REDUCING THE ENERGY USE OF HOUSES, by Willem Post, dated April 7, 2010
http://www.coalitionforenergysolutions.org/

INTRODUCTION

The US faces two major simultaneous challenges:
-reduce the impact of rising prices of energy and other natural resources on US global competitiveness. In 1973 the US was using about 60% more energy per dollar of GDP than other industrialized nations. After 36 years that percentage remains unchanged. The US needs to rapidly reduce that percentage by greatly improving the energy efficiency of buildings, transportation and industries.
-halt the rise of CO_2 in the atmosphere and ultimately reverse it to 1990 levels. The US needs to shift most of its power production from fossil fuels to alternatives, such as nuclear, and renewables, such as solar, wind, geothermal, tidal and biofuels.

Largely due to lobbying by well-organized interest groups, federal, state and local governments have allocated about $40 billion for incentives for alternative and renewable energy and, due to a lack of similar interest groups, only about $20 billion for energy efficiency improvements. These numbers need to be reversed, because opportunities for energy efficiency improvements exist by the tens of millions, they can be quickly implemented and have shorter paybacks than those for alternative and renewable energy. All such incentives need to be increased 10-fold to deal with the magnitude of the energy efficiency and reduction of CO_2 challenges.

Current incentives in Vermont and elsewhere to build ENERGY STAR houses, buy hybrid cars and solar, wind and geothermal systems, etc., benefit mostly the top 5% of households which do not need these incentives, whereas the 80% of households with low and medium incomes which live mostly in older, drafty, poorly insulated energy hog houses lack the funds to improve their energy efficiency and reduce their CO_2 emissions. A better policy is to limit all such incentives to households with incomes less than, for example, $75,000/yr.
The US residential and commercial sectors use about 21% and 17% of all energy, respectively. It will be necessary to reduce their energy use to about 20% of their current levels. In Germany demonstration office buildings use about 10% - 15% of the energy normal office buildings use and specially designed superinsulated houses use about 10% of the energy normal houses use. Such buildings require major changes in construction methods and in building equipment and systems. The US building industry has obstructed these changes, because most of its members have no knowledge of them. They prefer to stay with what they know. Large numbers of government-sponsored demonstration projects, financed with low interest loans, capital grants, tax credits, etc., are needed to jump-start the building industry towards energy efficient buildings.

With regard to houses, various studies, demonstration projects and actual experience in the US, Europe, Japan, etc., have shown that PASSIVE measures, such as roof overhangs that shade windows in summer and not in winter, superinsulating, sealing air leaks, using triple-pane windows and foam-core doors, are the most cost effective way to reduce the energy loss of the envelopes of NEW houses by up to 70% compared to houses built to the latest energy codes. The cost of these envelopes is about 5% - 10% more than envelopes built to the latest energy codes. Passive measures work no matter how careless the occupants.

ACTIVE measures, such as efficient heating, ventilation and air conditioning systems, water heaters, lighting and appliances ADDED to the above passive measures will further reduce the energy use of new houses by up to 20%. The cost of these measures is about 5% less than those for houses built to the latest energy codes, because the energy use of superinsulated houses is much less and can be provided by lower capacity but more efficient equipment and systems.

People will be very reluctant to reduce the energy use of EXISTING older houses, condos and apartments by at least 70%, because the capital costs are high compared to the annual savings. Tens of millions of such housing units cannot be upgraded for such low energy use and will need to be replaced. Low interest loans, capital grants, tax credits, etc., will be needed to jump-start the retrofitting of the remaining housing units. It will take decades and at least $15 trillion.

After the residential, commercial, transportation and industrial sectors are made more efficient, the electric power grid is upgraded to accommodate variable solar and wind power, user consumption and demand management systems are installed and about 100,000 mW of new nuclear plants are built to replace existing plants, most older coal, oil and gas fired power plants may be decommissioned. The US will use less than half the energy per dollar of GDP, emit less CO_2 in 2050 than in 1990, and be less dependent on foreign oil and gas.

