From Farm House to Eco-House:
Retrofitting and Building New
PASA 11, Friday, Feb. 4, 2011, 1-2:20 pm
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Neo-Terra
Experiments in Healthy Living

Description: We have spent twelve years retrofitting an old house, and are turning our attention to the alternative: designing a proper passive solar house on an adjacent village lot. In this workshop, we share our experiences and results from our retrofits, and our best ideas and preliminary design for a solar home based on a new concept current in Europe but just now being introduced to the U.S. – Passive House.

Introduction

We live in Lemont, PA, within biking distance of Penn State. Over the past 20 years we have become increasingly serious homesteaders on 0.8 of an acre. In 1997 we began converting our backyard to a

biointensive minifarm. Our aim was to get off industrial food. In 1999 we upped the ante and turned our attention to the house. Our aim was to make our house more energy efficient.

Our house was built by the Meyers family in 1937 as a modest wood-frame cottage with clapboard siding. In 1957 the Fitzgeralds built a 600 sq. ft. addition, bringing the finished space to 1780 sq. ft.

The traditional wisdom from energy retrofit gurus in 1999 was the sequence: (1) reduce energy use; (2) prevent heat loss; and (3) incorporate solar in some form. We followed this sequence and while we learned a lot, we found the effort challenging and the results disappointing.

In 2006 we bought an adjacent quarter acre lot, and this opened up the possibility of building a proper house from scratch.

But what is a proper house? Therein lay a puzzle and a challenge as deep as retrofitting our present house. For us, the phrase "green housing" must go beyond the mountain-top retreats built with lavish use of stone and wood. Green housing must be something we all *could* have and *should* have.

In addition, our houses should be extensions of our gardens, not the other way around. So much of what we have found in green housing has little to do with providing our own sustenance. Green housing seems targeted to provide domiciles for trendy urbanites who drive their Priuses to farmers markets. (For a refreshing contrast, see what the Dervaes family has done on 1/5th acre in Pasadena, CA at http://urbanhomestead.org/.)

With this workshop we aim to do the following:

- untangle competing and overlapping concepts of low energy house design;
- introduce the Passive House concept as a new and important concept for designing and retrofitting houses and other buildings; and
- apply the Passive House concept to two cases: a new house design and a retrofit.

We invite you to contact us through our website or at neoterraexpts@aol.com with your questions or comments.

PART 1. COMPETING CONCEPTS FOR GREEN HOUSING

1.1 The Search for a Greener Concept

The latest green design concept to hit the U.S. is the European concept Passive House. The originator of Passive House in Europe is Dr. Wolfgang Feist, a German physicist. He was inspired by Dr. William F. Shurcliff, an American physicist with a passionate interest in passive solar design, and physicist Amory Lovins, founder of the Rocky Mountain Institute. The Passive House concept has become the standard for new construction in many European countries, and is just now being imported to the U.S. by way of German-born architect Katrin Klingenberg. She built the first Passive House in the U.S. in 2003 and started the Passive House Institute US (http://www.passivehouse.us/), modeled on its German counterpart, the Passivhaus Institut. For essential information on Passive House, see

(http://www.passivhaustagung.de/Passive_House_E/passivehouse.html) and Martin Holladay's primer (http://www.greenbuildingadvisor.com/blogs/dept/musings/passivhaus-beginners).

While the two of us were familiar with Shurcliff and Lovins when we started our retrofits, we hadn't really investigated Passive House design until last November. We had heard of it through the first place award given to the University of Darmstadt (Germany) entry in the 2007 U.S. Solar Decathlon (http://www.solardecathlon.gov/). This was the same year Penn State came in fourth with its Morningstar House entry (http://www.cfs.psu.edu/programs/morningstar-solar-home.html). Ironically, this past year an American university, Virginia Polytechnic Institute, came in first in the European Solar Decathlon (http://www.sdeurope.org/index.htm?lang=en).

So much has changed in the past dozen years. In 1998 Ecovillage Ithaca had just completed its first neighborhood (www.ecovillageithaca.org). In 1999 Dana Meadows, professor at Dartmouth College, and one of the authors of the path-breaking 1972 book "Limits to Growth," was starting a new ecovillage near Hartland, Vermont (www.cobbhill.org). I recall listserve conversations among the then sustainable design gurus who were advising her, including Amory Lovins (author of Soft Energy Paths and director of the Rocky Mountain Institute http://www.rmi.org/rmi/), and Marc Rosenbaum (www.energysmiths.com).

For heating, Cobb Hill decided on a central wood-burning furnace that would supply heat and hot water. Now Passive House designers can get away with a hair dryer and solar hot water panels. At that time, good triple pane windows were available only from Canada. For fresh air in their more air-tight townhouses, the Cobb Hill design team recommended leaving windows open a crack. Now Passive House designers use Heat Recovery Ventilators (HRVs) or Energy Recovery Ventilators (ERVs). Other green materials were simply unavailable. Now, green materials are a growth industry. (For descriptions of HRVs and ERVs, see http://www.toolbase.org/Technology-Inventory/HVAC/energy-recovery-ventilators .)

In contrast to Ecovillage Ithaca and Cobb Hill Cohousing, we can look at Maine Cohousing and Ecovillage, now in formation in coastal Belfast (2011), to be built entirely using Passive House standards (image of prototype below). Folks, this is truly a revolution in low energy design, and judging from the enthusiasm among architects, builders and homeowners, we are going to see much more Passive House design in the U.S., residential and commercial.

Maine Co-Housing Prototype

Before we proceed, we must distinguish Passive House from the two competing and overlapping American concepts passive solar houses and net energy zero houses. To avoid confusion, we will follow the emerging convention to capitalize "Passive House," after the German passivhaus, to distinguish it from "passive solar house," which you will see is a different animal.

(See http://www.mainecohousing.org/video/video.html for 8-part construction video of the prototype [$160/sq.ft.] and http://www.gologichomes.com/blog/tag/passive-house/ for the architect's site.)

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, elec.	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
2. Reduce heat loss			
insulation	modest: R-30 walls, R-40 ceilings	modest: R-30 walls, R-40 ceilings	heavy: R-60 or more walls, 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, rely on air exchangers: heat recov-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
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, AGS, PAHS 1/	Solar Decathlon entries, McGreen mansions	15,000 in Europe, 15 in U.S. (150 under condtruction); 1 in 4 new houses in Austria follow PH standards.

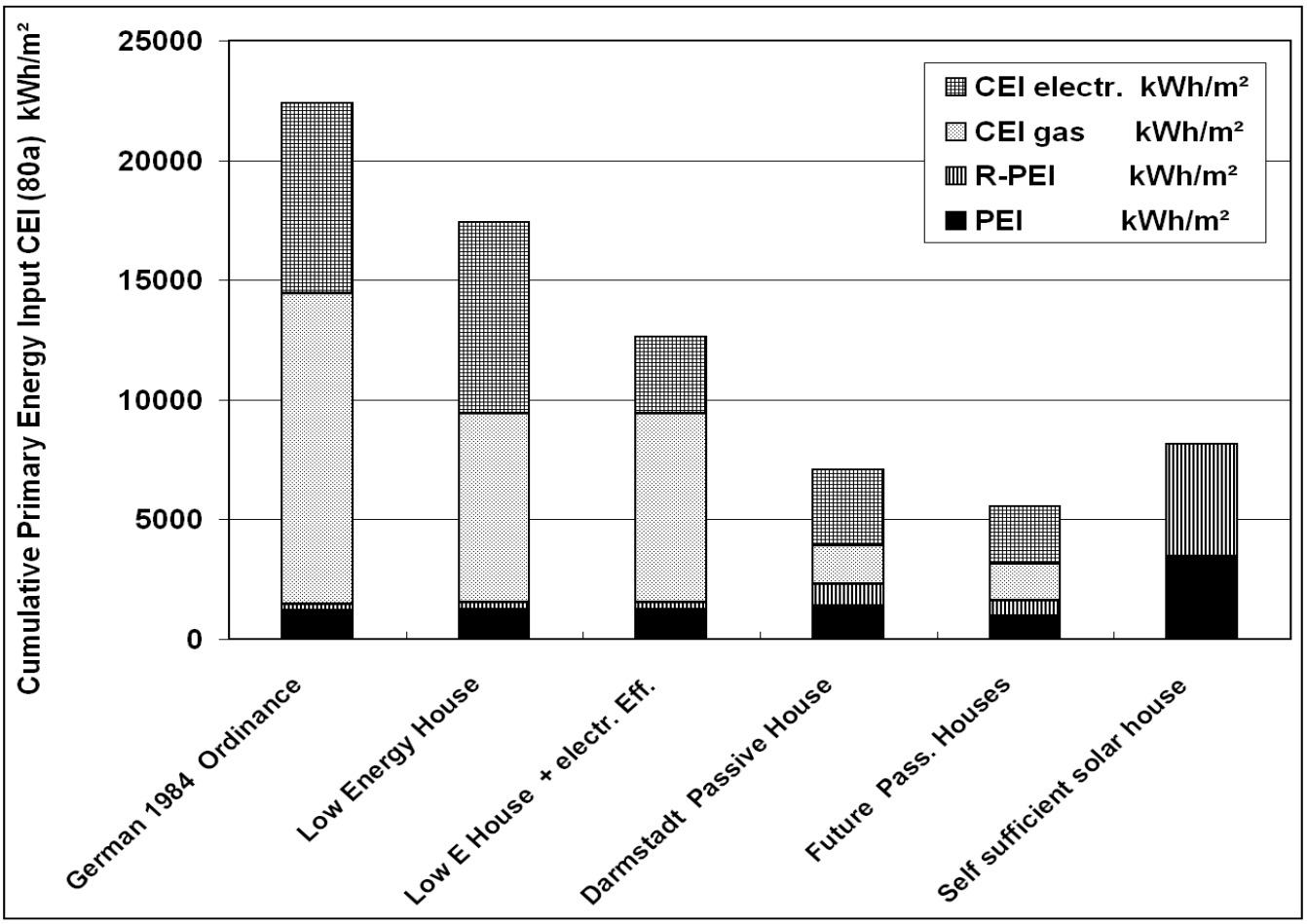
1/ Examples of good U.S. passive solar design concepts: James Kachadorian's solar slab (The Passive Solar House: Using Solar Design to Heat and Cool Your Home, Chelsea Green. White River Junction, VT, 1997); the Saunders house, from William Shurcliff's book (Super Solar Houses: Saunders's 100% Solar, 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/ .

Until we came across Passive House, we were sold on trying one of the passive *solar* house concepts. The net zero energy houses never interested us. These tend to be high tech, do not necessarily carry a low ecological footprint, evade energy conservation by using lots of expensive PV panels, and lead to the intrusion of off-grid housing into remote, even wild areas. This is not housing we all could and should have.

The Solar Decathlon entries fall into the net zero house category, even though these introduce innovations in energy reduction and small house design. Nonetheless, they achieve net zero energy by using lots of PV panels, often as much as the roof and even walls can support. The associated electro-mechanical control equipment, all computer monitored and controlled, is very high-tech, and would require technicians, preferably live-in, to keep them operating optimally. This is housing for energy geeks, not ordinary folks.

Dr. Wolfgang Feist compares the energy requirements of lower energy houses in Germany in the bar graph below (http://www.passivhaustagung.de/Passivhaus_D/Primary_Energy_Input_comm2007.pdf):

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



CEI: Cumulative Primary Energy Input (over 80 years)
PEI: Primary Energy Input for building production
R-PEI: Production and Replacement of extensive technical systems (pv panels, controllers, inverters, etc.)

The above concepts do not exhaust those available to provide protection from extreme temperatures. For example, neither Americans nor Germans have included underground houses because these use a lot of embedded energy (the concrete), can be gloomy and chilly, require careful design to keep out water, do not lend themselves to multi-unit structures because of the excavation costs, and consequently have never caught on. Two approaches at polar extremes are represented by the heavy concrete approach of Malcolm Wells (http://www.malcolmwells.com/) and the DIY approach of Mike Oehler (The $50 and Up Underground House Book, at http://www.undergroundhousing.com/). The PAHS and AGS approaches also involve at least partial underground construction, and also suffer from high embedded costs and other problems (e.g., moisture and potential mold buildup in earth tubes).

We bypass strawbale, cob, earthen, ceramic or similar "natural" houses. For starters, in their pure forms, these do not meet building codes around here. Possibly fine for a garden shed or outbuilding, but not legal for living quarters. While interesting, this is not housing we *could* have.

1.2 The Passive House Concept

What we now realize is that the Passive House concept is not limited to new housing, but can be applied to retrofits as well. This represents an intellectual breakthrough, not just for building scientists, but for architects, builders, contractors, equipment manufacturers, code enforcement officers, and finally, homeowners. Once you are clear on the key concepts, you can face the details with greater confidence. Here are the three key Passive House Features – retrofits or new construction:

Passive House Features and Standards

Key Features	Realized through	Threshold standards
1. Low space heating & cooling reqts	*** high insulation** *** reduced thermal bridges** *** air tightness (low infiltration)** *** excellent windows** *** passive solar design**	*** R-50 walls, R-60 ceilings** *** annual heat & cooling energy loads each ≤ 15 kWh/m^2/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**	*** total <u>primary</u> energy loads ≤ 120 kWh/m^2/year (38.1 kBtu/sf/yr) or 16,729 kWh/yr for a 1,500 sq.ft. house 2/** *** allowed plug load = 5,576 kWh/yr 3/**

1/ 15 kWh/m^2/yr x 1m^2/10.76sq.ft. x 1,500sq.ft. = 2,091 kwh/yr @ $0.10/kwh = $209/yr. For a description of how the 15 kWh/m^2/year was determined, see http://www.passivhaustagung.de/Passive_House_E/passivehouse_definition.html

2/ Primary energy is energy found in nature that has not been subjected to any conversion or transformation. The Passivehaus Institute uses multipliers to convert site energy (gallons of heating oil, therms of natural gas, kilowatt-hours of electricity, etc.) into the corresponding (primary) source energy, thus accounting for the losses in extracting and processing a fuel or in generating and transporting electricity. Primary (source) energy includes solar, wind, fossil fuels, geothermal, tidal, hydro, biomass, some nuclear (not plutonium which exists in nature in small quantities). In the Passive House Planning Package (PHPP) software, multipliers are applied to plug or end use energy to calculate primary energy. These factors differ from country to country. Thus, natural gas has a primary energy factor of 1.05,

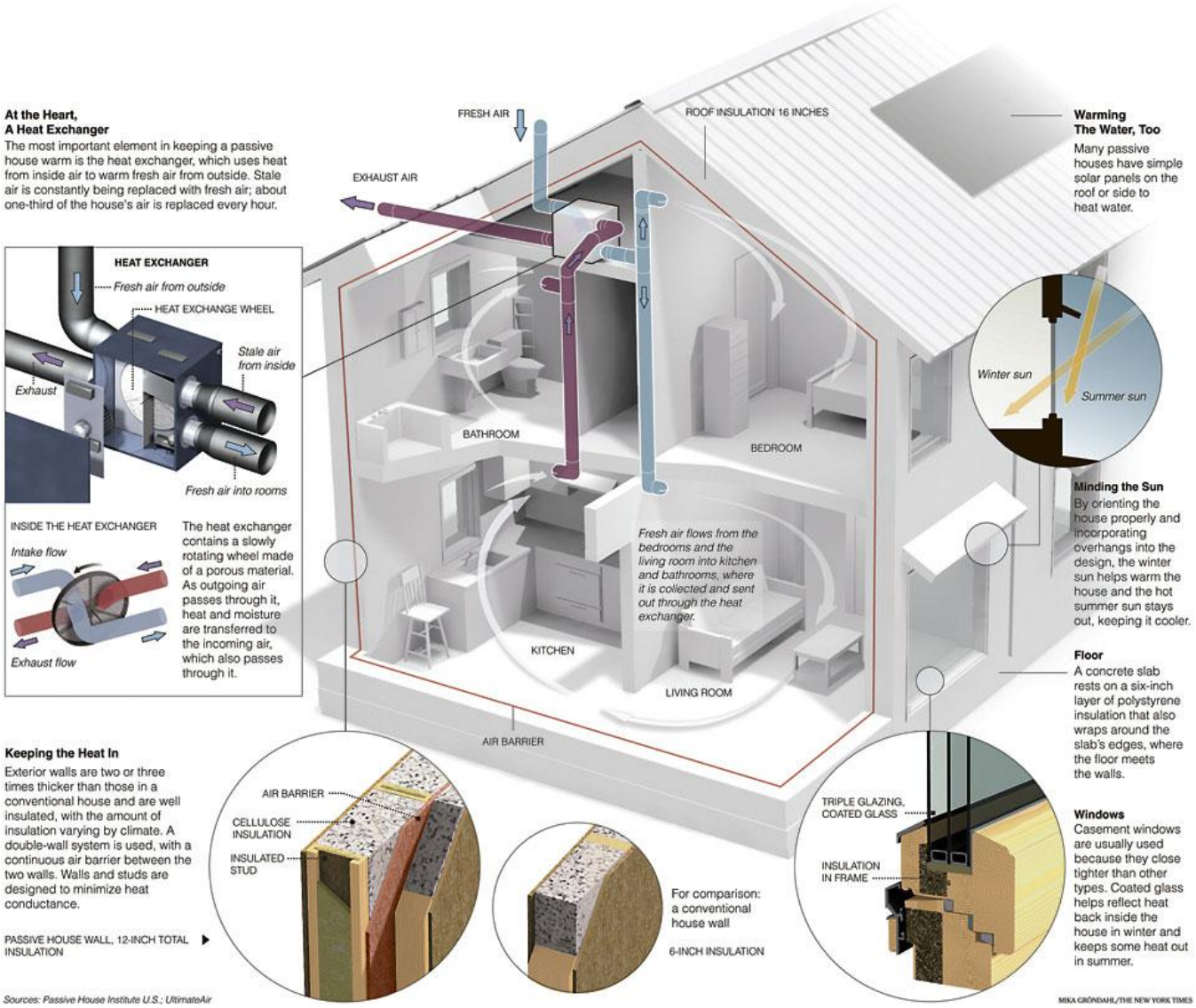
while electricity in the U.S. has a primary energy factor of 3 (2.7 in one analysis). In the example above, using 2,091 kWh/yr to heat a 1,500 sq.ft. house translates to a contribution to total primary energy use of 3x, or 6,273 kWh/yr. PHIUS currently relies on multipliers from Germany, and further research is required to translate these multipliers to U.S. conditions. Source: http://www.greenbuildingadvisor.com/blogs/dept/green-building-blog/defense-passive-house-standard.

3/ I calculate this number based on my possibly imperfect understanding of the PH standards. I subtracted the heating load of 2,091 kWh/yr from total allowed plug load of 5,576 (1/3 of total primary) leaving 3,485 kWh/yr at the plug, for a monthly non-heating power bill of only $29. This corresponds to 290 kwh/month to cover all non-heating uses, including summer cooling, HRV, appliances, cooking, domestic hot water, etc.

In short, a Passive House (PH) has heat requirements so low that a separate heating system is not necessary. Instead, heat is supplied through the ventilating air ducts (HRV or ERV) using a small electric heater. This condition is possible if the maximum heat load is less than 10 W/m^2 (1,394 watts for a 1,500 sq.ft. home, which is less than a hair dryer on high). The total end-use or plug energy requirement in actual PH houses, including household electricity and domestic hot water, is lower than 33 $kWh/(m^2yr)$ or 4,613 kWh/yr for a 1,500 sq.ft. house – a mere 384 kWh/month.

A Passive House is not a net-zero energy house. While passive solar gain and solar thermal can be included in the accounting, PV or photovoltaic systems cannot. Marc Rosenbaum, P.E., a certified Passive House consultant in Meriden, New Hampshire, and a past board member of PHIUS, asserts that "You can't [achieve the 15 kWh/m2 standard] in these climates without the sun… This is why the recommendation for Passive House windows includes a fairly high solar heat gain coefficient (SHGC) of 0.50, along with a very low U-factor (below 0.14)." Following is a schematic of a Passive House.

Schematic of a Passive House



From: http://www.nytimes.com/interactive/2009/04/30/business/energy-environment/20090430_businessofgreen_house.html?ref=businessspecial2

1.3 Passive House Concept: Challenges, Controversies and Questions

Since Europeans have already embraced and implemented Passive House standards, the challenges and questions come from Americans attempting to grapple with and reconcile Passive House with their long-held concepts and practices. Good articles, spirited and civil discussions, and quality information can be found at the following locations:

1. greenbuildingadvisor.com, in particular:
   a) An excellent interview with Passivhaus founder Dr. Wolfgang Feist that touches on many of the key issues at http://www.greenbuildingadvisor.com/blogs/dept/musings/conversation-wolfgang-feist ;
   b) Discussion among builders, designers and architects at Passive House Alliance: http://www.greenbuildingadvisor.com/blogs/dept/green-building-news/new-passivhaus-advocacy-group-us and for direct link: www.phalliance.com
   c) Excellent blogs and discussions on Passive Houses: http://www.greenbuildingadvisor.com/category/site-wide-tags/passive-house-institute-us .
2. Further discussions on a wide variety of topics at http://www.passivehouse.us/bulletinBoard/
3. An amazing "wikipedia" for Passive Houses! at http://passipedia.passiv.de/passipedia_en/
4. Passive House videos at: http://www.youtube.com/watch?v=qnks0WZ6UPs&feature=related

To certify a Passive House, its performance has to be modeled using the Passive House Planning Package (PHPP) software. This software is based on European standards, and requires adaptation to be useable in the U.S. PHPP is based on a sophisticated, Excel-based spreadsheet developed by Dr. Feist. Marc Rosenbaum says the PHPP spreadsheet is complex and time-consuming to work through, but he likes the fact that you can see exactly what's going on. "A lot of modeling programs are black boxes," he said; "with PHPP you can very clearly see the impact of modifying the glazing on the south or reducing thermal bridging through a wall component, and you can see the calculations behind it. It's a really good educational tool."

PART 2. PASSIVE HOUSE DESIGN IN NEW CONSTRUCTION

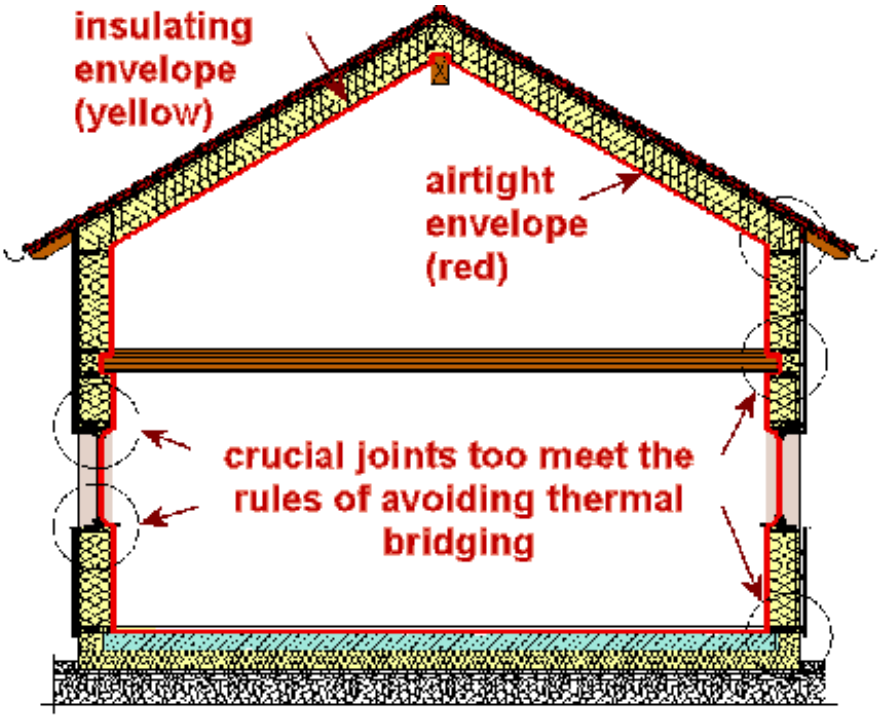
In Part 2 we elaborate briefly on the Passive House framework. In Part 3, we apply the framework to a new house for our adjacent vacant lot. In Part 4, we assess retrofits on our existing house against the Passive House framework. Presenting the "new" house first allows us to examine more clearly how well we did on our retrofits.

