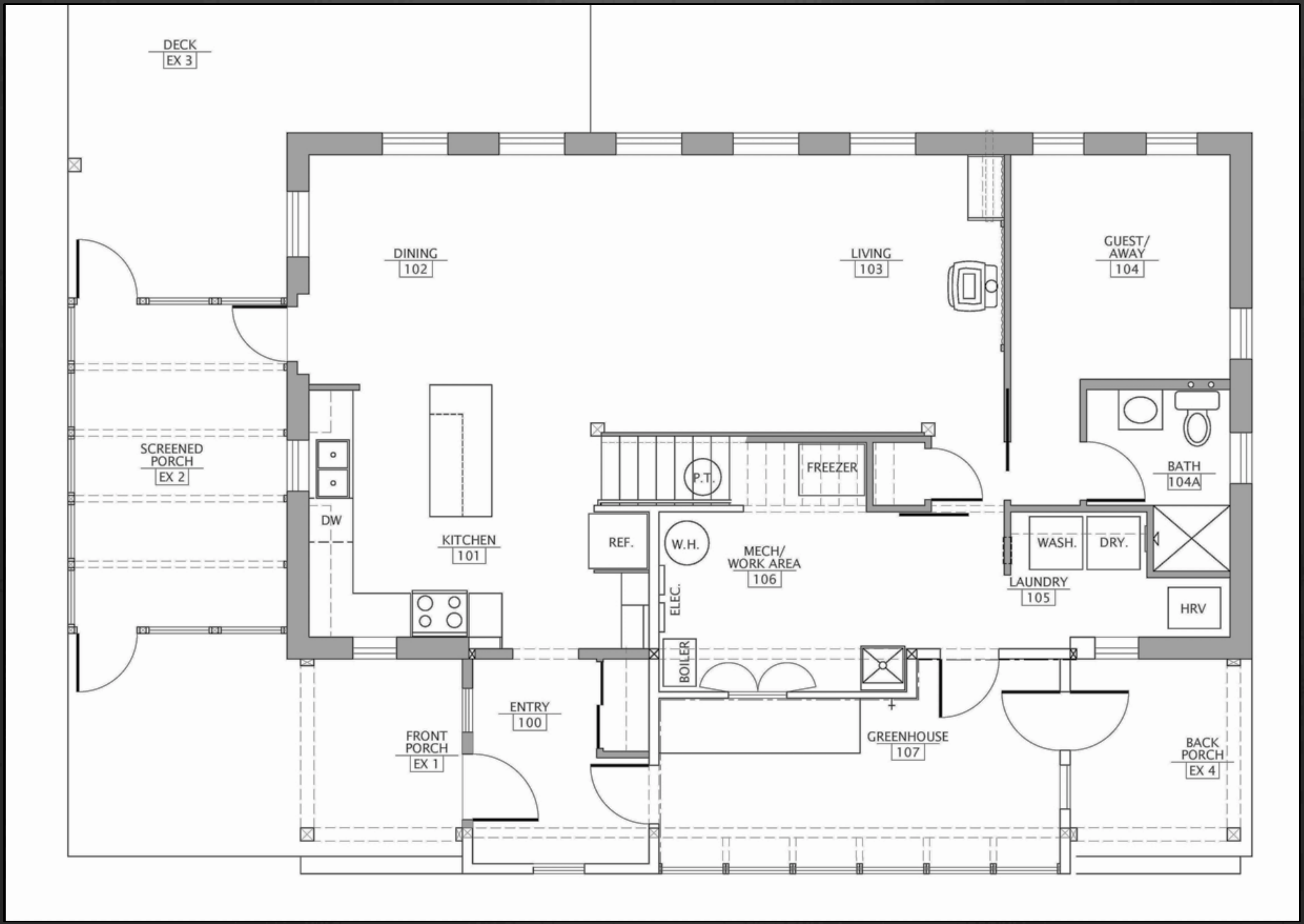



House orientation ended up
25 deg E of S

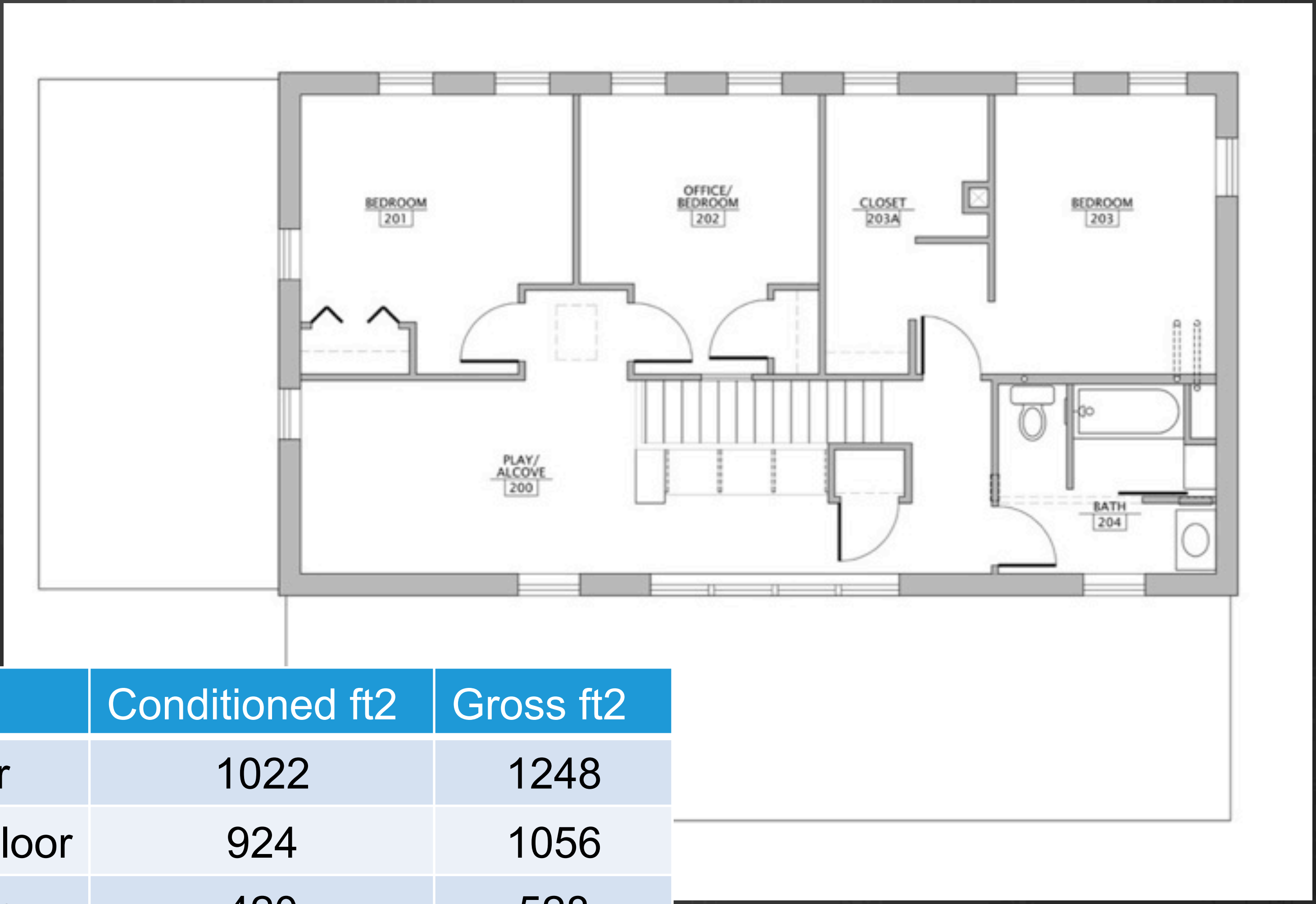
# Schematic Design



# Design – 1st Floor Plan

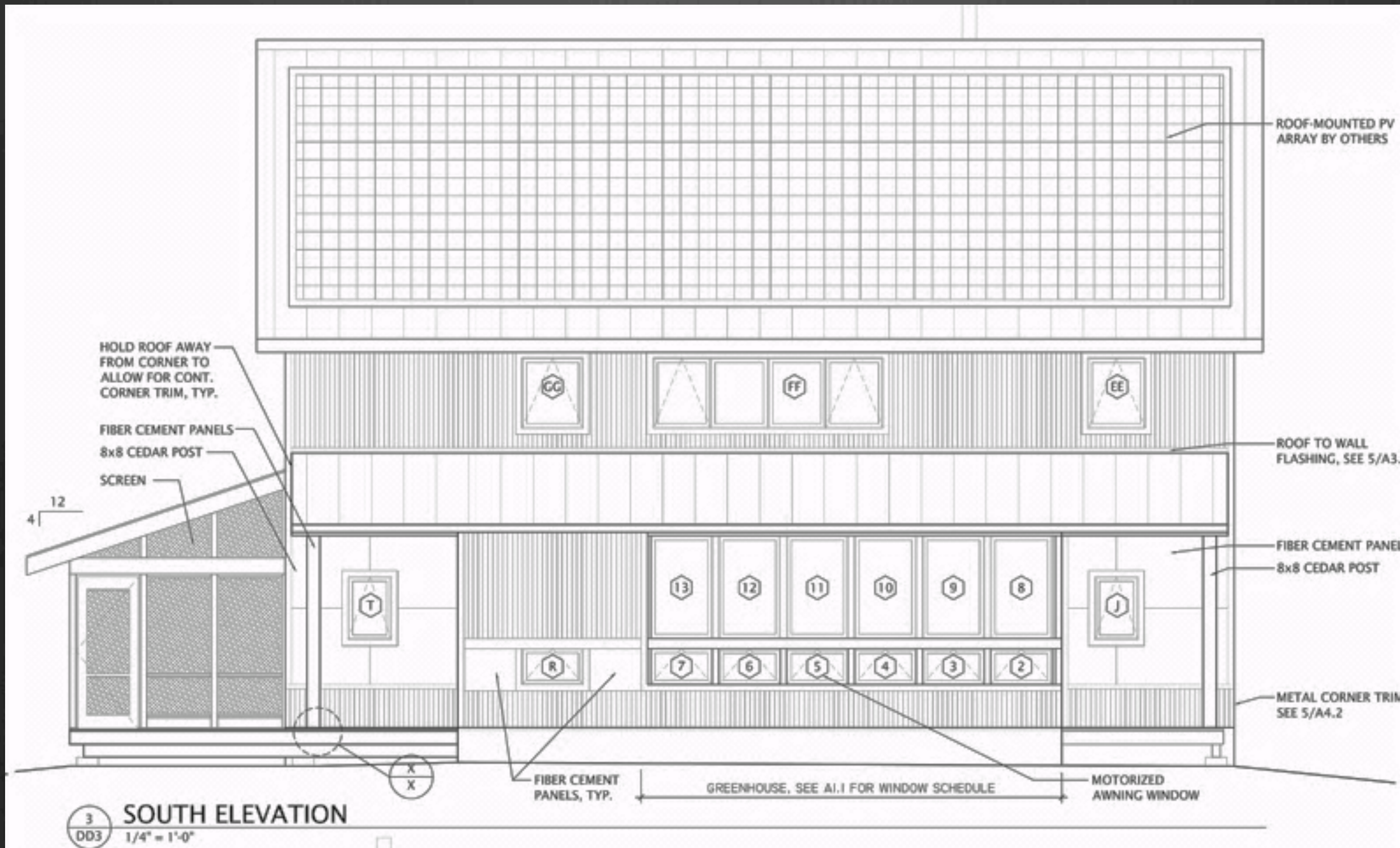


# Design – 2nd Floor Plan

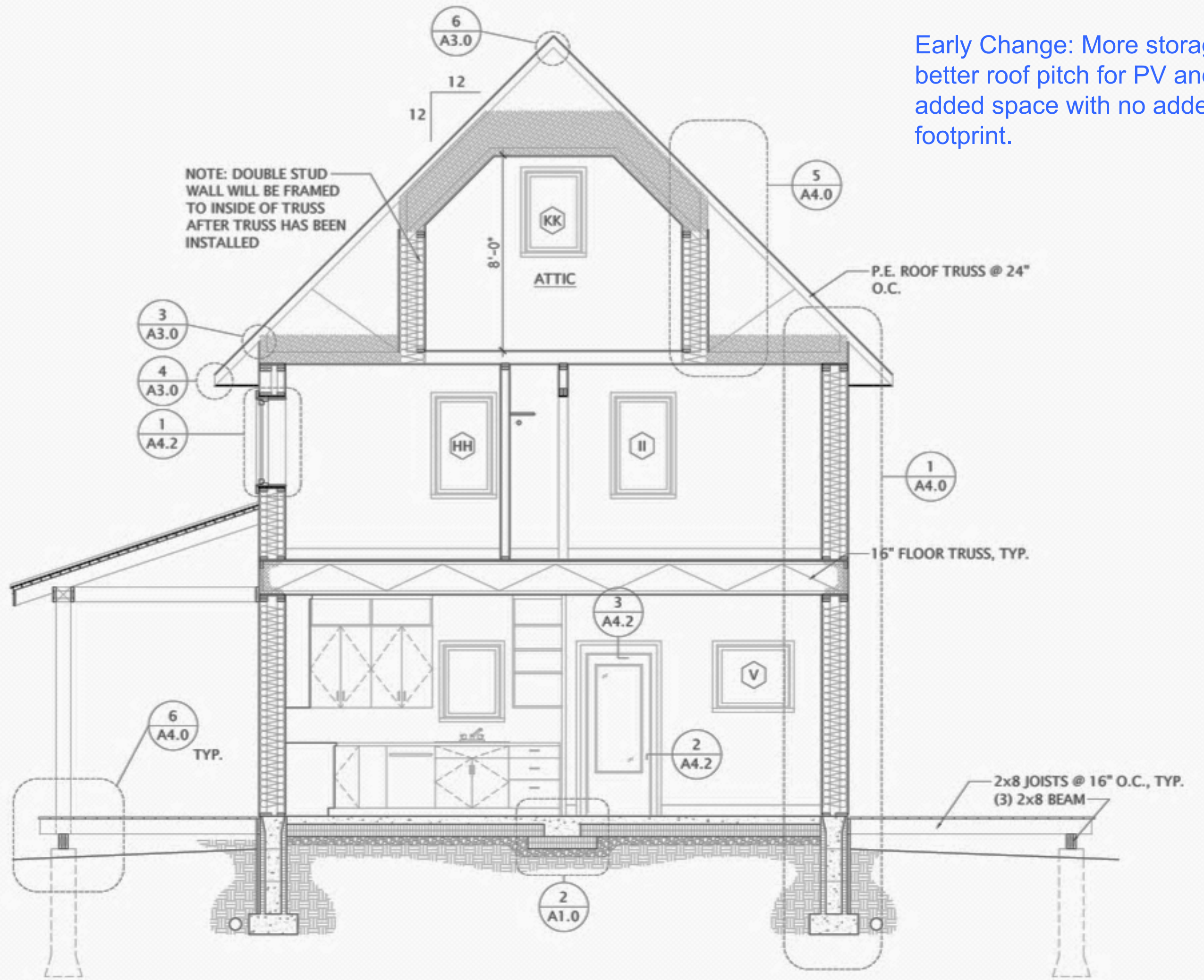



| | Conditioned ft2 | Gross ft2 |
|---|---|---|
| First Floor | 1022 | 1248 |
| Second Floor | 924 | 1056 |
| Attic Floor | 420 | 528 |
| Sunspace | | 118 |

# Design - South Elevation



# Enclosure (Integrated) Design




Early Change: More storage, better roof pitch for PV and added space with no added footprint.

# Defining Low Heating Energy

(Building on work by Energy Analyst Andrew Shapiro)

Peak Design Heating Loads:

| | |
|---|---|
| <u>Energy Efficient Home</u> | 30,000 – 50,000 Btu/hr |
| | 15 - 20 Btu/hr/ft2 |
| <u>Micro Load Home</u> | 20,000 – 30,000 Btu/hr |
| | 10 - 15 Btu/hr/ft2 |
| <u>Ultra Low Energy Home</u> | 6,000 – 20,000 Btu/hr |
| (Passive House) | 3 – 8  Btu/hr/ft2 |

