

Ross Residence

Amherst, MA

Deep Energy Retrofit Goes for Zero



Project designed by: Coldham & Hartman Architects

Location: Amherst, MA



Updated 2/14/2012

Case Study: Thousand Home Challenge

Coldham&Hartman Architects

Background

The Rosses came to Coldham&Hartman Architects with an idea for a new house.

After several years of traveling the continent, following jobs in finance, they had decided to exit the rat race. They were a young and growing family, and were looking for a place to settle down. Sara had grown up in Amherst, attended high school here, and still had her parents in the area.

They hoped to create a home that would be their last. They had priced out land, made some calculations about the proposed cost of new construction, and were laying the groundwork for their one final move.

Then they moved to Amherst, rented a house for the short term, and began to consider the costs of a new house and to weigh that against the costs of renovating an existing structure.

And they thought ecologically – about the value of walking to school, about the resources brought to bear in new construction, and the value to be found in existing homes. When the house next door came up for sale, they decided to invest in renovation.



Design Constraints

Were we still interested? Certainly – the challenges of retrofits were enticing to us, and we'd begun to see the writing on the wall in terms of existing housing stock.

As a firm, we'd made a commitment to Deep Energy Retrofits – radical reductions in existing homes' energy consumption, and to use the Thousand Home Challenge as a benchmark for our renovation work. Here was a chance to demonstrate the strategies that could be used in all kinds of existing housing stock, to show that older homes weren't lost causes.

The Rosses, in the meantime, had begun to articulate their goals – they wanted to be sure to make their investments wisely. (They both have advanced degrees in economics, after all). They would invest first in envelope – the static systems that they'd have only one chance to get right. Interior finishes and high-end kitchen gear could be re-done at any time. There was only one chance in 30 years to do the walls and the roof, and they wouldn't miss that chance.



A Real Building

The house next door needed work.

They would keep the existing footprint – to make use of the foundation and walls already in place. Any needs would have to be met with what they already had in place. It was a 2,200 square foot home, with three upstairs bedrooms and a couple of baths, and a detached garage – enough for their needs.

The home was in perfect condition for a retrofit: Built in 1884, it was last owned by an aging couple unable to keep up on maintenance and unwilling to invest in renovation.

The roof was failing, the chimneys needed rebuilding, the walls were uninsulated, and the furnace was more than 40 years old. The electric service was older and the wiring was a mixed bag of a hundred years of changes. The siding was asbestos over lead-painted clapboard. “Perfect”.



Ross Residence
Existing Home

Amherst, MA



Photo: Sara Ross



Case Study: Thousand Home Challenge

Coldham&Hartman Architects

Ross Residence

Amherst, MA

Inside the Existing Home



Photo: Sara Ross.