An excellent directory of the principle components of Passive House design can be found here: http://www.passivhaustagung.de/Passive_House_E/PassiveHouse_directory.html. In the discussion below, we will focus on the components from the Passive House Features and Standards table above.

2.1 Low Space Heating & Cooling Requirements

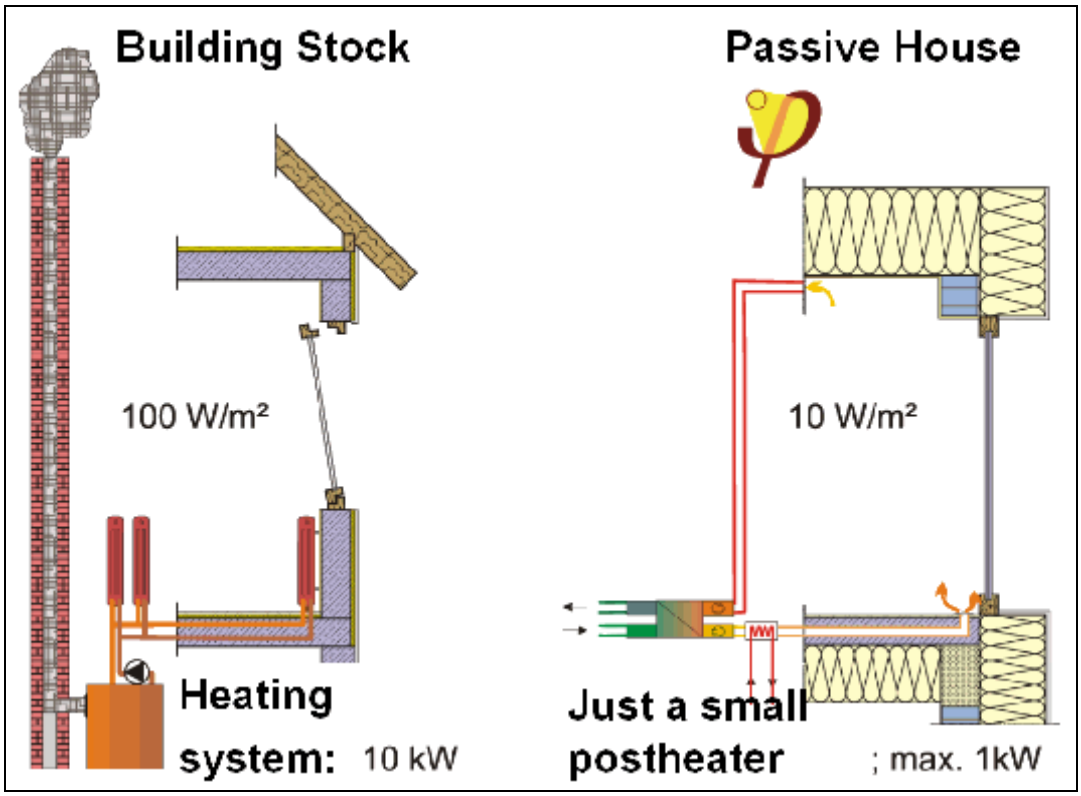
The key to realizing low space heating and cooling requirements lies in visualizing the internal space as surrounded by a single unbroken building envelope. You can take a pencil and complete a circumference of high insulation without taking your pencil off the paper (thick yellow border below).

Idealized Building Envelope for a Passive House



http://www.passivhaustagung.de/Passive_House_E/insulation_passive_House.html

With superior insulation, you will not require an expensive heating system. In the simplest case, you will be able to heat your Passive House through the ventilation system only, as shown in the schematic below.



From: http://www.passivhaustagung.de/Passive_House_E/passivehouse_definition.html

Space heat may be delivered by any means you want -- electric resistance baseboard heaters, gas space heaters, pellet stoves, furnaces, boilers, geothermal heat pumps, etc. Many of these systems will be vastly oversized for the minimal heating requirements of ≤ 15 kWh/m^2/year. For a radiant floor, too little heat is required for you to feel the heat coming through the floor. Similarly for wood stoves, including Tulikivis (large masonry stoves). Take the money you would have spent on large heating systems and put it in Passive House features. One way to go is to use closed combustion pellet stoves. For more on stoves, see http://www.passivehouse.us/bulletinBoard/viewtopic.php?f=6&t=121 . Of course, fireplaces as a source of heat (as opposed to accent value) do not make any sense, in a Passive House or any other.

Burning wood is not particularly or necessarily sustainable. For starters, the average forested woodland per capita is 1.4 acres for the U.S., and 1.2 acres for Pennsylvanians. This is not much. These woodlands carry many demands in addition to supplying building materials – woodlands must provide carbon sinks, convert CO^2 to O^2, provide habitat for wildlife, support a complex ecosystem, and supply botanicals.

The Passive House standard of 15 kWh/m^2/year, or 4.75 kBtu/sf/yr, translates to 7,125,000 BTUs per year for a 1,500 sq.ft. house at 68-70 degrees. How much wood is this? About ½ cord. (Divide 7,125,000 BTUs by 0.65, the efficiency of a typical wood stove, to give a required BTU input of 10,962,000 BTUs. Divide this by the heat value of a mixed cord of hardwood and softwood, say 21,000,000 BTUs, and that is the equivalent of 0.52 cords.)

Thus, if you're burning 7 cords to heat your house, and a well-insulated house requires only ½ cord, you can readily assess how your house stacks up against a Passive House.

2.1.1 High Insulation

A low space heating requirement is achieved through high insulation, and high insulation is achieved through thick walls using high R-value insulation. Builders use different ways to construct the walls to achieve the Passive House standard:

- Engineered framing members used as wall studs. Consider TJI – Truss Joists I shaped, with 14" deep cavities filled with blown fiberglass, foam, or other materials. For more info, search on "tji joists" and don't try making these joists yourself (http://forums.finehomebuilding.com/breaktime/construction-techniques/making-my-own-tji-joists);
- Conventional 2 x 6 walls on 24" centers, with 2" of foam board on outside;
- Double 2 x 4 walls, with more insulation between these two walls;
- AAC (autoclaved aerated concrete) in warmer climates can also work (http://www.passivehouse.us/bulletinBoard/viewtopic.php?f=7&t=241);
- SIPs (structurally integrated panels) hanging on 2 x 4 walls or post and beam construction. Many SIPs use foam; however Agriboard SIPs use straw, but have lower R than polyurethane: http://www.treehugger.com/files/2008/11/greenbuild-agriboard-sip.php ;
- Insulated Concrete Forms: example at http://www.greenbuildingadvisor.com/homes/foam-forms-create-energy-efficient-concrete-house.

For an interesting contrast of Passive House practices to those of contemporary new building recommended practices in the U.S., see the work of the Building Sciences group at http://www.buildingscience.com/, particularly the topic in the left hand menu titled High R-Value Wall Assemblies (http://www.buildingscience.com/resources/high-r-value). You will find some spirited tension between Passive House Institute practices and those recommended by the Building Science Corporation.

Katrin Klingenberg's first certified Passive House of 1,300 sq.ft. built in 2003 in Urbana had R-60 walls and ceilings, R-56 insulation beneath slab, and 0.25 ACH@50. http://www.greenbuildingadvisor.com/homes/first-us-passive-house-shows-energy-efficiency-can-be-affordable . A new house now under construction in Oregon claims an R-120 roof and R-80 walls.

To eliminate air leakage Klingenberg disallowed electrical sockets on exterior walls in her second design, but then suggested after completion that on her next house she might add a 2 x 3' stud wall inside the insulated wall to accommodate electrical work. This struck us as a lot of effort to hide a few wires. Why not simple chases hidden behind baseboards? A good description of her second design, with construction details, can be found in the May 2007 issue of Energy Design Update (http://www.passivehouse.us/passiveHouse/Articles_files/EDU%20May2007%20Postable.PDF).

The question of foam fill provoked several illuminating comments among builders in the Questions section of a blog on a Passive House being built in Asheville (http://www.greenbuildingadvisor.com/blogs/dept/think-spot/passive-house-what-do-you-think):

- Comment by Pat Morgan. "I just read today an article in the July '09 Fine Home Building on foam that has info germane to this discussion. Most importantly, that the efficiency of foam (open or closed cell) diminishes drastically beyond 3-4" thickness, so filling a 16" cavity is probably a waste of money. Also important is that installation of closed cell can be tricky, and if not applied in thin lifts causes problems. I agree with you about the issue of breathability for closed cell foam, although the manufacturers say its perm rating is as high as a piece of OSB, so maybe it's OK. Mixing other insulation in the ceiling with a good dose of foam instead of 100% foam will definitely save some serious money."

- Comment by Chris Otahal. "My insulation guy claims that dense packed cellulose, properly installed, is unrivaled. We're thinking of installing the drywall and blowing the cellulose into the cavity to achieve the proper density. I do like the idea of a thin layer of foam on the inside face of the plywood sheathing, and cellulose for the remainder of the cavity."

- Comment by Alan Abrams. "Just a note of caution regarding the use of open cell foam in roofs – we've had two instances of water leaks, and open cell will absorb alarming amounts of water – and retain it with annoying persistence. It suggests that we should apply the same care we take with vertical drainage to roofs – redundant planes, provision for ventilation, etc." (This was our experience – Gene and Tania's – with polyicynene on retrofit!)

One still critical limitation of certain spray foams (closed cell polyurethanes) and styrofoam is that manufacturers are using HFCs, a serious greenhouse warming gas. Review the following article (and "Related Content" to the right) for a recent (2010) article on this: http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/avoiding-global-warming-impact-insulation. The author's conclusions are contested in the Comments section, so read those as well.

Problem of moisture. One of the biggest issues in new standard construction is moisture. Moisture tends to collect inside houses in the wintertime – from cooking, bathroom, laundry, human occupation. The tighter the house, the greater the problem. This moisture works itself outward through the walls, and can be trapped within improperly built walls where it can condense and cause premature decay of wood.

With "a Passive House, the air leakage can be no greater than 0.6 air changes per hour at 50 pascals of pressure difference between the interior and exterior (0.6 ACH50). According to Klingenberg, this air-tightness standard arose as a quality-assurance feature. The German developers of Passive House calculated the amount of moisture that could be introduced into a house from outdoors with different air-exchange rates and picked a low enough exchange rate to ensure that introduced moisture would not cause a problem. 'If you build to that standard,' said Klingenberg, 'you will not have moisture problems'." Quote from an excellent article in Environmental Building News, April 1, 2010: http://www.buildinggreen.com/auth/article.cfm/2010/3/31/Passive-House-Arrives-in-North-America-Could-It-Revolutionize-the-Way-We-Build .

For examples of U.S. Passive Houses see http://www.passivehouse.us/passiveHouse/PHIUSProjects.html and http://www.greenbuildingadvisor.com/green-homes, scrolling down the right-hand column to "**Job**blog."

2.1.2 Reduced Thermal Bridges

Thermal bridges refer to areas of high conductivity in which heat can flow easily through the building envelope – from inside to outside in the winter, and in the opposite direction in the summer. A good building envelope reduces thermal bridges using superior building techniques and insulation in proper places.

You can easily see this on a winter day through an infrared imaging camera, where heat leaks show up in brighter hues of red, indicating heat flowing through these areas. Such short circuits for heat transfer occur through window frames and their joints with adjacent walls, at roof-wall connections, wall-foundation connections, and floor-wall connections. Preliminary points can be found at: http://www.passivhaustagung.de/Passive_House_E/passive_house_avoiding_thermal_brigdes.html .

2.1.3 Air Tightness

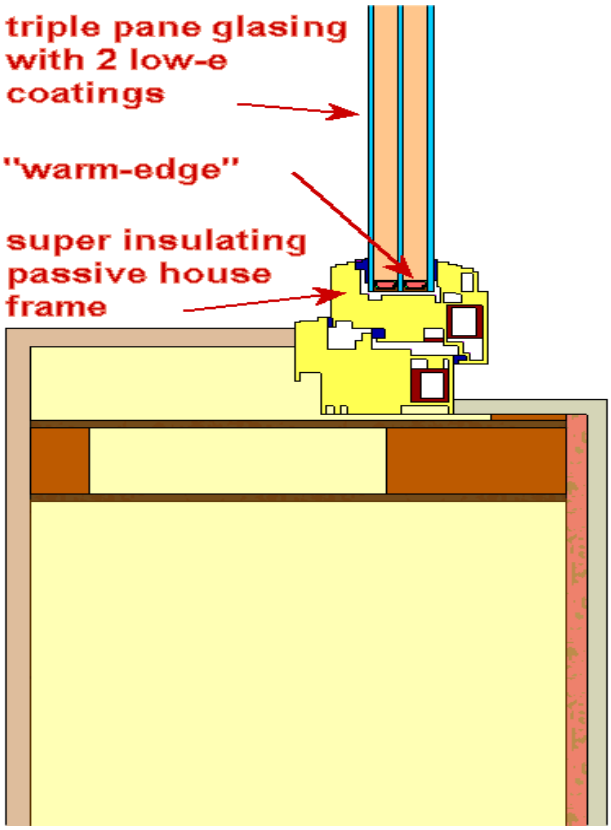
Air tightness is not the same as insulation. Further, air tightness should not be confused with a moisture or vapor barrier. "An oiled paper is airtight, but it allows moisture vapour to pass through. Conventional room plastering (gypsum or lime plaster, cement plaster or reinforced clay plaster) is sufficiently airtight, but allows vapour diffusion."
http://www.passivhaustagung.de/Passive_House_E/airtightness_06.html We will have more to say about air tightness below in Part 4, where we discuss our own retrofit.

2.1.4 Excellent Windows

High performance windows have three essential features:

- Triple glazing with two low-e-coatings (or another combination of panes giving a comparable low heat loss);
- "Warm Edge" – spacers; and
- Super-insulated frames.

Window Schematic of High Performance Window



(http://www.passivhaustagung.de/Passive_House_E/PH_windows.htm)

High performance windows must have a max u value of 0.14 (R 7+ or higher = 1/u). You can find a quick primer at http://www.passivhaustagung.de/Passive_House_E/PH_windows.htm which contains a link farther down the page to Additional information on Passive House windows.

The American building industry has labored for so long under tradition and lack of innovation in energy efficiency in windows that among U.S. builders there is a lot of confusion over window performance, technology, and terminology. Currently it is difficult to find high performance windows made in the U.S! Moreover, there are few choices in performance features, particularly R values and appropriate combinations of R values and Solar Heat Gain Coefficients (SHGC) for the cold northeast. With few exceptions, one must go to Canada or Europe to get good windows. A sense of the confusion and challenges can be read in the exchanges among builders on the bulletin board topic for "Passive House Windows" which at the moment (12-4-10) has 62 postings on 7 pages comprising over 12,000 views, the most sought after topic (http://www.passivehouse.us/bulletinBoard/viewtopic.php?f=7&t=59). A related topic, "An American Passive House Window" has additional information at: http://www.passivehouse.us/bulletinBoard/viewtopic.php?f=7&t=74 .

2.1.5 Passive Solar Design

Passive House requires solar insolation to meet the energy thresholds. With two exceptions, acquiring sufficient solar insolation requires the usual criteria with which we are familiar for passive solar design: south-facing house wall and roof combined with east-west orientation; larger windows on the south wall, smaller on others, few on north; high SHGC windows on south; good overhangs; and solar hot water panels on the roof to provide domestic hot water.

The two exceptions are photovoltaic panels to produce electricity, and mass to store heat. The first has embedded costs that are far too high, and the second is not necessary as high insulation prevents heat loss.

2.2 Mechanical Ventilation

Americans are used to having air-based heating and cooling systems (air conditioning). But the systems used in America often just recirculate indoor air at a high rate (> 10 ACH); stale house air is not exchanged with outside fresh air. The Passive House approach is very different. It replaces the indoor air with external fresh air at a very low rate (0.3 to 0.6 ACH) to obtain a very good air quality. There is almost no noise and no draft. This is close to the ASHRAE standard 62.2. By contrast, the International Building Code criterion of 7 ACH is overventilation.

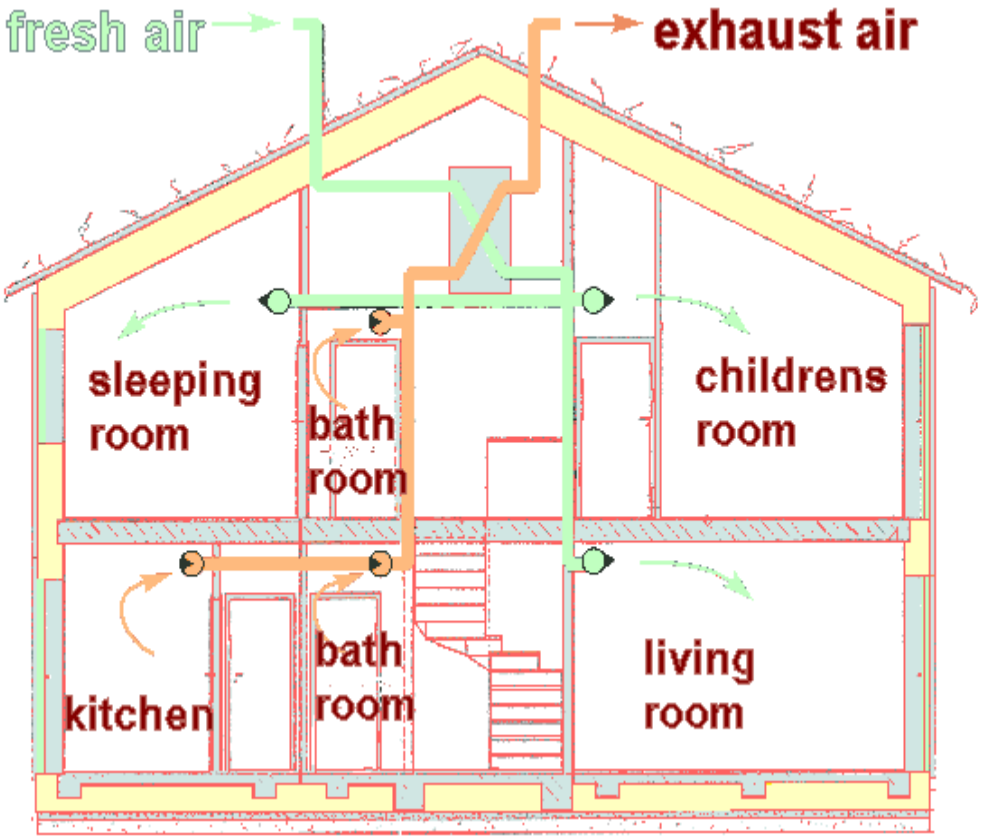
American builders have narrowed ventilation down to three main options:

- For the best air distribution, and lowest operating cost, choose an HRV or an ERV connected to a dedicated duct system. This is the strategy of choice for air-tight Passive Houses.
- For better fresh air distribution, choose a central-fan integrated supply ventilation system, making sure you use a low power draining ECM blower. (ECM stands for electronically commutated motor.)
- The simplest system is an exhaust-only ventilation system based on one or more bath exhaust fans. Here there are several good choices – e.g., the Panasonic Whisper Green fan at 11.3 watts (80 cfm), and the Broan SmartSense fans (see our notes below in Section 4.3.2 Ventilation).

On windy days, the air change is faster. In a conventional non-air-tight house, a simple fan can exhaust stale air out and bring in fresh air – through open windows, or infiltration, leaky doors and windows, or through other openings (e.g., chimneys). The drawback of this arrangement is that in the winter, heated air is exhausted and cold air is brought in, requiring additional heat to bring the cold air up to house temperature. This wastes energy. A second choice is a central-fan-integrated supply ventilation system.

Since Passive Houses are quite airtight, fresh air has to be brought inside mechanically and stale air exhausted. The Passive House solution is to use either a Heat Recovery Ventilator in the cold north (HRV) or an Energy Recovery Ventilator in the humid south (ERV). This device transfers the outgoing warm inside air to the incoming cold air in a box designed for this purpose. Efficiencies of heat transfer can range from 75-95%. In the summer, the outgoing cool exhaust air cools the incoming warm air. A schematic for this is shown below.

Ventilating a Passive House



From: http://www.passivhaustagung.de/Passive_House_E/ventilation_06.html

One can additionally use a ground loop, usually water-filled PEX tubing laid below ground during construction, to warm the incoming cold air in the winter and cool incoming warm air in the summer (http://passivehouseca.org/heat-extractor-shelf-hydronic-heating-coil-unboxed).

The cooling of incoming warm humid air in the summer may lead to condensation, as happens in dehumidifiers, requiring a way to drain condensate. An excellent discussion of HRVs and ERVs by Martin Holladay, including a list of manufacturers, can be found at http://www.greenbuildingadvisor.com/blogs/dept/musings/hrv-or-erv . The many comments following this article provide additional insights and information.

The broader topic of designing a good ventilation system is covered, also by Holladay, in two recent articles: http://www.greenbuildingadvisor.com/blogs/dept/musings/designing-good-ventilation-system and http://www.greenbuildingadvisor.com/green-basics/ventilation-choices-three-ways-keep-indoor-air-fresh .

Holladay concludes his comments by mentioning "that it's possible to have a well-ventilated home without an HRV or an ERV. It's much cheaper to install a central-fan-integrated supply ventilation system controlled by a FanCycler. If you choose this route, be sure that your furnace has an energy-efficient ECM blower." (ECM stands for electronically commutated motor.)

2.2.1 Design Paramters and Considerations

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has established a residential ventilation standard (Standard 62.2) calling for 1 cfm of mechanical ventilation for every 100 square feet of occupiable space, plus an additional 7.5 cfm per occupant. For example, a 1,500 square-foot house with four occupants would require 45 cfm (cubic feet/min) of mechanical ventilation.

Ventilation in the 1,500 sq.ft. Maine Cohousing prototype, is provided continuously at a rate of 70 cfm. This means the entire volume of air in the house will be changed once every 3 hours, ensuring healthy air quality for a family of 4 or 5. According to the architects, "The air flow is very low and generally delivered to points in the house where it's not noticed, so one never feels a draft."

There is a two-part energy cost to running an HRV. The ventilation (heat) losses for a high quality HRV for Passive Houses is currently 2-7kwh/m^2/year. For a 1,500 sq.ft. house, this would cost $28-$100/yr to replace the heat (@ 0.10/kwh. The second cost is the electricity to run the fans. For the Venmar EKO 1.5 (with two ECM blowers) drawing 13.5 watts at low speed to deliver 40-80 cfm of fresh air, this cost would run ~$12/yr.

Some builders contest these figures as being underestimates, claiming the power draws are higher than rated, while defenders blame poor installation as the source of the higher costs.

One of the claimed drawbacks of an HRV in northern climates is that dry winter air drawn in leads to dry indoor air. On the other hand, normal occupation, showers, laundry, and cooking raises the humidity in a tight Passive House, counteracting this tendency. Good relative humidity (RH) is 30-40%.

Due to a longer history of using the Passive House concept, Europeans have more choices among devices for obtaining ventilation. For example, they have small heat pumps to extract heat from exhaust air in the HRV, can integrate a small biomass heater with the ventilation and hot water systems, or use small gas-fired condensing boilers. This degree of integration is hard to find among U.S. equipment manufacturers, and perhaps this is the reason why the downside of such integration is emphasized in the U.S., namely, that if one element of the system breaks, then the entire operation is compromised. (See http://passipedia.passiv.de/passipedia_en/planning/building_services/compact_hvac_systems.)