Superinsulated houses rated HERS = 15 or less will be the way forward to reduce house energy use to 15% or less of houses built to the latest energy codes. Such houses need to be built using:
- Roof R-60 or better, properly inclined and facing South for future solar systems. No skylights; they are major heat losers.
- Walls R-40 or better, such as offset double 2x4 walls, or sprayed foam insulation between studs, or SIPs and ICFs
- Basement R-20 or better, 4” styrofoam on the OUTSIDE of the walls and footings and 2” styrofoam under the slab.
House on a concrete slab: Slab R-20 or better, 4” styrofoam under slab. Outer edges R-30 or better, vertical 6” styrofoam about 2’ deep.
- High efficiency heating and cooling systems, appliances and lighting, windows R-7 or better (R-12 windows exist), foam core doors R-10 or better (R-12 doors exist); a typical double pane window is R-3, a typical six-panel exterior wood door is R-2
- Building envelopes rated for 2 or less air changes per hour (ACH) @ 50 Pascals, as determined by a blower door test.
- Heat recovery ventilation systems, 80% efficient or better, to provide 0.6 ACH
Solar, wind and geothermal systems must be added to make these houses Net Zero Energy houses or Energy Surplus houses.

MAJOR RATING SYSTEMS OF HOUSES

In the US there are three major rating systems aimed at reducing the energy use of houses: HERS, or Home Energy Rating System; LEED, or Leadership in Energy and Environmental Design; and ENERGY STAR. The three rating systems are described below. HERS, because of its versatility and simplicity, and the increased emphasis on much greater energy efficiency, appears to increasingly replace the ENERGY STAR rating system. The less strict parts of the rating systems can be implemented with conventional wood frame construction. The more strict parts require unconventional construction methods, such as wood frame with sprayed foam insulation, structural insulated panels (SIPs) and insulated concrete forms (ICFs).

HOME ENERGY RATING SYSTEM (HERS)

HERS was established by RESNET, or Residential Energy Services Network. HERS compares a home under construction with a reference home that meets the minimum requirements of the 2006 IECC, or 2006 International Energy Conservation Code. The IECC is upgraded as required by future energy prices.

The HERS rating is a measure of heating and cooling efficiency, insulation levels, appliance and lighting energy use, window efficiency, solar orientation and onsite renewable energy production for a home in a specific climate zone. There are 8 climate zones; Vermont is in Zone 6.

The HERS rating, calculated using RESNET accredited computer software, factors in actual measurements from a home, such as the results of a blower door test, a visual inspection of thermal envelope components and a duct leakage test for a home with ducts in unconditioned spaces.

The 2006 IECC Reference Home requires the following house envelope insulation levels for Zone 6: Windows, U = 0.35; Skylights, U = 0.6; Ceiling, R-49; Wood frame 2x6 wall, R-19; Floor above unheated basement or crawl space, R-30; Basement wall or crawl space wall, R-10; Basement slab, R-10. Visual inspection of the thermal envelope components or blower door test results showing an infiltration rate of less than 8 air changes per hour (ACH) at 50 Pascals (Pa).

The 2009 IECC has been issued. The stricter 2009 IECC, if adopted and ENFORCED throughout the US, will reduce residential energy use by about 12%-15% compared with the 2006 IECC. In most areas of the US, many requirements of existing energy codes are rarely enforced. Because of future increases in energy prices IECC codes will likely become stricter and enforced.

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The 2030 Challengeis is a campaign to reduce greenhouse gas emissions, calls for homes built after 2007 to be HERS = 65 and HERS = 0 by 2030. Thus far few houses built after 2007 are HERS = 65.

Examples of HERS Ratings
Energy hog house; HERS = 150+
Average US house; HERS = 130
2006 IECC Reference Home; HERS = 100
ENERGY STAR house, climate Zones 1,2,3,4,5; HERS = 85 or less
ENERGY STAR house, climate Zones 6,7,8; HERS = 80 or less
VT law 446 requirement for new houses; HERS = 80 or less. No state wide inspection and enforcement measures are in place.
Rural Development Inc. (RDI) house without photovoltaic (PV) system; HERS = 60
RDI house with PV system; HERS = 43
Near Zero Energy house (produces almost as much energy as it consumes); HERS = 5 - 15
Passivhaus standard, over 20,000 built, mostly in Germany, Austria, Sweden; HERS = 10 or less. See Passivhaus below.
Net Zero Energy house (produces as much energy as it consumes); HERS = 0
Energy Surplus house (produces more energy than it consumes); HERS less than 0

Example of a Near Zero Energy Housing Development
The RDI designed Wisdom Way Solar Village is a development of 20 superinsulated, 2-story, 1,400 sq ft houses with roof-mounted PV and solar hot water systems, located near the center of Greenfield, MA, priced at $210,000 - $240,000; HERS = 7 - 17
A state subsidy allowed 16 of the houses to be sold to low and medium income households at about $110,000; an example of Massachusetts helping low income households.

