From Farm House to Eco-House:
Retrofitting and Building New

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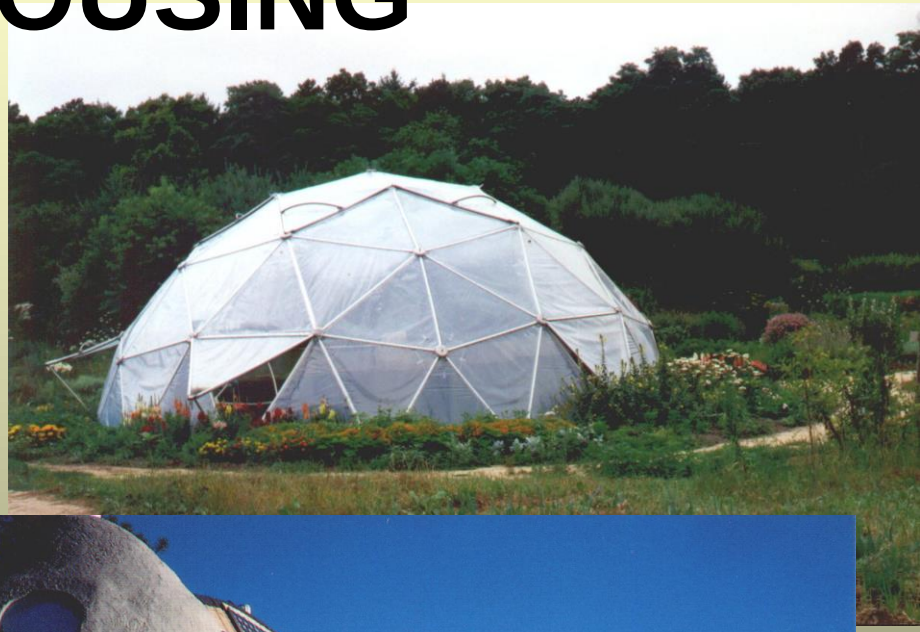
PART 1.
COMPETING CONCEPTS FOR GREEN HOUSING



Maine Co-Housing Prototype

Comparison of Three Low-Energy Housing Concepts

Distinguishing Characteristics	Passive Solar House	Zero Net Energy House	Passive House/ Passivhaus
1. Heat Gain:			
heating source	From sun, but hard to get above 50% of total winter heat load, therefore requiring supplemental heat, e.g., oil, gas, wood, elect.	ditto, plus pv systems w/wo grid to achieve annual net zero	passive solar, and additional heat reduced to absolute min, equivalent to heating with hair dryer supplied through HRV
south-facing orientation	key feature, together with shallow east-west axis	ditto, esp for pv panels on roof	less important but still necessary
south facing windows	Large, requiring shutters to prevent winter heat loss, and shades/awnings/ overhang to prevent summer overheating	less critical, as pv-grid make up shortfalls	less important, windows smaller but high performance (very low u values – German or Canadian)
thermal mass	large windows coupled with thermal mass (floors usually) to store day's heat	ditto, but less critical	not necessary

Comparison of Three Low-Energy Housing Concepts

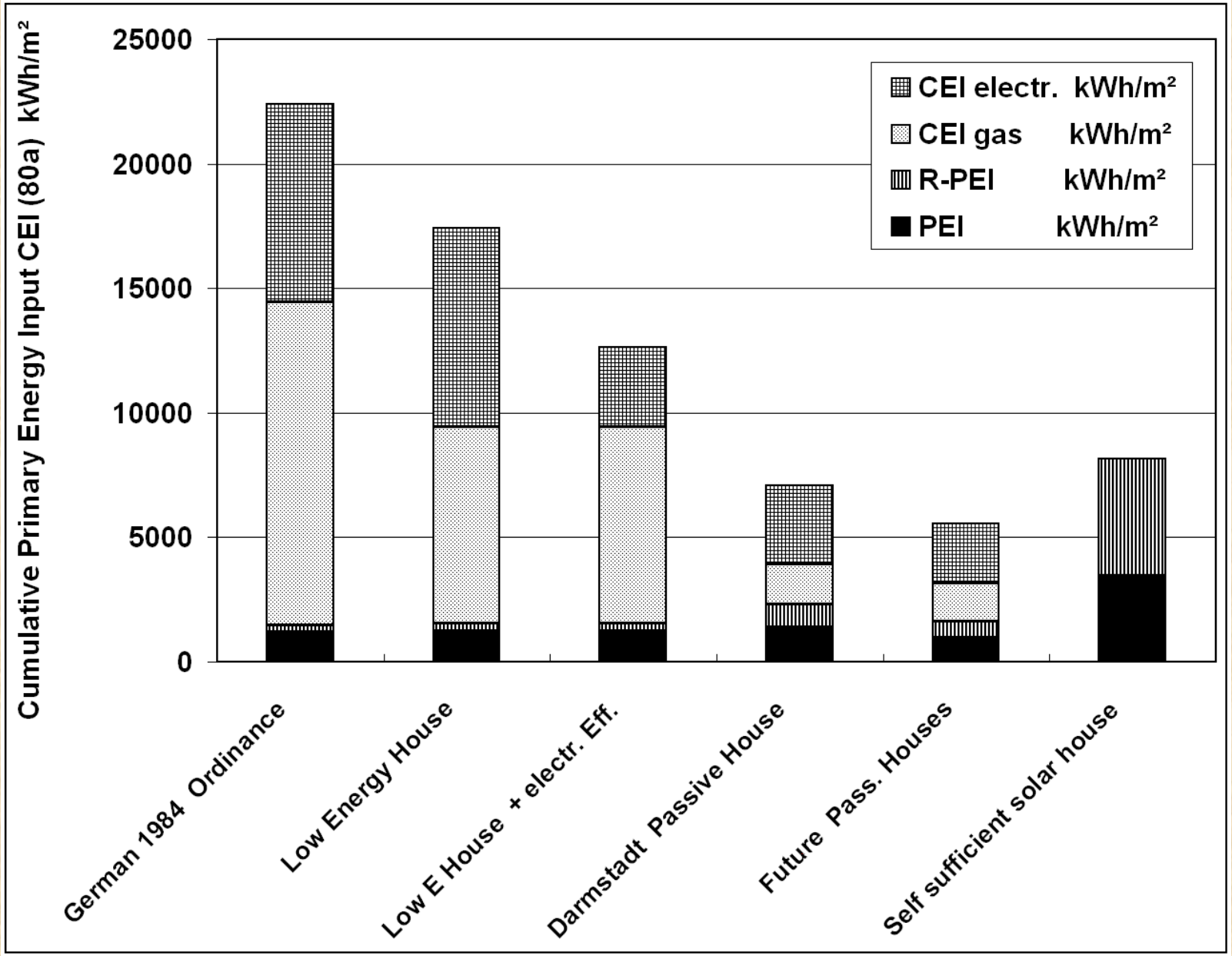
Distinguishing Characteristics	Passive Solar House	Zero Net Energy House	Passive House/ Passivhaus
2. Prevent heat loss			
insulation	modest: R-30 walls, R-40 ceilings	modest: R-30 walls, R-40 ceilings	heavy: R-60 walls and roofs; R-24 foundation perimeter; R-40 to 56 slabs
Air infiltration/ fresh air in winter	air infiltration through bldg envelope as a source of outside air; ventilation through open windows	Ditto	reduce to minimum and rely on air exchangers: heat recovery ventilators in north (HRVs) and energy recovery ventilators in south (ERVs)
cooling	ventilation through open windows, solar chimneys, fans; roof overhang; smaller windows east and west, few and small windows on north	ditto, plus pv systems w/wo grid to achieve net zero; heat pumps	high efficiency air exchangers (HRVs), small heat pump

Comparison of Three Low-Energy Housing Concepts

Distinguishing Characteristics	Passive Solar House	Zero Net Energy House	Passive House/ Passivhaus
3. Energy-efficient			
total energy use	energy-saving appliances using grid electricity (ac)	no real limit. Use as many pv panels as desire, w/wo grid	reduce total requirements to absolute minimum, under 120 kwh/m^2/year
4. Examples:	Kachadorian, Saunders house, Annual Geothermal Storage (AGS), PAHS 1/	Solar Decathlon entries, McGreen mansions	15,000 in Europe, 15 in U.S. 1 in 4 new houses in Austria follow PH standards.

1/ Examples of good U.S. passive solar design concepts: James Kachadorian's solar slab (The Passive Solar House: Using Solar Design to Heat and Cool Your Home, Chelsea Green. White River Junction, VT, 1997); the Saunders house, from William Shurcliff's book (Super Solar Houses: Saunders's 100% Solar, Low-Cost Designs. Brick House Publishing Co. 34 Essex St, Andover, MA 01810); Annual Geothermal Storage (AGS) at http://greenershelter.org/; and Passive Annual Heat Storage (PAHS) at http://earthshelters.com/ .

Life-Cycle Energy Analysis: Comparison of Low Energy House,Passive House, Self-Sufficient House (1997 article)



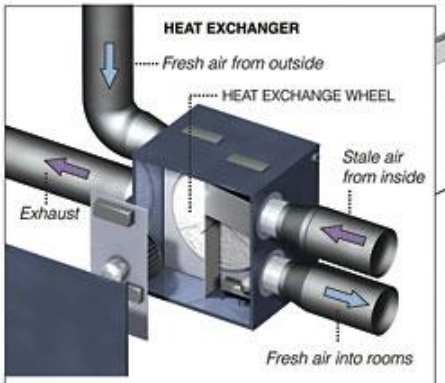
Passive House Features and Standards

Key Features	Realized through	Threshold standards
1. Low space heating & cooling requirements	* high insulation, • reduced thermal bridges, * air tightness (low infiltration), and * excellent windows * passive solar design	* R-50 walls, R-60 ceilings * annual heat & cooling energy loads each ≤ 15 kWh/m2/year (4.75 kBtu/sf/yr) or 2,091 kWh/yr for a 1,500 sq.ft. house ($209/yr) 1/ *Double for retrofits.* * airtight building shell ≤ 0.6 ACH @ 50 pascal pressure, measured by blower-door test. *1.5 ACH50 for retrofits.* * windows with a max u value of 0.14 (R-7+ or higher)
2. Mechanical Ventilation	* Heat Recovery Ventilators (HRVs) for cold north or * Energy Recovery Ventilators (ERVs) for humid south	* 0.3-0.6 ACH as far as I could determine * device efficiency ≥ 75%
3. Energy efficiency	* high efficiency appliances to reduce total electricity use	* (2/) total <u>primary</u> energy loads ≤ 120 kWh/m2/year (38.1 kBtu/sf/yr) or 16,729 kWh/yr for a 1,500 sq.ft. house * allowed plug load = 5,576 kWh/yr 3/

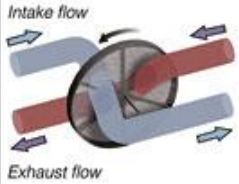
Schematic of a Passive House

At the Heart, A Heat Exchanger

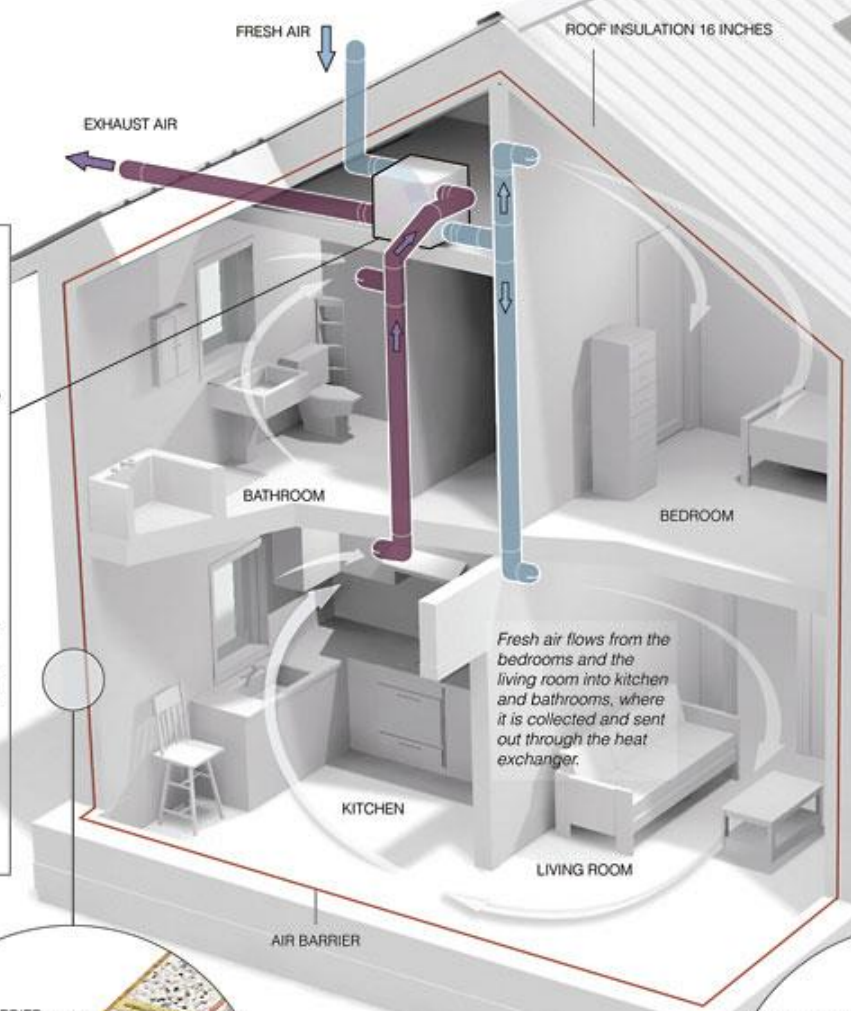
The most important element in keeping a passive house warm is the heat exchanger, which uses heat from inside air to warm fresh air from outside. Stale air is constantly being replaced with fresh air; about one-third of the house's air is replaced every hour.