These integrated systems that cover a multitude of functions in European Passive Houses bear the name "magic boxes" (http://www.greenbuildingadvisor.com/blogs/dept/musings/magic-box-your-passivhaus). These are not available here, and are expensive. Their high cost is one reason why North American Passivhaus builders will probably continue installing separate HRVs with well-designed dedicated ductwork – independent of the heat-delivery system. For DIY fans, you can build an HRV yourself: http://makeprojects.com/Project/Heat-Exchanger/279/1, but (1) keep the inlet duct and outlet duct 10' apart, and (2) this low tech HRV may freeze up in the winter as cold air is drawn across the heat

exchanger, freezing the moisture in the air exiting the house. Manufactured HRVs have built-in defrosters to offset this problem.

Creative American builders have suggested alternatives to HRVs that can do the job, are much less expensive, but have drawbacks.

- A small load can be easily met with a motel-style "Packaged Terminal Heat Pump (PTHP). These cost under $700 installed. They just plug in like a through-the-wall (TTW) air conditioner. One builder claims that "Amana makes a good one." Drawbacks: noisy, low COP (coefficient of performance) during cold spells, and no ECM fan (which means higher power draw).
- Another builder: "Let's say this is a two story house, and you want an HRV/ERV. Use one Panasonic WhisperComfort Spot ERV on each floor, $600 total. That's enough fresh air for up to 5 bedrooms, and no ductwork to install."

The old trick of using windows to provide fresh air is regarded as ineffective and inefficient It would require 4 window purges/day (all windows open), to ventilate a Passive House, during which you would lose considerable heat in the process. (http://passipedia.passiv.de/passipedia_en/planning/building_services/ventilation/basics/types_of_ventilation#purge_ventilation_through_windows).

2.3 Energy Efficiency

The Passive House standard for total energy consumption, qualified as primary energy loads, is $\leq$ 120 kWh/m^2/year (38.1 kBtu/sf/yr) or 16,729 kWh/yr for a 1,500 sq.ft. house. Using a primary energy factor of 3 for electricity in the U.S., this comes to an allowed plug load of 5,576 kWh/yr.

I calculate this number based on my possibly imperfect understanding of the PH standards. I subtracted the heating load of 2,091 kWh/yr from total allowed plug load of 5,576, leaving 3,485 kWh/yr at the plug, for a monthly non-heating power bill of only $29. This corresponds to 290 kwh/month to cover all non-heating uses, including summer cooling, HRV, appliances, cooking, domestic hot water, etc. This is a pretty stringent energy budget, and comes down to 9.5 kwh/day, or less than $1/day worth of electricity.

PV cannot be used as a way to meet this energy threshold under the Passive House standards. For an interesting alternative, see the pedal-powered kitchen: http://www.treehugger.com/files/2010/11/pedal-powered-kitchen-center.php.

2.4 Examples of Passive Houses

In addition to those already mentioned, more examples of Passive House designs can be found at:

http://www.passivehouse.us/passiveHouse/PHIUSProjects.html,

http://planetgreen.discovery.com/home-garden/readerschoice-winners-bestofgreen-designarchitecture.html, and

http://www.greenbuildingadvisor.com/green-homes, in the right-hand column under "**Job**blog."

2.5 Further Information on Passive House

Useful links can be found at: http://www.passivehouse.us/passiveHouse/Links.html.

PART 3. PROPOSED DESIGN FOR A PASSIVE HOUSE ON OUR LOT IN LEMONT

When designing, Buckminster Fuller urged us to consider the system one up from the one of interest. In *A Pattern Language*, Christopher Alexander moved in both directions, considering the smaller patterns that constitute the subject pattern as well as the broader patterns which affect the subject pattern. In her wonderful book *Gardening From the Heart*, Carol Olwell suggests we conceive of the house as an extension of the garden, rather than the other way around.

With these principles, we aim to counter the prevailing presumption that the house is a mere way station for humans on their trips to buy and sell in the great marketplace. Instead, the two of us want to supply our own sustenance, to subsist on our own actions in greater harmony with and cognizance of the living world around us. In particular, we want to get off industrial food and grow our own, use simple devices we can build and repair ourselves, turn off the flush toilet, and occupy ourselves and our friends at our place and our pace, thereby reducing the living we would otherwise have to earn in the destructive market economy to support the lifestyle of consumption that our market-driven culture defines and delivers for many of us, increasingly directly to our doors.

Therefore, in addition to designing a Passive House, we want also to consider how we can realize the following functional arrangements: food growing (biointensive + permaculture), storage, and preparation (with good diet and nutrition); waste water treatment – grey and black water – including humanure composting; the growing of plants rich in phytonutrients; preparation of plant-based compounds to promote well-being and to help with chronic or acute ailments; and facilities and occasions to share our experiences with others through internships, tours, talks, our website and professional assistance.

With these aims in mind, we continue with an analysis of the site, invoking elements of permaculture and biointensive design. From this we move to a scheme of how we might physically inhabit the site, what architects call the program. We then pose one answer to the question, "How would a structure employing Passive House principles look?" Other analyses and arrangements are possible. Our object is to work through how and why we arrived at this one, to stimulate discussion, and to gather feedback on our design.

We already have considerable knowledge and experience with our larger aims. We have created a biointensive mini-farm on the main property which we have run for the past 14 years. On it we grow 95% of our vegetables year-round, 60% of our fruit, 20% of our vegetable protein (but only 10% of our calories) for the two of us. We have spent the past 12 years or so retrofitting our old house, and have faced first hand various aspects of green design.

What our experience and knowledge have revealed to us is the importance of design constraints in helping reduce the infinitude of possibilities to a reasonable number of alternatives worthy of closer consideration. Thus, we grow our own food, which eliminates trips to restaurants, supermarkets, and CSAs. Our biointensive mini-farm stands for a school of thought in growing food. Therefore, we plant in beds, not rows; use hand tools not rototillers; amend our soils with compost not synthetic fertilizers. Similarly, our selecting a Passive House approach rules out a host of other possibilities. By converting features to design constraints, we make it easier to wade through and eliminate alternatives.

Another way to think about design is as manipulation of known and familiar patterns. In traditional cultures, whether examining house or rug design, you will find only a small number of patterns in any given region, and it is these that get manipulated or arranged in different ways. These patterns and their arrangements define that regional culture.

Similarly, solar design implies certain patterns – east-west orientation of buildings, south-facing roofs and windows, wide overhangs, placement of trees as sun and windbreaks, and so forth. We do not start with a blank canvas, nor do we want one.

We take our thinking here only so far. At this broad level, decisions on wall siding, interior appointments, furniture, appliances and other detailed considerations are outside our purview. What we want to examine here is the implications of certain ideas for this particular combination of climate, site and functions.

3.1 Eco-House Background and Vision

The Site: 0.28 acre lot in Lemont on the flank of Mt. Nittany. This view, taken from the southeast corner of Neo-Terra's mini-farm shows the fence edge (left), view to north (and to road), plus row of sugar maples on ascending slope along the east edge of the 80 ft wide x 150 ft deep property.

With the help of friends and family who were taken by her ideas and visions, Tania became shared owner of the 0.28 acre lot above ours in 2007. Her plans to expand our biointensive mini-farm onto the

lot necessitated on-site water and a small tool shed. Zoning, however, prohibits sheds and other such ancillary structures unless there is first a house on the site (presumably so the township can collect higher property taxes). This provided us with the impetus to consider designing and (ultimately) constructing an "eco-house," one based upon the best principles, greenest features, and cutting-edge technologies that passed our many layers of analysis.

The goal would be to use the eco-house as an experiment: to put into practice the greenest technologies appropriately integrated, monitor the performance of the ensemble, and then use the results to make improvements. We envisioned that we could house seasonal interns there to live and work with us on the backyard biointensive mini-farming as well as to engage them in hands-on projects in the community with clients of Neo-Terra. The eco-house would itself serve as a demonstration and test site for a wide array of possible technologies and practices.

For example, if you had human-powered appliances, would you use them? Here is an opportunity to try out such devices and assess their feasibility. If you like the technology, can you get others to try it? If you don't like it, why not? Could the device be improved? Re-engineered to something more practical? Many "good idea" inventions languish until good engineering addresses the reasons the device doesn't work well for people.

Similarly, solar ovens and solar food dehydrators are seemingly reasonable technologies that have not caught on. Could a combination oven/dehydration unit be constructed, tested and improved? In this manner, the eco-house residents would have the opportunity to innovate along with the staff of Neo-Terra. We note here that while many "green" technologies exist, few are found in conventional homes and construction. With energy costs escalating and new incentives for "greener" design, there are new opportunities to engage a broader audience. While personal tastes in home design vary considerably, could the eco-house be the kind of house that most of the visitors to it point to and say definitively "*This* is the kind of house I really want to live in," and, if so, would it be "what we all could have and should have?"

The eco-house design is motivated by a desire to live in healthier ways, integrating plants and people (and animals, if desired) in sensible ways that mimic healthy natural systems. Why send your organic nutrients to the sewer when they can be recycled via dry composting toilets? (See Joe Jenkins, *The Humanure Handbook.*) Why send your graywater to the sewer when it can be treated and used on site to nourish gardens? (For this, consider Art Ludwig's, *Create an Oasis with Greywater.*) Why not make the best and most appropriate use of passive solar energy? How can we best use the gifts of the land? (Recall Bill Mollison's path-breaking book, *Permaculture.*) How can the house serve as an extension of the garden? (Carol Olwell inspires with *Gardening From the Heart.*) How can we reduce our Ecological Footprint with an eco-house?

In *Solviva*, author Anna Edey reflects on how plants provide us with fresh, clean air and how this restores our stale, often polluted, indoor environment. Edey was inspired by the first bioshelters constructed at the New Alchemy Institute – passive solar greenhouses with a complex internal ecosystem of plants, aquatics, insects and animals. Edey's own *Solviva* bioshelter built upon some of the New Alchemy findings, and she housed sheep, rabbits and chickens through the long New England winters, while also growing greens for market. Her experience, which she shares in her book, is inspiring and educational, and the latter is important because we can learn from her mistakes. For

example, she discovered that ammonia from the manures of her animals was detrimental to the health of the tomato plants she was growing. Another problem apparent to outsiders was the destructive effect of indoor moisture on wooden building materials.

Darrell Frey is another person who was inspired by the New Alchemy bioshelters and Edey's work. He designed a large bioshelter for the commercial production of organic greens in winter. (See Darrell Frey, *Bioshelter Market Garden* and www.bioshelter.com.) Darrell's Three Sisters Bioshelter was the original inspiration for Tania's initial eco-house design for two reasons: in the dead of winter it was a lush paradise, and Darrell commented that if he had known how well it was going to turn out and how nice it would be in winter, he would have built his home into the north side of the structure (where animals are typically bedded).

Darrell's offhand comment got the wheels turning in Tania's mind about how to merge the home with a bioshelter. "I want to live in THAT," Tania thought. However, what seems possible on the surface is not necessarily easy to achieve. The bioshelter is a very moist environment, as are all plant-filled greenhouses. Darrell's structure is very large compared to a conventional house, and the passive solar

heating, which is regulated by available thermal mass and clever circulation of heat, is easier to achieve in a structure larger than in a typical house.

Thermal mass is the key to the proper winter heating of the bioshelter, and because such a huge area is glazed (R-values of 1 or 2), the heat collected in daytime is quickly lost at night. Consequently, multiple sources of heat are required.

Darrell reported that while the temperature could get quite toasty on a sunny day in winter, most of the time the bioshelter temperatures hovered in the 50's. On cloudy winter days, it felt chilly. The deep soil beds, concrete block walls and gravel foundation of the bioshelter absorbed heat on sunny days. 55-gallon drums of water, and water filling a large concrete tank in the center of the greenhouse also stored some of this passive solar heat. Chickens housed on the east end of the bioshelter contributed BTU's from their body heat. These sources alone heated the bioshelter sufficiently that Darrell reported he only had to fire up the snorkel stove in the concrete tank of water a handful of times during the coldest days of the winter to keep the temperature up to par.

While he designed an area for bedding animals in the north corridor of the bioshelter structure as well as large compost bins (whose heat would be piped under the grow-beds), he never implemented the use of these features: they were an additional hassle that proved unnecessary.

Of course the bioshelter bakes in the summertime. Darrell plants the beds to cover crops, opens the doors and roof vents, and uses a large fan to draw the air through the structure in every attempt to cool the place. The problem of course is the glazing. No one removes the glazing on a greenhouse. On a structure the size of the Three Sisters Bioshelter, this is too enormous a task to consider, but one can imagine it to be more feasible for a home-scale bioshelter.

It is important to note that the north wall (including the north roof section) of the bioshelter is thickly insulated. Imagine then that the north wall of a home-scale bioshelter is the well-insulated house itself!

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

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

"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 it's warm outside."

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

With Paul's comment in mind, we try to get past "eco-snobbery" in the preliminary design process. Tania was able to take her ideas only so far. She got stuck when considering how to design the house part and what materials to use. As a materials scientist, she knew about the toxicity and embodied energy involved in manufacturing many materials, and these had to be weighed against durability, thermal performance, off-gassing, ability to handle moisture, flammability, and so forth. Walls, roofing, and all insulation materials were problematic.

While director of Penn State's Center for Sustainability, Tania had constructed (with students) small structures with earthen and natural materials: plastered strawbale, "light clay" construction (a mix of clay slip and straw packed into wall cavity forms), and cob (sand, clay and straw). We have an abundance of subsoil clay on the western edge of Mt. Nittany, but would have to import straw. But does this make the most sense in the long run? Plastered strawbale is the only earthen technique that makes some sense in our climate as long as there are large roof overhangs that help to keep the walls dry. The R-value of the strawbale wall depends on the packing density of the bales and other factors that cannot be controlled easily. Thus, you could have a 20-inch thick wall with an R-value ranging from 35 to 55.

On a small lot, wall thickness of structures becomes a major consideration. In fact working with a small lot can be challenging in comparison to open acreage where you are less restricted, but the principles of design are largely the same. The constraints imposed by small systems can aid in good ecological design whereas when unconstrained, there is a temptation to be more wasteful, less thoughtful about how we are effectively utilizing the space. However, a non-load bearing plastered strawbale house might still be a contender as a possible wall material if the lot size was larger. In our case it is not.

The Passive House concepts and standards have now helped clarify our thinking. While not open to it at first, Tania reconsidered SIPs (structural integrated panels typically filled with foam). Filled with a closed-cell, non-CFC, non-HCFC urethane foam, the long-term R-value would settle around 6 - 6.5 per inch (sometimes called the "cured" R-value). Ten-inches of this foam would then yield R-60 to R-65 wall. Sandwiched in SIPs and cut to exact specifications at the factory, the wall sections would be under a foot thick and would join precisely, eliminating air infiltration.

While it is a petroleum product, urethane foam, like many other foams, is generated from a very small amount of petroleum. A small amount of liquid (which consists of mostly non-petroleum liquid components) is sprayed thinly and foams up to fill the cavity. You may be burning more petroleum driving your car for a week than the amount of petroleum that could get "parked" into SIPs or wall cavity that will easily pay for itself in energy savings. If ever there was a respectable use for the precious and limited resource of petroleum, foam insulation in Passive House structures is a good candidate.

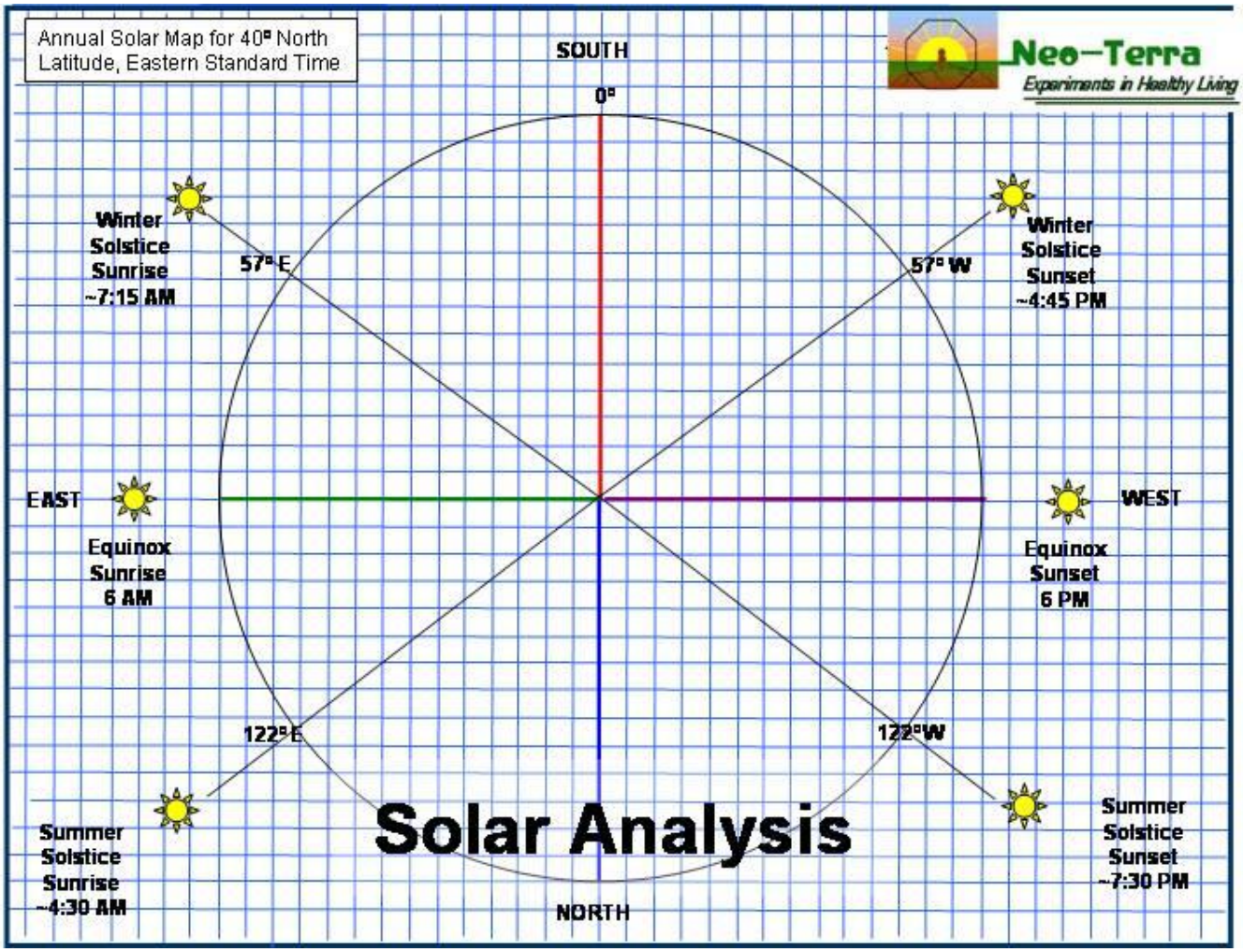
The only eco-house goal that is immediately not possible within the shell of the Passive House is the root cellar, which Tania had hoped to locate in the basement. The super-insulated foundation and basement walls of a Passive House preclude the "cool basement" conditions and necessary air vents

required for a basement root cellar. The simple solution is to move the root cellar outside, where it's been for centuries anyway!

It is also true that we are not aware of any Passive House that has been joined to a greenhouse structure. The effect this would have on Passive House thermal performance must be assessed through careful analysis of the combined structure using the specially designed Passive House Planning Package software (PHPP). We have not yet undertaken this analysis, and until such analysis is done, we cannot conclude that the Passive House plus bioshelter combination is feasible.

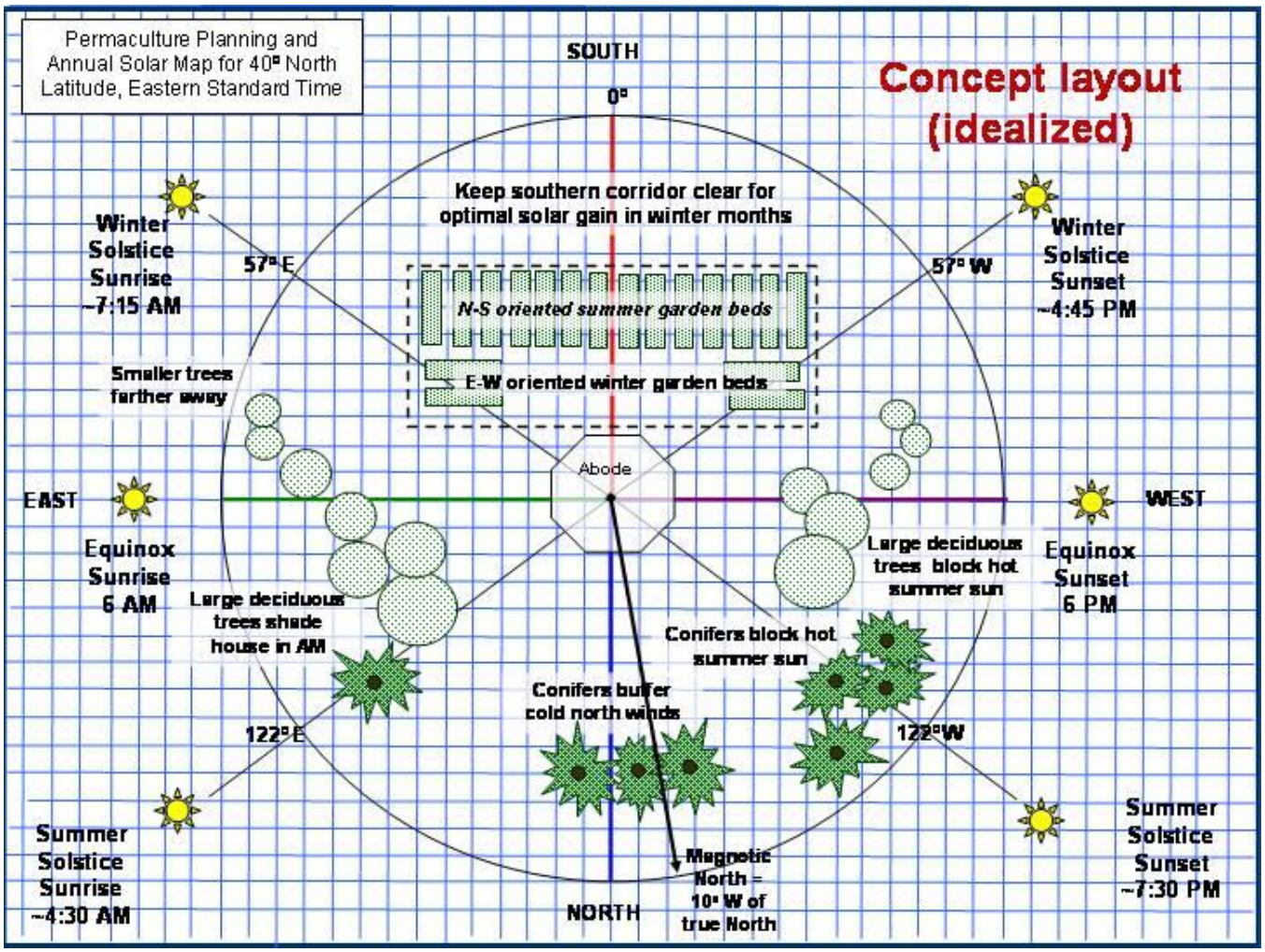
3.2 Site Analysis

Solar Analysis. Details of the eco-house design hinge upon site analysis. While the Passive House utilizes some passive solar heat gain, it does not rely upon it. However, wintertime passive solar heating of a greenhouse requires careful consideration of available solar insolation. The solar analysis diagram below serves as a first step in orienting us to the sun's position in the sky at different times of the year.



If you imagine yourself standing at the center of the circle on the diagram and facing south, you can see the large variation in the sun's position from summer to winter. If an azimuthal angle is added to show the sun's position above the plane of the diagram, for 40° north latitude, the sun is about 28° above the southern horizon at noon on the winter solstice, and about 73° above the southern horizon at noon on the summer solstice. At all other times it is somewhere between. Sun angle charts can be found online (see for example, http://solardat.uoregon.edu/SunChartProgram.html), but if you can remember these extremes in location of the sun, you can generally think through a basic solar analysis.

Next we present an idealized layout for any site. Consider the site where your home is. The "abode" at the center is represented by an octagon to indicate that your own house might face any direction.