# Energy Modeling – Finding the Sweet Spot

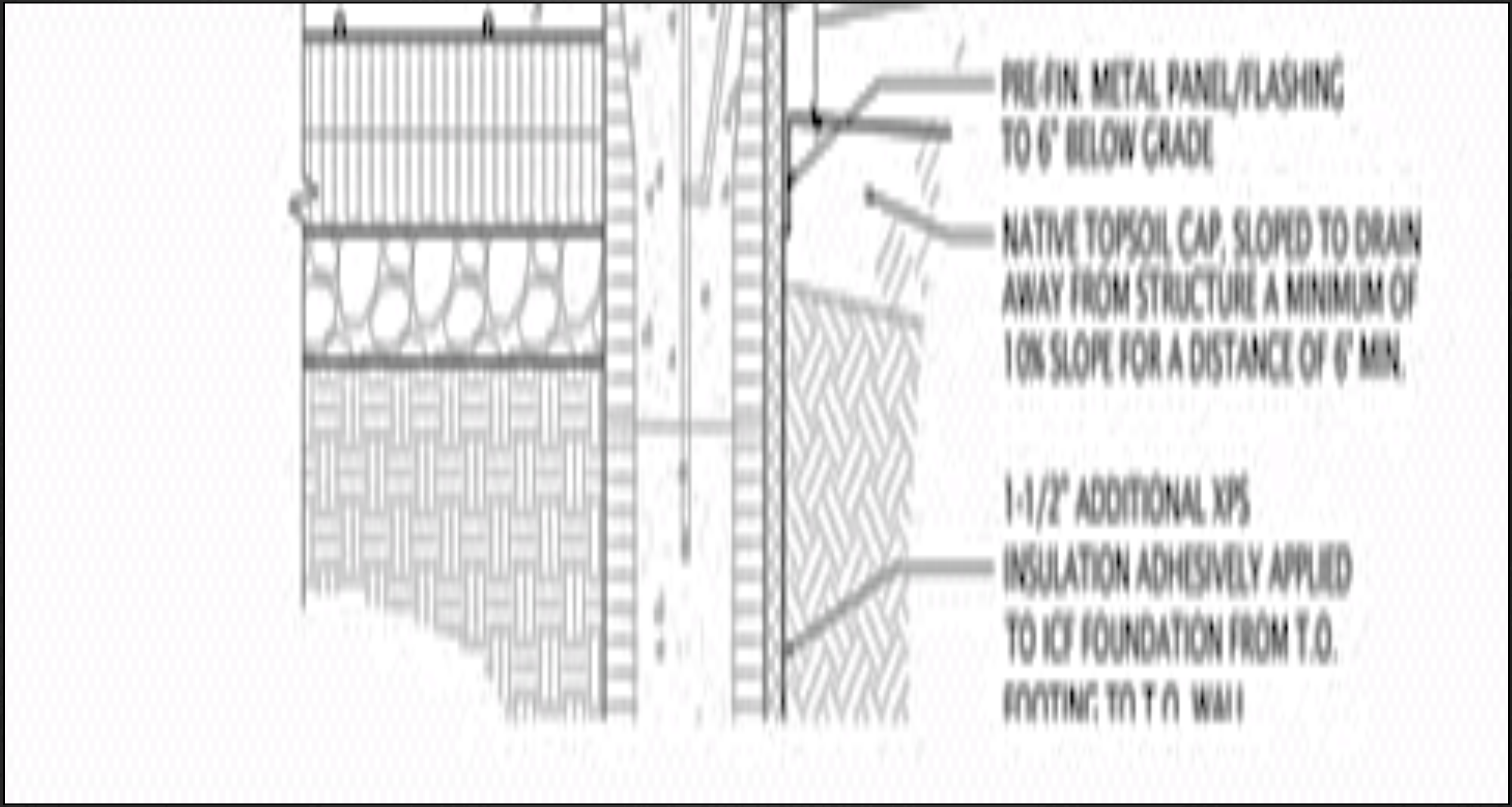
| | Ultra Low/PH | Ecologist House | 2015 Code |
|---|---|---|---|
| Under Slab | 40 | 27 | 10 |
| Above grade walls | 34 cav/19 c.i. | 34 cav/11 c.i. | 21 cav |
| Windows (U) | .18 | .23 | 0.32 |
| Roof | 86 | 70 | 49 |
| ACH50 | .4 | .7 | 3 |
| | | | |
| Peak Heating Load | 13,500 Btu/hr | 17,700 Btu/hr | 33,900 Btu/hr |
| Peak Load/ft2 | 5.7 Btu/hr/ft2 | 7.5 Btu/hr/ft2 | 14.3 Btu/hr/ft2 |
| | | | |
| AHD* | 16.3 MMBtu | 25.6 MMBtu | 66.4 MMBtu |
| AHD/ft2 | 6.9 Kbtu/ft2/yr | 10.8 kBtu/ft2/yr | 28 kBtu/ft2/yr |
| * AHD = Annual Heating Demand | | | |

Note: Loads modeled with REMDesign – multiple models with the same house design, 2366 ft2 conditioned space. Actual design was modeled with and without sunspace. Without sunspace peak load was 19.9 kBtu/hr and AHD was 32.1.