INSIDE THE HEAT EXCHANGER

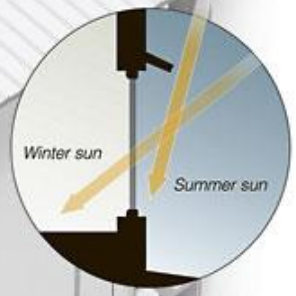


The heat exchanger contains a slowly rotating wheel made of a porous material. As outgoing air passes through it, heat and moisture are transferred to the incoming air, which also passes through it.



Warming The Water, Too

Many passive houses have simple solar panels on the roof or side to heat water.



Minding the Sun

By orienting the house properly and incorporating overhangs into the design, the winter sun helps warm the house and the hot summer sun stays out, keeping it cooler.

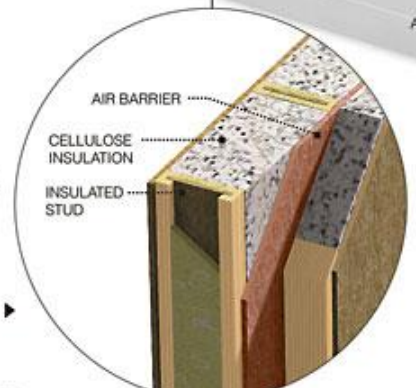
Floor

A concrete slab rests on a six-inch layer of polystyrene insulation that also wraps around the slab's edges, where the floor meets the walls.

Keeping the Heat In

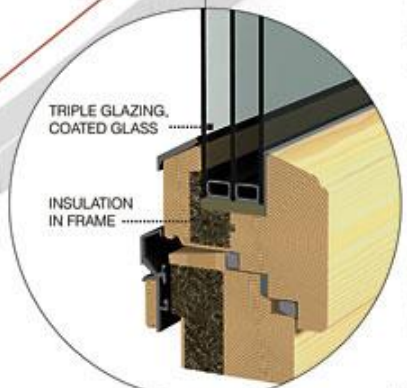
Exterior walls are two or three times thicker than those in a conventional house and are well insulated, with the amount of insulation varying by climate. A double-wall system is used, with a continuous air barrier between the two walls. Walls and studs are designed to minimize heat conductance.

PASSIVE HOUSE WALL, 12-INCH TOTAL INSULATION ▶



For comparison: a conventional house wall

6-INCH INSULATION

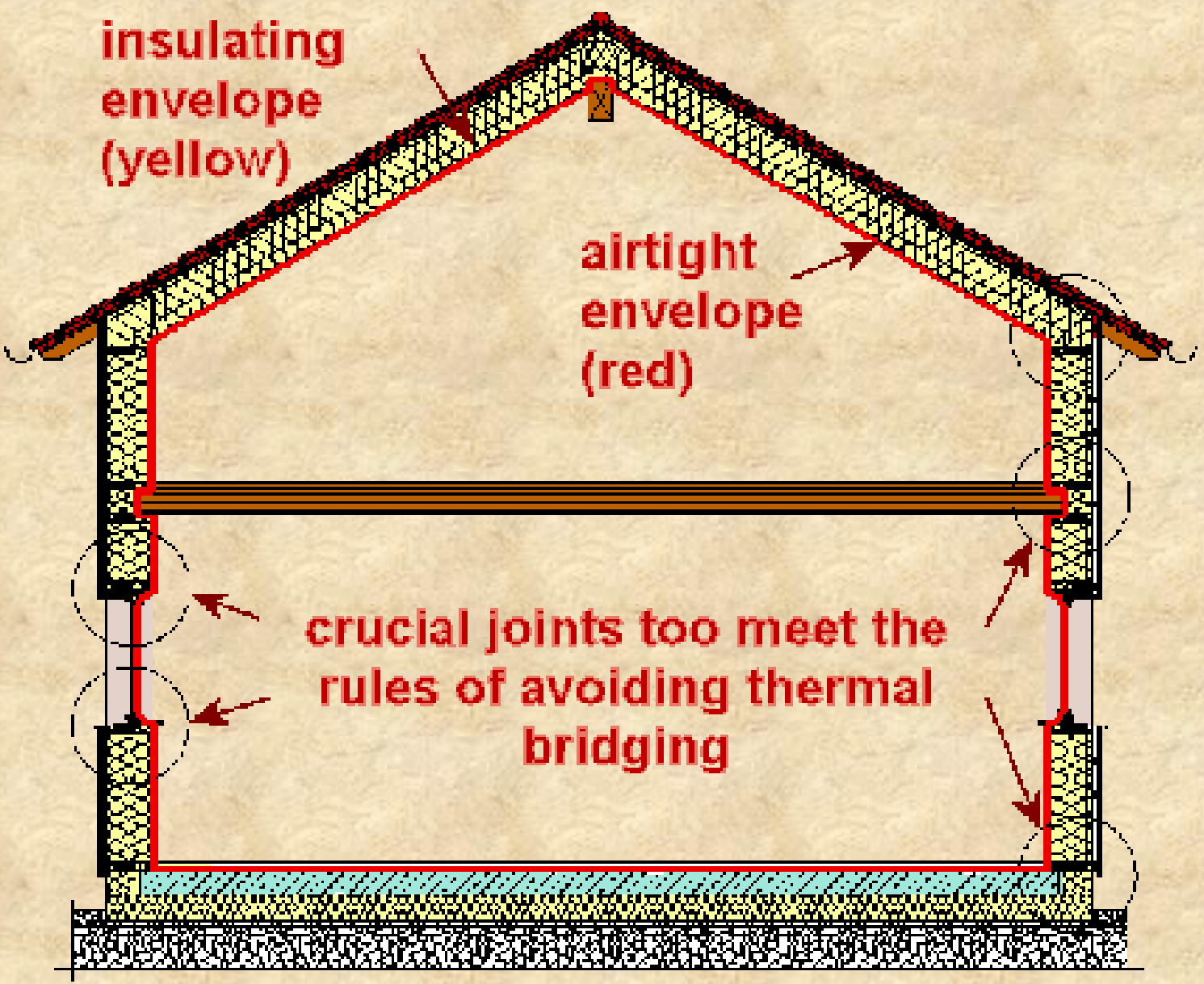


Windows

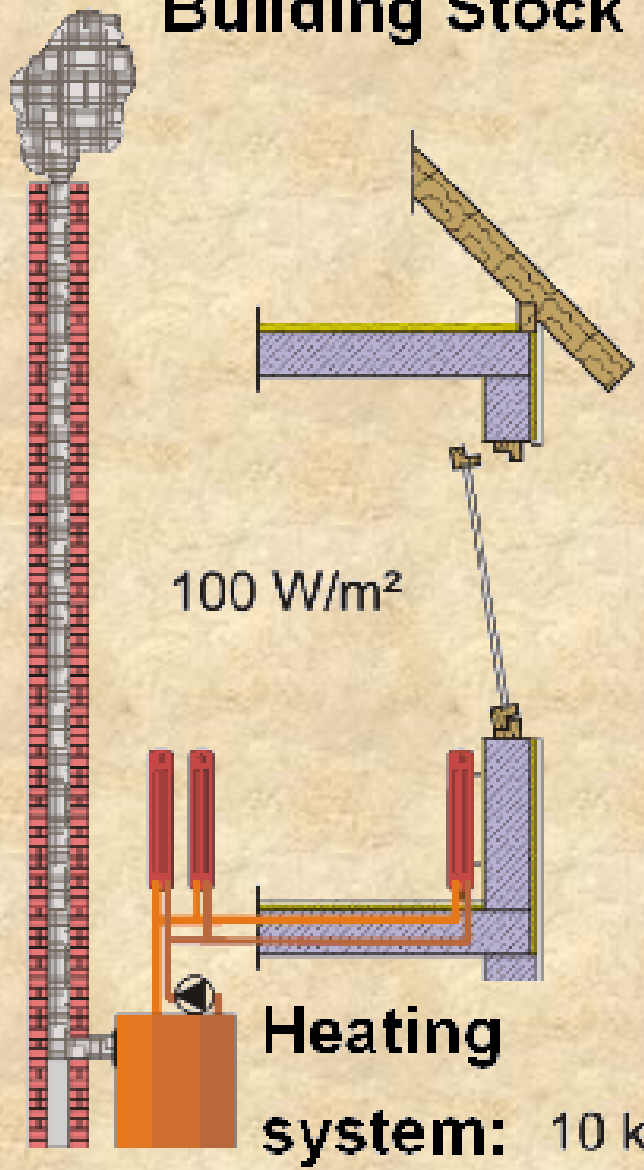
Casement windows are usually used because they close tighter than other types. Coated glass helps reflect heat back inside the house in winter and keeps some heat out in summer.

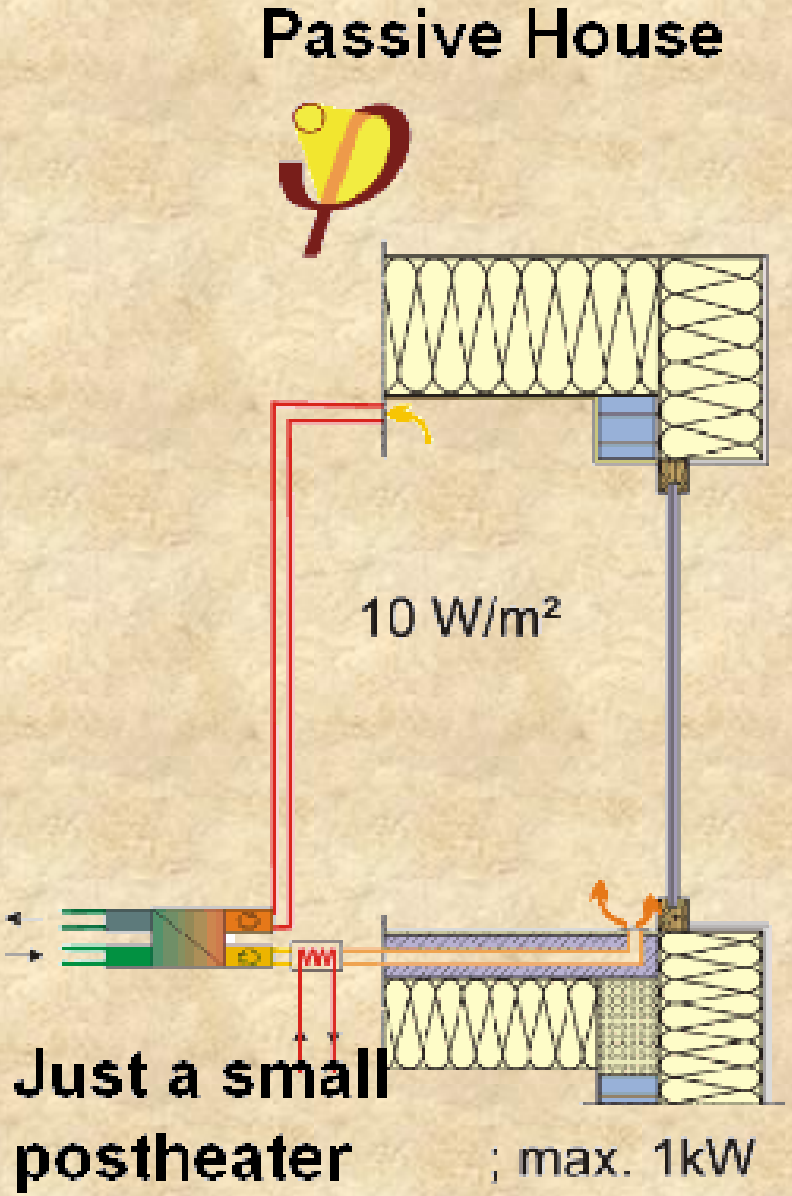
PART 2.
PASSIVE HOUSE DESIGN IN NEW CONSTRUCTION