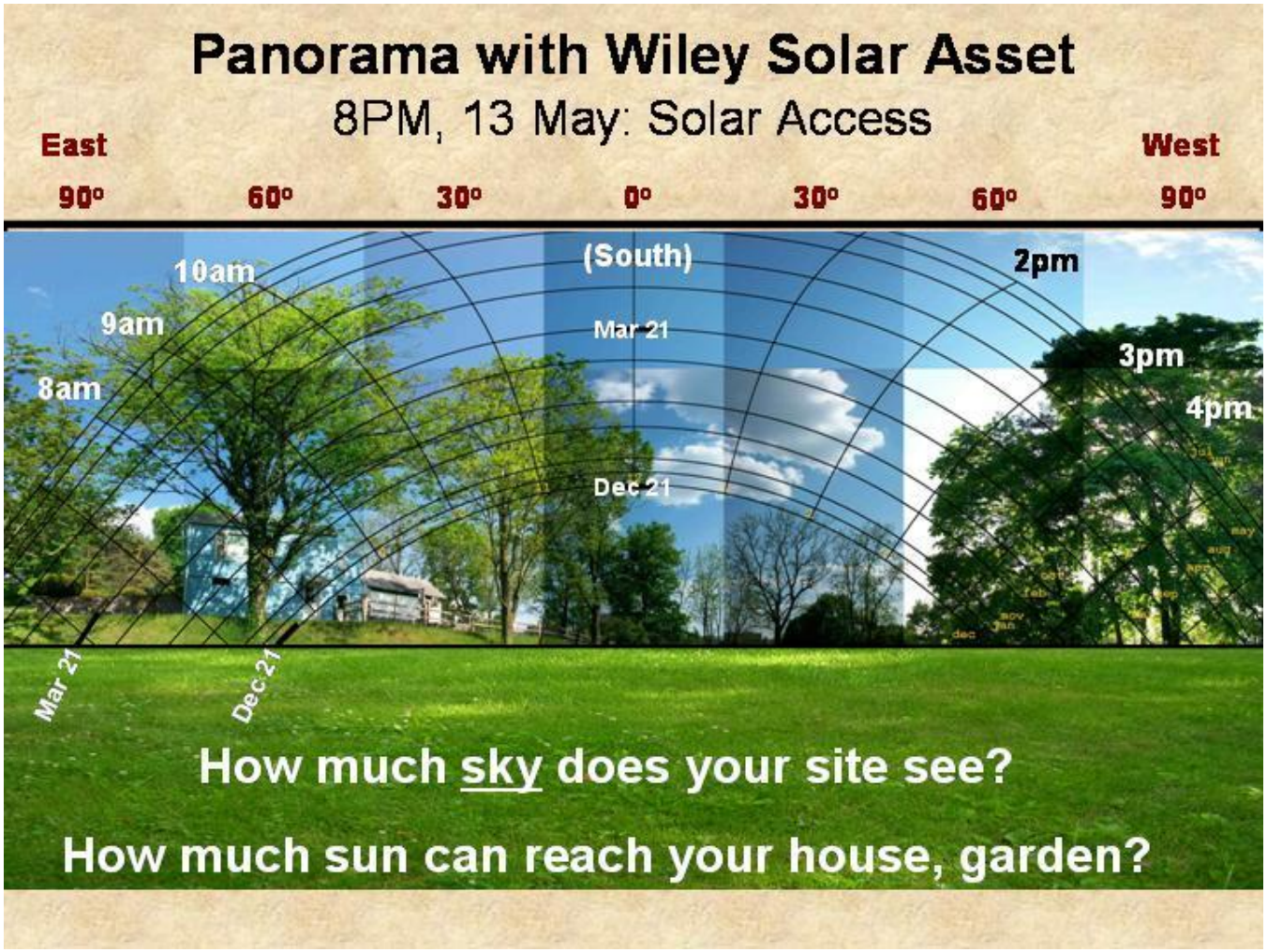
The "ideal" Permaculture layout at and around a building (Permaculture Zones 0 and 1), would make the best use of the sun if:

- These two zones are fully open to the sun during all seasons.
- Large deciduous trees are planted in the northeast and northwest quadrants to keep the house cool in the summer months while not shading the main gardens.
- Conifers can be planted to help block wintertime prevailing winds, which are typically from the north and west in Pennsylvania, but may vary with your topography and state.

- Shorter trees, such as fruit trees, can be planted to the east and west of the house as long as they are not shading the house from the sun around the equinox, as this is a key turning point in the weather and typically more solar heat is still desirable at that time. Taller trees can be planted east and west as long as they are further away from the house.

No matter where south is relative to your house, *if* you can arrange the landscape such that the southern corridor is open to the winter and summer sun, then that is the ideal place for your gardens. Trees should not occupy the southern corridors if you wish to make good use of solar energy in both home and garden. The myth of planting deciduous trees to the south of the house must be dispelled: they will not shade the house in summer and their branches will substantially reduce solar insolation in winter. Of course it is rarely the case that your land will offer this idealized condition (regardless of the direction your house faces).

The eco-house lot is one such non-idealized location: mature sugar maples and black walnuts line the perimeter as are visible in this panoramic composite view taken with the Wiley Solar Asset. In May, when the photos were taken, the maples have leafed out but the black walnut trees along the southern edge are still bare.



The Solar Asset helps you evaluate numerically how much sky your site "sees." By placing the camera at the tentative location of a house, you can assess how much sun the house will receive. The Solar Asset software generates a sun chart on top of the photo panorama as shown above. We have added in, using white text, the time and dates of a few of the lines on the chart.

If you have never seen a sun angle chart before, this is your quick introduction to one. The sun rises on the left in the location where the arc hits the ground, and it sets to the right in the west where the same arc hits the ground. The lowest arc is for the winter solstice (Dec 21) and the highest arc (which exceeds the photo height) is for the summer solstice (June 21). All the other months are represented by the arcs in-between. The equinoxes share the same line (marked in white as March 21, but this is also the arc for Sept. 21). The sun's position along any given arc varies with the time of day, with whole hours being denoted by the vertically rising black lines on the sun chart. You will notice that at 8 am on the Dec 21st curve, the sun is barely above the horizon, whereas at 8 am on June 21st, it is already quite high in the sky.

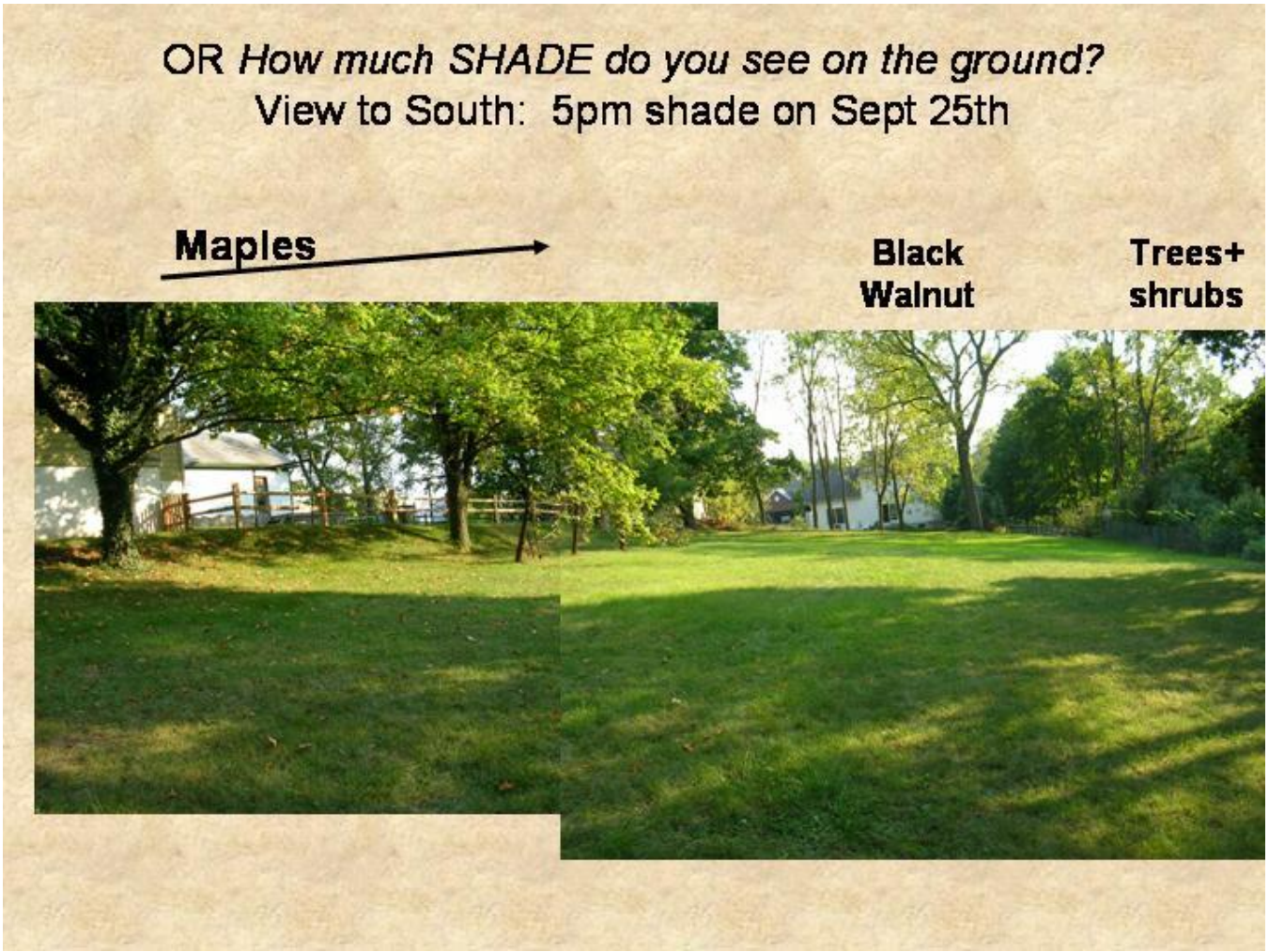
The Solar Asset software also produces a numerical analysis. An excerpt from the MS Excel spreadsheet below summarizes the solar data taken from the panoramic composite photo.

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	Total=773
			shading factor = 0.69		

Because of the tall trees surrounding the property, about a third of the lot is shaded all the time, as can be seen from the "light shaded %" column. There is an overall "shading factor" listed at the bottom of the spreadsheet of 0.69. *The shading factor is the amount of sunlight admitted to the site in comparison to full sun on that site*. Therefore the shading factor = 1.00 if you have full sun, nothing to obstruct sunlight. To qualify for most solar tax credits, you must prove that the site has a shading factor > 0.90. Clearly, our lot and proposed eco-house site is not ideal for good solar access; this information will have to be used in more detailed calculations for the proposed Passive House and greenhouse portions of our structure.

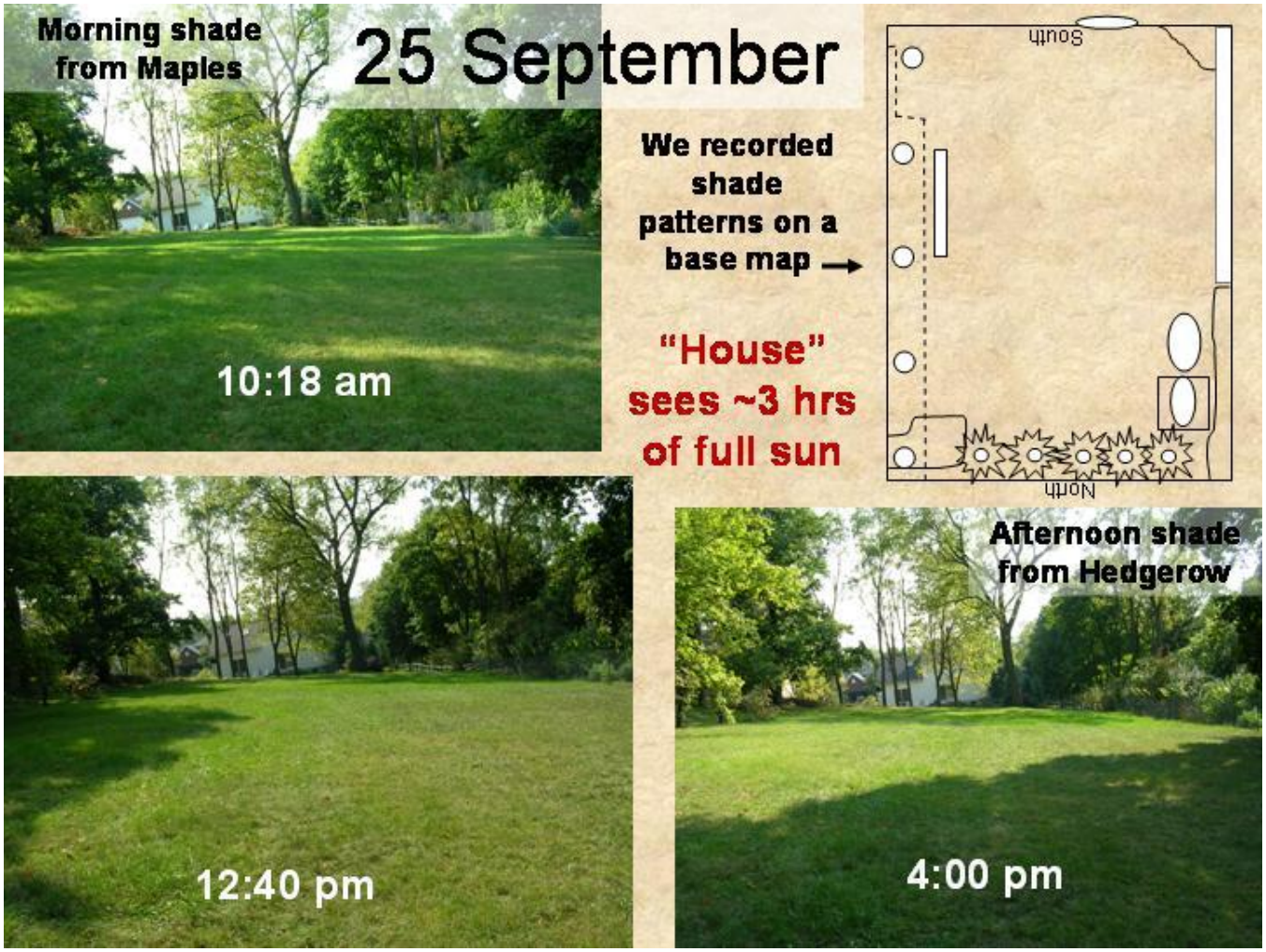
The hours of sunlight per day (column 3) multiplied by the shading factor yield (column 4) the *available* sunlight hours: those useful for collecting solar energy. From these two columns, the anticipated electrical energy (kW-hrs) that can be collected from the sun per kilowatt of "capacity" of a solar photovoltaic (PV) panel are calculated in the last two columns. The "potential" energy of column 5, when corrected by the shading factor, yields the energy available (column 6) per kW of peak-rated PV panel capacity that you could reasonably expect to collect under these conditions. For the eco-house site, it's not very much. The Solar Asset spreadsheet also provides a summary of available sunlight as a function of time of day for each month (data not shown here).

If you don't have a Wiley Solar Asset, you can still get a good sense of how much sun falls on a site by drawing your own shade maps. Once a month (aim for around the 21st to be able to get data on the equinoxes and solstices) visit your proposed site every hour on the hour and sketch on a set of base maps where the shade lines are relative to other landmarks around the site. The photo below shows the evening shade near the fall equinox, which is about the time you want to make sure you're starting to get more sun on your site to gear up for winter growing. Of course you have to take your shade data on a sunny day. If the day starts out sunny and becomes cloudy, you can finish taking the data within the next couple of days, whenever the sun next shines.



The photos below show how the maples to the east cast heavy shade on the potential house site (foreground) until nearly 1 pm, but that shade no sooner subsides when the shade from the hedgerow on the west side creeps in and has nearly eclipsed the site by 4 pm. It is easy to see how the Solar Asset arrives at an average 3.28 hrs/day of available sunlight in September.

Tania completed a set of base maps showing shade line sketches on the site for one day out of each month for a year. She also documented the shade with photos, but because of the angle at which each photo is taken, it is hard to gauge the true location of a given shade line until you compare it with photos from one or more other locations that show it… that is, the perspective of a camera held by short person yields a photo that distorts the shade on the ground, so some common sense must be used when trying to interpret photos.



The next two photo sets show the seriousness of shade from deciduous trees in winter.

Shade Factors: Even in Winter

9 AM

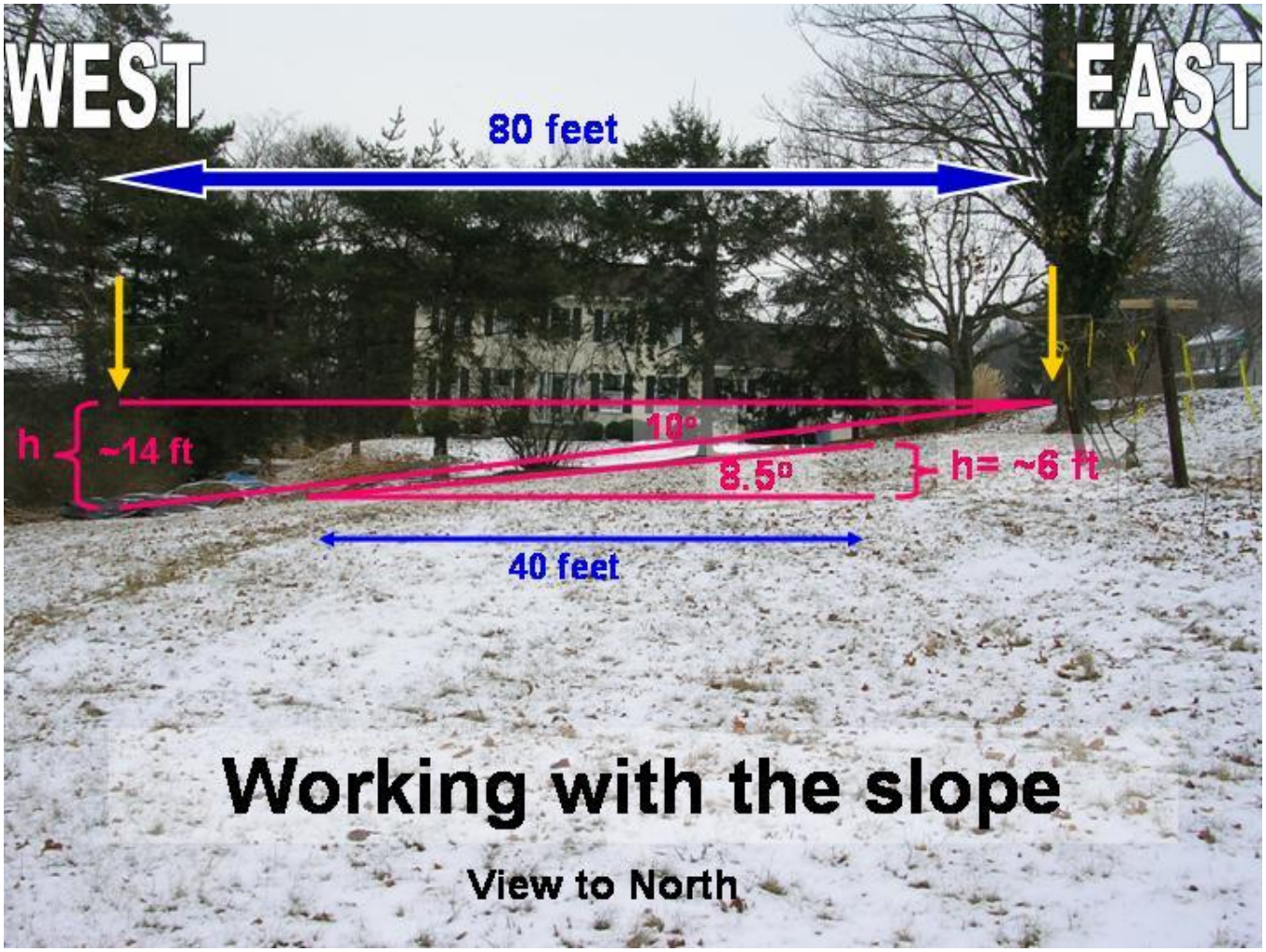
vs

1 PM

Photos: 20 January 2008

In January, the sun rises quite late and is obstructed by nearby buildings. It only clears the tree tops and floods the eco-house site with full sun around 1 pm. The shade lines from trees are easier to sketch on fresh snowfall.

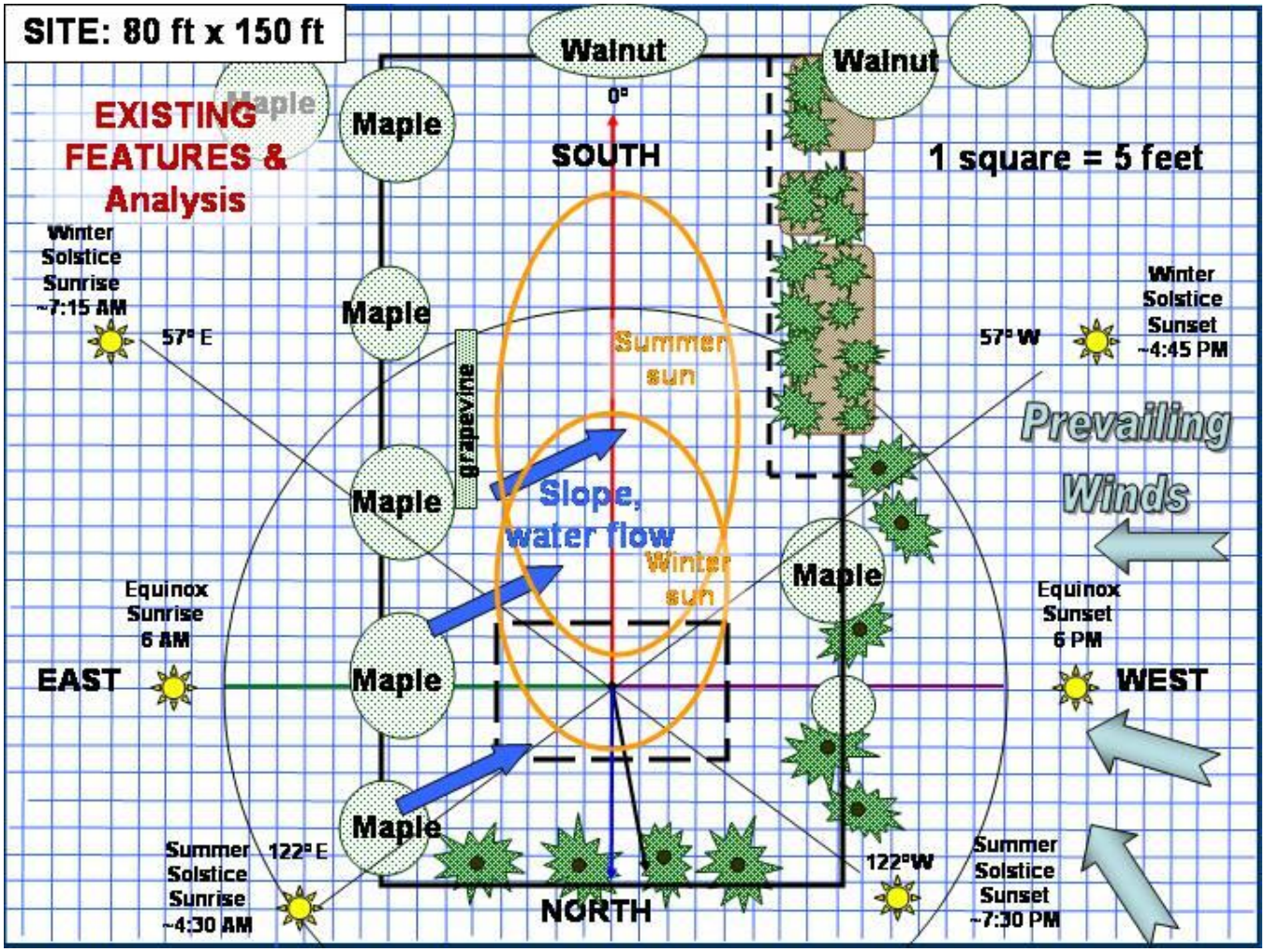
Slope Analysis. The next key aspect to analyze is the slope of the land. If you have a flat piece of land, be grateful!