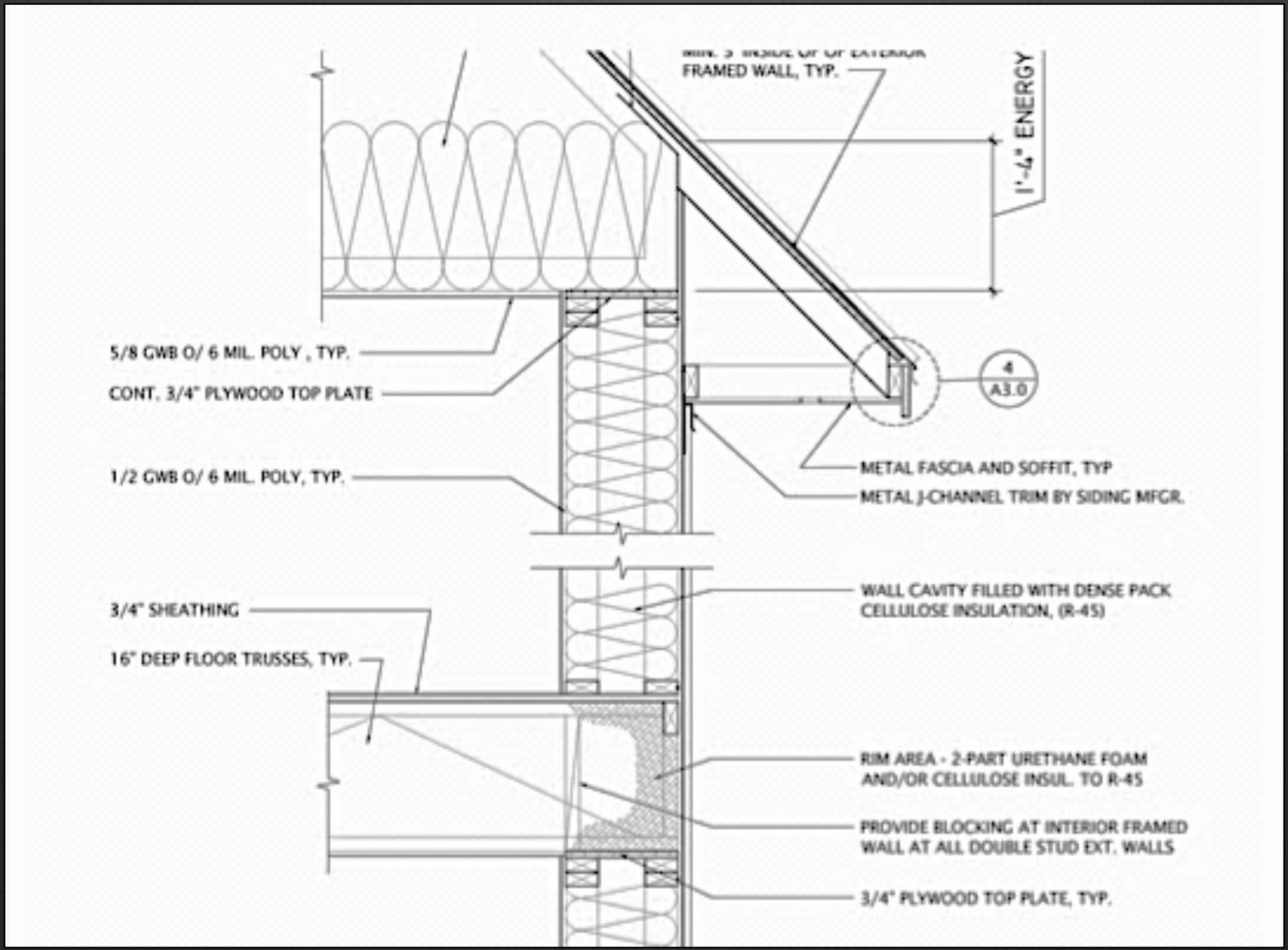
# Enclosure Defined

- Foundation: insulated slab on grade
  - ICF stem wall w/Additional 1.5” XPS (slab edge R-18)
  - 6” high density EPS underslab insulation (R-27)
- House Framed Walls:
  - 12” double stud with dense pack cellulose insulation (R-45)
  - Interior poly air barrier/vapor retarder; exterior plywood sheathing
- Roof: energy heel trusses with blown cellulose insulation (R-70)
- Rim: dense pack cellulose (R-45)
- Sunspace exterior walls: 2 x 6 studs with dense pack cellulose and 1” exterior mineral wool rigid insulation (~R-24)
- Sunspace shared walls: 2 x 6 studs with mineral wool batts and interior foil faced polyiso insulation/vapor barrier (~R-24)
- House windows: wood frames (made in MN) w/triple glazing
- Sunspace windows: triple glazed insulated fiberglass frames