Idealized Building Envelope for a Passive House

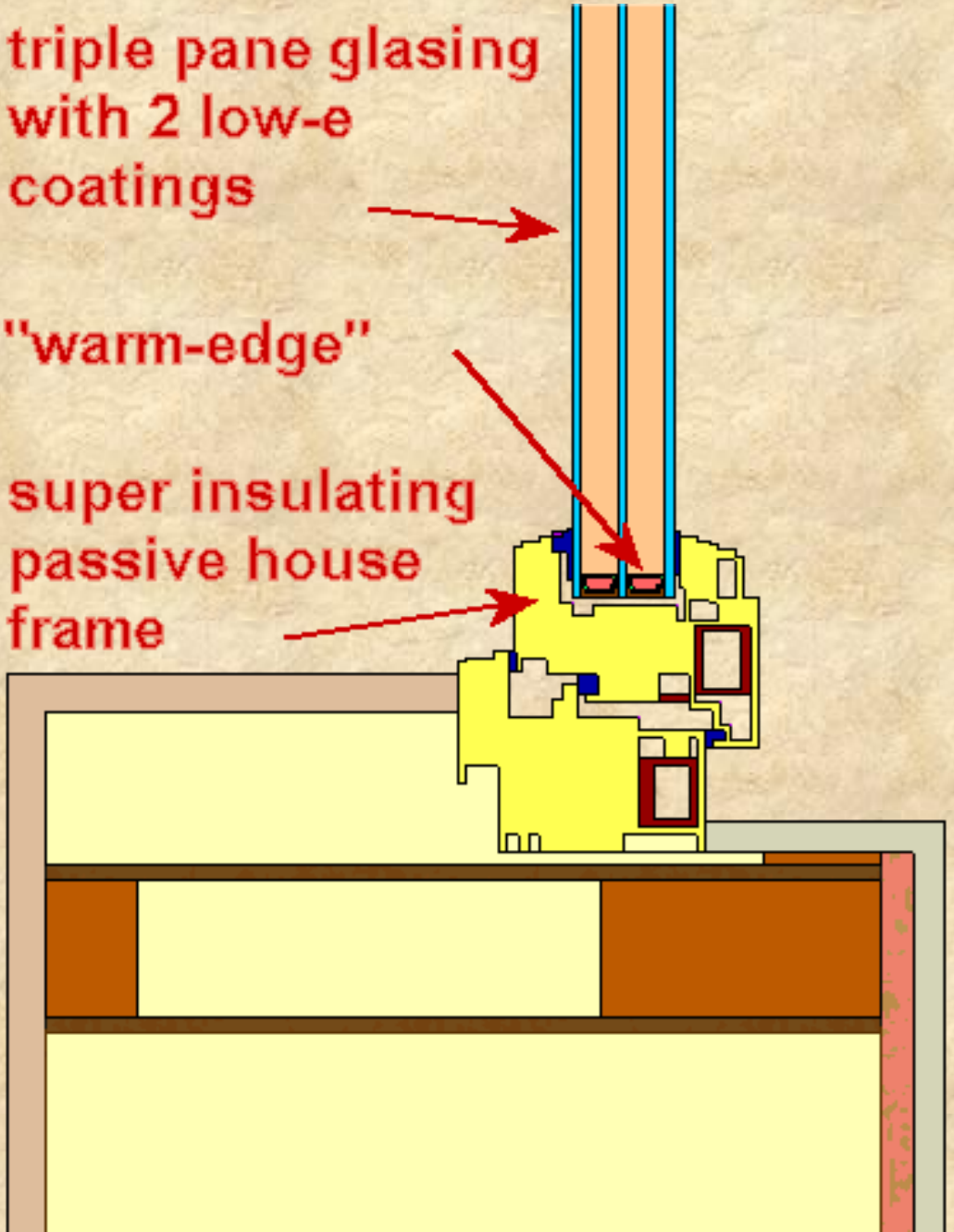


Standard vs. Passive Heating Requirements

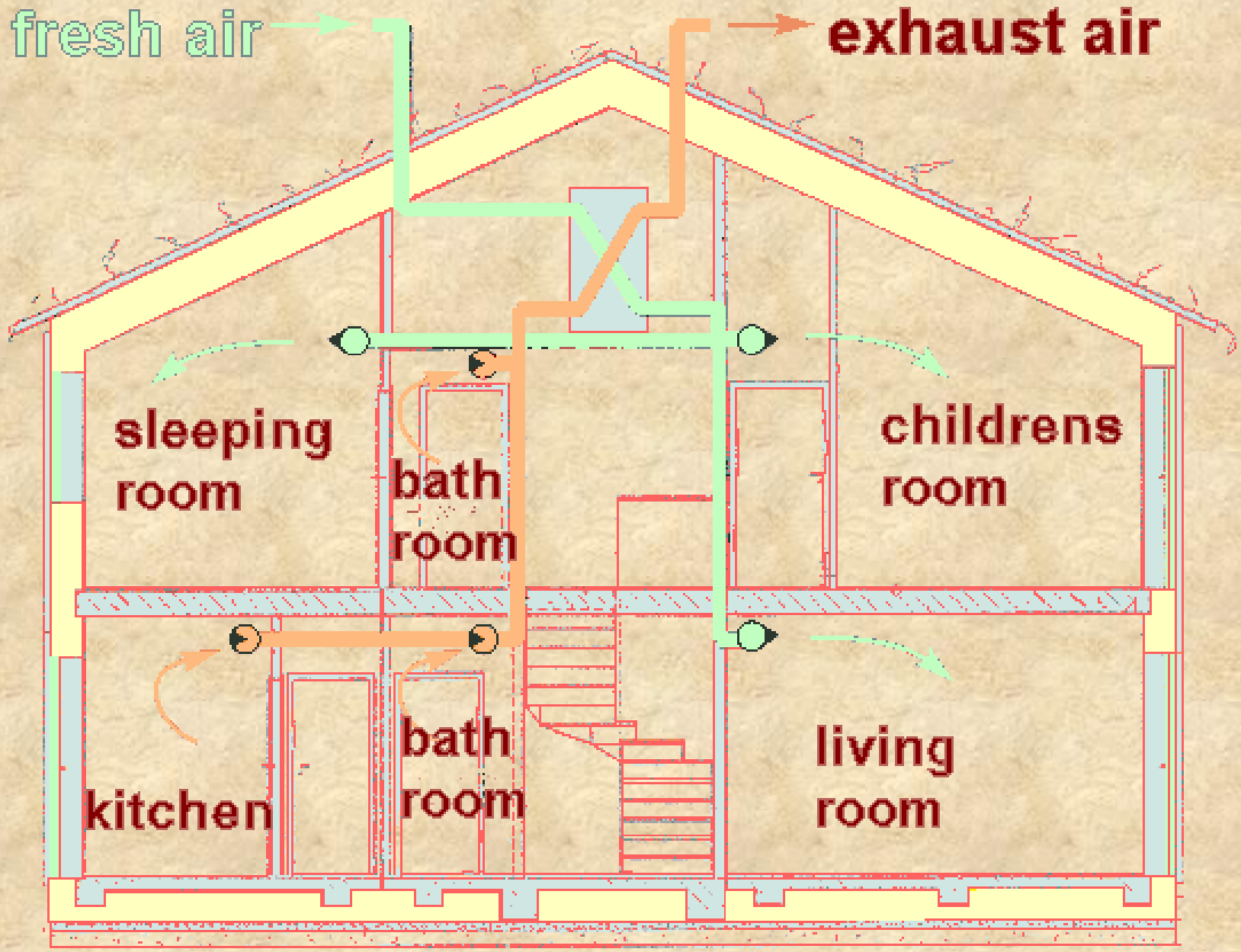




Schematic of High Performance Window



Ventilating a Passive House



PART 3: PROPOSED DESIGN FOR A PASSIVE HOUSE ON OUR LOT IN LEMONT, PA

0.28 acres

Original inspiration for Eco-House: Three Sisters Bioshelter

Bioshelter: thermal mass is key

- Concrete water-filled tank w snorkel stove
- Gravel/soil beds to south
- Compost bins and barrels of water to north
- BTUs of body heat (chickens)
- Well-insulated north exterior wall

= 50°F+ in winter + moisture can obstruct view, overheats in summer

“The Passive House should be the baseline, before you start adding renewables.”

–Katrin Klingenberg, co-founder,
Passive House Institute US

Eco-House Goals

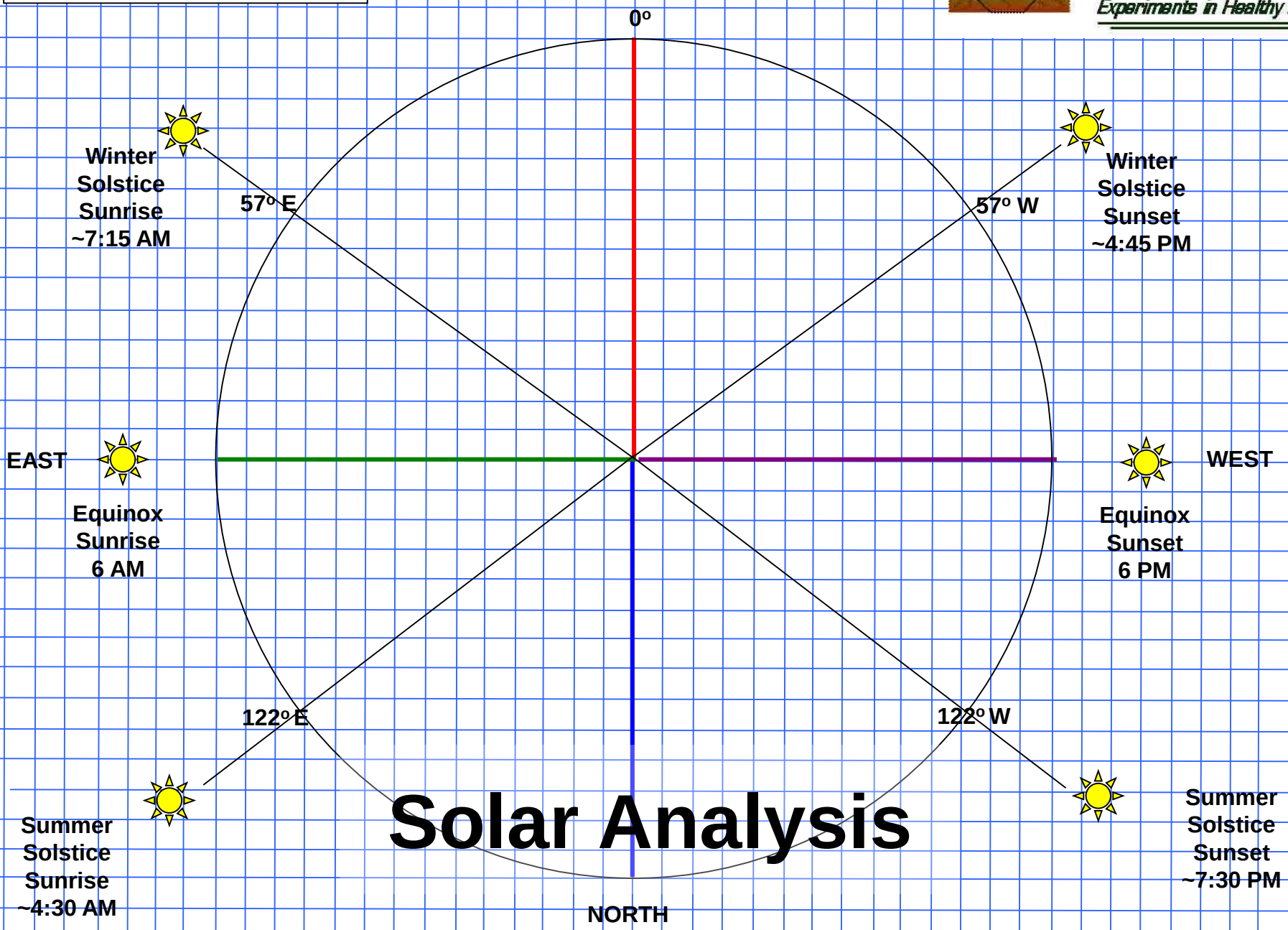
- Test/Assess "green" technologies:
  - Living technologies: using plants to clean air and water (e.g., attached bioshelter with constructed wetlands)
    - **graywater treatment with constructed wetlands**
    - **"Living" shower**
    - **vegetated "green" roof**
    - **"breathing wall" to clean air**
    - **dry composting toilets**
  - Passive House + Passive solar greenhouse
  - Eco food preservation, storage: root cellar, solar food dehydrator, solar oven
  - Solar hot water heating
  - Use of DC electricity from photovoltaic (PV), including most appliances
- House interns/visitors
- Improve on or scrap as data dictates! Learn from it…

“There’s nothing fundamentally green about a house, I’m sorry to say. We want it to be warm when it’s cool outside, cool when its warm outside.”