Ideally we want to be able to work *with* the natural slope, not against it. The slope will affect the flow of water, the flow of activity, the layout of the garden beds and more. Slopes can provide the opportunity to create earth bermed structures or terraced formations.

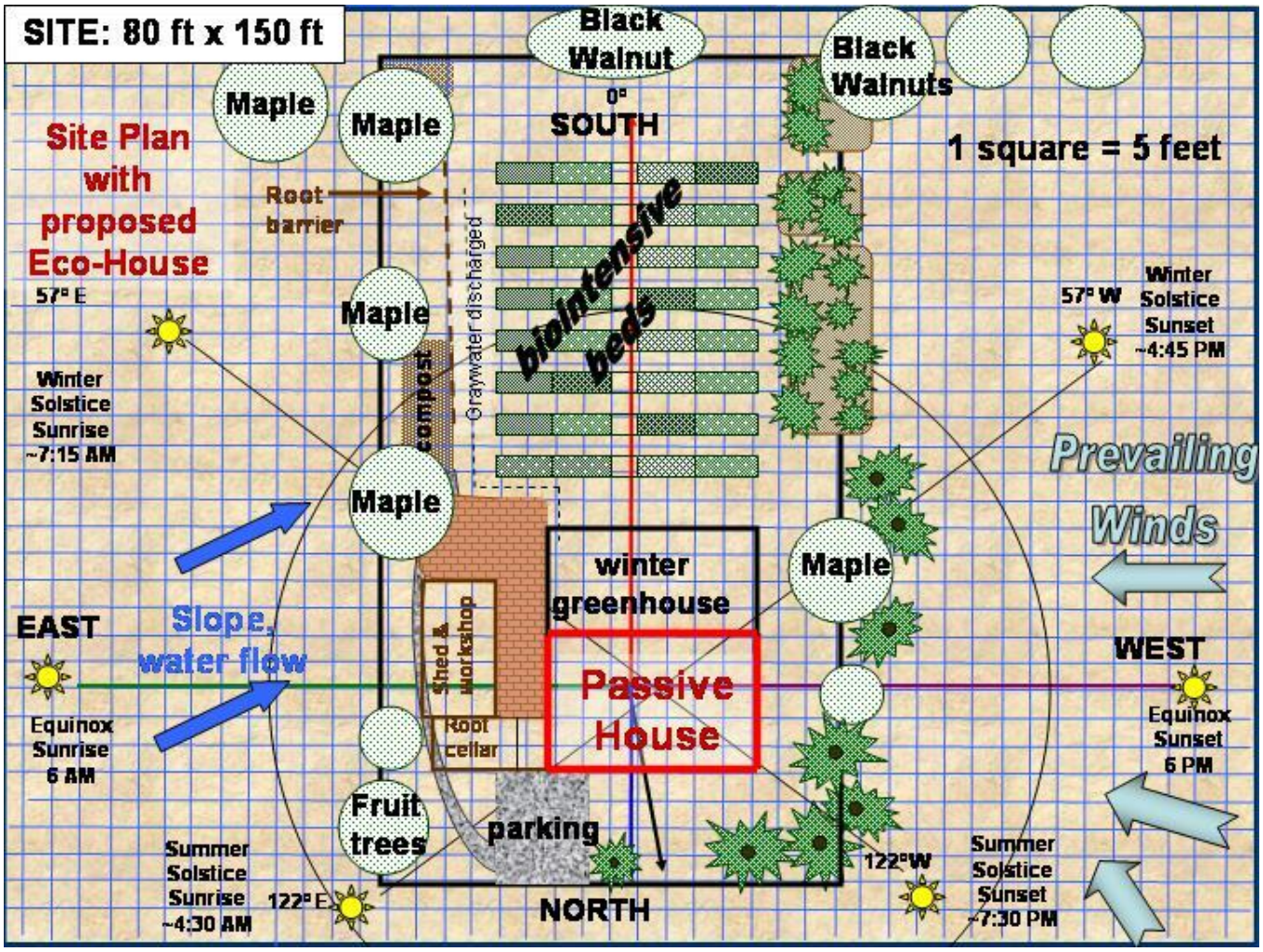
Site Map: On the site map below we combine the information we have gathered and plot it to scale on a grid. The site map should denote key features of the landscape and natural systems. Our site map indicates the key regions (orange ellipses) of sunlight in summer and winter; the lot has a roughly 8° westward slope (steeper along the east edge) and scant 3° southward slope, hence the slope and water flow angle west-southwest. The black dashed-line rectangle is the rough location of a house, and the

solar analysis centers on this. Neo-Terra's fenced fruit beds along the southwest edge already occupy some of the new lot.



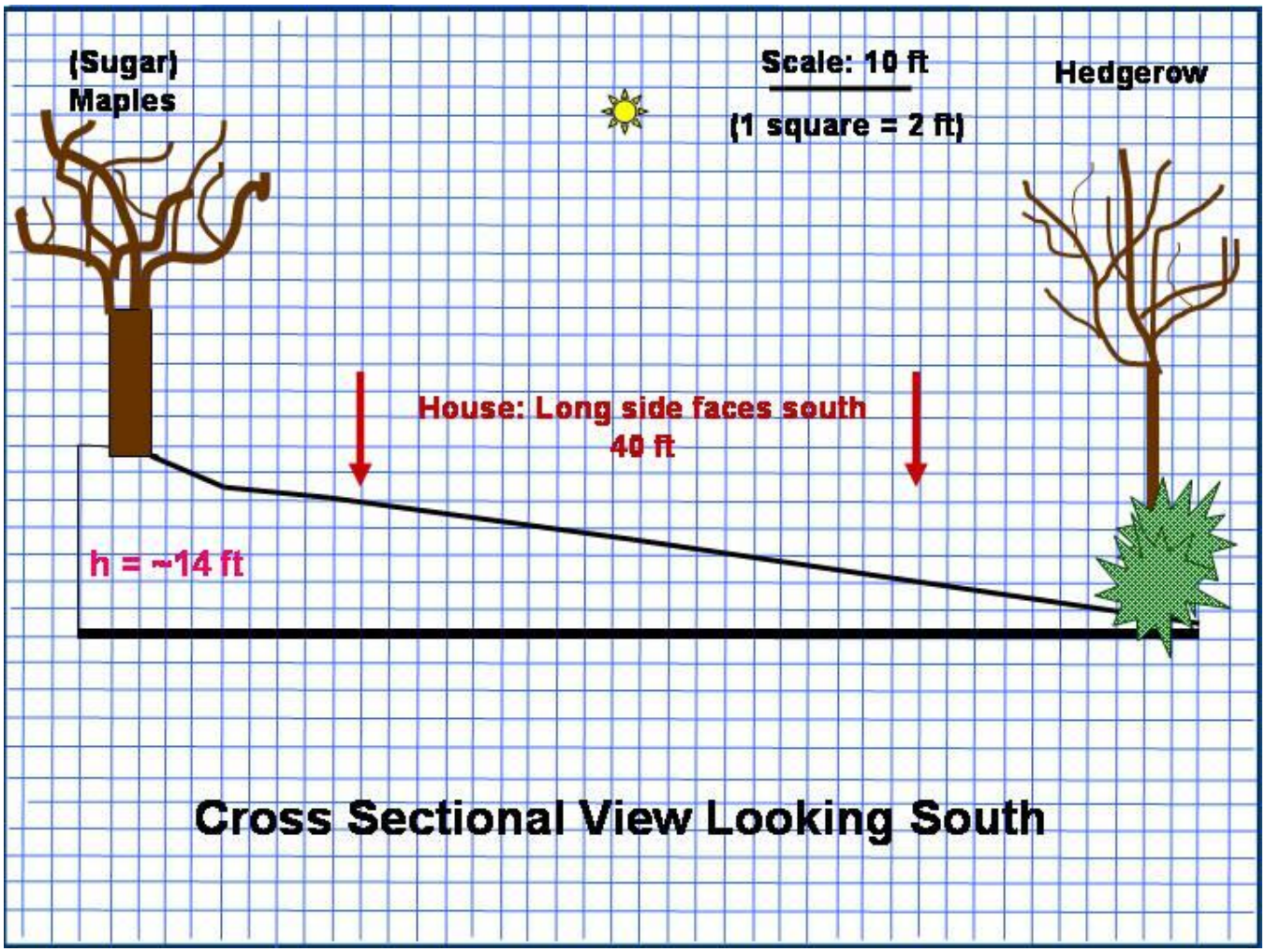
We next present a proposed site map that would incorporate the eco-house and other key features for a biointensive mini-farm. We have made the following key changes:

- Removed two sugar maple trees. House construction would destroy the root structure of one, and the other near the road was decapitated years ago and is in decline. We would plant another tree nearby.
- Added a workshop and root cellar, built into the slope, with roofs draining downhill.
- Removed the conifers along the north edge, as they were decapitated years ago because of the power lines along the road. We are considering planting a shorter pignoli, and a white pine (for its acidic needles) back from the northwest corner.
- Added a short gravel (or porous paver) parking area to minimize the impact of the car on the site and to reduce site runoff.
- Installed a 2' root barrier along the east edge of the mini-farm against the surface-feeding roots of the maple trees.



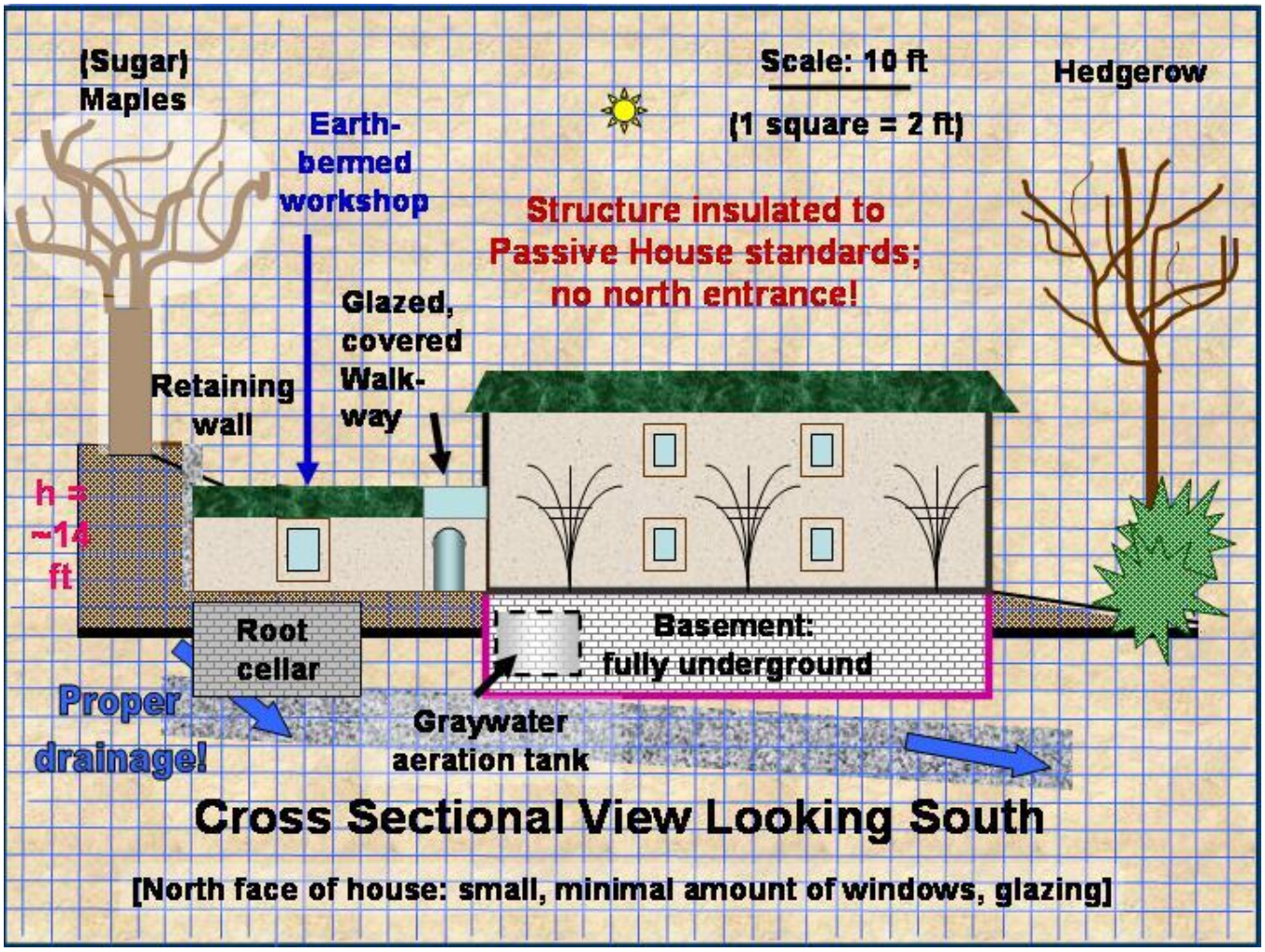
The rest of the features are self-explanatory. A good size level patio is very helpful to have available for various projects. Also, an inspection of most of the houses on our street in Lemont revealed that the homes have their driveways on the upper side of their sloped properties, and no one uses their front doors, if they have any. Nearly all enter the home though an east-side entrance next to the driveway. Thus, we took this into consideration in placing the parking area as well as house entrance.

To get a better sense of how we might nest this configuration into the slope on the site, we first show a cross-section of the site looking south:



There are five maple trees along the east edge, all in a line as you look at it from the road.

It is very common in our area to see the houses jutting out from the sloped landscape like ugly monoliths. The photo to the right is what we DO NOT want! To handle this, we propose sinking the entire basement level *below the natural ground level* for the *lower* (west) edge of our proposed eco-house, and compensating for the sloping terrain to the east of this by excavating out as needed. Michael Oehler conceived of the "uphill patio" in his *$50 and Up Underground House Book*, the understanding of which has fed into our thinking, shown next.



For the cold northeast, it is best that the Passive House not have a north-face entrance. In fact, the Passive House has very small windows everywhere except along the south face. In the diagram above, the bareness of the front wall is filled in with fanning trellises for shade-loving plants in summer.

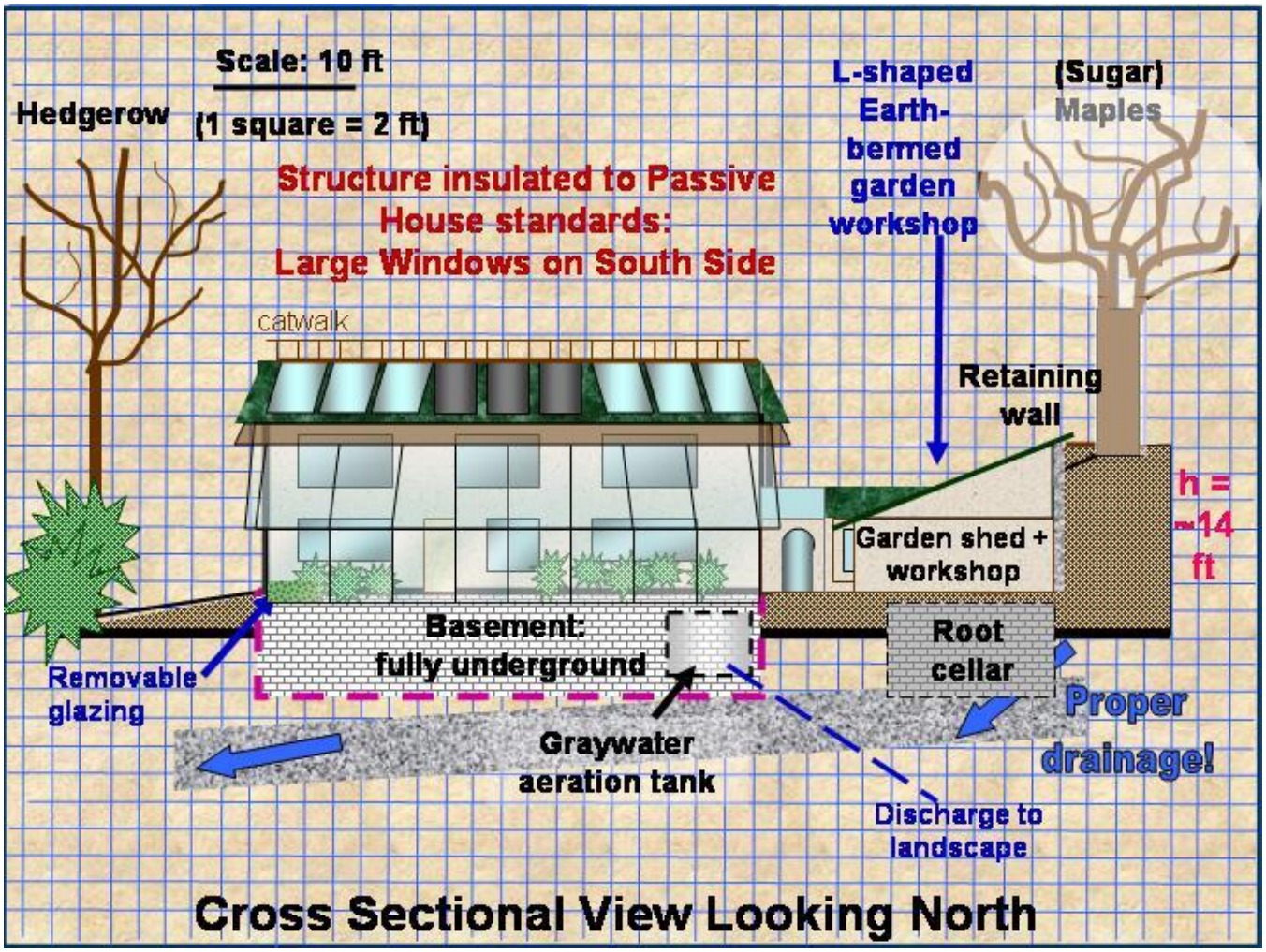
The main entrance to the house will be from the east side (the plan view will clarify this detail). The earth-bermed workshop to the left is not an insulated structure. In fact, this could be made of "light clay" earthen construction to make use of some of the on-site clay and provide an educational workshop opportunity.

The sugar maple immediately to the left of the house will be removed, but there will still be sugar maples visible from this viewpoint further along the east edge of the property. This removal is denoted by the ghost-white overlay on the tree in the diagram.

Vegetated "green" roofs are not part of Passive House design. These do not provide any additional insulating value to the structure in winter, their shallow angle and rough surface do not shed snow, and they necessitate additional structural trusses and reinforcement to handle the possible weight load. On the other hand, they can be very attractive, aid in blending the structure with the natural landscape –

especially since the uphill neighbors will look down onto the eco-house roof! – and help to mitigate stormwater runoff (while also cleaning the water). Thus, the roof is colored green to denote implementing this option. Alternatively we would likely use a green-colored metal roof.

Not shown in this diagram, but shown in the next one, is the idea of adding a catwalk to the roof to permit easy access to the vegetated roof (it requires some maintenance and care) as well as to access the south-facing active solar panel components.

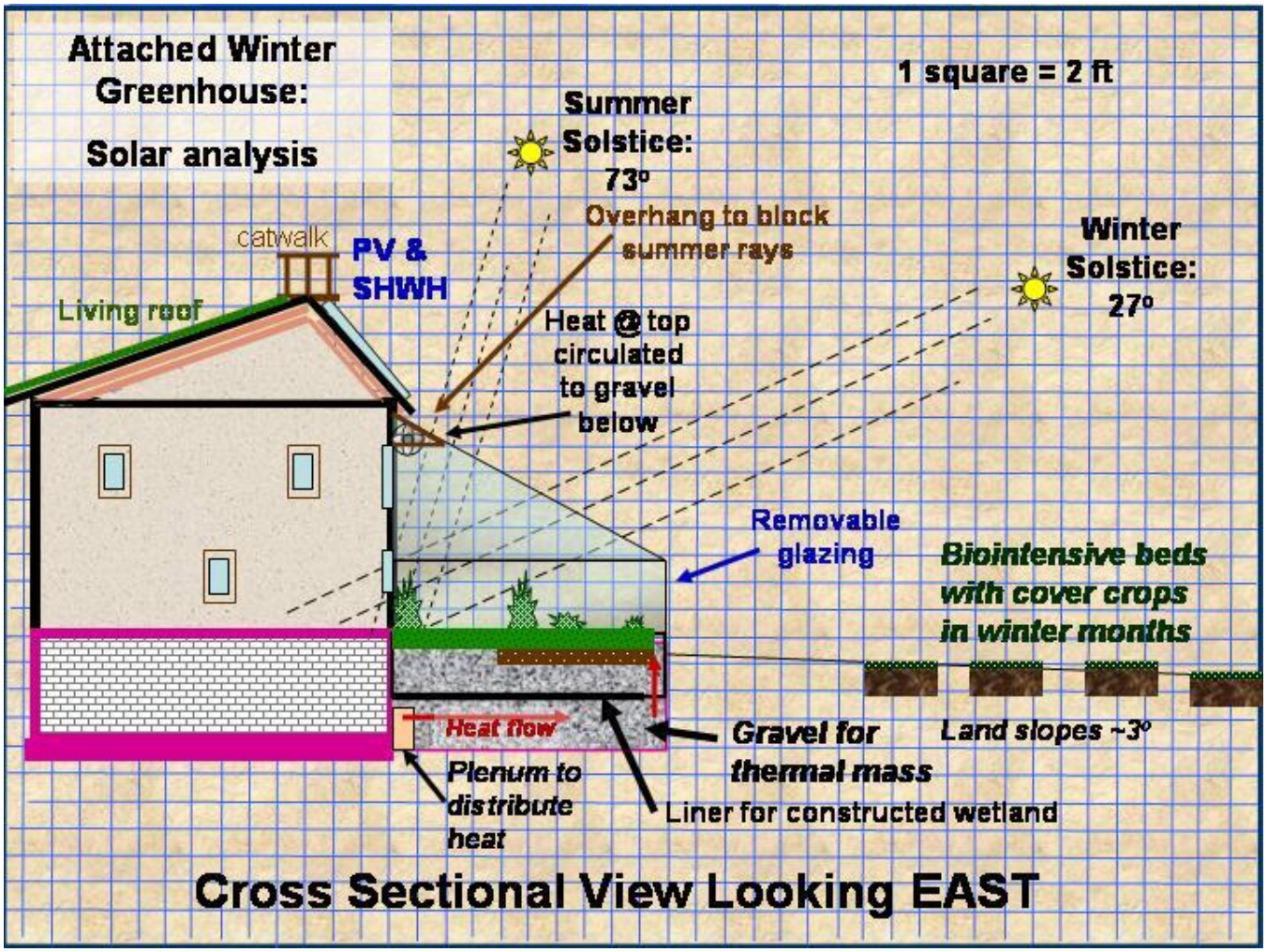


The south face of the structure in winter shows the glazed greenhouse over the large south-facing windows of the Passive House. Since the glazing will overheat the interior in summer, the plan is to innovate a removable glazing system. (Tania has an idea in mind to fabricate and test "proof of concept".) If there is such as system in existence already, we have not come across it.

Unlike sunrooms or solar greenhouses whose wintertime purpose is to collect heat to warm the house, the use of this greenhouse, akin to a bioshelter means it will be an extremely humid environment. The heat recovery ventilators (HRVs) in the house will *not* draw air from here because it is too moist, but, again, this provides an opportunity for innovation if someone in Germany hasn't already figured it out.

The south face shows photovoltaic and solar hot water heating panels mounted on the 45° sloped roof as well as the catwalk previously mentioned to use to service them. Access to the catwalk would likely be from a ladder that is stored in the garden shed.