A typical 2-story, three-bedroom house in the development has a heating load of 12,600 Btu/hr when the outside temperature is 2F. It has the following features:
- Southern orientation, open floor plan, 1,392 sq ft of heated space above an unheated full basement
- Roof-mounted 3.4 kW PV system generates about 4,000 kWh/yr and provides for most of the electricity use
- Roof-mounted 87 sq ft solar hot water system with 105-gal storage tank provides for most of the hot water use
- Building envelope ACH = 2 or less @ 50 Pascals
- Recycled blown-in dry cellulose encircling the building envelope: 12 inches in the offset double 2x4 walls, R-42; 14 inches in the ceilings, R-52; 11 inches in the basement ceiling, R-38
- High efficiency windows north, east, and west; U = 0.18, Solar Heat Gain Coefficient (SHGC) = 0.26, Visible Light Transmission (VLT) = 0.42
- High efficiency windows south; U = 0.26, SHGC = 0.36, VLT = 0.53
- Continuous 50 CFM exhaust ventilation
- ENERGY STAR refrigerator, dishwasher, and clothes washer (plus natural gas cook stove and clothes dryer)
- Compact fluorescent light bulbs throughout
- On-demand natural gas hot water heater as back up to solar hot water system
- Sealed combustion Monitor room heater in the central living area on the first floor (no fossil fuel-based central heating system is necessary)
- No air conditioning
- Air distribution system to move air and heat from the first floor to the second floor bedrooms. The ducts for this system, as well as the vent fans, are sealed with mastic; duct tape deteriorates with time.

Energy Surplus Houses
In the future, to reduce CO2 emissions, tens of millions of Energy Surplus residences (houses, condos and apartment buildings) will be needed to provide power to tens of millions of plug-in hybrid and all-electric vehicles. The residences will have user consumption and demand management systems that will feed power from the vehicle batteries (and/or from wind and solar systems) into the grid to augment utility electric services.

LEADERSHIP in ENERGY and ENVIRONMENTAL DESIGN (LEED) RATING SYSTEM
The LEED for Homes rating system was established by the US Green Building Council. The LEED for Homes standard is periodically updated. The latest, LEED - Homes V2008, was released January 2008. It has 130 possible points, plus an additional 6 points available for innovation in design. Houses and other buildings can qualify for four levels of certification: Certified, 45 - 59 points; Silver, 60 - 74 points; Gold, 75 - 89 points; Platinum, 90 - 136 points. LEED - Homes V2008 covers 8 categories: Innovation & Design, Location & Linkages, Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality and Awareness & Education. LEED certified homes must be HERS = 80 or less, and have healthier work and living environments which contribute to improved health and comfort.

Example of a LEED Platinum House
Vermont's first LEED Platinum house is in Charlotte, Vermont; it is a net zero energy house, HERS = 0
Construction cost: 2,700 sq ft X $196/sq ft = $529,200. The cost does not include the land and $30,000 for septic system and well.

A 10 kW wind turbine located 400' from the house generated electricity from January 2008 to January 2009. The unit generated 10 kW X 8,760 hrs/yr x 0.0715 capacity factor = 6,286 kWh during that year of which 6,094 kWh was used and 192 kWh was sold to the utility as part of "net-metering". The owner pays the utility $9/mo. for standby power. Note the very low 0.0715 capacity factor. For 400 tall wind turbines it would be about 0.30 - 0.35, depending on location and wind conditions, etc. See spreadsheet.

The wind turbine capital cost was $40,500 ($4,050/kW) which was reduced to $28,000 due to a $12,500 grant from Efficiency Vermont; an example of Vermont giving subsidies to higher income households that do not need them, instead of to lower income households with drafty, poorly insulated houses that do need them. These grants are politically attractive, but promote an uneconomical technology. They are a wasteful use of scarce government resources which should be used for projects with SHORT payback periods, such as insulating, sealing, etc., that would quickly benefit the bottom 90% of households.