Ross Residence

Amherst, MA

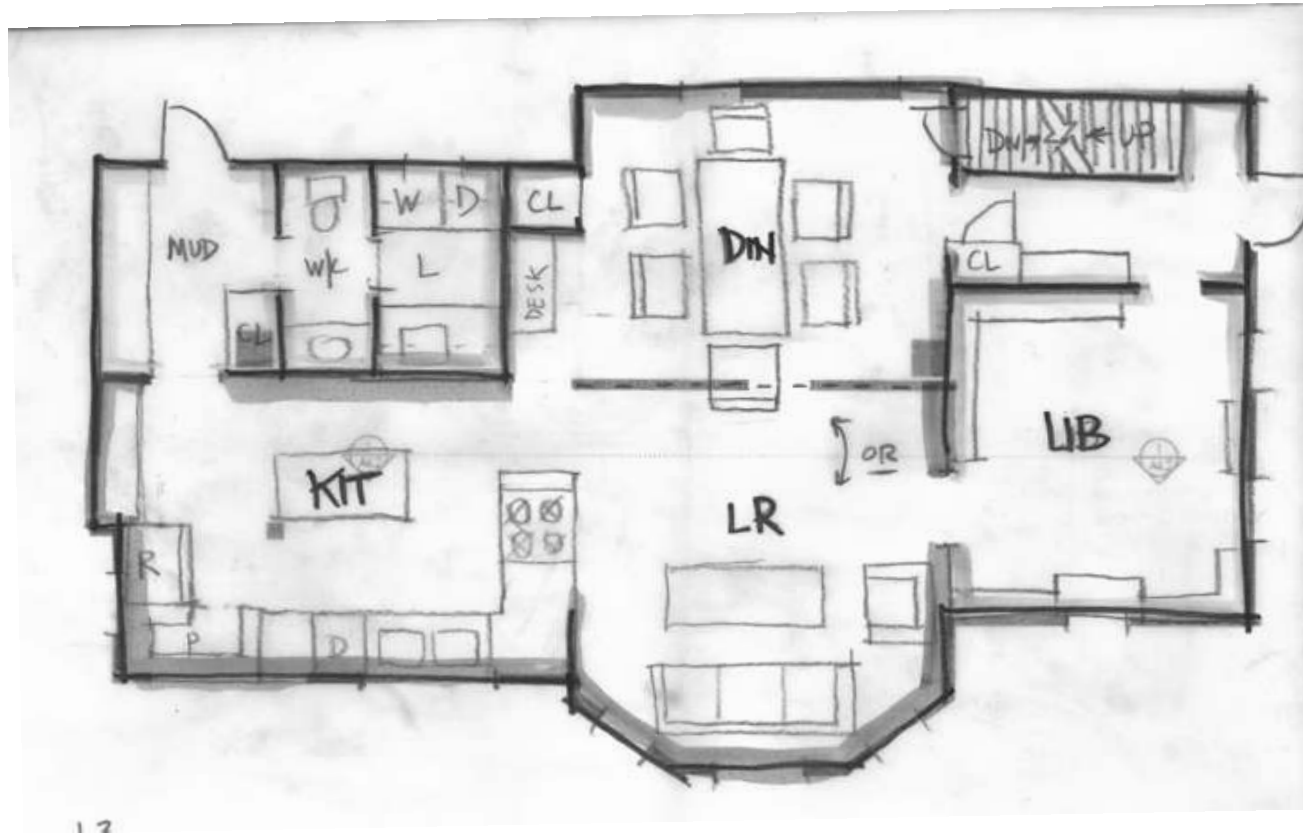
Existing Attic



Photo: Coldham&Hartman Architects. All Images by Coldham&Hartman unless otherwise noted.



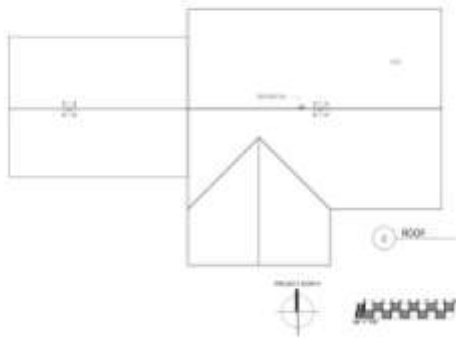
Proposed Floorplans – 1st Floor



The Rosses had spoken with a contractor, as well, at the beginning of the process, seen some work, liked what this company had done, and brought them to the table. We brought Marc Rosenbaum, PE of Energysmiths to help with the energy process, and Ryan Hellwig, PE. Now we had a team, and were off!