Graywater from the house can be treated on site in a number of ways. The simplest, according to Al White of Millerton, PA (www.bestcompostingtoilet.com) is to collect it in a tank and super-aerate it. Aerobic microorganisms proliferate and digest the wastes; it can then be discharged to the landscape. This is shown in the diagram above. In the cross-sectional view below, we show in the greenhouse a lined (contained) constructed wetland for graywater treatment.

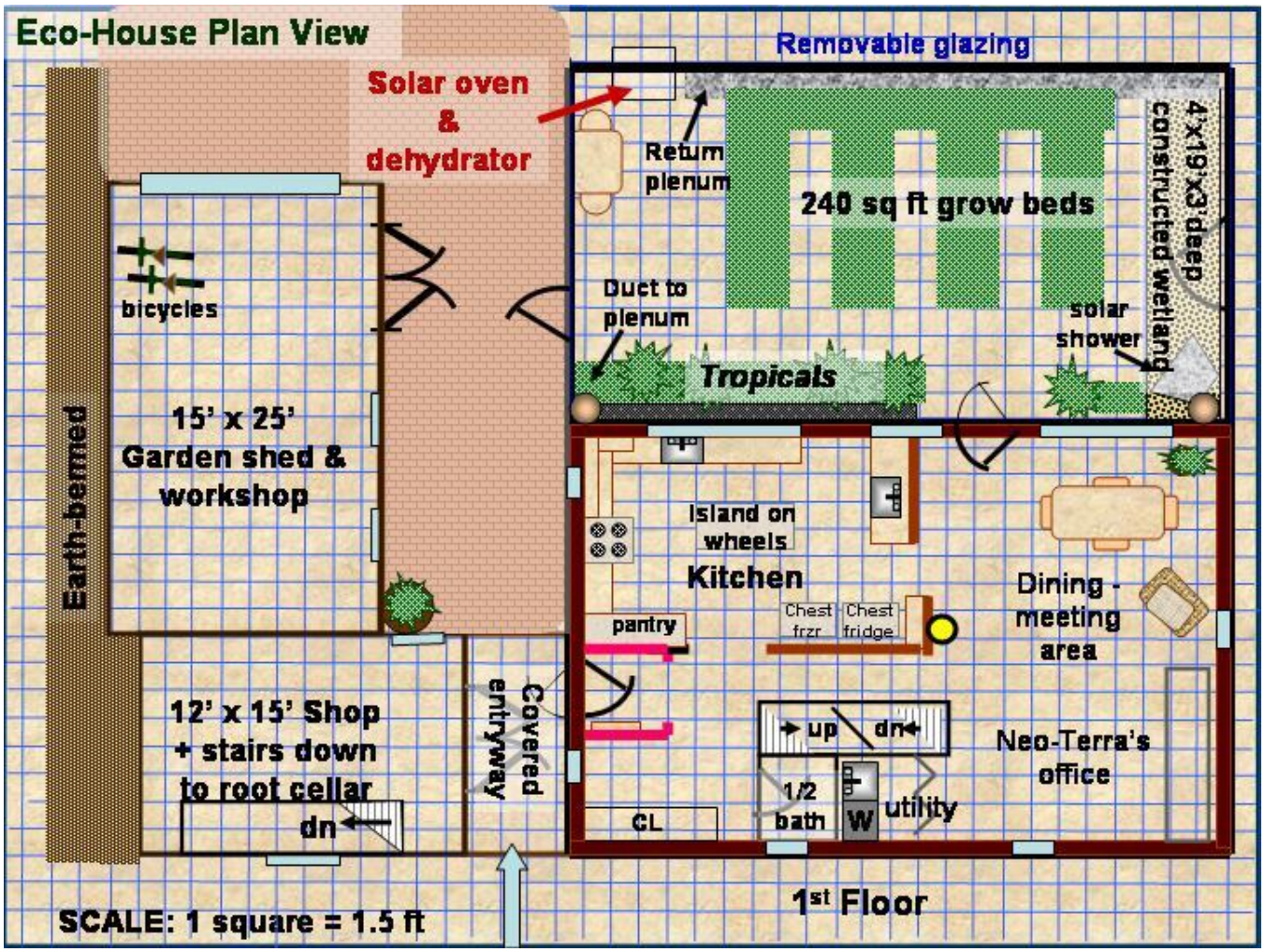


Constructed wetlands can be attractive and functional, but may not be necessary in addition to the graywater aeration tank. The original idea was to have all of the graywater filter first through the wetland and then to the tank for what is called "final polishing" – the last little bit of cleaning the water – before discharging it to the landscape. The wetlands would also serve as good thermal mass for the wintertime performance of the greenhouse, storing a lot of heat in its three feet depth of water and gravel.

In both the Saunders' 100% passive solar house designs (William Schurcliff, *Super Solar Houses*) and in a 1000 sq. ft Massachusetts "green" greenhouse experiment (http://www-unix.oit.umass.edu/~caffery/greenhouse/index.html), the designers collected warm air and directed it through a duct down along the north wall (of the greenhouse, in our case) and down to a distribution plenum in the gravel, where heat would then flow in a gravel bed below the house or greenhouse floor from north to south. The return plenum would be up through a dry gravel bed along the south edge of the structure. This was reported to work well and we will try it here. In the above diagram, a small fan symbol at the peak of the greenhouse roof denotes that the heat will be directed down through two ducts to the subsurface plenum. The red arrows in the gravel denote the flow of heat from the plenum, through the gravel and up the south edge.

The cross-sectional view also allow us to look at the noontime sun angles to aid in decisions about roof overhangs and solar insolation calculations.

A tentative plan view of the main buildings on the site helps tie things together:

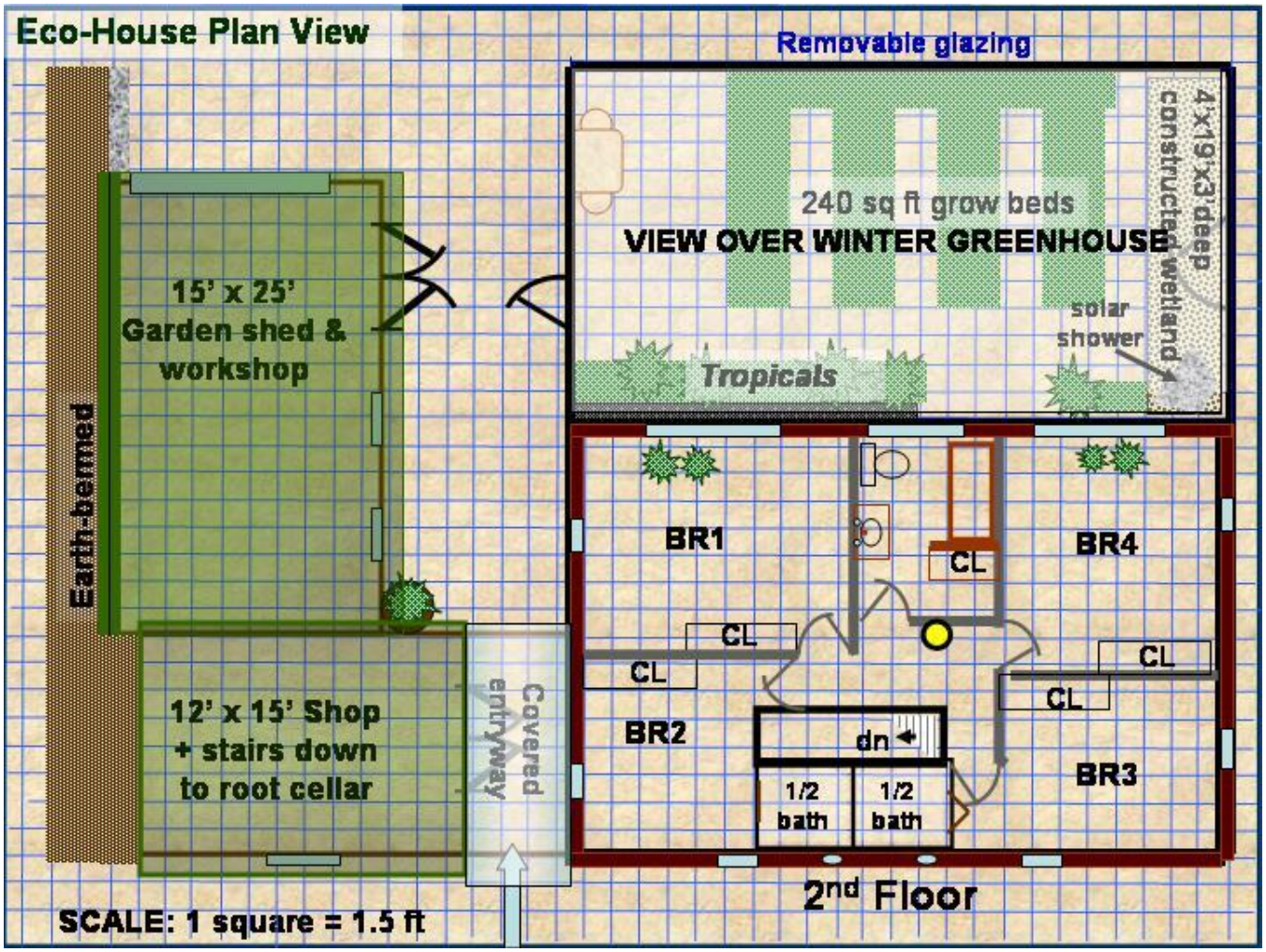


We find that a lot of our time is spent in the kitchen, especially in the summertime. If we are not preparing meals or cleaning up after one, we are doing something with our produce. The kitchen is

really the heart of the operation and should be the most easily accessible room from the outdoors. Ideally we want it to be a pleasant place to work, brightly illuminated with sunshine. Some unusual things Tania would like to try in the kitchen include installing and testing pedal-powered appliances, and using separate DC-powered chest refrigerator and chest freezer (if sufficient PV power is feasible on the site).

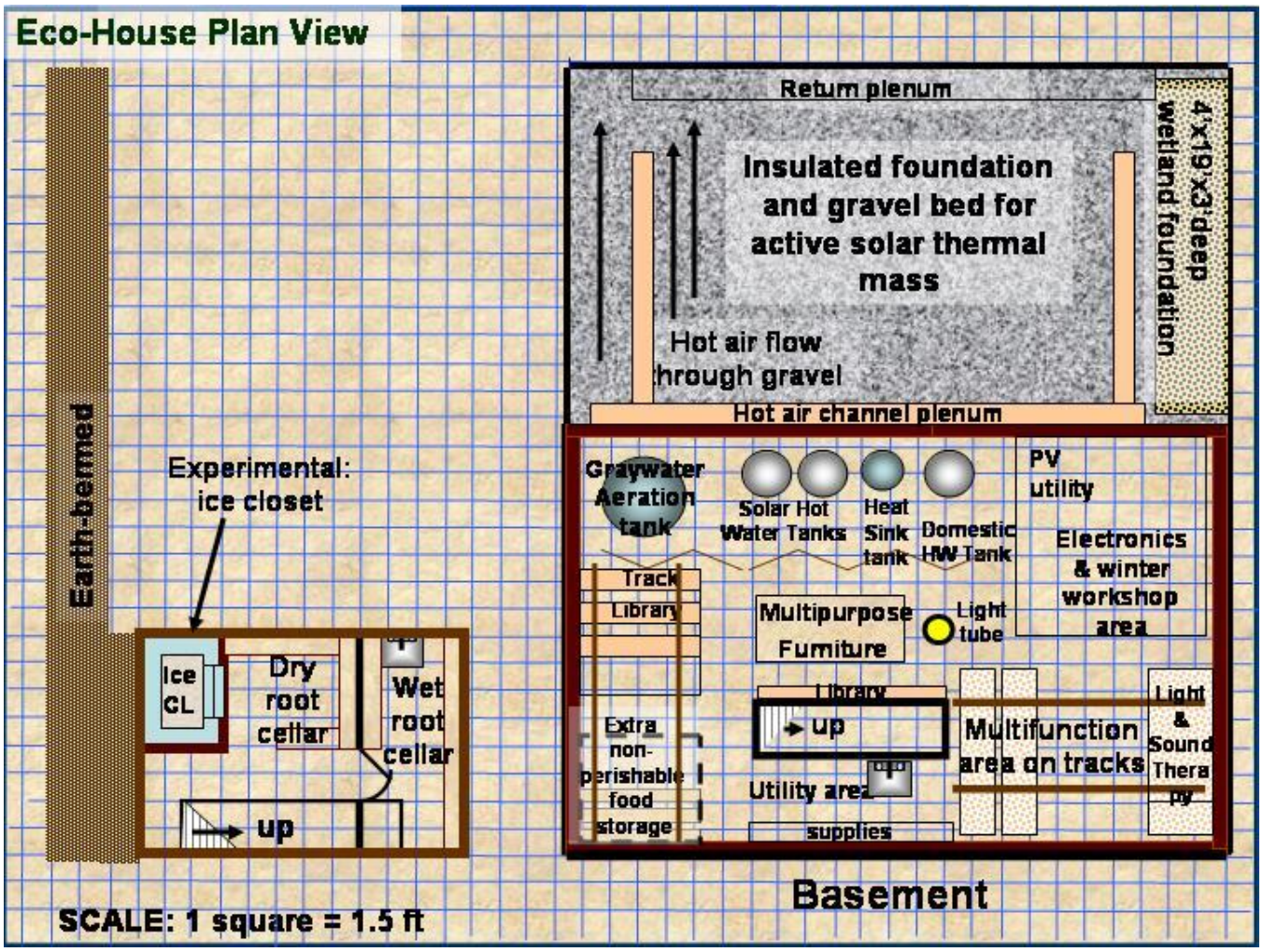
Another unusual feature in the greenhouse is the "solar shower." Located in the corner over the inflow end to the constructed wetland, the concept is to construct a solar hot water heated shower surrounded by natural vegetation that requires no scrubbing or maintenance as do in-house shower stalls. You stand on a small slab stone and the water runs off for immediate graywater treatment in the wetlands. The shower "curtain" can be an array of plant vines or other dense foliage planted around the shower "stall."

The next two plan views show the upstairs and basement levels.



From the second floor, large windows on the south side overlook the greenery inside the greenhouse in winter and, with the glazing removed in summer, overlook the biointensive gardens in summer. The ½-baths shown in two of the bedrooms consist of a small sink and a composting toilet. Only the main full

bath with tub has a flush toilet (to the sewer, alas) while the sink and tub get plumbed to the graywater treatment system (with sewer backup).



At the basement level, there are many functional components: the bowels of the system. These should be easily accessible. In general easily accessible tools and infrastructure is something you learn to appreciate when you do all of your own home repairs.

For making the best use of small spaces, engineers are turning to moveable walls and collapsible furniture that can open up into large, functional areas, or tables and beds, but then fold back down into a little desk alcove or end table. See, for example: http://www.permies.com/permaculture-forums/4790_0/alternative-building/genius-furniture-for-small-living-spaces and http://www.youtube.com/watch?v=UBs0u8TY6jk&feature=player_embedded#

The basement can serve as space for additional dry, non-perishable food storage; extra storage space since there is no attic in the house; a library/resource center for interns and visitors; and other functions Tania has envisioned. The yellow circle which appears on each floor in the middle is a proposed light tube to deliver daylight to the subterranean basement. For a critical look at light tubes, see:

http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/tubular-skylights-introduce-daylight-dark-homes, including the informative comments, and especially the last two comments.

While we're taking liberties on paper, we can draw in the underground root cellar with Tania's proposed "ice closet." The idea borrows somewhat on the practice of storing large blocks of ice in barns under sawdust years ago. These blocks were cut from lakes in winter, stockpiled, cut into smaller blocks and delivered by "the ice man" in summer for use in the early ice boxes that pre-dated the refrigerator. We know we have sufficiently cold weather to create ice. Could that cold be directed into a highly insulated box to freeze a critical mass of water such that it would remain frozen (or mostly frozen) for the year until the next year's winter cold could re-freeze it? A central cavity would serve as the place to store frozen goods and would be used for longer-term storage. PV powered fans would direct the cold air down to keep the ice frozen in winter; these ducts would be insulated during the warm season. It may be that the critical size required exceeds that of the envisioned ice-closet: Tania will have to work through those calculations to determine feasibility. Tania has a lot to keep her plenty busy….

On paper we can imagine the infinite. In reality, every desired feature must undergo rigorous scrutiny and analysis, and the vision presented here will likely be severely pruned by financial costs and constraints. The days of Ken Kern's *The Owner-Built Home* are largely over since the process of building a new house imposes time constraints and immediately catapults the property value, and the Passive House is a technology which, while it performs exceptionally well, is beyond ordinary owner-built capabilities. We need to think not only about how to finance the house, but how to generate sufficient revenues from the use of the house and property to cover the mortgage payments, taxes and utilities (modest though these last may be). Zoning and building codes allow all kinds of innovations as long as the "conventional backup system" is in place, so you wind up paying for nearly double the infrastructure: DC power from PV and AC electricity from the grid; plumbing to graywater treatment on site and plumbing to the sewer, etc.

The U.S. Green Building Council recommends that the best "green building" is *no* building on a site. While this remains an option, we'll keep working on the eco-house design. It's an opportunity. Imagine being able to demonstrate the following:

"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

And so we can imagine….


Merged with garden in summer...

PART 4. APPLYING PASSIVE HOUSE TO RETROFITS

For most of us, the houses we own, or are likely to own, are older, energy inefficient, and require too much maintenance. The question for many of us, therefore, is not how to build a proper house, but how to improve the one we have.

When we began retrofitting ours in 1999, we followed the recommended sequence: (1) reduce energy use; (2) prevent heat loss; and (3) incorporate solar in some form. We learned a lot, but the effort was challenging and the results disappointing. We came to appreciate why many homeowners balk at making their homes more energy efficient beyond modest efforts to plug up drafts.

The same framework that applies to Passive House design can also be used to undertake retrofits. In addition, the Passive House benchmarks can be used to assess how well our retrofit program is going.

In this section we aim to accomplish three things:

- Present the Passive House framework for retrofits;
- Describe and assess our own retrofits, done under an older framework, in the light of the Passive House framework;
- Select actions that we might now undertake, with the benefit of the Passive House framework.

4.1 The Passive House Framework for Retrofits

The current thinking on retrofits is to "Relax the Passive House requirements for retrofits …. Doubling the heating and cooling limits to 30 kWh/m^2/yr (9,500 Btu/ft^2/yr) and adjusting the airtightness limit to 1.5 ACH50 (instead of 0.6 ACH) might be more reasonable. Perhaps a relaxation of the energy performance requirements should be somehow tied to access to sun with existing houses – which will be a limiting factor in many situations."
http://www.buildinggreen.com/auth/article.cfm/2010/3/31/Passive-House-Arrives-in-North-America-Could-It-Revolutionize-the-Way-We-Build

Retrofits are easier to achieve in Europe because of social housing companies that own many apartments or units of similar construction; thus, a standardized approach can be used, and economies realized by duplicating similar efforts. The main elements of energy retrofits are tied to the Passive House concepts:

- Excellent insulation level of opaque building elements: u-values range from 0.10 W/m^{2}K for walls and roof to 0.18 W/m^{2}K for basement ceilings (conversion factor imperial = metric/5.65. Thus, U imperial = 0.10/5.65 = U of .0177 or an R of 1/.0177 or R=56.5 for the walls).
- Triple glazed windows with adequate frames and proper installation.
- Thermal bridges reduced to a minimum.
- Airtightness improved by a factor of 6–10 to the PH standard for new houses usually achieved.
- A ventilation system with highly efficient heat recovery installed (85% efficiency).
- Thermal solar collectors installed covering up 60% of the annual energy demand for domestic hot water.
- Supplemental heat supplied by highly efficient condensing gas or biomass boilers, using supply ducts insulated to a very good level.
  (http://www.passivehouse.us/passiveHouse/Articles_files/RenewableEnergy2008April3.pdf)

A comprehensive retrofit guide using European standards can be found on the Passive House website under the "Passive House Retrofit Kit" (http://www.passivehouse.us/passiveHouse/Links.html). Examples with images are at http://www.passivhaustagung.de/Passive_House_E/modernisation.htm.

4.2 Describing and Assessing Our Own Retrofits Against the Passive House Framework

The first act we undertook on purchasing our house in 1989 was to turn down the thermostat by twelve degrees to 62 degrees. We saved 200 gallons of fuel/year on that act alone. None of our subsequent actions save installing a geothermal heat pump in the fall of 2009 has done as much to reduce our use of fuel oil.

In 1999 we began a serious program of retrofits including improving insulation, increasing solar insolation, installing a geothermal heat pump, and then installing high performance replacement windows. An overview of the actions, with costs, savings, and paybacks, is shown in the table below.

The payback period represents the time, usually measured in years, required to pay for an energy improvement out of the expected savings from the improvement. The payback period is calculated by knowing: (a) $ cost of retrofit and (b) projected or measured savings of energy (fuel oil in our case) per year as a result of doing that retrofit. Consider the example of foam board shutters placed on 17 windows on the north & west sides of the house. At the time, fuel oil to heat the house was $1.39/gallon, so if we saved 25 gal/year (our estimate at the time). Total projected saving was $1.39/gal x 25 gal/yr = $34.75 per year. Divide the cost of making the shutters of $100 by the $34.75 = a payback interval of 2.9 years. Later we found that total measured fuel oil savings of all improvements was only half of what we originally estimated, 100 gallons rather than 200 gallons a year. Therefore, we reduced all the projected savings by half, leading to an increase of the payback period for shutters to 7.2 years. It is these revised paybacks that we show.

Paybacks are sensitive to dollar savings in energy costs. We stuck with the fuel oil costs at the time of the project's completion. A more sophisticated calculation would account for yearly changes in fuel oil costs, and the present value of future savings. We kept it simple. Fuel oil costs have not consistently gone up, but peaked, then declined, and are now on the way up again. It is also important to include maintenance and repair costs. These have proven minimal for most of our improvements, other than for the solar hot water system, which already has a long payback period.

While we tracked heating degree days and compared these to fuel oil costs, we concluded that this would not add much resolution to our calculations.

Neo-Terra Farmhouse Retrofits

Updated 11-5-2010

Strategy House Retrofits	**$/gal**	**$ Cost**	**Saving gal/yr**	**Year done**	**Pay-back yrs**
Reduce use:					
Lower thermostat, wear warmer clothes indoors		0	200	89	**0**
Prevent Heat Loss:					
make foam board shutters ……..	1.39	100	10	00	**7.2**
improve insulation in 2 attic areas (glass wool) ..	1.39	400	15	00	**19**
improve insulation in 3rd attic (polyicynene) …..	1.39	1,600	15	01	**77**
replace old insulation in 3 living room walls with polyicynene 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 with high R triple-pane windows (includes $1,500 Fed tax credit) ….	2.90	21,388	?	10	**?**
Increase Solar Insolation: (see Note 1)					
Duggin hot air collector (‘03), never undertaken ..	1.50	2,000-2,700	(50-100)	No	**18-27**
Install salvaged hot water collectors for domestic heat (winter) and summer hot water …….	2.10	2,854	10+$60 elec	05	**35**
Kreamer hot air collectors …….	2.90	738	10	08	**25**
Reduce Use: Second Round – Geothermal					
Install geothermal heating (fuel oil cost Sept 09) Total cost includes 30% Federal tax credit	2.35	18,000	450 – elect↑ $208	09	**21**

Note 1. For paybacks greater than the 10 years we assumed the rate of return on investment to be negative, that is, you cannot get your money back in savings sufficiently high to pay for the collector (and therefore its replacement) within the life of the collector (projected at 10 years).

In what follows we elaborate on these actions within the Passive House framework for retrofits.

4.2.1 Insulation

To date we have improved the insulation in all of our three attic areas and five of our seven wall areas. In the table below we summarize the treatments with their before and after R-values and compare these with Passive House standards (PH in the last column).

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 [1]
SLAB	1	not done	20 [1]

1/ I could not find explicit standards for foundations or slabs, and the target R values seem to vary considerably. I came across one Passive House slab R value of 40.