Other features are:
- Ground source heat pump, GSHP, with variable speed drive
- Heat recovery ventilation system
- Basement: 4" concrete slab on 4" expanded polystyrene, R-16. Poured 8" concrete walls lined with 2" EPS plus 2x4 studs, 24" o.c., filled with dense-packed cellulose (to avoid sagging) contained by reinforced netting, R-21 total
- Floors: I-joists, 24" o.c., 3/4" oriented strand board, OSB, subfloor, 4" ground and polished concrete floor enclosing radiant heating system, denim batting insulation between I-joists, R-21
- Walls: 2x6, 24" o.c., 5.5" closed-cell sprayed polystyrene, 1" polyisocyanurate over exterior sheathing, caulked and sealed, housewrap, cedar breather mesh, painted clapboards, R-40
- Windows: fiberglas frame with thermal breaks (less heat loss than wood frames), triple-pane, low-e, argon filled, U = 0.17
- Roof: 2x10 rafters, 24" o.c., 9" closed-cell sprayed polystyrene, 3/4" OSB, waterproof membrane, standing seam metal roof, R-58

ENERGY STAR RATING SYSTEM

The ENERGY STAR program was set up in 1992 and is administered by the US Environmental Protection Agency and US Dept. of Energy. ENERGY STAR qualified NEW houses in climate Zones 1,2,3,4,5, must be HERS = 85 or less and in climate Zones 6,7,8, must be HERS = 80 or less. ENERGY STAR houses typically perform better than that, in the range of HERS = 60 - 75. Insulation requirements are the same as for the 2009 IECC Reference Home, except windows and skylights must be U = 0.30 or less, SHGC = 0.30 or less, and exterior doors U = 0.30 or less. Additional energy efficiency requirements exist for the heating, ventilation and air conditioning systems, water heaters, lighting and appliances.

An ENERGY STAR qualified NEW house is a major improvement compared with an energy hog house or an average US house. The NAHB likes the ENERGY STAR rating system; it is easily complied with and makes a house easier to sell. In the future, greater energy efficiency will be required for NEW houses, i.e., HERS = 15 or less requiring offset double 2x4 walls, or sprayed foam insulation between studs, or SIPs and ICFs.

ALTERNATIVE ENERGY SOURCES

Below are described four alternative energy sources for houses: small wind systems; solar PV systems; solar hot water systems; and ground source heat pump systems. Each of them has advantages and disadvantages. Solar PV and small wind systems produce high cost electricity and have very long paybakc periods relative to solar hot water systems and ground source heat pump systems which payback periods of less than 10 years.

Residential Wind Power

Example of residential wind system for a LEED Platinum house, Charlotte, Vermont: Capacity 10 kW, grid-connected, 80-ft mast, all-in cost $40,500, or $4,050/kW, grant from Vermont's taxpayers $12,500. It produces about 6,286 kWh/yr, 6,094 kWh is used, 192 kWh is sold to the utility as part of "net-metering". Capacity factor, CF = (6,094 + 192) kWh/yr/(10 kW x 8,760 hr/yr) = 0.0712. The owner pays the utility $9/mo. for standby power. The useful service life is about 10-15 years. The levelized cost of buying electricity from the utility for 25 years is about $0.230/kWh, from wind with no incentives about $0.459/kWh, from wind with current incentives about $0.319/kWh. Residential wind power systems are very uneconomical investments. See spreadsheet.

Residential PV Solar Power

Example of a residential PV system in Burlington, Vermont: Capacity 4 kW DC/3.3 kW AC, roof-mounted, fixed-tilt, grid-connected, all-in cost $24,000, or $6,000/kW. It produces about 5,043 kWh/yr (as calculated by the NREL pvwatts program), which is about 65% of total use, and has a value of $650.55/yr at $0.129/kWh. The warrantee period of PV panels is 25 years, the useful service life of a PV solar system is about 30 years. The levelized cost of buying electricity from the utility for 25 years is about $0.230/kWh, from PV solar with no incentives about $0.404/kWh, from PV solar with current incentives about $0.258/kWh. Residential PV solar systems are very uneconomical investments. See spreadsheet. http://www.pvwatts.org/

It is much more cost-effective to improve energy efficiency than to buy a PV solar system. For example, a new energy-efficient refrigerator, which can cost $1,000, could reduce energy consumption by about 360 kWh/yr compared to the old model, which has a value of $46.44/yr at $0.129/kWh; a tax-free payback of $46.44/$10 = 4.64%. The additional cost of a larger PV solar system to run the old model could be around $2,000. Thus, the newer model would reduce net capital costs by about $1,000 , which has a value of $70/yr at 7%/yr, plus about $46.44/yr in electricity, for a total of $116.44/yr. Energy efficiency PAYS.