New Floorplans – 3rd Floor



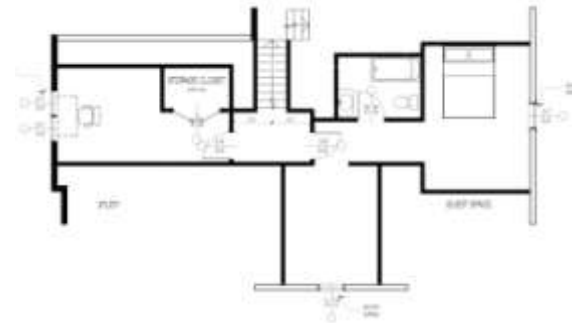
Existing Roof Plan



Cross Sections – Front, Middle, Back



New Roof Plan – already started dreaming of PVs

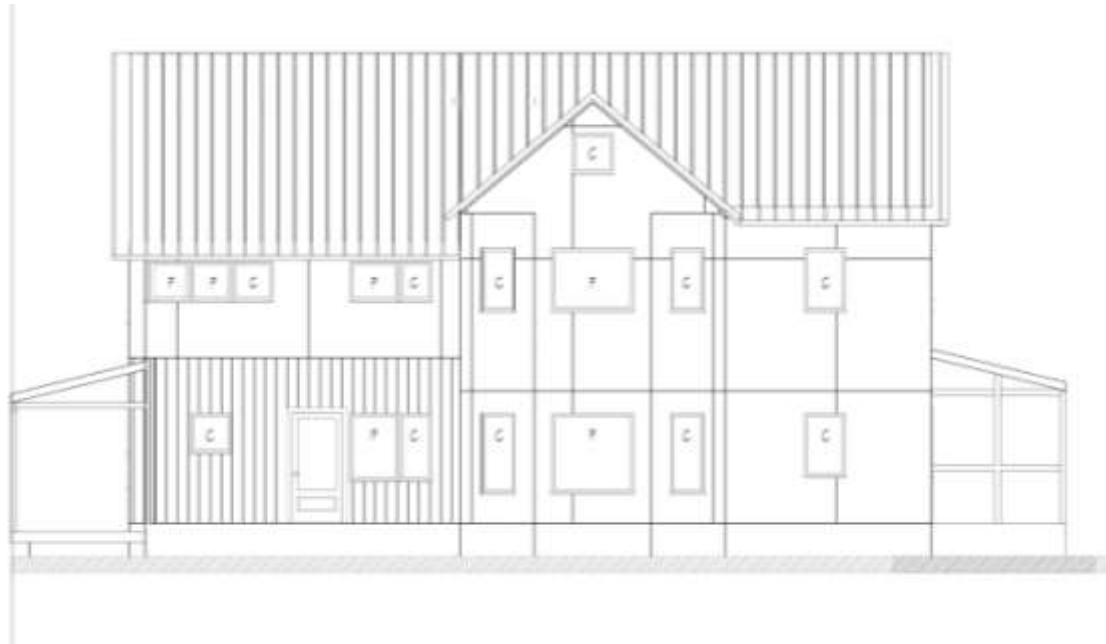


New Attic Plan

We'd decided early on to do away with the two roof planes – and rebuild the back half to match the front in order to give full height for an attic office. Gareth works at home early in the morning and late at night, so he wanted a place to go, out of the way and quiet, while the rest of the family slept. So we chose a new third floor plan.



Elevations – Single Roof with Bay



What about photovoltaic (PV) generation? PV is usually the most expensive single part of the puzzle, and seldom the first dollar a project should spend. It's also easy to add on later, if you made arrangements early.

We started to look at the existing roof framing in the front of the house. Were the 100-year-old 2x8s strong enough for the well-insulated roof (which would likely retain more snow rather than melting it) and the PV loads we anticipated?



Ross Residence

Amherst, MA

One Big Roof



Then – after a bit of soul-searching and a change from the original contractor – we decided to tear off the bay. Sara had always hated it, and that one move would clear the now-unified roof plane for anything they wanted to put up there. Plus, It added a back porch that wraps from the west around to the south side.