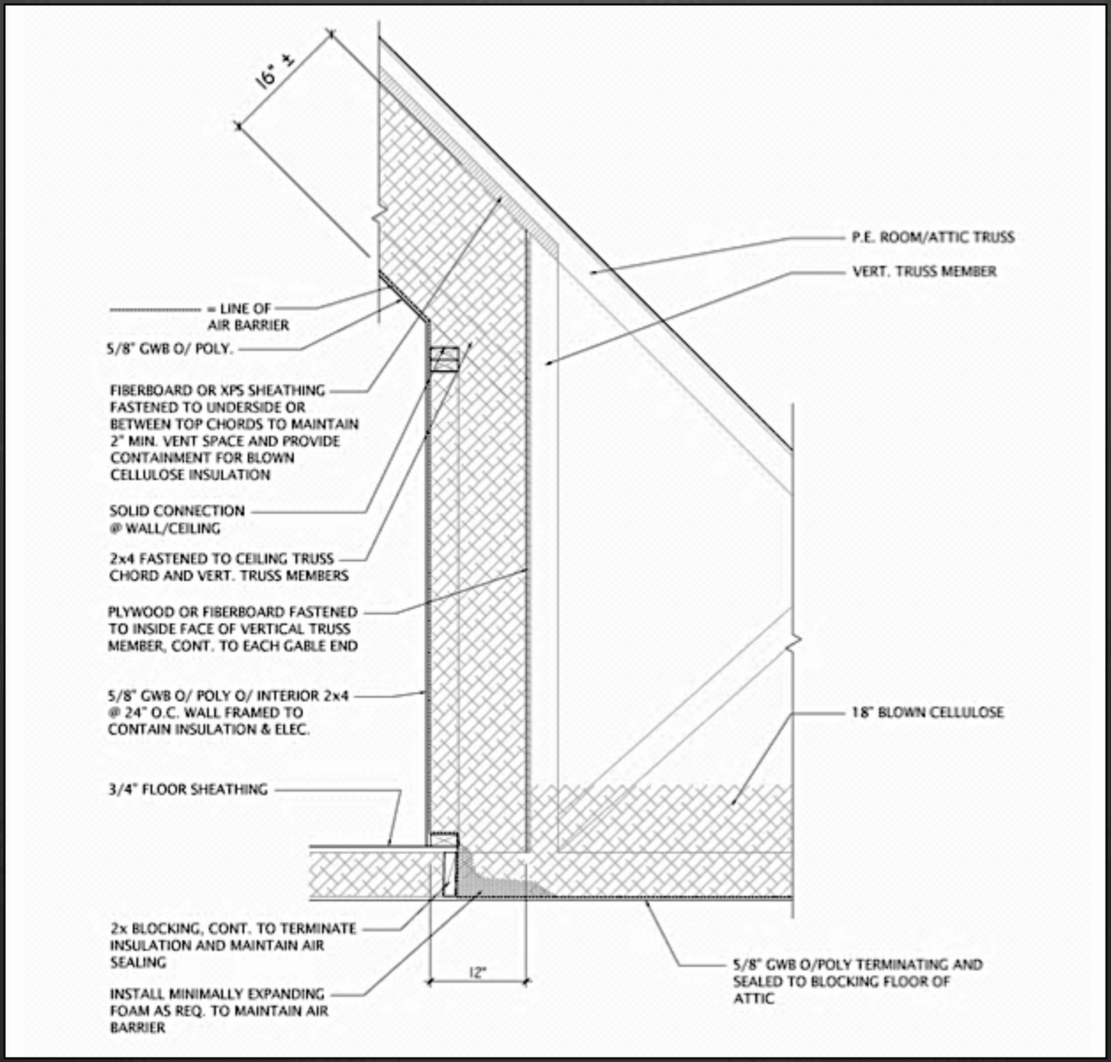
# Wall to Slab


PRE-FIN. METAL PANEL/FLASHING
TO 6" BELOW GRADE
NATIVE TOPSOIL CAP, SLOPED TO DRAIN
AWAY FROM STRUCTURE A MINIMUM OF
10% SLOPE FOR A DISTANCE OF 6' MIN.
1-1/2" ADDITIONAL XPS
INSULATION ADHESIVELY APPLIED
TO ICF FOUNDATION FROM T.O.