–Paul Eldrenkamp, owner, Byggmesiter, a residental remodeling company

Annual Solar Map for 40º North Latitude, Eastern Standard Time

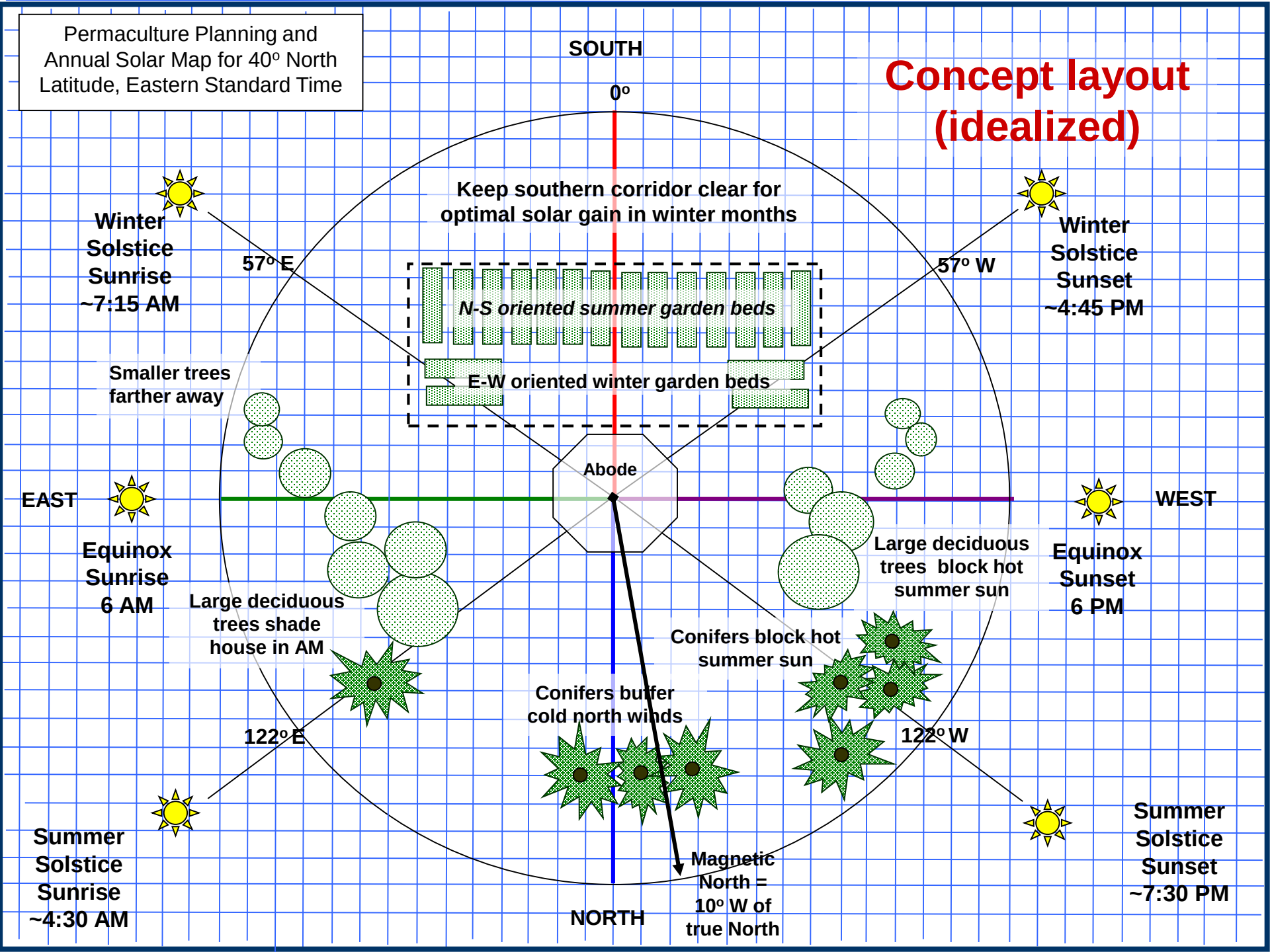
Neo–Terra
Experiments in Healthy Living



Solar Analysis

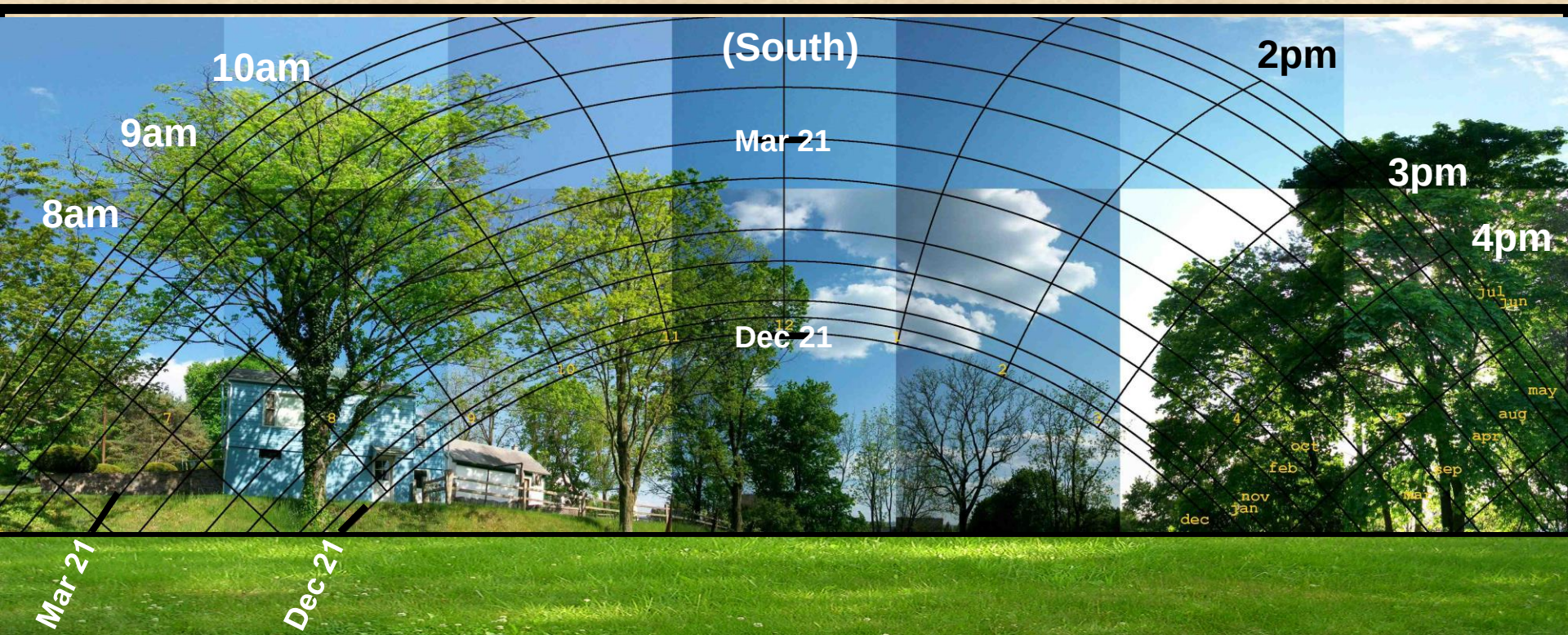
Permaculture Planning and Annual Solar Map for 40º North Latitude, Eastern Standard Time

Concept layout (idealized)



Panorama with Wiley Solar Asset

8PM, 13 May: Solar Access



How much <u>sky</u> does your site see?

How much sun can reach your house, garden?

RESULTS from Wiley Solar Asset

Month	light shaded (%)	sunlight/day (hours)	available sunlight (hours)		potential energy (kW-hr/kW)	available energy (kW-hr/kW)
January	34.9	3.12	2.03		78	51
February	33	3.64	2.44		81	55
March	33.3	4.49	3		106	72
April	27.9	4.53	3.27		99	73
May	30	5.02	3.52		109	79
June	27	5.14	3.75		106	80
July	29.1	5.24	3.71		110	81
August	30.2	5.1	3.56		108	77
September	28.3	4.57	3.28		98	71
October	33.4	3.79	2.53		85	57
November	31.6	2.61	1.78		58	40
December	35.8	2.39	1.53		57	36
average	31.2	4.14	2.87	total	1095	773