Residential Solar Hot Water (SHW) System

The installed cost of a 64 sq ft roof-mounted SHW system with an 80 gallon storage tank is about $8,000. In Vermont it produces about 50% - 60% of hot water use. Compared with fuel oil or propane hot water systems, the payback period of an SHW system is about 8 - 12 years, depending on hot water use. With financial incentives, the payback period is about 6 - 9 years. An SWH system needs a supplementary hot water system when solar heat is insufficient. In cold climates, closed-loop systems with a 50/50 glycol/water mix must be used which adds to the installed cost. Typical applications are swimming pool heating, domestic water heating and radiant floor (tubing in concrete) heating.

Residential Ground Source Heat Pump (GSHP) System

The installed cost of a 10 kW (3 ton) GSHP closed loop system may be as much as $30,000; the installed cost of the ground loop depends on site factors. The installed cost of a conventional heating and cooling system may be $20,000. Typically a GSHP system saves about 1/3 of the annual heating and cooling costs compared with a conventional system. If these costs are $3,000/yr, the saving is $1,000/yr and the payback is ($30,000-$20,000)/$1,000/yr = 10 yrs. A GSHP system moves heat from the ground to the house in winter and from the house to the ground in summer. If a GSHP system is sized to cool a house during summer, it will need a supplementary heating system during cold winter days.

SIPs AND ICFs

SIPs are used for walls and roofs. They have a layer of closed cell foam between two 1/2" OSBs; the thicker the foam, the higher the R-value. Three foams are in use: most common is expanded polystyrene (EPS), R-3.85/inch; second is polyurethane and polyisocyanurate (PUR), R-6.76/inch and third is extruded polystyrene (XPS), R-5/inch.
Winter Panel, Brattleboro, VT, has EPS and PUR SIPs rated R-25 to R-38. They are 4 or 8 ft wide varying from 8 to 24 ft long.
Murus, Mansfield , PA, has EPS SIPs rated R-16 to R-45, PUR SIPs rated R-26 to R-40 and XPS SIPs rated R-19 to R-58. They are 4 or 8 ft wide varying from 4 to 24 ft long.
RAY-CORE, Idaho Falls, Idaho, has 2x4, 2x6 and 2x8 SIP panels rated R-26, R-42, and R-52, respectively. Its factory-built panels are similar to stud walls but with sprayed foam insulation between the studs and reflective foil-facing on both sides. They are 4' wide and 8', 10' and 12' long.

ICFs are mostly used for concrete basements but can be used to construct an entire house. The forms consist of two foam sections that are held about 8" apart with plastic braces; the thicker the foam the higher the R-value. The ICFs lock together into walls, similar to LEGO blocks. After placing reinforcing steel, concrete is poured between the foam sections to form walls. Because of its large concrete thermal mass, the temperature in an ICF house varies little and slowly with outdoor temperature changes.
Quad-lock, Surrey, B.C., has ICFs rated at R-22, R-32 and R-40

Construction with SIPs and ICFs can reduce house energy use by more than 50%, making it easy to qualify for ENERGY STAR and a low HERS rating. SIPs and ICFs perform better because they do not have the voids, gaps, and compression of fiberglas and cellulose insulation in stud walls. SIP and ICF houses are significantly more airtight than houses with stud walls. The foam core of SIP panels function as a complete air barrier, and working with large panels means there are fewer joints to seal.

Studies by Oak Ridge National Laboratory (ORNL) show that when whole wall R-value is measured, SIPs and ICFs far outperform wood framed walls. ORNL evaluations of a SIP test room revealed it to be 14 times more airtight than an equivalent room with 2x6 construction, sheathing, fiberglas insulation and drywall. For ENERGY STAR rating purposes, the EPA does not require a blower door test for houses built with SIPs and ICFs.

Passing the required Thermal Bypass Checklist is practically automatic when building with SIPs and ICFs. Properly installed SIPs and ICFs provide the whole-house air barrier that the checklist requires, and if a SIP roof is used as well, additional areas of air leakage are avoided.