Analysis. We improved the back and new attic areas substantially merely by adding more fiberglass. This was relatively easy to do, and we realized great improvements in performance.

The old attic had old moldy and dirty rock wool between the floor joists, and we replaced this with polyicynene sprayed to the underside of the roof deck and rafters, first installing cardboard baffles to allow for air circulation beneath the deck, a necessary condition to installing new (and thinner) fiberglass roof shingle. This was a requirement of shingle manufacturers in 2001 because their thinner shingle curled under the excessive heat of unventilated roof decks, invalidating the 20 year warranty.

We selected polyicynene over urethane foams at the time as the blowing agents for urethane were HCFCs, ozone depleting hydrochlorofluorcarbons, which have since been outlawed. Urethane foam has a higher R-value, and we have since used it in our south wall retrofit, but this is an open cell foam, which we understood did not use HFC blowing agents. The big benefit of using spray foams is that they reduce infiltration substantially; as owners of an older and leaky house, we gave priority to this argument. Notice that we did not increase the R-value of the old attic. For a good discussion on spray foams and foam board see http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/avoiding-global-warming-impact-insulation. The author's advice to avoid XPS (expanded polystyrene) and closed

cell spray polyurethane foams (SPF) gets contested in the Comments following this article, so read these.

Open celled foams such as polyicynene and open cell urethane foams admit passage of moisture (water vapor) and water, the former from condensation of warm interior air against the roof deck, the latter from leaks in the roof. Both these have happened to us. We were able to repair the water leak, but the moisture from condensation remains a chronic though minor problem, particularly now that we have installed a geothermal heat pump. Why? The old oil burner sucked in dry winter air to combust the oil, offsetting winter-produced internal humidity, while the heat pump does not. With a thicker insulating layer, condensation is not a problem because the R-value is so much higher, preventing the temperature in the insulation under the roof deck from decreasing to the dew point, where condensation occurs. Nonetheless, you will want to install a vapor barrier anyway.

On the walls, while we thought we made dramatic improvements in R-values, and reduced air infiltration considerably, we now understand we are a long way from the Passive House R-values. To get close to the PH standard would have required 2-4" more of foam board. Such addition poses a challenge: window frames fall beneath the new plane of the wall and have to be built out, which we did on the east and south walls; soffit vents may become obscured, reducing roof deck and attic ventilation; and roof overhangs get reduced. On inside corners, doors or windows close to the corners may be blocked from opening.

One can insulate walls from the inside, but this is a messy and disrupting job, best done prior to moving in, if at all. We re-did one north concrete block wall from the inside on the lower level, pulling down the old gypsum, ripping out the old firring strips, and replacing 2" of decrepit fiberglass insulation with 3" of foam board. That helped considerably, and improved the R-value from 8.9 to 16.5, a long way however from the PH wall value of 50. One builder repeated the claim, asserted by our polyicynene installer, that foam, either open or closed cell, becomes less efficient past 4" at reducing heat transfer. That doesn't seem to dissuade PH builders from using lots of foam or other insulation (e.g., cellulose). One new Passive House owner in Oregon built a R-120 roof and R-80 walls!

We have put off retrofitting the remaining two house walls because a previous owner nailed the present cedar siding over the original Dutch lap. Getting to the old rock wool insulation and replacing it will require pulling off both layers, a job we don't relish. The east wall has vinyl siding, and we carefully removed that for re-use, revealing a thin insulating layer over which we easily nailed two 1" layers of foam board. Improving the insulation on foundations will prove difficult, and re-doing the slab next to impossible. Even adding 2" of foam, plus pouring another slab will add at minimum 4" to the floor height, reducing headroom considerably.

When calculating the present R-value of a given wall, you must determine the materials comprising the wall. In the best case, you can find an opening somewhere to view directly – behind a knee wall, inside a cabinet or closet, etc. In other cases, you may have to drill a circular hole and explore that way.

Below we show our analysis of the two alternatives we considered for improving our east (vinyl covered) wall. Replacing the rock wool would have been a messy, difficult and costly job. We realized a considerable improvement by keeping the rock wool in place and adding two layers of 1" polyisocyanurate foam board, overlapping the seams and taping all seams to reduce infiltration.

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 foam board
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	**18.1**	**24.9**	**28.1**

You may wish to consider the information on wall retrofits published by the Building Science Corporation on their website, www.buildingscience.com, especially under the menu topics "High R-Value Wall Assemblies" and "Energy Efficient Retrofits." Their approach may be more relevant for some retrofits, particularly if you are unable for financial or practical reasons to realize the PH standards. If you investigate both approaches deeply, you will become aware of the controversy between adherents of both approaches.

Removable thermal shutters, 1" polyisocyanurate, silvered side facing out, cut precisely (and with a slight bevel) to fit snuggly in the window frame, and then painted black.

Attics: We used polyicynene foam to insulate an interior attic-eves area (left), sawing off excess before installing drywall. In the unfinished attic areas (right) contractors sprayed cavities and rafters to cover the area fully.

Living room walls: We removed the cedar siding, cleaned out the old fiberglass insulation, and then sprayed polyicynene in the cavities (above, left). Gene worked with the contractors to salvage and re-use about half of the original cedar siding.

East wall: We removed the vinyl siding and added two inches of overlapping (blue) foamboard over the old ¼” foam layer. We left the rock wool in the stud cavities in place. At right, we taped the mating pieces of foamboad to prevent air infiltration, and reinstalled the vinyl siding. Note frame buildout around windows.

South wall: Original wall (above, left) consisted of cedar siding over another layer of unfinished wood siding (middle photo) and 2”of old fiberglass insulation. With a contractor, we removed and saved half the cedar siding, gutted the stud cavities, and framed the openings for two solar hot air collectors (above, right).

South wall: We used polyurethane foam to fill the stud cavities, completely sealing all cracks and crevasses to stop air infiltration (left). The foam oozed through crevices around the window frame, even into the hollow sash weight cavities (right).

South wall: After foam, we added sheathing (above, left), and then framed the hot air collectors. We added an inch of foamboard (silver panel) over the sheathing (above, right) before replacing the cedar siding.

Apartment north wall: We removed the wallboard, thin batts of old fiberglass insulation, and firring strips (above left); then glued three inches of blueboard (Styrofoam) to the wall as one 2" layer (above, right) and then another 1" layer offset to cover the seams.

Apartment north wall: We glued gypsum board to the blueboard (left) to finish the room (right).

4.2.2 Thermal Bridges.

Older houses abound in thermal bridges. For examples of thermal bridging in our own house, note in the infrared pictures below the hot areas in the foundation, window frames, and chimney. The improved wall to the right of the chimney is cooler (darker) than the brighter orange-yellow wall around the corner on the right. The left wall has the coolest surface. This shows the reflective property of foil-covered foam board, whereas the vinyl covered wall to the right of the chimney retains heat at night a bit longer,

probably also because warm air is trapped behind the vinyl cladding. The white-hot chimney could be due to retained heat in concrete, or warm air thermo-siphoning from the house cellar through the furnace exhaust duct.

Thermal Bridging in Our House – Foundation, Window Frames, Chimney, Dormer Seam Sept. 8, 2008, 11 pm

4.2.3 Windows

Our house has 24 windows, original to the 1937 house or its addition in 1957. Many are old fashioned double hungs with aluminum storms; others old Anderson double-paned casements or picture windows. All leaked air and moisture. All suffered condensation on the inside storms or panes, even freezing of condensate on cold winter nights. The glass area of all our windows is equivalent to the entire east wall of our house below the attic. Imagine, then, one whole wall of your house having an R value of 2 (and leaky at that).

We first considered replacing the windows 10 years ago, but the prohibitive cost of high quality windows deterred us, and we did not want standard replacement vinyl under any circumstances. Vinyl, made with PVC, is toxic in production and disposal. We decided to start with the lower cost measures indicated in our Neo-Terra Retrofits table above. Having exhausted these, we replaced the worst windows on the weather walls – windows on the north and west sides of the house – late in the fall of 2010.

The biggest challenge was identifying high quality windows and their installers. From the listserve discussions among Cobb Hill designers ten years ago, we learned of two Canadian manufacturers (Thermotech and Accurate Dorwin) that were the best then available. These had high R values (actually, the Canadians use a different rating called "ER" which measures the ratio of energy admitted to energy lost), triple-paned glass, insulated fiberglass frames, and tight seals. No one at that time produced similar windows in the U.S., and neither U.S. consumers nor producers were aware of the advances being made in Europe at that time.

Ten years later, things have improved only marginally. The extent of American ignorance can be seen in the confusion and consternation among builders when it comes to windows. The windows pages on the PH site have the most comments and questions of any PH subject. (For more information see http://www.passivehouse.us/bulletinBoard/viewtopic.php?f=7&t=59 and a related topic, "An American Passive House Window" at: http://www.passivehouse.us/bulletinBoard/viewtopic.php?f=7&t=74.)

We identified and compared several North American window manufacturers and finally settled on Serious Windows (www.seriouswindows.com), which bought out another company whose product we had looked at several years ago, Quantum II. Serious Windows (and Quantum before it) substitutes a thin mylar film for the middle pane of a three pane window, reducing weight and cost. The company also offers krypton as a gas fill, and a higher Solar Heat Gain Coefficient package for south-facing windows in the frigid northeast, a rarity among U.S. window manufacturers. Their Series 725 fiberglass replacement picture windows have an R-value of 7.1, higher than any other U.S. window, and their Series 1125 picture has an R-value of 11.1 which they achieve with five panes – two glass and three mylar.

The other U.S. companies we identified came nowhere near this performance (e.g., Marvin, Milgard). Among the Canadian companies (Thermotech, Accurate Dorwin, Inline, and Fibertec), the chief obstacle we faced was finding a certified installer willing to come to Central PA for a small job. Websites for the Canadian firms are: www.thermotechfiberglass.com, www.Accuratedorwin.com, http://www.inlinefiberglass.com/products.html#windows , and www.fibertec.com. Thermotech gets its windows from Inline. To secure the warranty, you must have a certified contractor install the windows. After watching the 5-man team install ours, we realized this was not a job for the average DIYer.

An informative article comparing Serious Windows with Thermotech and Fibertec and Inline can be found at http://www.greenbuildingadvisor.com/community/forum/energy-efficiency-and-durability/14850/serious-windows-vs-thermotech-fibertec-inline .

In a retrofit application, we used replacement windows. The installer takes out the old windows by removing the retaining molding only and then removing the sash. Since operating replacement windows require a frame, your resulting glass area will be smaller. This is not the case with fixed windows (e.g., picture). You could go to the adjacent studs, but that is a more expensive proposition.

Installers are reluctant to use spray foam to take up the difference between the window and your house frame, but use fiberglass strips instead. We had to monitor the installers to make sure they filled the entire space. Keep in mind the necessity to fill any sash weight cavities. The best thing to do is to blow in cellulose or fiberglass to fill in the cavity. We went with cellulose as it is less toxic than fiberglass fibers. You would require many cans of spray foam (e.g., cans of Right Stuff) to fill a cavity, and

probably not fill it completely. Installers do not like to use foam primarily because they are worried about the foam expanding and bending the frames (more a problem with vinyl), and the foam squirting out on finished woodwork or siding through various cracks.

Installers usually cover the old outside molding with aluminum coil, which they bend and cut on site using a metal brake. Our installer, Mt. Pleasant Window and Door Company, used a special high performance caulking to seal the coil to the siding, leaving the bottom seam unsealed to allow moisture to escape, a necessary precaution.

Windows: High performance windows reflect incoming summer heat, and also reflect house heat back *in* the house in winter, as demonstrated with a heat lamp (above, left). Non-operating windows (picture windows at right) have higher R-values than operating windows. Here contractors are removing the old ones prior to installing the new.

Window installation: Metal "coil" is installed over top of the existing window frames (above, left). Contractors drilled holes into the sash cavities of the old double-hung windows (middle photo) so they could blow in cellulose insulation. The two sash weight cavity holes were taped over, the cavity was filled with cellulose (above, right), and then that filled hole was taped over.

Coil installation:

Left: before

Right: after coil installation: protects wood; no painting

Kitchen windows: The original double-hungs were drafty, and either steamed up or iced over in winter (above, left). We used Venetian blinds to reflect summer heat and sun. We replaced these with high-performance casements which seal out the drafts, reflect the winter house heat back in and neither fog up nor ice over in winter (above, right). In summer, selective coatings reflect summer heat and reduce glare.

4.2.4 Air Tightness

Air infiltration is another difficult performance metric to meet. The Passive House standard turns the practice of air infiltration control in the U.S. on its head. Traditionally, builders and renovators aim for a "house that breathes." Sounds so natural, but what this disguises is inadequate air control, technically inferior building design, sloppy construction practices, and poor choice of materials (that enough drawbacks?). Whenever you hear or read this phrase, a red flag should go up in your head.

By contrast, the Passive House mantra is "build tight, ventilate right." Ventilation is done through Heat Recovery Ventilators or Energy Recovery Ventilators, which also double as the device (and ducting) for supplying the minimal heat the house requires to be comfortable.

Air tightness is measured in units of Air Changes per Hour @ so many units of pressure differential. Air changes refers to moving the entire air volume inside your house and replacing it so many times per hour. Thus, the Passive House Retrofit Standard of 1.5 ACH@50 pascals (1.5 ACH50 for short) means that the total air in the house is changed 1.5 times per hour under a pressure differential of 50 pascals. Recall that the standard for a new Passive House is 0.6 ACH50. Air tightness is measured by a blower door test. This low level is equivalent to having a totally sealed house except for a small hole 6-8 or so inches in diameter.

The principle reason we used foam in our walls was to get the walls air-tight. We installed high quality windows to reduce air infiltration further. The question remaining is whether our house is now sufficiently air-tight to warrant mechanical ventilation, a question answered by conducting a blower door test. We did this in December 2010, and will return to this topic in Section 4.3.2 below where we cover the one remaining area about which we have done nothing: ventilation. Up to this point, our house

was sufficiently drafty that we "enjoyed" the natural ventilation of porous walls and leaky windows, among other leaks (e.g., chimneys, kitchen exhaust fan ducts, clothes dryer ducts, electrical or plumbing chases open at one end, door sills, leaks through foundation sill plates, attics, etc.).

4.2.5 Solar Hot Water and Hot Air

Having improved the building envelope of our house, we next turned our attention to increasing solar insolation. The Passive House standard cannot be realized unless classic passive house principles are incorporated in the design and siting of the house: east-west house axis, south facing wall with properly sized windows, wide overhangs, etc. Thermal mass is less important in a Passive House as the insulation is so great. Passive House design uses solar hot water collectors to provide domestic hot water.

Though our house faced south, only two of 24 windows faced south. Interior brick walls in the living room, absence of concrete mass on the existing floors, and tall trees on the south property boundary mitigated against improving solar insolation by increasing window area. Therefore, we turned to solar hot water and hot air collectors.

Solar Hot Water Collectors. A friend of ours had salvaged 70 or so high quality collectors off the roof of the manufacturing plant near Philadelphia and brought them to his back yard. The company owning the plant went out of business with the expiration of the Carter era solar tax credits under Reagan. With the assistance of Andy Lau, a solar engineer at Penn State, we tested the collectors and figured out how to retrofit them with new covers made from greenhouse twinwall polycarbonate. The cost was about $150/collector plus our time.

We installed four of these on the south-facing roof of our house and did all the plumbing work ourselves for a total cost of $2,854. The collectors provide domestic hot water during the summer, and space heat via baseboard heaters to a lower level room during the winter. We also incorporated a loop to allow transfer of heat from a Jotul wood burning stove in the living room to this same lower room. After we finished, I came across a marvelous book which I would recommend to anyone wanting to do this as a DIY project: "Solar Hot Water Systems: Lessons Learned 1977 to Today," by Tom Lane, 2004, available from him directly at 6120 SW 13th Street, Gainesville, FL 32608 (http://www.ecs-solar.com/).

Tom lays out all the options in considerable detail. In retrospect, we should have considered a drainback system as an option in addition to the pressurized glycol antifreeze system we installed. The former is simpler, has fewer parts, and is more foolproof. Nonetheless, we have been largely satisfied with our system and its performance so far, though the energy savings are not as high as we anticipated: 10 gallons of fuel oil, plus $60 off of our electricity bill due to a decreased requirement for supplemental electric heat in the lower room heated by the baseboard heaters. Payback period: 35 years, well beyond the life of the system.

Installing Solar Hot Water Heating Panels: Gene first affixed strong brackets to the roof (above). Panels were hoisted up to the roof by sliding them along a ladder (right) while a small crew of friends assisted from above and below (far right).

Above: Positioning solar collector.

Right: Many thanks to our crew!

Solar Hot Water Heating: Tanks and plumbing in basement (left) and loop to heat-exchanger box on Jotul woodstove in living room (above).

Solar Hot Air Collectors. In 2002 I had come across an interesting design for a solar hot air collector during a discussion with Jim Duggin, whose name I had found linked with a SARE funded project to incorporate solar heating within a farmer's winter greenhouse. For the collector surface, Duggin used five layers of fan-folded black screening, similar in appearance to ordinary aluminum window screening. The folds were done at acute angles so that incoming sunlight would strike the surface and be reflected (and absorbed) ever more deeply into the mesh rather than being reflected back to the outside.

I built two test modules in 2003 to measure performance, and was pleasantly surprised by the data. The hitch lay in the screening. Ordinary window screening is painted black, and this paint is not heat resistant, so it off-gasses fumes at collector operating temperatures. Duggin warned me of this, but would not disclose the product he actually used. I could have gotten a custom roll of black-painted aluminum screening from a manufacturer without the offending fixative that holds the paint onto the screening, but the minimum order was for a roll of 1,000 feet, much more than I required for my collector, so I abandoned this design and turned my attention to hot water collectors.

During the winter of 2007, I came across another design for a hot air collector by Bill Kreamer on a DIY solar website (http://www.builditsolar.com/). I was impressed with the design, and corresponded with Kreamer on some details. Kreamer's design is simpler and cheaper than Duggan's. We decided to include it as part of our south wall retrofit in 2008. Its performance drops significantly as the winter sun drops below the branches of tall maples standing on the south border of our property. Consequently, we are getting perhaps only a third (10 gallons) of the estimated gallons of fuel oil saved during the heating season, which increases the payback period considerably – to 25 years – beyond its life.

Kreamer's design uses foam board, black polyester felt (fabric) as the absorber surface, and aluminum coil folded to make the small rails that support the polyester. This fabric can be bought inexpensively at a fabric shop. The collector box is covered with Plexiglas (acrylic) sheeting. Both collectors cost $738. On a sunny winter solstice I measured a top temperatures of 131 degrees F. Earlier in October I measured a top temperature of 146 degrees. Kreamer's design, while simple in concept, requires careful execution of details, but is a reasonable DIY project. You can find a description of our application on our website at http://neo-terra.org/Documents/CASE%205%20hot%20air%20collect.pdf, which also contains pictures and comments. If you scroll down on http://www.builditsolar.com/Projects/SpaceHeating/Space_Heating.htm#Active you will find Kreamer's project sketched under Active Space Heating – Air Heating Systems, together with a link to a person who, as we did, actually built one. Kreamer's direct link to his free pdf download is at: http://www.builditsolar.com/Projects/SpaceHeating/Homebuilt%20Solar%20Collector%20Instructions.pdf. There are other hot air collector designs on this website, so you may find another one more suitable to your circumstances.

Solar Hot Air Collectors: The insulated backing is silvered polyisocyanurate foam board (above, left). Above right I am gluing black polyester felt (the absorber surface) to the aluminum coil rails.

Solar Hot Air Collector details: Testing the heat-triggered fan assembly (above, left). An interior view of one of the completed units (above, right). A small muffin fan draws in cool air from the room through the lower, downward-directed louver, forces it along the outer collector surface, and then pushes heated air through the upper, upward-directed louver.

Solar Hot Air Collectors: Completed, fall 2008 (above, left). In summer, when the sun's angle is much higher, the heat and light nonetheless build up in the collectors. We taped a mylar sheet to the plexiglass to reflect heat to keep the collectors cool, and added a trellis for morning glories in front to provide additional shading (above, right). UV light degraded the mylar after two years. This fall we fabricated a new cover using rubberized fabric (curtain lining) and will try that this summer. We also cover one or two of the solar hot water collectors on the roof with a silvered tarp in the peak summer months to prevent overheating of our hot water tank.

4.2.6 Supplemental Heat

With a well-designed or well-retrofitted Passive House, you will find that your heating requirements are reduced considerably – to the equivalent of a hair dryer for a new Passive House (15 kWh/m^2/year, or 4.75 kBtu/sf/yr) or twice this for a retrofit. This comes to 2,091 kWh/yr for a 1,500 sq.ft. house ($209/yr). Double this for a retrofit Passive House.

Coincidentally, this is almost exactly our electricity consumption (and heating bill) for our new geothermal heat pump (our house has 1,780 sq.ft). Of course, we use a much more complicated and expensive heater than a mere hair dryer. Nonetheless, replacing our old coal-converted oil burner was probably the smartest retrofit we have done to date. We got off oil at a heating cost of $208, for a reduction of oil consumption from 450 gallons to 89 gallons at $2.35/gallon (the $209 cost for electricity). This cost for electricity overestimates the true cost, as we had no easy away to estimate the electricity consumption of our oil-burning furnace. We installed two separate electric meters for the heat pump so we can monitor its electrical consumption.

Furnace retrofit: The old coal-converted-to-oil furnace (left) and the completed ground-source or geothermal heat pump system (above, right).

Drilling the wells: Drillers bored two 300 ft. deep wells using a small drilling rig (left), turning the side yard into a moonscape (above, right). A loop of black plastic tubing protrudes from the first of the two wells.

Geothermal system: A T-shaped trench was dug 5 feet deep to bring the plastic tubing from each well loop to the basement wall (left). Inside the basement (right), the tubes were insulated and connected to the heat pump. We had electricians install dedicated watt-meters so we could monitor our heating & cooling electricity use..

The prior retrofits – insulation, air tightness, solar – reduced the size of our heat pump, the depth to which the wells had to be drilled, and therefore the overall cost of the entire geothermal system.

But we use an electric space heater in a cold lower room, and that consumes 668 kwh/year. We also burn ~ 3/4 cord wood, the equivalent of 2,997 kwh. (Here is the calculation: 0.75 cords x 21,000,000 BTUs/cord x 0.65 stove efficiency x 1 kwh/3415 BTU = 2,997 kwh.)

Thus, our total heating load for 2009-10 was 2,081 kwh + 668 kwh + 2,997 kwh = 5,746 kwh. Dividing this by the number of square meters of our house (1,780 sq.ft. x 1 sq m/10.76 sq.ft = 165.4 sq.m) gives us a heating performance of 34.7 kwh/m^2/year, just over the 30 kwh/m^2/year heating parameter for Passive House retrofits. Not bad overall, though we kept our thermostat at 64 degrees, below the 68-70 degrees used in Passive House standards.

We happened to have the geothermal system contractor's estimate of our heat load at 70 degrees F: 5,090 kwh. At this house temperature, we would not have to use the spare heater or the wood stove. This gives us a heating parameter of 5,090/165.4 or 30.8 kwh/m^2/year, very close to the Passive House standard of 30 kWh/m^2/yr. This lower figure makes intuitive sense, as a heat pump produces heat much more efficiently than either burning wood or using electricity.

In the table below we summarize results and compare them with the baseline case of burning 450 gallons of fuel oil. In the last column, we compute our total energy load for all uses.

Comparing Energy Consumption,
Fuel Oil vs Heat Pump

Electricity Use	Winter, fuel oil kwh at 62 deg 2008-2009	Winter, heat pump kwh 64 degrees 2009-10	Winter, heat pump kwh at 70 degrees	Total energy use in kwh 2009-10
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

Note: Recording year was from Oct. 1 to Sept. 30

Passive House makes a distinction between heating/cooling loads and total loads. The total loads are subject to a qualification known as "primary energy." We covered this in Note 2 of the Passive House Features and Standards table in Section 1.2 above. Briefly, primary energy is energy prior to any processing, conversion or transformation losses. Factors relevant to the U.S. have yet to be worked out. Tentatively, the primary energy factor for electricity in the U.S. is estimated at 3. Applying this to the last column of the above table gives us a kwh/m^2 of 3 x 83 or 249 kwh/m^2, well beyond the PH standard of 120 kwh/m^2/yr/.