Shading factor reference:
1.00 = total sun

shading factor
0.69

Site shading factor > 0.90
for most solar tax credits

OR *How much SHADE do you see on the ground?*

View to South: 5pm shade on Sept 25th

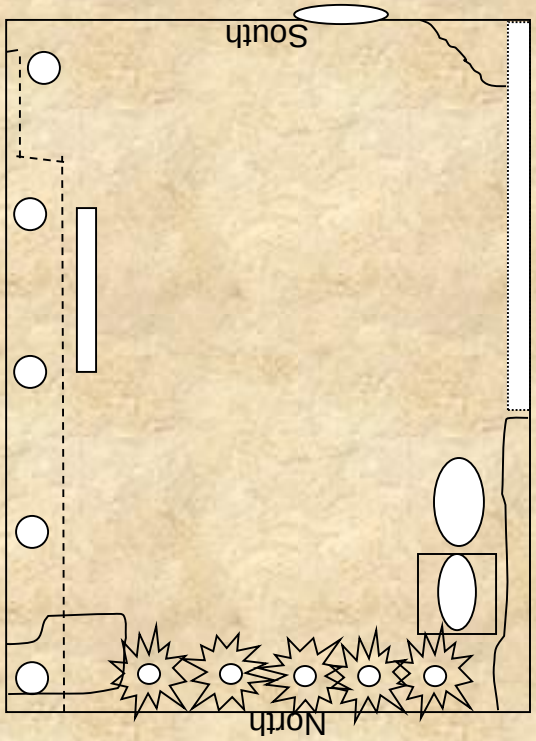
Maples →

Black Walnut

Trees+ shrubs

25 September

We recorded shade patterns on a base map →



“House” sees ~3 hrs of full sun

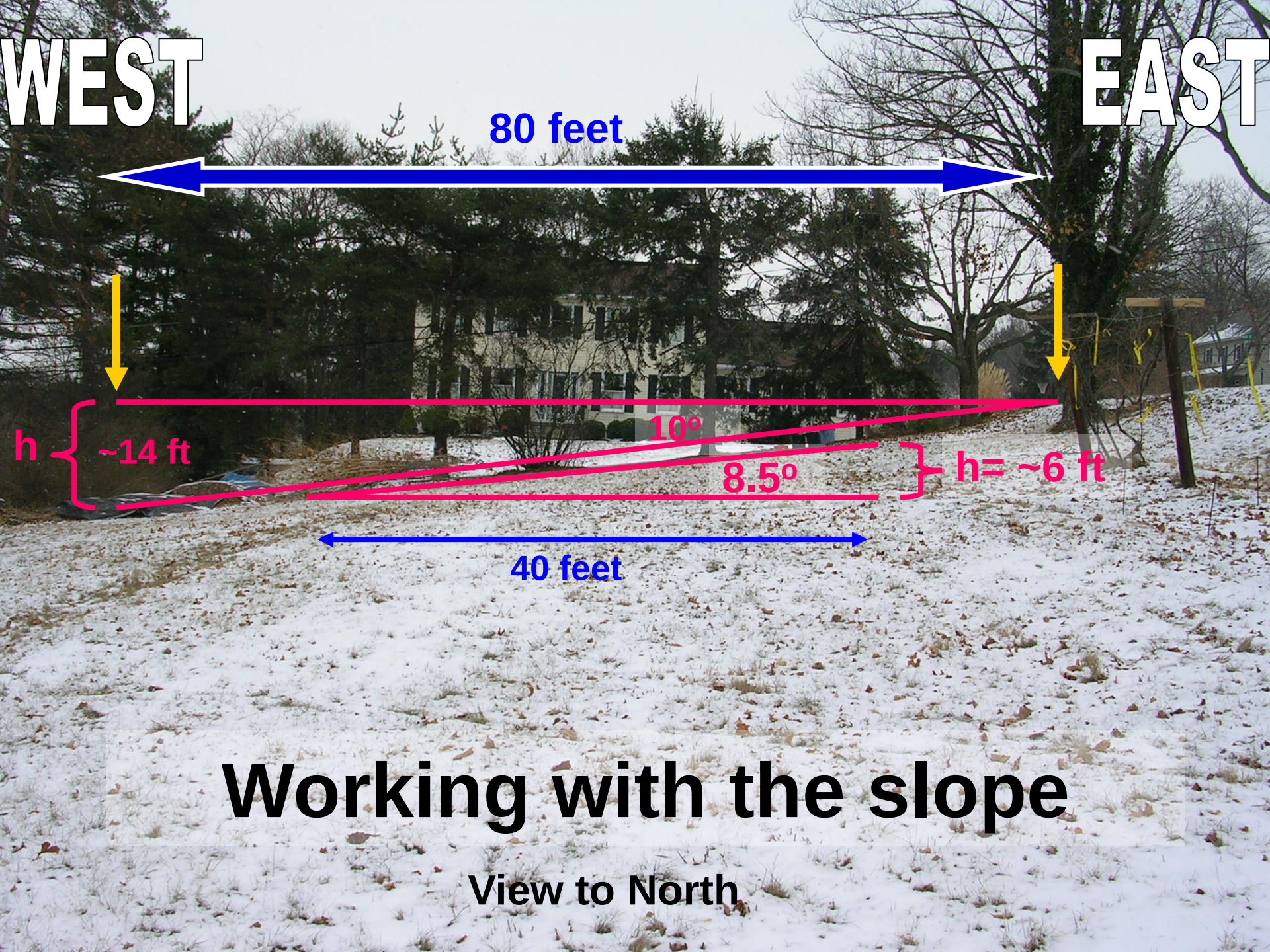
Shade Factors: Even in Winter

9 AM

vs

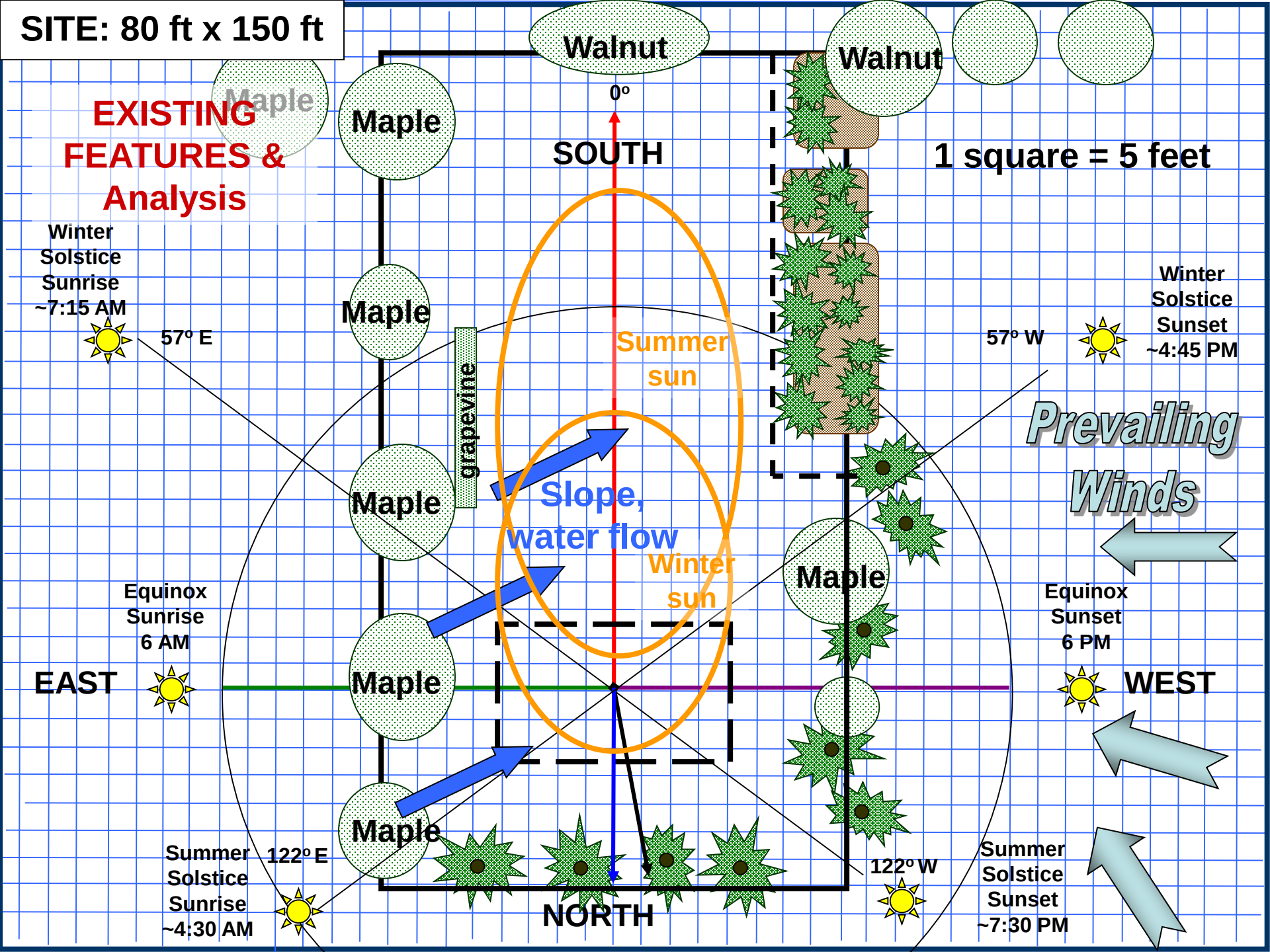
1 PM

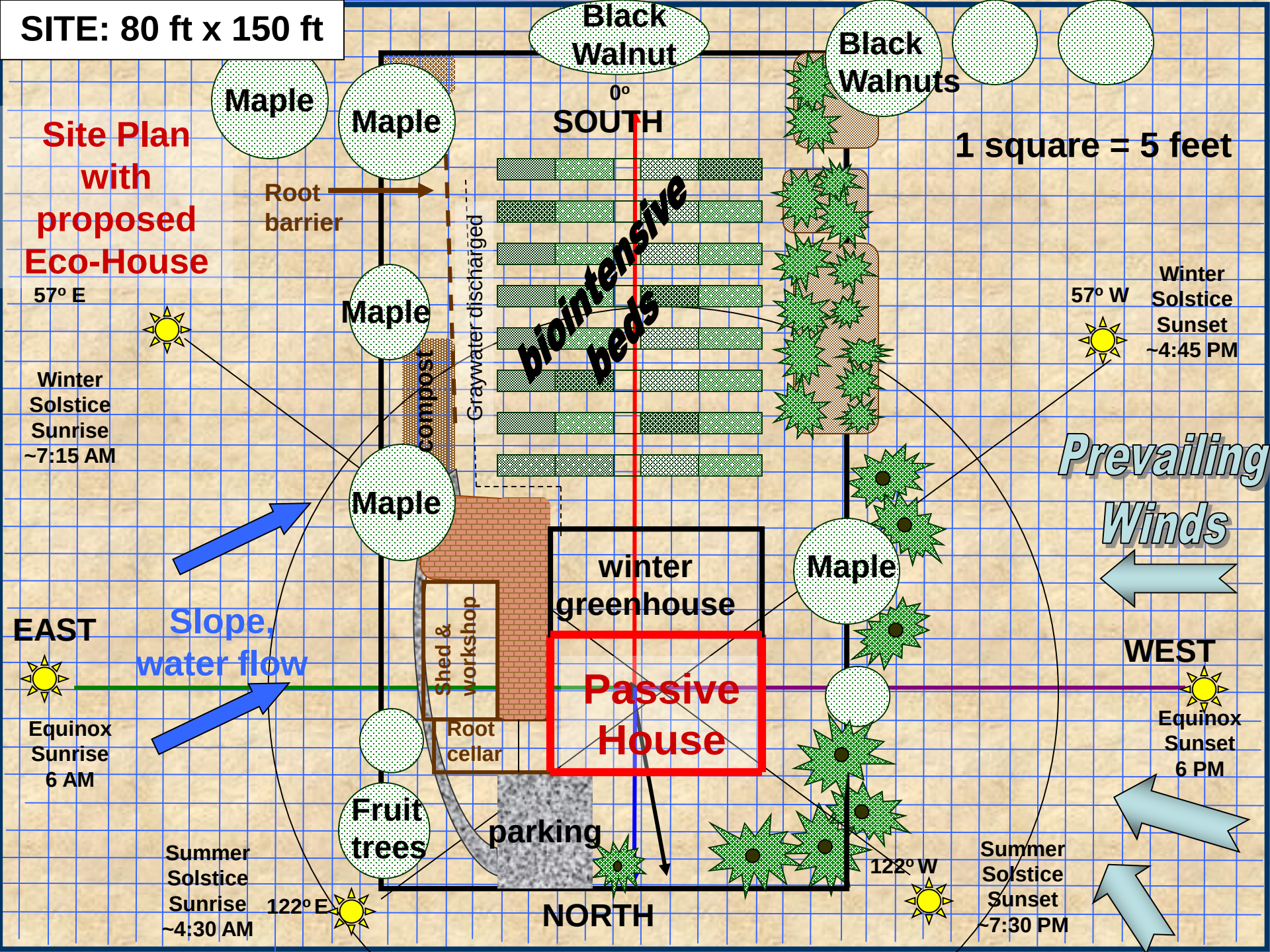
Photos: 20 January 2008

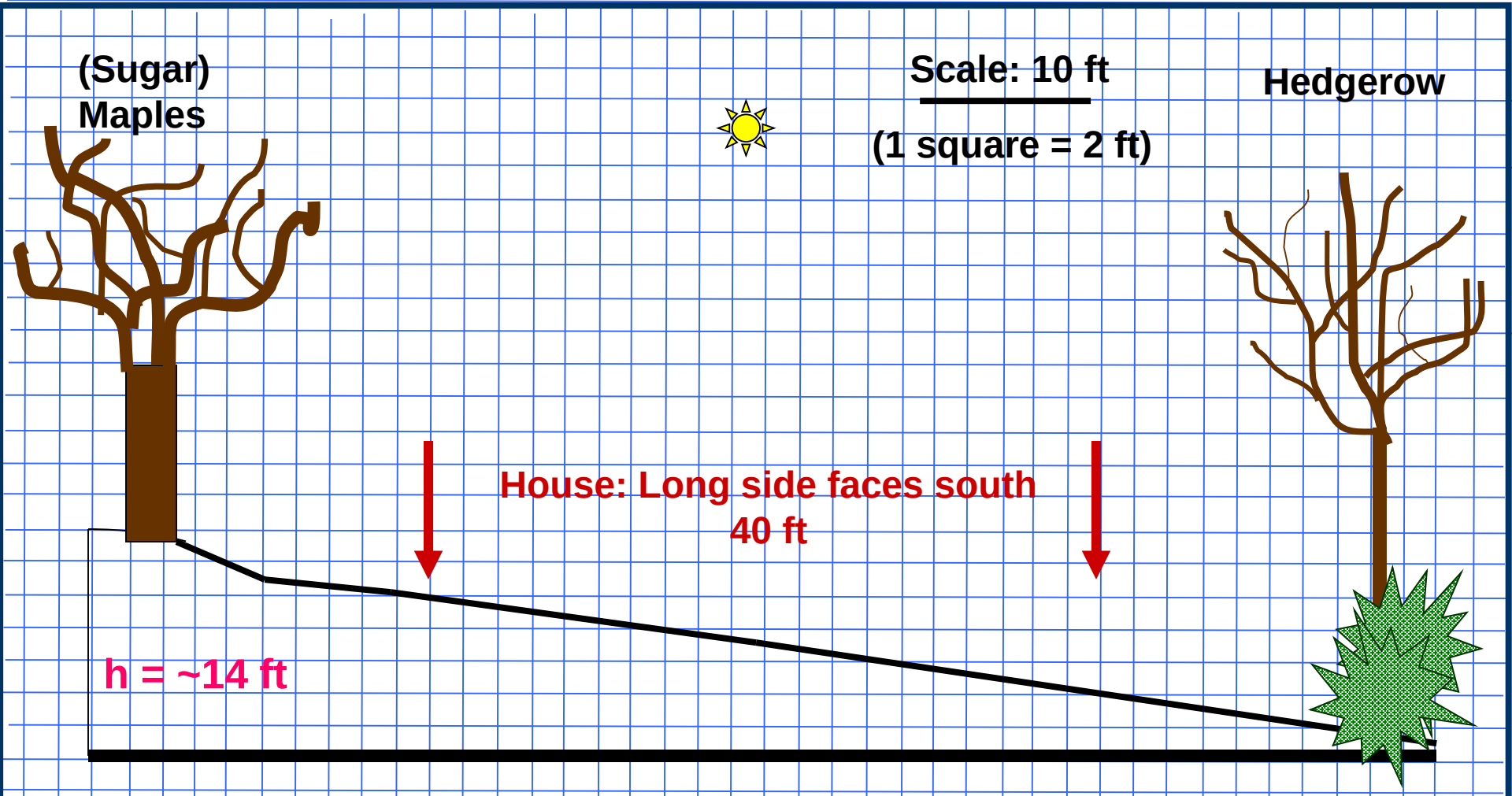


Working with the slope

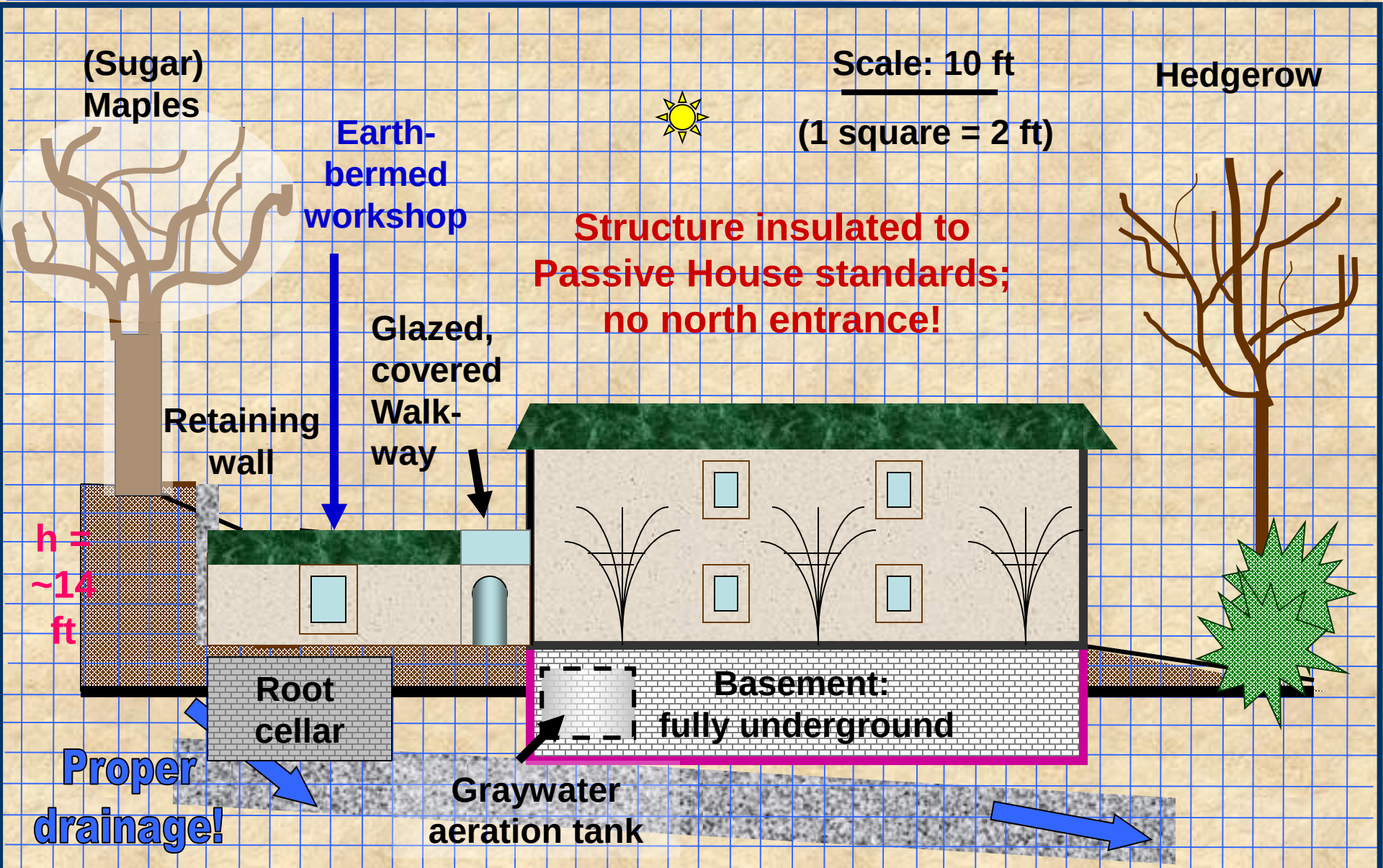
View to North


SITE: 80 ft x 150 ft
EXISTING FEATURES & Analysis
Walnut
Walnut
Maple
Maple
Maple
Maple
Maple
Maple
Maple
0º
SOUTH
1 square = 5 feet
Winter Solstice Sunrise ~7:15 AM
57º E
Winter Solstice Sunset ~4:45 PM
57º W
grapevine
Summer sun
Winter sun
Slope, water flow
Prevailing Winds
Equinox Sunrise 6 AM
Equinox Sunset 6 PM
EAST
WEST
Summer Solstice Sunrise ~4:30 AM
122º E
122º W
Summer Solstice Sunset ~7:30 PM
NORTH


SITE: 80 ft x 150 ft
Site Plan with proposed Eco-House
1 square = 5 feet
Black Walnut
Black Walnuts
Maple
Maple
Maple
Maple
Maple
Maple
0º
SOUTH
NORTH
Root barrier
Graywater discharged
biointensive beds
compost
57º E
57º W
Winter Solstice Sunset ~4:45 PM
Winter Solstice Sunrise ~7:15 AM
Prevailing Winds
winter greenhouse
Shed & workshop
Root cellar
Passive House
EAST
WEST
Slope, water flow
Equinox Sunrise 6 AM
Equinox Sunset 6 PM
Fruit trees
parking
Summer Solstice Sunrise ~4:30 AM
122º E
122º W
Summer Solstice Sunset ~7:30 PM