TYPICAL HEAT LOSSES FROM HOUSES

Some major measures to reduce the heat losses from houses, listed in order of energy saved are: seal HVAC ducts, insulate the basement to R-20 or better, install programmable thermostat, insulate attic to R-40 or better, seal home air leaks, upgrade heating equipment. Below are some calculations of typical heat losses.

Heat Loss from an Insulated Concrete Basement

For a 2-story house with a heated INSULATED concrete basement, the basement heat loss is about 1/3 of the heating season heat loss. Such a basement may have 2" styrofoam panels under the concrete slab and on the outside walls, but some of the heat will be transmitted from the basement to the soil via the walls and uninsulated footing.

Assuming a 4-month heating season, R-4 for the concrete path from basement to soil under the footing, a 28' x 40' basement with 1.5' wide footings will loose about 1/4 x 204 sq ft x (68 - 50) F x 1/0.70 AFUE x 8,760/3 hrs/yr = 3,829,371 Btu/yr, or about 27 gal/yr of fuel oil.

The heat loss for the insulated slab, R-10, will be 1/10 x 1,120 sq ft x (68 - 50) F x 1/0.70 AFUE x 8,760/3 hrs/yr = 8,411,029 Btu/yr, or about 60 gal/yr of fuel oil; it will be less if a lower floor surface temperature is assumed. Using 4" instead of 2" styrofoam under the slab would half the heat loss.

The loss calculation for the insulated walls is complicated due to varying air temperatures, frost depths and temperatures in the soil. It likely will be more than 100 gal/yr. Using 4" instead of 2" styrofoam on the outside of the basement walls would half the heat loss.

Thus the total heat loss of a heated INSULATED basement is equivalent to about 200 gal/yr of fuel oil.
If the basement had 4” styrofoam panels, equivalent to one built with ICFs rated R-22, the heat loss would be about 100 gal/yr of fuel oil.

Heat Loss Reduction with Styrofoam Panels under the Concrete Basement Footing

A concrete basement with 9' tall, 8" thick walls and a 1.5' wide footing weighs about 1,000 lbs per linear foot. It exerts about 5 psi on the soil. The rest of a 2-story house adds about 5 psi, for a total of 10 psi.

Owens-Corning makes foam panels, R-5/inch, and 40, 60, and 100 psi compressive strengths. The 100 psi panel sizes are 2' x 8' x 2" thick. In various northern European nations individual houses are required to have such foam panels UNDER the footing and standard 15 psi panels on the sides of the footing. They are also used in Canada and the northern US.

Placing 100 psi, R-10 foam panels under the above footing will reduce the heat loss from 27 gal/yr of fuel oil to 1/(4 + 10) x 204 sq ft x (68 - 50)F x 1/0.70 AFUE x 8,760/3 hrs/yr = 1,094,106 Btu/yr, or 8 gal/yr of fuel oil, a saving of 19 gal/yr of fuel oil.

Heat Loss Reduction by Superinsulating and Sealing an Existing House

A house, 80 years old, 2-family, 2-story, 3,000 sq ft total, located in Arlington, Massachusetts, was selected to demonstrate the energy reduction that can be achieved by superinsulating, etc. The house was in need of new roofing and siding. Fuel oil consumption for space heating and hot water was about 2,500 gal/yr. The project cost was about $100,000, of which $50,000 was donated by the state and participating vendors and contractors which benefitted from the publicity. After improvements the fuel oil consumption for heating and hot water is about 800 gal/yr, for a saving of 68%.

Whereas the payback will be several decades, the house will be more comfortable, and just as the Toyota Prius market value went up when gas was $4/gal, so will the market value of superinsulated houses go up in the future which will greatly shorten the payback period.

- The existing roof was R-25. To obtain an R-60 roof, existing roof shingles were removed, 2 layers of styrofoam, 7" total, were added. All seams were taped. Roof reshingled and retrimmed.
- The existing walls were R-13. To obtain R-33 walls, existing clapboards were removed, 2 layers of styrofoam, 4" total, were added. All seams were taped. Walls reclapboarded and retrimmed.
- Existing windows were replaced with double-pane energy efficient windows
- Existing exterior doors were replaced with foamcore doors
- Heat recovery ventilation system was installed to ensure fresh air
- Carbon monoxide monitors were installed

A future project could be insulating the interior basement walls.