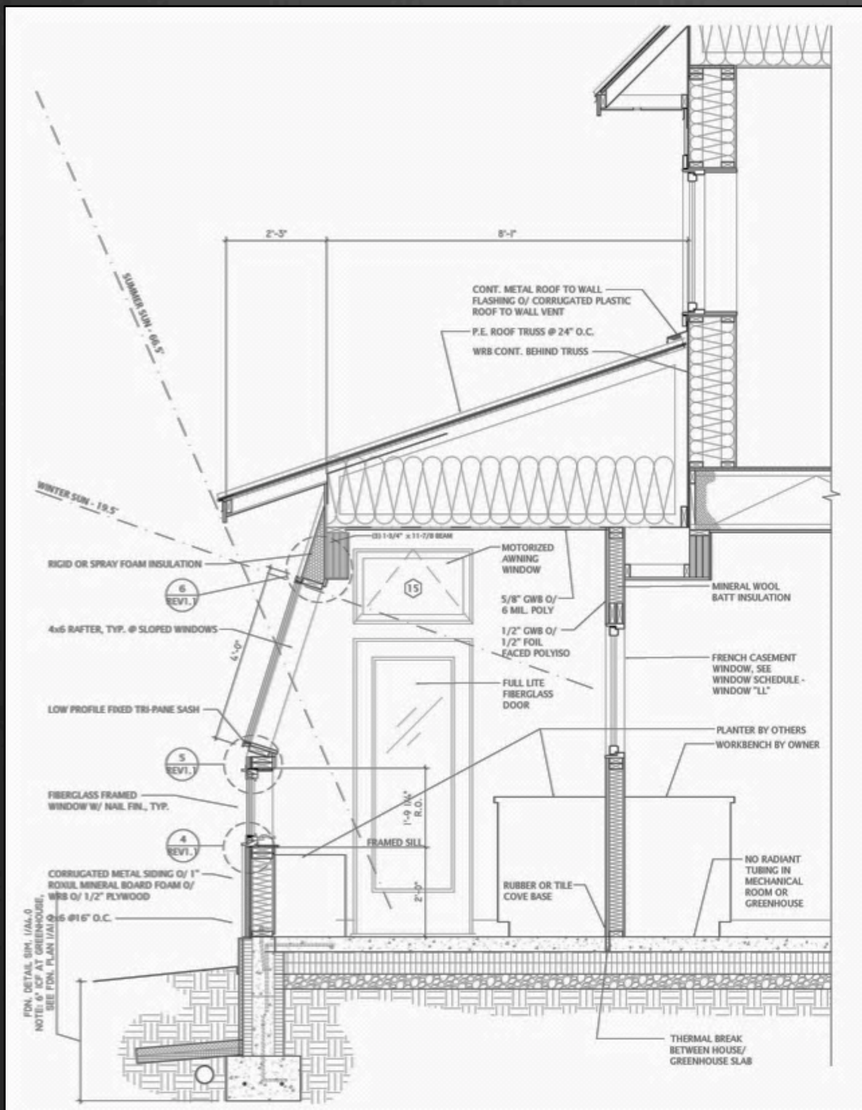
# Roof to Wall and Wall to Floor

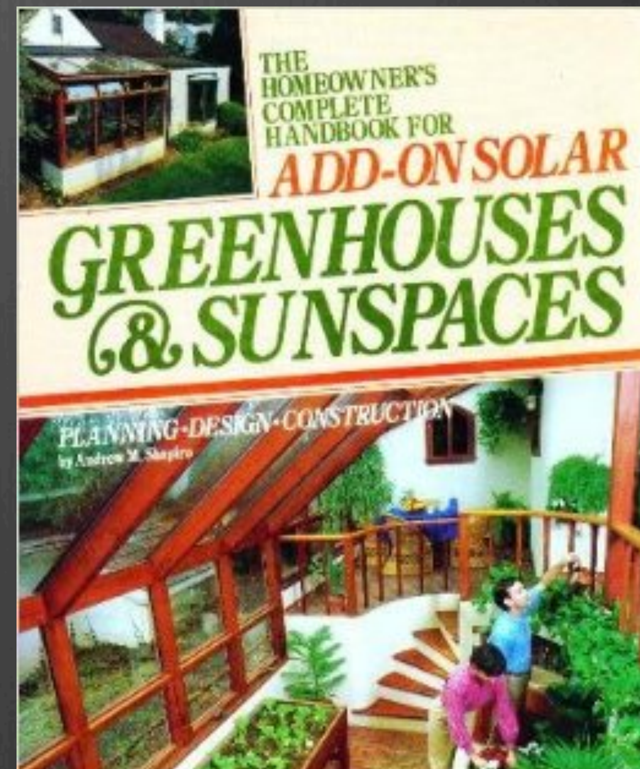


# Special Details at Attic Space



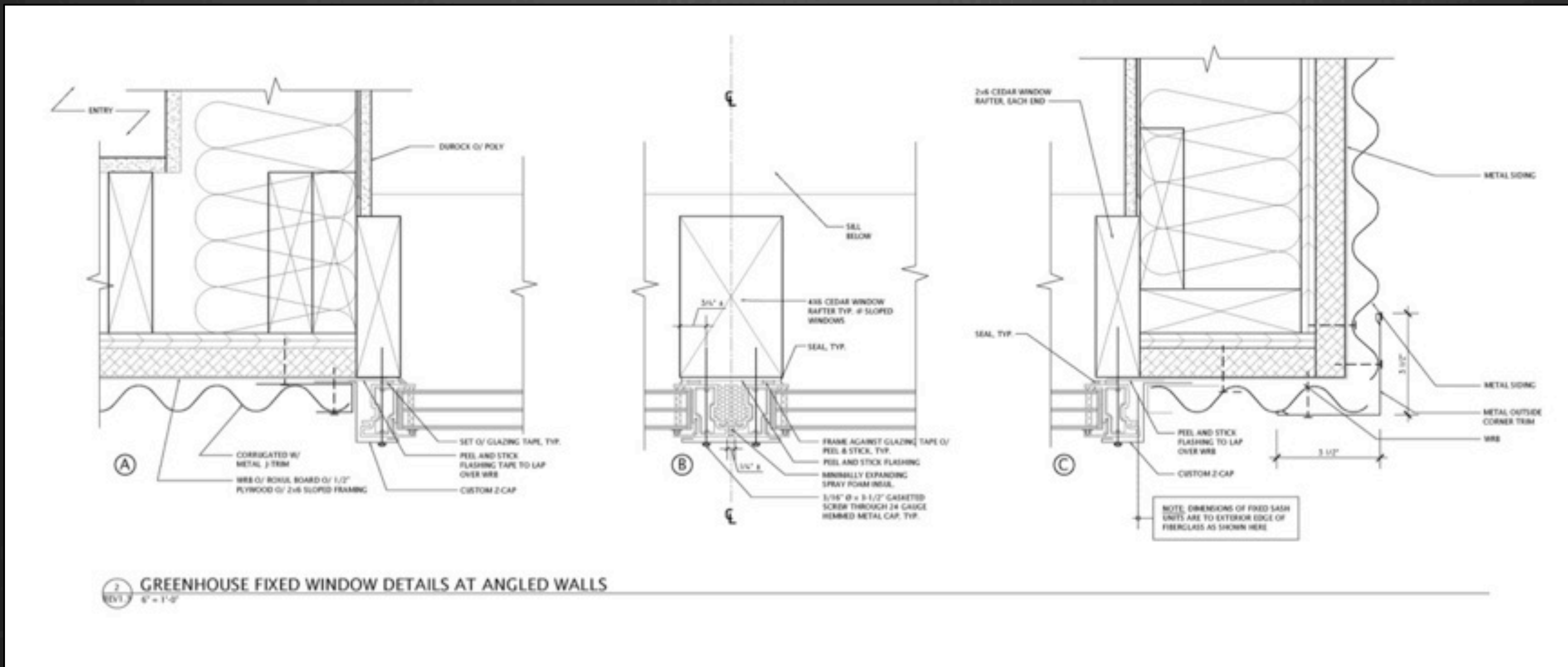
# Greenhouse Design




The Homeowner's Complete Handbook for Add-on Solar Greenhouses & Sunspaces by Andrew Shapiro

# “Home made” glazing details




Detail, discussion and collaboration with builder and others, before and during construction.

# Systems Design

## Goals: reliability, resiliency, and opportunity for ZNE

- Owner decides to go “all electric”, except for wood
- Grid-tied rooftop PV array
- Wood stove in living area
- Desire for in-floor heat
  - Concrete slab floor
  - Living spaces face north
  - Simple system, can be set to “background temp”
  - Some resilience since warmer floor can “coast”
- Does the second story need heat? What about the bath?
- No heat in sunroom, but design passive means for sunroom to heat house and vice versa
  - Also means to keep sunroom from overheating

# Systems Selection

Matching the systems to the Goals and the Enclosure

- 6.6 kW grid-tied rooftop array
- 6 kW fully modulating electric boiler with in-floor heat
- Cold Climate ASHP for second floor space conditioning
- Marathon electric water heater
- Venmar EKO 1.5 HRV w/make-up air divert system design
- EPA-rated wood stove with dedicated combustion air intake