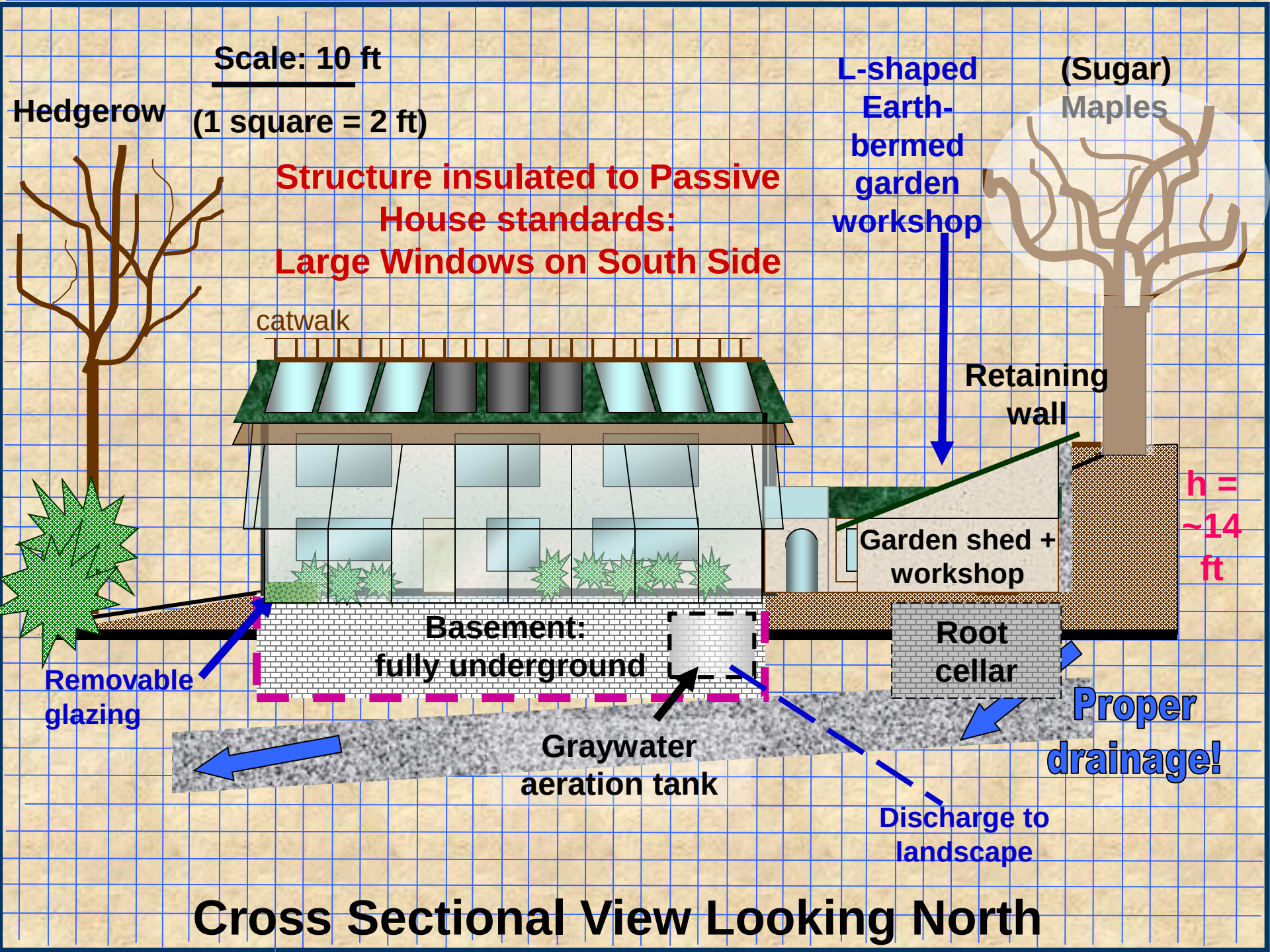


Cross Sectional View Looking South



Cross Sectional View Looking South

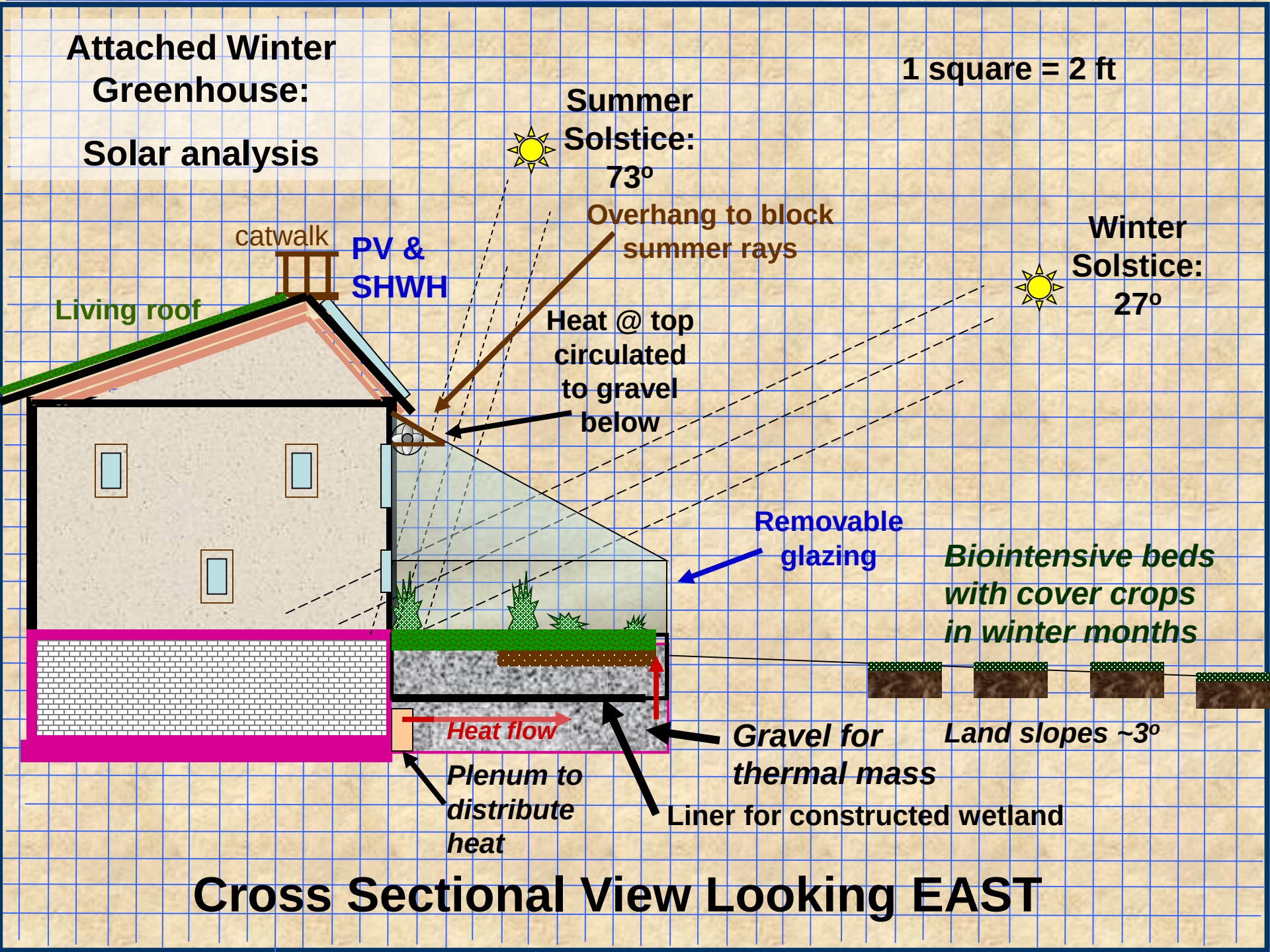
[North face of house: small, minimal amount of windows, glazing]



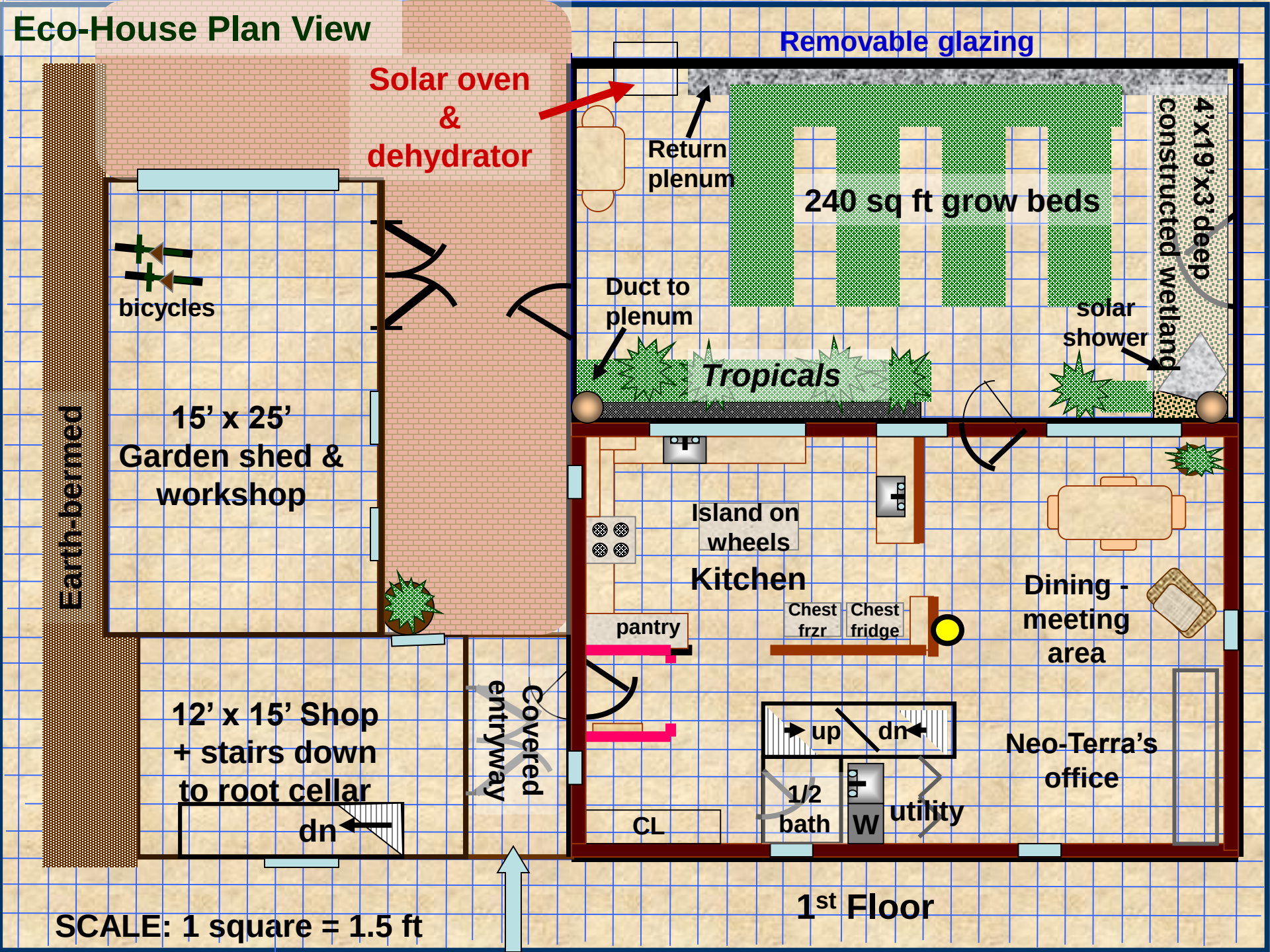
Cross Sectional View Looking North

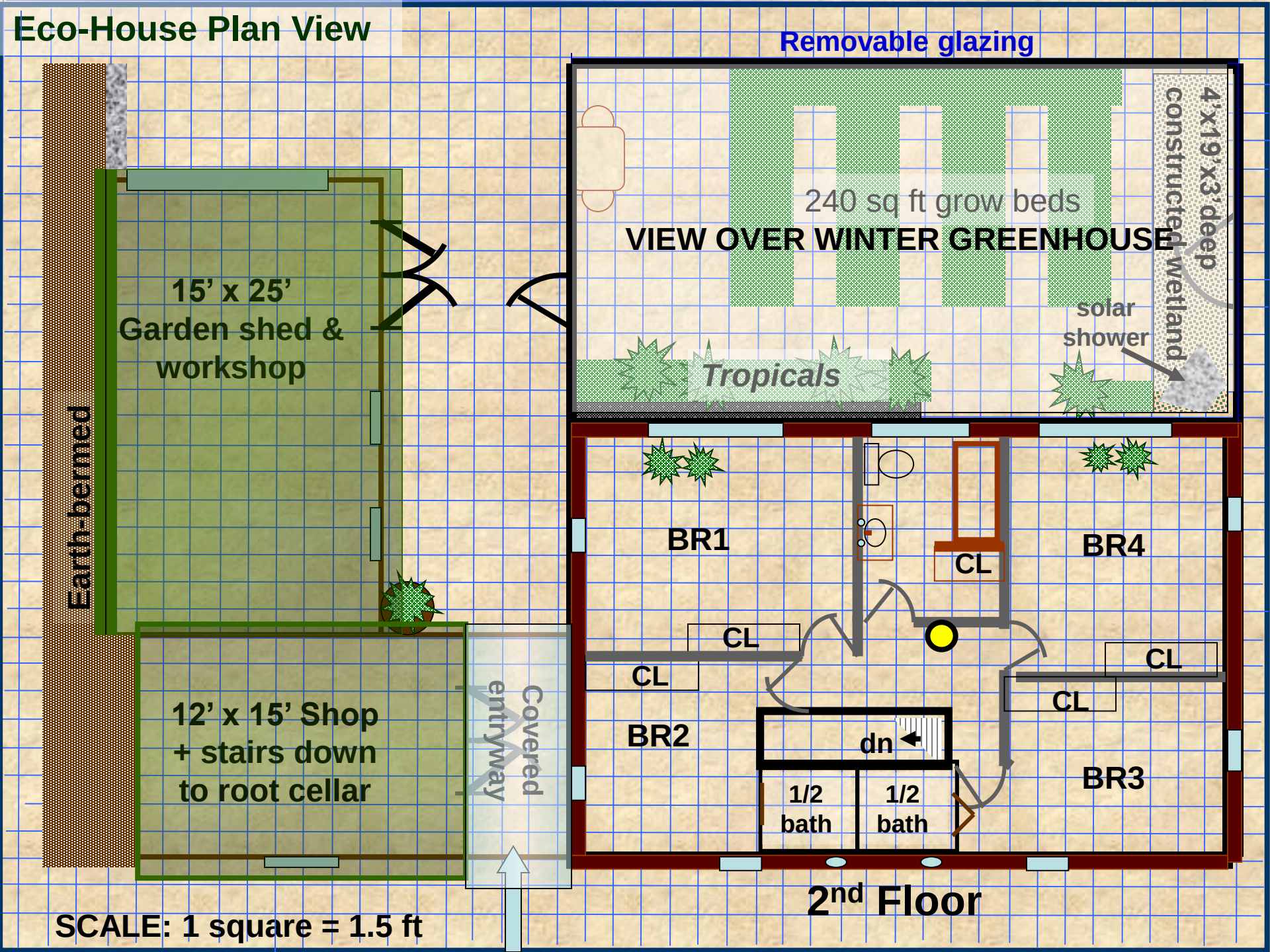
Attached Winter Greenhouse:

Solar analysis

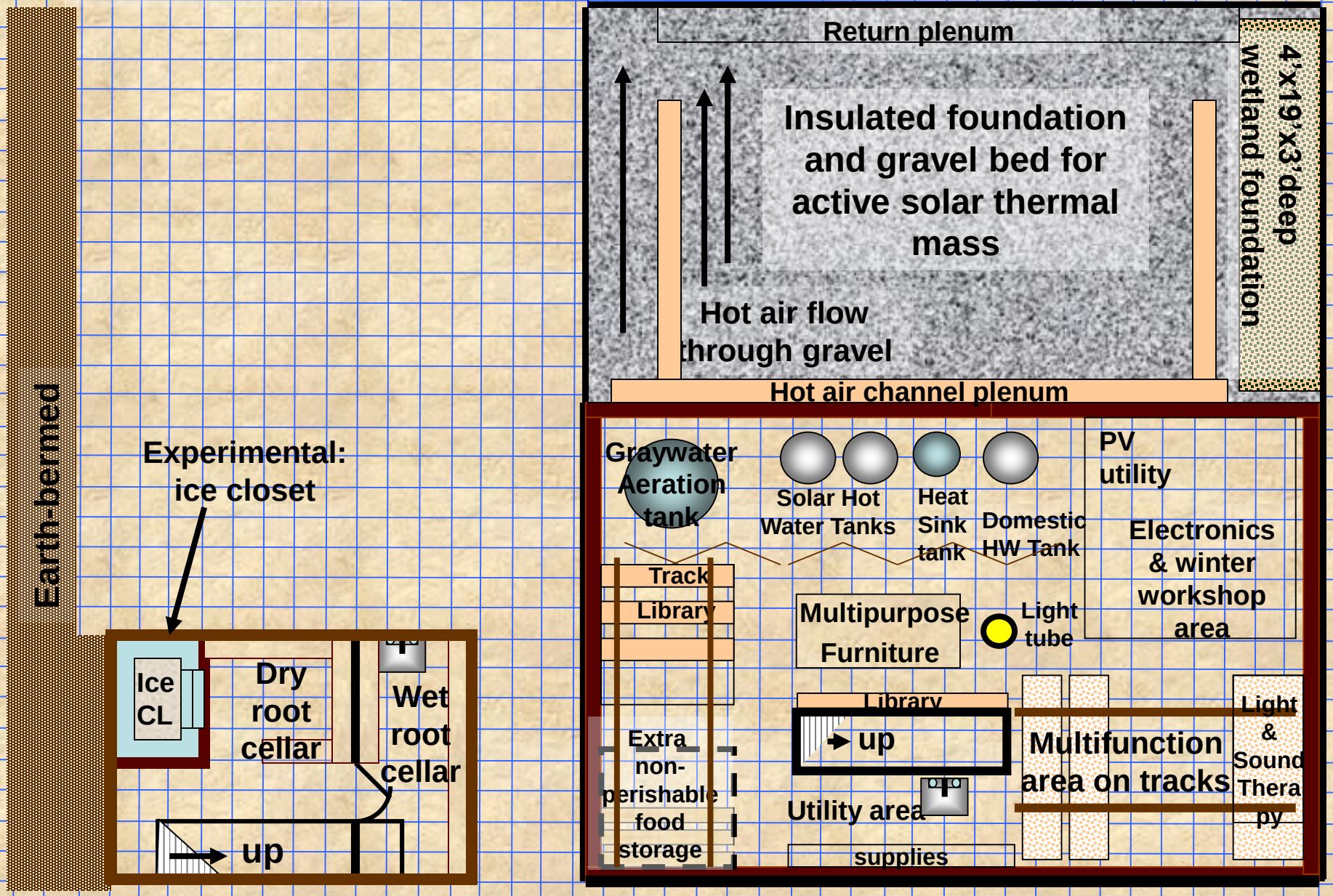


Cross Sectional View Looking EAST


Eco-House Plan View
Solar oven & dehydrator
Removable glazing
Return plenum
240 sq ft grow beds
4'x19'x3' deep constructed wetland
Duct to plenum
solar shower
Tropicals
bicycles
15' x 25' Garden shed & workshop
Earth-bermed
Island on wheels
Kitchen
Chest frzr
Chest fridge
pantry
Dining - meeting area
12' x 15' Shop + stairs down to root cellar
dn
Covered entryway
up
dn
Neo-Terra's office
1/2 bath
W
utility
CL
1st Floor
SCALE: 1 square = 1.5 ft


Eco-House Plan View
Removable glazing
240 sq ft grow beds
VIEW OVER WINTER GREENHOUSE
4'x19'x3' deep constructed wetland
solar shower
Tropicals
15' x 25' Garden shed & workshop
Earth-bermed
12' x 15' Shop + stairs down to root cellar
Covered entryway
BR1
BR2
BR3
BR4
CL
CL
CL
CL
CL
dn
1/2 bath
1/2 bath
2nd Floor
SCALE: 1 square = 1.5 ft

Eco-House Plan View



Basement

SCALE: 1 square = 1.5 ft

“If you have a heating or cooling system in your house you have made a mistake in construction.”

— Gunter Lang, chief executive director of IG Passivhaus Austria

“I invite friends.”

— Katrin Klingenberg, on how she heats her house

North American Passive House Conference 2009

Warm, bright and green in Winter…

Merged with garden in summer…

PART 4. APPLYING PASSIVE HOUSE TO RETROFITS

Current Thinking on Passive House Retrofits

- Double the heating and cooling limits to 30 kWh/m2/yr (9,500 Btu/ft2/yr)
- Adjust the air tightness limit to 1.5 ACH50 (instead of 0.6 ACH)
- Ensure insulation levels with high R values (50-60)
- Install triple glazed windows with insulated frames
- Reduce thermal bridges to a minimum
- Install a ventilation system with highly efficient heat recovery (85% efficiency or above)
- Install thermal solar collectors providing up to 60% of the annual energy demand for domestic hot water
- Provide heat using highly efficient condensing gas or biomass boilers, using well-insulated ducts.

Neo-Terra Farmhouse Retrofits Strategy House Retrofits	$/gal	$ Cost	Saving gal/yr	Year done	Payback yrs
Reduce use:					
Lower thermostat, wear warmer clothes		0	200	89	0
Prevent Heat Loss:					
make foam board shutters ……..	1.39	100	10	00	7.2
improve insulation in 2 attic areas	1.39	400	15	00	19
improve insulation in 3rd attic ……..	1.39	1,600	15	01	77
replace insulation in liv room w foam ...	1.39	7,600	20	01	273
improve insulation in east, south walls ..	2.90	5,780	20	08	100
replace 13 old windows …….	2.90	21,388	?	10	?
(includes $1,500 Fed tax credit)					
Increase Solar Insolation: 1/					
Duggin hot air collector (‘03) ……..	1.50	2,000-2,700	50-100	No	18-27
install hot water collectors for winter heat, summer hot water ……..	2.10	2,854	10+$60 e	05	35
Kreamer hot air collectors ……	2.90	738	10	08	25
Reduce Use, 2nd Round, Geothermal					
GTh heating (w. 30% Fed. tax credit)	2.35	18,000	450 – e↑ $208	09	21

COMPARING INSULATION RETROFITS Insulation Project	R-value before	R-value after	R-value PH
ATTICS			
Back attic: more fiberglass	13	43	60
New attic: more fiberglass	19	50	60
Old attic: replace rock wool with polyicynene	19	20	60
WALLS			
Living room walls: replace old fiberglass with Polyicynene and 1” foam board	9	22	50
East wall: add two 1” layers of foam board	18	28	50
South wall: replace old fiberglass with urethane foam plus 1” foam board	11	26	50
Interior apt north wall: replace old fiber-glass with 3” foam board over concrete block	8.9	16.5	50
Kitchen wall: has rock wool, sheathing and two layers of wood siding	12	Not done	50
North porch wall plus dormer “	12	Not done	50
FOUNDATION	1	Not done	14
SLAB	1	Not done	20

Assessing Two Alternatives for East Wall Retrofit

East Wall Components	As Is R-values	Alternative 1: replace insula-tion w foam	Alternative 2: adding 2” of foamboard
change in wall thickness		-0.50”	Adds 2”
15 mph wind	0.17	0.17	0.17
Vinyl siding	-	-	-
¼” Styrofoam	1.25		1.25
1” foam board	-	5.00	-
2” foam board (1” over 1”)	-	-	10.00
¾” wood siding	0.75	-	0.75
1” brown board sheathing	1.00	-	1.00
½” CDX	-	0.50	-
3 5/8” urethane foam	-	18.13	-
3 5/8” rock wool (but some has settled!)	13.84	-	13.84
½” gypsum	0.45	0.45	0.45
still airspace inside	0.68	0.68	0.68
Total R	**18.14**	**24.9**	**28.1**

Thermal Shutters

Attics

Living Room Walls

East Wall

South Wall

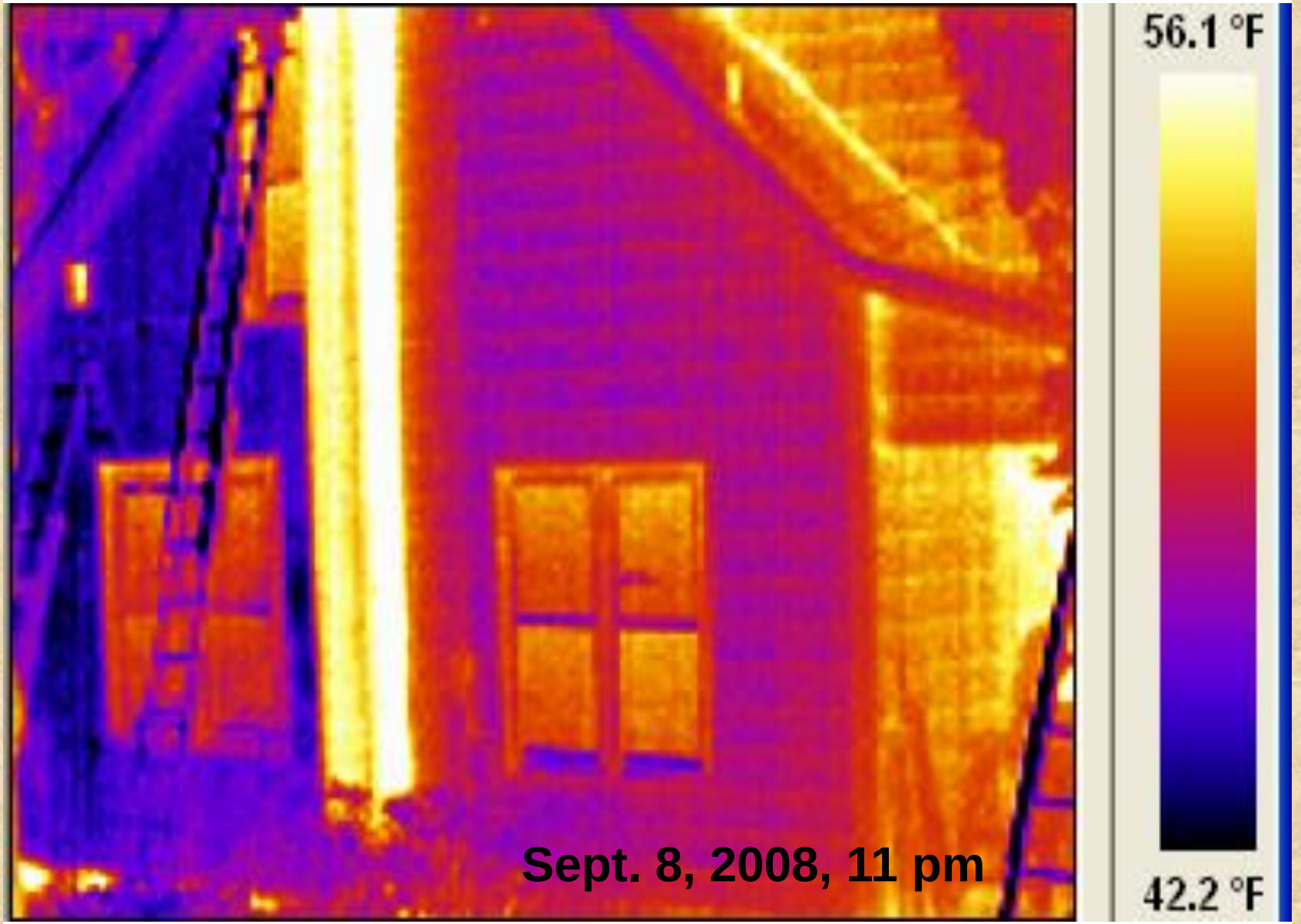
Urethane Foam on South Wall

South Wall:
Spray Foam -> Sheath -> Foam board

… plus prepare for solar hot air collectors

Apartment North (interior) Wall

Thermal Bridging in Our House: Foundation, Window Frames, Chimney, Dormer Seam



New Windows

Serious Windows Co.