Heat Loss from a 2006 IECC Reference Home on a Cold, Windy Day

Infiltration rates for most houses are primarily driven by the pressure difference (delta p) due to the stack effect in the house and the higher pressure on the windward side relative to the leeward side of the house. The natural delta p on mild windless days = 0.1 Pa - 0.3 Pa, on cold windy days = 20 Pa or more. ACH varies according to the square root of delta p. If ACH @ 50 Pa = 8, then it equals V20/V50 x 8 = 5 ACH @ 20 Pa. The heat loss on cold windy days = 5 ACH x 11,688 cu ft house volume x 0.075 lb/cu ft x 0.24 air specific heat x (68F - 20F) = 50,492 Btu/hr. An equivalent size house designed to the much stricter Passivhaus standard would have a heat loss of 1,010 Btu/hr on a cold windy day. See Passivhaus below.

The above shows the 8 ACH @ 50 Pa of the 2006 IECC Reference Home and the 7 ACH @ 50 Pa of the 2009 IECC Reference Home are grossly inadequate. In the future ACH = 1 or less @ 50 Pa is needed to significantly improve energy efficiency. However, various interest groups, such as the National Association of Home Builders (NAHB), are opposed to stricter ACH standards because it would require major changes in the construction of housing. Houses with wood frame walls are difficult to build to have ACH = 1 or less @ 50 Pa. Few members of the NAHB are ready for these changes. See SIPs and ICFs below.

MY HOUSE

I designed and built my house in 1987. Gross floor surface 3,360 sq ft, including 1,120 sq ft of heated basement. The house has 2x6 walls with 6" fiberglas insulation, 10" fiberglas between the roof joists, a concrete basement with 9' tall, 8" thick walls and a 1.5' wide footing, basement exterior walls covered from footing to sill with 2" styrofoam covered with 1/2" PT plywood, 2" styrofoam under the basement slab.

Each year I buy the following energy:
Electricity 6,000 kWh/yr = 3,413 Btu/kWh X 6,000 kWh/yr = 20,478,000 Btu/yr
Propane 400 gallon = 400 gal x 100,000 Btu/gal = 40,000,000 Btu/yr
Fuel oil 600 gallon = 600 gal x 145,000 Btu/gal = 87,000,000 Btu/yr
Total Purchased Energy = 147,478,000 Btu/yr/3,360 sq ft = 43,892 Btu/sq ft/yr
If a Passivhaus is HERS =10, my house is HERS = 43,892/13,289 X 10 = 33

Actual experience with my heated insulated finished basement: During a winter day, the basement-located propane stove (output 14,000 Btu/hr, AFUE = 70%) maintains 65F in the basement during the heating season; the basement located oil furnace comes on periodically during colder days. During a winter night, with the house thermostats set to 55F, warm air rises into the house through the open basement door; the oil furnace rarely comes on, except on colder nights. During 90F summer days when the upstairs bedrooms are warm and the basement temperature does not rise above 70F, we comfortably sleep in the basement. Because of its large concrete thermal mass, the temperature in the basement varies little and slowly with outdoor temperature changes.
A future project could be replacing the propane stove, AFUE = 70%, with a condensing unit, AFUE = 90%; savings 80 gal/yr.

PASSIVHAUS

The Passivhaus standard was developed in Germany in 1988. The Passivhaus Institut was founded in Darmstadt, Germany, in 1996. Over 20,000 Passivhauses have been built since the early 90s, mostly in Germany, Austria and Scandinavia.

After some decades of experience, the cost of building to the Passivhaus standard is now only an additional 5% to 7%. Passivhaus builds the walls and roof as much as possible in the factory, ships them to the site, and has a certified builder erect and finish the house. The insulation, plumbing, wiring, etc., are pre-installed as much as possible. Connections are made in the field. There are over 30 German suppliers of Passivhaus specified walls, roofs, windows, doors, heat exchangers, duct systems, etc. They are a part of Germany's Efficient Buildings industry that provides market-tested products and services.