- Energy Star appliances
- 100-160 cfm range exhaust hood

# Construction: mostly "standard high performance"

"Outie" Windows U = 0.23 Cardinal Low-e 180, w/ high VT And SHGC

# Durability and Fire Resistance

# Construction – Mechanicals


# HRV w/make-up air divert

Tight fit? Owner reports it’s fine, but a little more room would be a good thing.

# Sunspace/Greenhouse

- Thermally isolated space with manual and electronic connectivity to the house.
- Built to withstand higher R.H.
- Designed for 3 purposes:
  growing things
  passive solar heating
  provide pleasant space


# Greenhouse Mechanicals

Motorized awning window

Transfer Fan

# Clients provided character

# Field Reports (i.e. Living in the House)

# In general, their goals and program have been met.

# Comfort and Resiliency

"We're used to it now, but I suppose it was a surprise that most of the time we could heat the house for 24 hours with about 4 hours of wood stove use."

# Infrequent Need for upstairs heat

# The Greenhouse is working

“For supplemental heat it's almost perfect. In the shoulder seasons (March, April, October) if there's any sun, we don't need the woodstove at all. For sitting at the small table, it's comfortable most of the year except winter. In winter it's usually in the 40s when cloudy, 50s when sunny. In summer it rarely gets too hot; the windows provide more than enough ventilation.”