Mt. Pleasant Remodeling

28 September 2010: Heat mirror demonstration

14 December 2010: Installation

Installing Coil; Filling Weight Cavities

Cellulose insulation, blown in

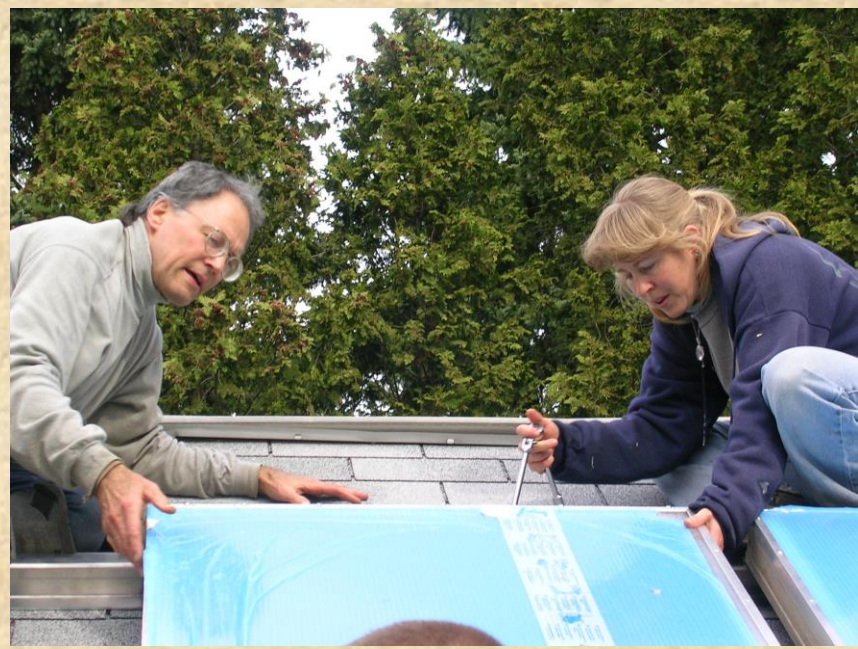
Before and After New Windows and Coil

Kitchen Window:
Old double-hungs -> New Casement

Solar Hot Water Heating

SHWH: Raising the Collectors

SHWH: Team help



SHWH: Tanks, plumbing

SHWH: Tailoring your system

Heat exchanger box on Jotul woodstove

Pipes feed through duct to baseboard heaters

Solar Hot Air Collectors

Solar Hot Air Collector

Testing the fan

Inside view, finished

Solar Hot Air Collectors

Supplemental Heat:
Ground Source Heat Pump

Old

New

Drilling the Wells

Ground-Source Heat Pump: “Geothermal”

Comparing Electricity Consumption, Fuel Oil vs Heat Pump

Electricity Use	Winter, fuel oil kwh, 62 deg, 08-09	Winter, heat pump kwh, 64 deg, 09-10	Winter, heat pump kwh 70 degrees	Total electrical kwh, 09-10
Total Electric	9,250			10,791
Furnace/Heat Pump	13,652	2,081	5,090	
Electric Heater	668	668	0	
Wood	2,997	2,997	0	2,997
Total Heat Energy:	17,317	5,746	5,090	
Total All Energy:	26,567			13,788
Our kwh/m^2	105	35	31	83
PH retrofit kwh/m^2	30	30	30	120

Blower Door Test

Air-Tightness

House Types	CFM50	ACH50
Passive House Standard for new housing 1/	113	0.6
Passive House Standard for retrofits 1/	283	1.5
Canadian R-200 program	283	1.5
New homes in Minnesota	471	2.5
New homes in Wisconsin (study of 24 homes)	735	3.9
A typically tight house	500-1,500	2.7-8.0
Threshold rule-of-thumb below which one should install whole-house mechanical ventilation 2/	*1,000*	*5.3*
Older houses	6,500-8,500	4/
Passive House standard for our house 3/	420	1.5
Actual blower door test results for our house	1,910	6.9
ASHRAE 5/ with 4 occupants	45	0.24

Air Tightness References/Notes

1/ Standard house of 1,500 sq.ft. w 7.5’ ceilings

2/ Holladay article

3/ Our house is 1,780 sq.ft. to which we must add the cellar (another 451 sq.ft.) giving a total of 2,231 sq.ft., or 420 cfm using the PH standard for retrofits.

4/ Without knowing the volume of an older house, we cannot determine ACH.

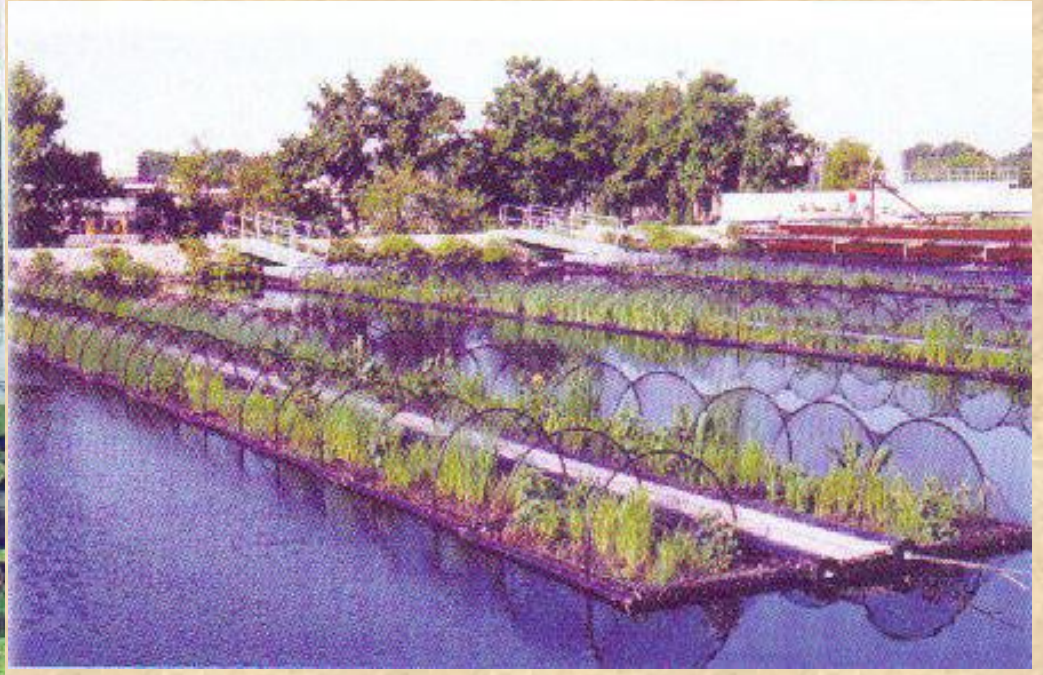
5/ American Society of Heating, Refrigeration and Air Conditioning Engineers. This is a ventilation standard, not an air-tightness standard.

Actions to Improve Air Tightness

- Caulk the remaining 9 old windows and 3 door frames.
- Seal two storage rooms on the perimeter in the cellar and a cubby off an upstairs room.
- Investigate the area around the attic door for leaks there and through attic floor to living room.
- Retrofit the two remaining walls of the house, including dormer (big bucks – $10,000 to $16,000).
- Replace remaining 9 windows (big bucks – $12,000).
- Replace three doors with high performance, well insulated doors (more big bucks).

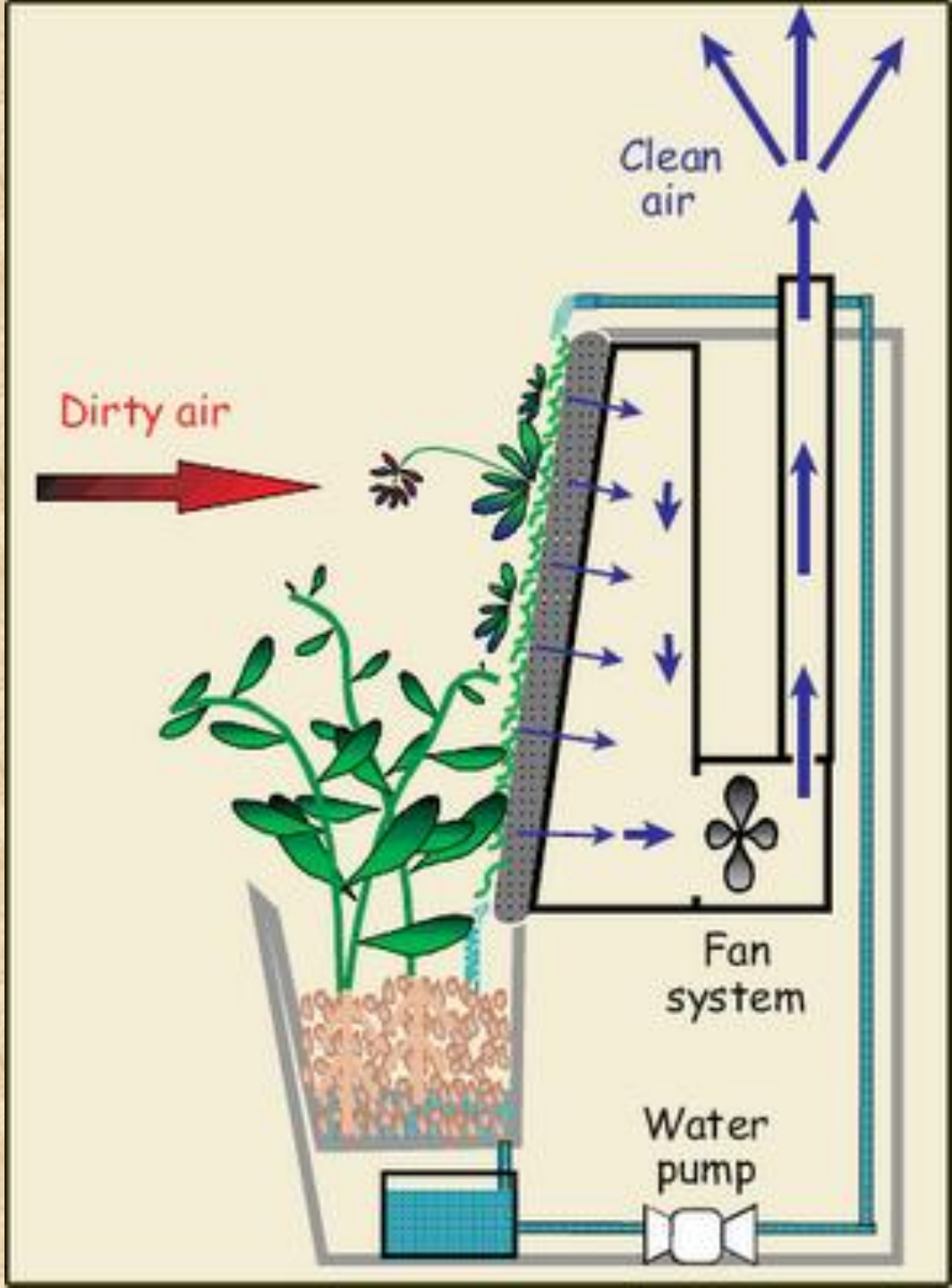
First 3 might reduce leakage by 200 cfm, not a lot.

Key Idea: Microorganisms on plant roots render toxins harmless (Dr. John Todd)



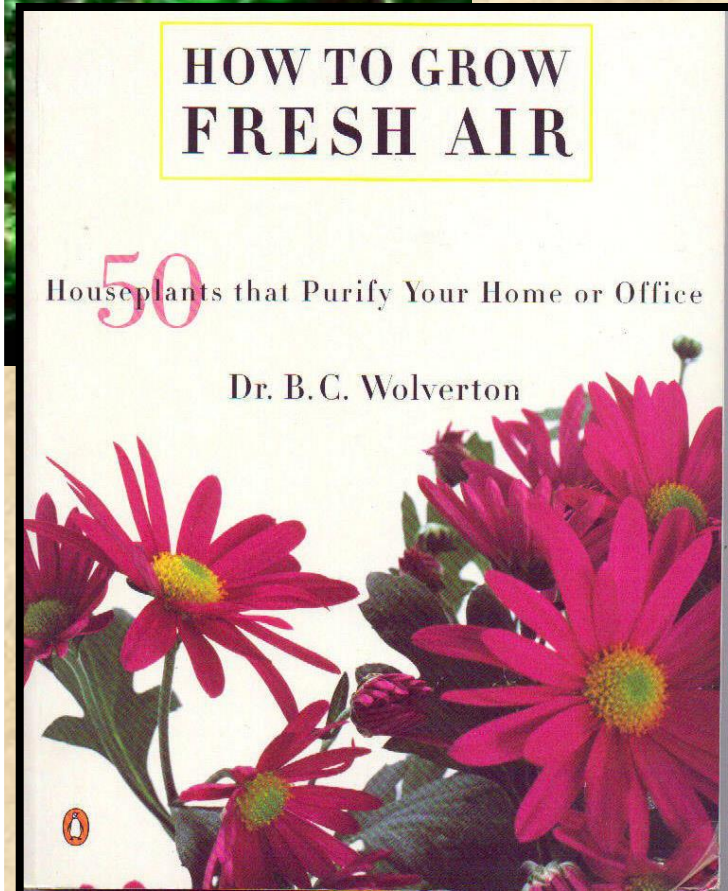
Living Machines & Lake Restorers

Concept Diagram For Breathing Wall



Environmental Room with Breathing Wall

Plants: Natural Scrubbers



Tax Credits and Other Assistance

- Federal Tax Credits (Form 5695) $1,500 for energy efficiency improvements (better windows, furnaces), and a 30% tax credit for PV, wind, geothermal devices.
- USDA has programs focused on your farm as a business. Each state also has an Energy Coordinator.
- PA DEP has an Energy Program, PA Sunshine Solar Program but these seem geared to projects that produce energy as part of a business.
- Check out our website for web links.

Lessons Learned

- Until everything is done, you will not realize the savings you had hoped for.
- Technology and building practices are changing rapidly in response to rising energy prices and more widely shared assumptions on global warming and the destructive impacts of petroleum and natural gas development.
- Passive House is the new standard for energy-efficient design & retrofits.
- Focus on the building envelope: “build tight and ventilate right.”
- We should have used more insulation – more layers of foam board!
- We should have reduced window area in the LR retrofit in 2001.
- Choose drainback over pressurized glycol and drainback for flat plate solar hot water units.
- Be skeptical of performance claims and advertised payback periods. Do your own math.
- During retrofits, correct mistakes as you (or your contractors) make them.
- One way to build a proper structure inexpensively is to buy a fabricated structure (e.g., a Morton building) and super-insulate it.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