Design Criteria:
- Less than 15 kWh/sq m/yr, or 4,746 Btu/sq ft/yr for space heating
- Less than 15 kWh/sq m/yr, or 4,746 Btu/sq ft/yr for space cooling
- Less than 42 kWh/sq m/yr, or 13,289 Btu/sq ft/yr for space heating and cooling, hot water, electricity
- Less than 120 kWh/sq m/yr, or 37,969 Btu/sq ft/yr as primary energy. This standard requires the use of energy efficient electrical appliances, heating and cooling systems, etc.
- Insulation minimum for concrete basement or slab R-40, walls R-40 and roof R-60
- Windows are fiberglass-frame, triple-pane, argon or krypton-filled, low-e, U = 0.14 or less
- ACH = 0.6 or less @ 50 Pa below atmospheric pressure, as measured in a standard blower door test. This requirement is about 12 times more strict than for the 2006 and 2009 IECC Reference Homes
- Energy recovery ventilator, at least 80% efficient, to provide a constant, balanced fresh air supply via a duct system
- Electric resistant heater element, a maximum of 10 W/sq m, or 0.93 W/sq ft, in the duct system to provide auxiliary heat on very cold days
- HEPA filter (optional) to remove particulate 1 micron or larger, i.e., germs, dander, viruses, air pollutants, etc.

Notes:
1. In Germany a "Niedrigenergiehaus" uses less than 50 kWh/sq m/yr, or 15,850 Btu/sq ft/yr for space heating.
2. In Switzerland a "Minenergiehaus" uses less than 42 kWh/sq m/yr, or 13,289 Btu/sq ft/yr for space heating.
3. Primary energy is unconverted energy; i.e., energy to make electricity, uncombusted fuel, etc.
4. Anderson, Marvin and Pella windows are wood-frame, double-pane, low-e, U = 0.32; they lose twice the heat lost by Passivhaus windows. Thermatech windows, fiberglass-frame, triple-pane, argon-filled, low-e, U = 0.17.
Serious Windows, fiberglass-frame, triple suspended films between two glass panes. U = 0.09 - 0.13, VT = 0.30 - 0.39, SHGC = 0.20 - 0.26
Therma-Tru fiberglass or steel doors, polyurethane core, R-10.
http://www.efficientwindows.org/factsheets/vermont.pdf
5. 1 atmosphere = 101,325 Pascals = 406.8 inches of water = 10,333 mm of water; thus 50 Pa = 5.1 mm of water = 0.2 inch of water.

Below is a simplified calculation of a Passivhaus heat loss and heat gain.

Example: an approximately 1,600 sq. ft. Passivhaus on a concrete slab, R-40; 1st floor walls, R-40; 4 ft knee wall on the 2nd floor, R-40; 2nd floor has 45 degree cathedral ceilings, R-60. Inside ambient 68F, at cathedral ceiling 73F, outside 20F, soil under slab 50F. Air-to-air heat exchanger eff. = 80 %.

House volume = 9,792 + 4,896 = 11,688 cu ft
Slab heat loss = 1/40 x 24 x 34 x (68 - 50) = 367 Btu/hr
First floor walls heat loss = 1/40 x 2 x 9 x (24 + 34) x (68 - 20) = 1,253 Btu/hr
Knee walls heat loss = 1/40 x 2 x 4 x (24 + 34) x (68 - 20) = 557 Btu/hr
Roof heat loss = 1/60 x 2 x 1.41 x 12 x 34 x (73 - 20) = 1,046 Btu/hr
Forced ventilation heat loss at 0.5 ACH = 0.5 x 0.075 x 0.24 x 11,688 x 0.20 x (68 - 20) = 1,010 Btu/hr
Total heat loss = 4,233 Btu/hr

Two people heat gain = 2 x 397 = 794 Btu/hr
Electrical appliances, computers, lights, etc., heat gain = 0.5 kW x 3,413 = 1,707 Btu/hr
Total heat gain = 794 + 1707 = 2,501 Btu/hr

Heat loss - heat gain = 4,233 - 2,501 = 1,732 Btu/hr which can be provided by a 1.5 kW hairdryer- size heater in the ventilation system even on the coldest days.

- Solar heat gain through windows and cooking heat gain were not considered
- A 3 kW PV system and an 80 sq ft solar hot water system would provide for most of the electrical and hot water use

Actual experience by a Passivhaus homeowner: During a power outage for several winter days, the ambient temperature in the house did not drop below 60F. When cooking with a gas range it rose to 62F and when the sun shone it soon became 70F while the outside temperature was 20F.