Ross Residence Wall Systems

Amherst, MA



Double Wall – Flash Coat and Cellulose



Strapped Inside – Foam or Cellulose In, Rigid Outside

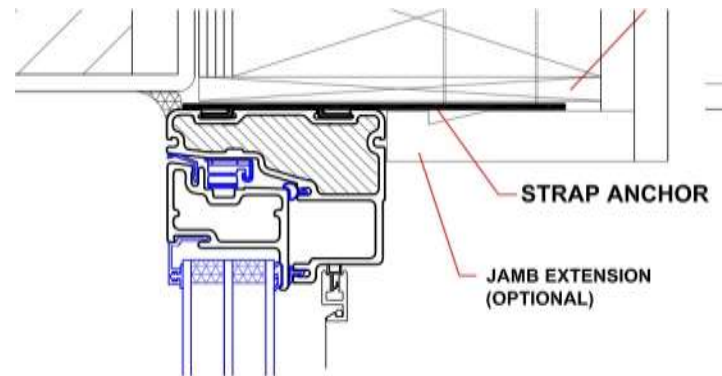
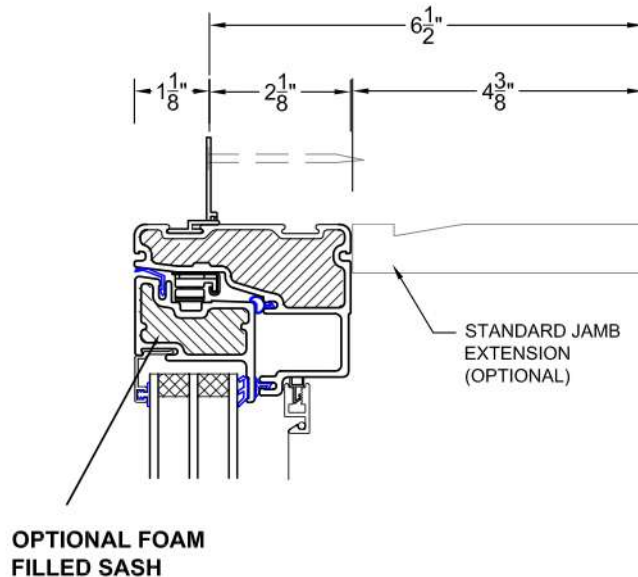


Cavity Foam and Rigid Outside

We knew we were going for a high-R wall with a good air barrier. We were stuck with the existing board sheathing – full of gaps and holes – so we needed a solution that addressed that condition. Here are my first sketches of how we might do that. A double stud wall, filled with cellulose, is another great solution, but a foot-thick wall added inside an existing structure cut down on interior dimensions quickly.