The table above focuses on heating energy. If we add in all other electrical use for the baseline year 2008-9 of column 2 (9,918 kwh – 668 kwh = 9,250), the total energy use for this baseline year, expressed in kwh, equals 26,567 kwh, almost twice as much as the Total All Energy use for 2009-10 given in the last column (13,788 kwh). By replacing our oil burner with a heat pump, we have reduced total energy consumption by half.

4.3 Actions We Might Still Take

4.3.1 Air Tightness

Whether your retrofitted house is tight enough to require ventilation can be shown by a blower door test. We had a blower door test conducted locally in December 2010 by Envinity. Martin Holladay's article on this test is quite useful and contains a checklist for homeowners to use before they conduct this test. (http://www.greenbuildingadvisor.com/blogs/dept/musings/blower-door-basics)

Blower Door Test: Brian Henderson from Envinity installed their blower unit in our front door and revved up the fan (above, left). Once the pressure level stabilized and we collected data, he used a "smoke" pencil (above, right) to identify air leaks around windows and other openings.

Air tightness can be measured in cubic feet per minute (cfm) or in air changes per hour (ACH) using a standard air pressure difference of 50 pascals. The blower door test has a meter which reads cfm. Knowing the volume of your house, including cellar, you can convert the cfm to ACH. For example, a 1,500 sq. ft. house with 7.5' ceilings would have 11,250 cubic feet. At the Passive House standard of 0.6 ACH, this is 6,750 cf/hr. Divided by 60 minutes/hr yields 113 cfm. This is the first entry in the table below. In this table we compare various degrees of housing tightness using these two measures. The data for our house is shown in the last line as 1,900 cfm.

For the purposes of comparison, we place the ASHRAE standard separately at the table's bottom because this is a ventilation standard, not an air-tightness standard. Air tightness is not the same as ventilation. Air tightness is a condition of the leakiness of your house and is measured by a blower-door test under a pressure differential of 50 pascals. Ventilation is a property of the mechanical equipment moving air around inside your house. A leaky house allows cold, dry air to enter in the winter (or hot, humid air in the summer), and this plays havoc on your heating and cooling loads. Not so with a tight (and well-insulated) house. In Passive House design, you strive for air-tightness and ventilate mechanically below the threshold of 1,000 cfm to get fresh air using HRVs or ERVs – in short, "build tight and ventilate right."

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**

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.

While we did not do as well as we might have hoped, at 1,910 cfm (6.9 ACH50), we were definitely better than the usual older house, though a little outside what is regarded as a "typically tight house." We have a way to go. In order of increasing expenditure, here's what we could do:

- 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 (more big bucks – $12,000).
- Replace three doors with high performance, well insulated doors (still more big bucks).

The technician conducting the blower door test felt the first three items might result in a decrease in air leakage by 200 cfm, not a lot. It is not clear what the remaining possibilities would do to increase air tightness. These would decrease our heating requirement, but since the present heating cost is quite reasonable, the payback on further wall, window, or door improvements will be quite long.

4.3.2 Ventilation

A general introduction to ventilation can be found in http://www.greenbuildingadvisor.com/green-basics/ventilation-choices-three-ways-keep-indoor-air-fresh. Follow this with Martin Holladay's more

detailed article "Designing a Good Ventilation System." (http://www.greenbuildingadvisor.com/blogs/dept/musings/designing-good-ventilation-system). The comments from builders following both articles add valuable perspectives.

For new Passive Houses, the ventilation system takes precedence over the heating system; consequently, the heating device is most simply installed in the ventilating ducts. This is the origin of the hair dryer sized heater. In Europe, one device handles heating and ventilation (with heat recovery) simultaneously. These devices are sometimes called "magic boxes" and are expensive ($5-28k) and largely unavailable in the U.S., though this picture is changing rapidly as the U.S. market begins to open (http://www.greenbuildingadvisor.com/blogs/dept/musings/magic-box-your-passivhaus). In the near term, the budget-minded American Passive House enthusiast will want to consider separating the heating system from the ventilation system – for example, using a small heat pump or pellet stove with a separate HRV.

Ventilation rates for Passive Houses are on the order of 0.3-0.6 ACH. The Maine Cohousing prototype achieved 0.33 ACH (70 cfm). The ASHRAE ventilation standard is close to this (0.24 for a 1,500 sq.ft. home for 4-5 individuals).

For retrofits, homeowners will not have to face ventilation unless they have made their homes sufficiently air tight such that a blower door test returns a reading under 1,000 cfm (for a 1,500 sq.ft. dwelling). Here are three current strategies in decreasing order of effectiveness, but increasing order of practicality and inexpensiveness.

1) The best approach would be to install a separate air duct system with its dedicated HRV or ERV, but this may prove too costly or difficult in a retrofit.
2) Next, consider adapting an existing air duct system belonging to your current heating system by adding an HRV or ERV.
3) An inexpensive and practical though less desirable option is to use simple exhaust fans, relying on remaining air leakage to exhaust stale air.

There is a fourth strategy, but this is unconventional, though gaining favor in Canada. This is the concept of "living walls" which use plants to clean air circulated over or through them.

You will find plenty of information on the first three in the first two articles referenced above, especially in the comments sections. In what follows, we highlight a few points that helped our understanding.

Using An Existing Air Duct System. Martin Holladay sheds light on this option with the following comment: "Armin Rudd likes to set up his systems for a 7% outside air fraction. You need to know the rating of your blower, too. If you have a 1,500 cfm blower and a 7% outside air fraction, you are ventilating at 105 cfm. Depending on the size of your house, that might be just right – or it might be twice as much outside air as you need. Here's the rub, though: a lot of HVAC installers don't measure the air flow through the fresh air duct when they commission the system. (Because they don't really commission the system.) They just hook up a 6-inch duct and they're done. In that case, you might end up with a 15% or 20% outside air fraction, and you are really overventilating. The outside air fraction needs to be measured, and a damper (not the motorized damper, just a regular damper) needs to be adjusted to get the outside air fraction right. Then, you still need a motorized damper so that the

FanCycler control can shut the fresh air duct when the blower has been running for hours at a stretch. Remember, Rudd advocates ventilating at LESS than the ASHRAE 62.2 rate. I'm (Martin Holloday) not saying you should do that, but a lot of people do, especially in hot, humid climates."

For this approach to work, you must have an ECM blower motor (Electronically Commutated Motor). New furnaces and heat pumps will likely have one, but check. Older motors use too much energy. I estimate that our own ECM blower on our new geothermal heat pump uses 95 watts at stage 1, much more than the 11.3 watts of a Panasonic exhaust fan, but close to the 100 watts of an HRV.

Using Simple Exhaust Fans. Even Martin Holladay is a fan of simple high performance exhaust fans, e.g., the Panasonic Whisper exhaust fan, drawing 11.3 watts. A couple of these installed in your house retrofit could well satisfy your air ventilation challenge inexpensively.

Holladay had much to praise in the Broan SmartSense fans, which he reviewed in the April 2007 issue of EDU, where he wrote:

> "The fans come with controls that are able to communicate with other fans in the home, keep track of the minutes of manual operation of all the home's exhaust fans, calculate the amount of additional ventilation required each hour to meet ASHRAE 62.2 requirements, and automatically operate all of the home's fans when necessary to meet ASHRAE 62.2 minimum ventilation rates. Moreover, the fans are quiet and energy-efficient. "The fans are designed to be installed in homes requiring two or more exhaust fans. Each fan includes an integral control module. Using a table that comes with the installation instructions, the installer programs one fan – the master unit – with the desired ventilation rate for the entire home, according to the ASHRAE 62.2 formula; the factory default rate is 90 cfm.
>
> "Like most bathroom exhaust fans, Broan SmartSense fans can be operated with a manual wall switch. Once each hour, the SmartSense control calculates the total manual run time of each fan during the previous hour. (The fans communicate with each other over the home's power lines; no communication wiring is required.) Before initiating a cycle of automatic ventilation, the SmartSense control gives credit for any operation time resulting from use of the manual wall switches. Automatic ventilation run times are distributed evenly among all the fans in the house. If manual fan operation during the previous hour exceeds ASHRAE 62.2 requirements, no additional automatic ventilation occurs.
>
> "For example, assume that a house has a four-fan system and an ASHRAE 62.2 ventilation requirement of 60 cfm (3,600 cubic feet per hour). The ventilation rate is programmed into the control when the system is commissioned. If none of the fans has been operated manually for a full hour, then the control will direct each of the fans to operate long enough to exhaust 900 cubic feet (one fourth of the ASHRAE 62.2 requirement). Ventilating from four fans provides a better distribution of fresh air than ventilating from a single fan.
>
> "The control can be set to 'vacation mode,' suspending all automatic ventilation until the next time the master fan is manually operated, at which point automatic ventilation resumes."

There is an energetic discussion on kitchen exhaust fans which makes the following points: http://www.askthebuilder.com/725_Kitchen_Exhaust_Fan.shtml

- Avoid downdraft fans and island stovetops/grilles. These are the worst solutions.
- Clean regularly to prevent grease fire.
- Put a makeup air duct near stovetop exhaust, so you avoid drawing air from other parts of your house. This way, cold air picks up moisture and odors and exhausts them directly up the exhaust vent.
- There is little agreement on sizing the fan. Some suggest a high-speed fan (1,000-1,500 cfm) to exhaust grease, others say 150 cfm is sufficient. Of course, one should use grease filters to protect against grease collecting in the air exhaust duct and causing a fire. .
- Put stove against wall, use hood, with low-velocity fan (100-150 cfm or 5 ACH for kitchen). You want to exhaust grease and moisture-laden air.

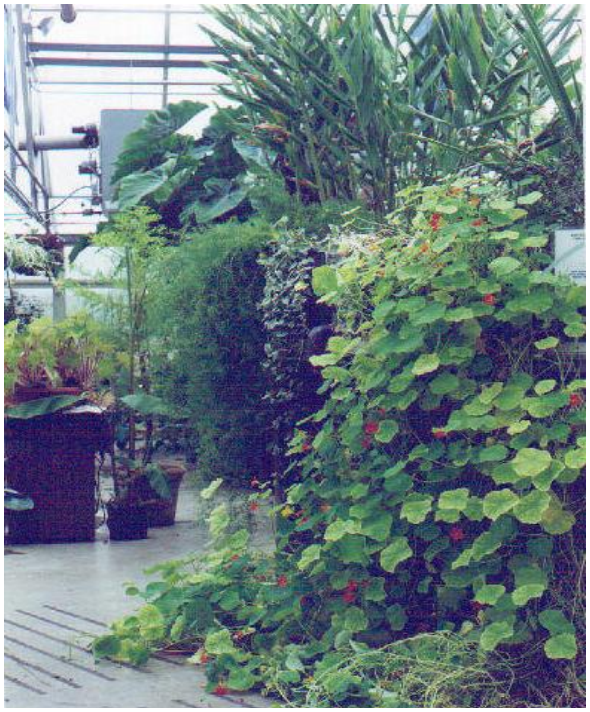
HRVs and ERVs. There are a modest number of possibilities, and these are listed at the end of Martin Holladay's article http://www.greenbuildingadvisor.com/blogs/dept/musings/hrv-or-erv. For a DIY project, you can build your own HRV from a design at: http://makeprojects.com/Project/Heat-Exchanger/279/1. Keep in mind the following items, particularly in a DIY project:

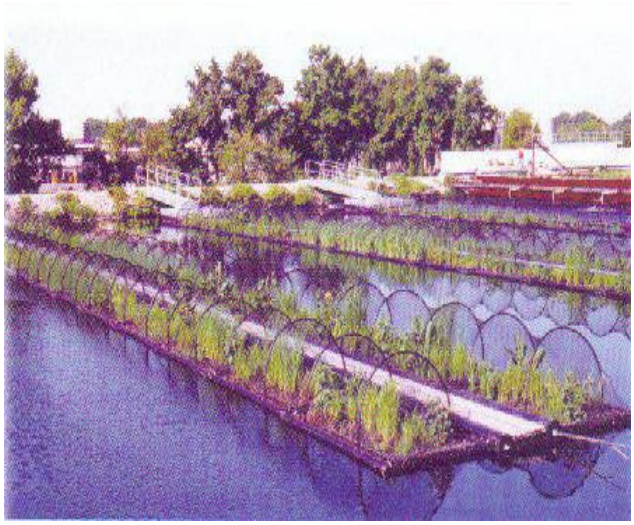
- For an HRV, inlet and outlet ports should be 10' apart;
- You may require a defrost cycle on HRV if indoor air is too high in moisture. The cold incoming air will cool the moisture-laden air, forming ice crystals, and plugging up the air exchanger or causing large drop in heat transfer; and
- One should use source moisture (and bad air) exhaust fans – bathroom, laundry, kitchen. Otherwise, your HRV has to handle all the pollution and moisture.

Breathing Walls as an Alternative or Adjunct to Ventilation and HRVs or ERVs. A breathing wall contains plants arranged vertically in a variety of ways, and then air is drawn through the wall past the leaves and the roots of the plants.

The key idea behind breathing walls, that microorganisms on plant roots remove toxins, was developed in the U.S. by John Todd, a Canadian by birth, and a biologist who developed the idea of Living Machines to clean chemically contaminated water (see image below).

John Todd's Living Machine and Lake Restorer





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

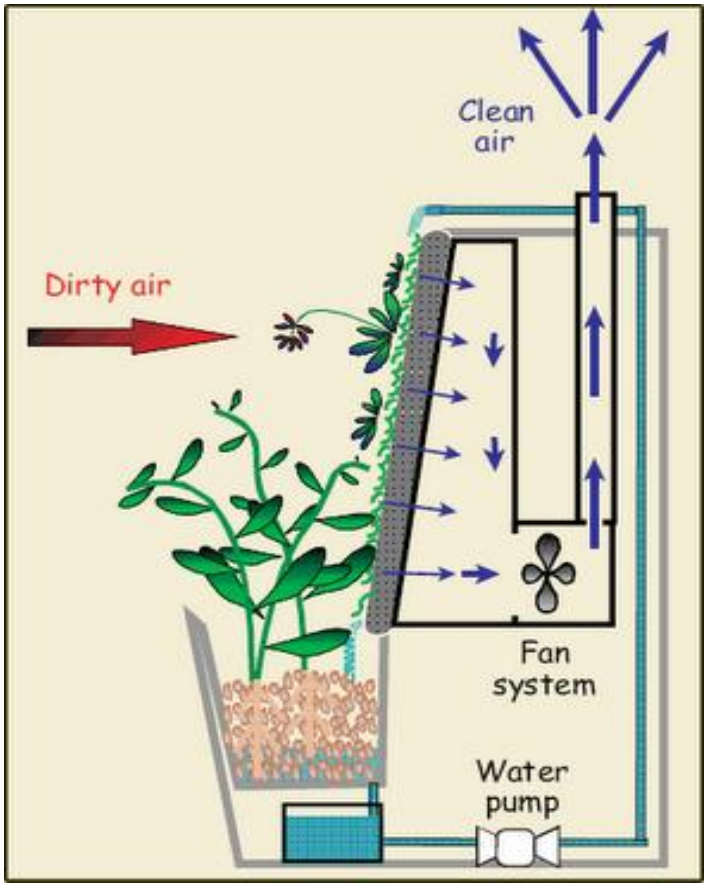
Living Machines (left) and Lake Restorers (right)

A breathing wall acts as a biofilter to remove contaminants, and exchanges CO_2 for O_2. Such walls are particularly appropriate in air-tight buildings where chemical contaminants may build up, or where indoor air quality is a problem for other reasons. Having an interior way to improve air quality reduces the load on, and therefore the size and energy requirements of, a separate ventilating system. For a new NSF-funded project on this point see http://www.colorado.edu/news/r/593723d89181056e551d9249c4788696.html.

The original concept for a breathing wall was undertaken as a joint project of Canada Life Assurance, Genetron Systems and the University of Guelph. Since that time, a number of commercial firms have adapted the idea in many forms (search under "living walls" or "breathing walls").

The biofilter in its initial conception was composed of three main sections: (1) a hydroponic area that contains many different types of green plants; (2) an aquatic system that aids in the dispersal of contaminants to the roots of the plants; and (3) the scrubber, composed of five fiberglass panels with external faces of porous lava rock, known as the "breathing wall". Panels 2-5 were covered with moss in the original configuration.

Concept Diagram For Breathing Wall



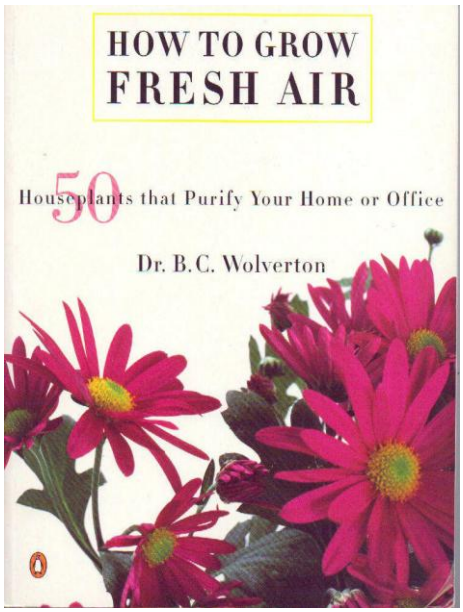
Source: http://ecologicdesignlab.com/2009/04/house-plants-living-walls-and-iaq/

The faces of the panels, largely covered with moss, are wetted by recirculating water. Air is drawn through the scrubber and the immediately adjacent hydroponic region by a dedicated air handling system. Once the air is drawn through the scrubber it then goes into the general ventilation system, the HVAC (heating, ventilation, and air conditioning) system, then through the air duct system and back into the room with the breathing wall.

In its research configuration, the breathing wall was home to hundreds of different types of plants including several species of mosses, ferns, and orchids. The ecosystem also included amphibians (tree frogs and salamanders) and over a dozen different types of fish. The larger Environmental Room also contained insects, earthworms and many other microbes (picture below). This arrangement proved successful at removing volatile organic compounds (formaldehyde, toluene, trichloroethylene, particulates, molds, and bacteria).

Environmental Room with Breathing Wall

Plants: Natural Scrubbers



Key Parameters. Following are key parameters of performance and further information on breathing walls:

1) For VOC removal, a lower air speed leads to higher removal. Aim for less than 0.2m/s. Highest removal was at 0.15 m/s
2) For size, the rule of thumb is 1 square foot of breathing wall can clean 100 square feet of floor space. For a 1,500 sq.ft. house, this comes to 15 sq.ft. of area (e.g., 6 x 2.5').
3) Tropical plants work better than native plants, because native plants are subject to seasonal variation to survive, and you would have to mimic this variation inside a building for them to survive.
4) Survival rate of plants: 90% annually.
5) Organic measures, not pesticides, are used to control pests in the wall. In a large environmental room, "white flies, fungus gnats, spider mites and their respective predator species are necessary, even desirable. They contribute to the ecosystem's species diversity and ecological stability."
6) Good information can be found at: http://ecologicdesignlab.com/2009/04/house-plants-living-walls-and-iaq/
7) For reviews of commercially available product see: http://www.impactlab.net/2009/05/16/living-wall-systems/ ; http://www.naturaire.com/home_owner_faq.php#q7 ; and http://gardenbeet.wordpress.com/2010/11/28/easiwall-living-wall-treebox-on-flushing-and-their-new-diy-living-wall-system/.
8) For a simple approach to building your own wall see http://www.wikihow.com/Make-a-Living-Wall.

Breathing walls should not be confused with vertical gardens or living walls that do not have active air circulation. The filtering of pollutants is at a much lower level in these latter. Nonetheless, check out http://www.lushe.com.au/2009/10/23/how-to-build-a-vertical-garden/ and the Recent Posts to the right.

Tax Credits and Other Assistance

1) Federal Tax Credits, Form 5695, Residential Energy Credits. $1,500 Federal "Energy Property" tax credit for energy efficiency improvements to your residential property, and a 30% Federal "Energy Efficienct Property" tax credit for PV, wind, geothermal devices, and fuel cells. The first credit only applies to existing homes (retrofits), whereas the second applies to existing and new homes. There are exclusions and fine print regarding minimum performance standards of purchased energy improvements, and in general, you cannot get the credit for DIY systems you build or install yourself. It is not clear to me whether or how much of these credits will continue for 2011 and beyond, so confirm before continuing.

2) For USDA, check out http://www.rurdev.usda.gov/Energy.html, in particular, their "energy matrix" at http://www.energymatrix.usda.gov/ . Programs are focused on your farm as a business rather than your farmhouse as such. Each state has an Energy Coordinator. For PA, this person is:

   Bernard Linn, USDA Rural Development
   One Credit Union Place, Suite 330
   Harrisburg, PA 17110-2996
   (717) 237-2182
   Bernard.Linn@pa.usda.gov

3) Pennsylvania's Dept. of Environmental Protection has an Energy Program, but it seems to be geared to projects that produce energy as part of a business. With the change in administration in Harrisburg, you should contact them directly to get better information. (http://www.depweb.state.pa.us/portal/server.pt/community/energy/6001). Also, PA Sunshine Solar Program for rebates for installing solar facilities (http://www.homelandsecurity.state.pa.us/portal/server.pt/community/in_the_news/10475/pa_sunshine_solar_program/553019)

Lessons Learned

The Passive House framework provides a clear benchmark against which to compare our retrofits. Here are the lessons we learned, and what we might have done differently:

1) Until everything is done, you will not realize the savings you had hoped for. Leaving something undone – insulation, windows, infiltration reduction – is equivalent leaving windows or a door open all winter. In our case, we didn't have the money to do it all at once. Moreover, it takes time to investigate alternatives, figure out what you can do yourself, talk with and line up contractors. If you wait until August to start a retrofit, you may find yourself finishing in mid-December. That's how long it took us to get the windows installed.

2) Technology and building practices are changing rapidly in response to rising energy prices, and more widely shared assumptions on global warming and the destructive aspects of petroleum and natural gas development. Using less energy is better for us, other species, and the planet. We expect to see Passive House becoming a new standard for residential and commercial construction and retrofits as it already has in Europe.

3) Focus on the building envelope; this must be highly insulated and airtight at all points for energy use to be dramatically reduced. The Passive House mantra is "build tight and ventilate right."

4) With the benefit of the Passive House standard, we should have used more insulation – more layers of foam board!

5) In addition, we should have reduced total window area by reducing the size and number of windows in the living room during that retrofit in 2001. These five windows – five pictures with matching casements -- were the largest in the house, and therefore, the most expensive to replace. Even our R-20 wall is much better than our new R-7 windows. An R-30 wall would have been even better. Retaining all five large picture windows was a mistake.

6) We would urge anyone contemplating a flat plate solar hot water system to go with a drainback system rather than a pressurized glycol system. A drainback system is foolproof, doesn't require glycol because it drains when the sun is not out, or in the event your power fails. A glycol system does not drain, could overheat and compromise your collector fluid, spring a leak, or blow your pressure release valve.

7) Be skeptical of performance claims. The simple fact is that energy prices are still too low to yield reasonable payback periods for many improvements. Therefore, verify claims on payback periods by

doing your own math, and talking with those who have used the technology or made an improvement. Get their performance data and assessment and apply to your own case. While tax breaks act as an inducement, they can distort the picture of what is really going on.

8) If, while making a retrofit, you find that you (or the contractor) have made a mistake, stop work and correct it right there! The stakes are too high. Once you put the siding on, it is too late. You will forever regret it (or the next owner will realize just what a dope you were).

9) One lesson Wes Jackson applied in the design and construction of the new research building at The Land Institute was to take a manufactured metal building you could purchase inexpensively on the market, and insulate it properly from the inside. This is much cheaper than designing and building a custom building.