# Electrical Energy Use & Production

Stats 12/15-11/16

| | |
|---|---|
| Produced | 7,534 kWh |
| Purchased | 4,807 kWh |
| Sold | 5,754 kWh |
| Consumed | 6,587 kWh (549 kWh/month) |

(Net Positive Energy)

We don't know the breakdown, but can infer from modeling and other actual high performance homes with energy monitors:

| | |
|---|---|
| Hot Water | ~2,000 kWh |
| Lights, Appliances, Pumps, etc | ~3,000 kWh |
| Electric Heat | ~1,587 kWh |

# Heating Energy Analysis

~ 1,587 kWh (5.4 MMBtu) of purchased electricity was used for space heating.

Burned oak, aspen and birch (39 MMBtu) at ~60% efficiency, estimated at 23.4 MMBtu

Estimated heating energy load:

28.8 MMBtu/year or

12.1 kBtu/ft2/year

(11% more than model predicted)

# (Estimated) Annual Total Energy Load

Includes all net site produced energy and firewood (sort of)

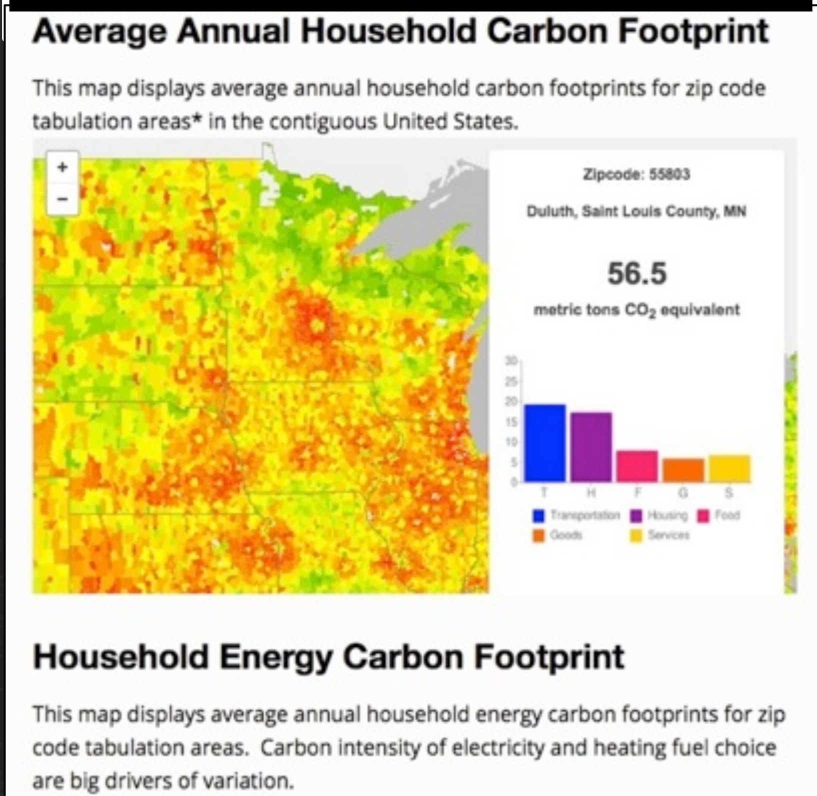
| | kWh | MMBtu |
|---|---|---|
| Electricity Usage | 6,587 | 22.5 |
| Wood | 6,857 | 23.4 |
| Total | 13,444 | 45.9 MMBtu/yr |
| | kWh | kBtu |
| Total per ft2 (/2366) | 5.7 kWh/ft2/yr | 19.4 kBtu/ft2/yr |

# Project Construction Costs

| Item | Cost |
|---|---|
| House | $416,350 |
| Utilities (not including PV) | 27,700 |
| 6.6 kW PV system, designed and installed | 38,060 |
| Federal PV Tax Credit | -11,253 |
| Net PV ($4 per watt) | 26,807 |
| Utility Program House Efficiency Rebate | -2,800 |
| | |
| Total House Construction Cost | $468,057 |
| | |
| Cost Per Square Foot (2950 ft2) | $159/ft2 |
| | |
| House completed summer 2014 (minimal owner sweat equity) | |

# Cost Effectiveness and Impact

House operation is $CO_2$ neutral, perhaps offsetting about 17 metric tons of $CO_2$ every year.




From shrinkthatfootprint.com

Cost to operate the house is affordable and predictable.

In a power outage, they can heat and cook with the wood stove.

A new generation battery could provide critical loads without grid connection.

According to a 2015 LBNL study, homebuyers are “consistently willing” to pay $4/watt of installed PV when purchasing a home that has PV, so this system has already paid for itself.

# Lessons Enclosure

1. Would use a rigid air barrier on exterior framed walls.

2. Would choose different doors for sunspace, with more condensation resistance.

3. Would detail the siding, windows and flashing on the sunspace differently. Details were very fussy.

4. Would adjust glazing design on the sunspace, to allow more light in winter to reach “front” planters.

# Lessons: Mechanicals

1. For this client, who uses their wood stove, the in-floor heat could have been replaced with another mini-split.
2. Would look for additional ways to dehumidify the sunspace/greenhouse.
3. Would look for better/different integrated controls in sunspace/greenhouse.
4. The combustion/make-up air intake for the wood stove is useful and could be better integrated/controlled.
5. Newer non-exhausting appliances might be better for water heating (HPWH) and clothes drying. But the energy consumption is impressive even without these more efficient appliances.

# What Have I Learned?

- ✧ Owner behavior and motivation make a big difference.
- ✧ I still have things to learn about integrating a wood stove into a super-tight house.
- ✧ Using “micro-load” heating load targets for enclosure design can work for zero-net-energy performance.
  - ✧ In this case, the isolated sunspace dropped the house heating profile from micro-load to ultra-low load.
- ✧ Specify an energy monitor for houses like this!!!!
- ✧ ***This is worth doing***, and it isn’t as arduous as I’d imagined.

  So, to up my game, in 2016 I took the NESEA Master’s Course on Zero Net Energy Design.

*Thank you.*

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ARCHITECTURE

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