Windows

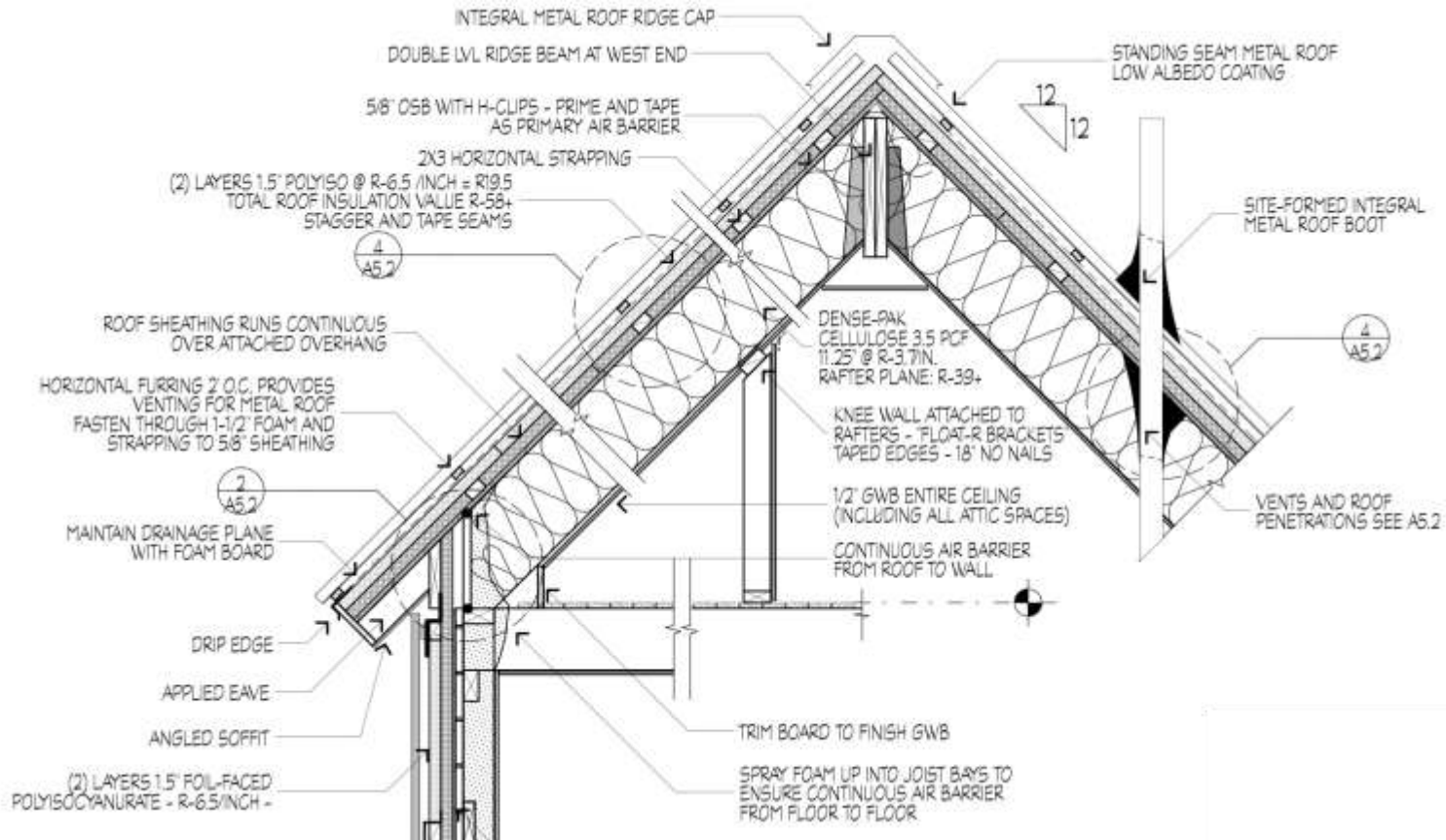


To strap anchor or not strap anchor? We used 3/4" plywood bucks around all four sides of the windows, to make sure we didn't have any sagging – especially 3" beyond the framing with big, heavy fiberglass triple-glazed windows. Therefore, we knew they weren't going anywhere. We just had to work out the details of how to attach (and air seal) this particular window configuration to the window blocking. We picked strap anchor. Next time: avoid the strap anchor – a thin but real thermal bridge between the inside and the outside...

We chose Fibertec triple-glazed fiberglass windows, in casement and awnings. The modern look of the design didn't miss the double-hungs traditional in New England, and the design team was glad to rule out the leakiest of window choices. The whole-unit U-value was great. Window-wall ratio of under 30% – small windows (mostly fixed) on the north, generous windows on the south and east for light and heat.



Roof Assembly



Our original roof design had been designed during the phase when we were keeping portions of the existing framing, so we designed a system to work with that. It is, as Rosenbaum noticed, a good retrofit roof. If we'd known from the start that we'd rip the whole thing off and start over, would we use deep TJIs instead? Maybe.



Roof Re-done

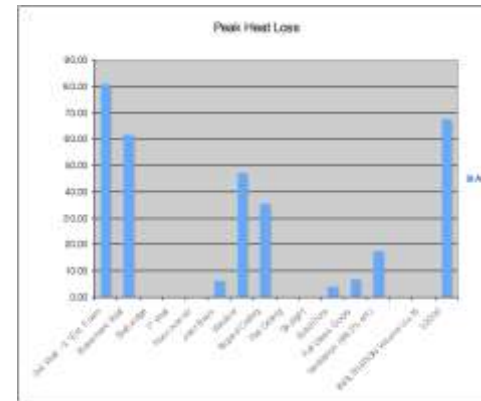


We started with a roof air barrier from the College of the Atlantic: OSB primed, taped, and sealed as the air barrier, deep cavities filled with cellulose. However, we had trouble finding the right primer for the taped joints. Plus, the replacement tape failed after the first rain. We backpedaled rapidly, and made the air barrier with a flash coat of foam applied to the underside instead. We used foam board insulation outboard, like the walls.

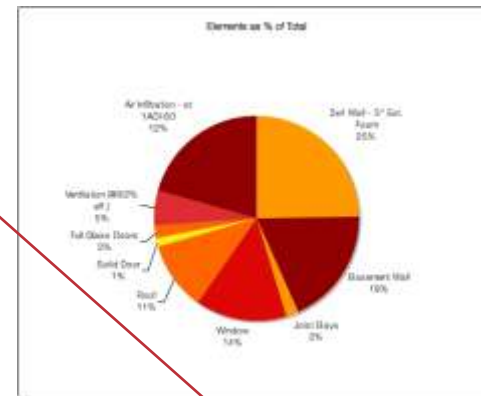


Peak Heat Loss Calcs

Ross Residence- Proposed			
R VALUES			Design Temperature Diff. 69
2x4 Wall, 3" Ext. Foam	33	Flat Ceiling R Value	1
Wall Type 2	1	Joist Bays	18
Floor over air	1	Skylight R Value	1
Window R Value	7	Solid Door	5
Sloped Ceiling R Value	50	Full Glass Door R Value	8
Slab edge	1	Basement Wall R Value	18
ELEMENT	AREA	ALU	
2x4 Wall - 3" Ext. Foam	2,680	80.84	
Basement Wall	267	61.56	Basement perimeter 150
Slab edge	x	0.00	Slab edge perimeter 0
7" Wall	0	0.00	
Floor over air	0	0.00	
Joist Bays	112	6.22	
Window	330	47.14	
Sloped Ceiling	1,775	35.50	ALU*DeltaT 2449.5
Flat Ceiling	0	0.00	Roof % of Total 0.1083
Skylight	0	0.00	
Solid Door	21	4.20	
Full Glass Doors	42	7.00	
Ventilation (862% eff.)		17.50	Ventilation system capacity 90
		0.00	Composter ventilation rate 0
INFILTRATION Volume (cu.ft)	ACH (Nat)	Equip. ALU	
32000	0.12	67.78	
ALU Conduction Only		242.47	
ALU Total (Btu/deg/hr)		327.73	
Design Heat Loss, BTU/hr	22,613		(capacity of heater required)
Design Heat Loss, Kw	6.63		
Floor area, sf (finished, incl. attic)	2700		
	8.4		Design heat loss per unit area Btu/hr/sf



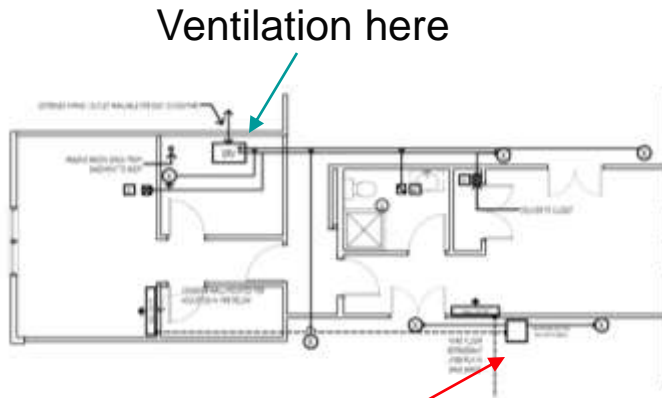
The familiar bars and a pie chart I made to see the weighted value of each element (as % of whole).



Our schematic design peak heat loss: Note the target infiltration – still listing at around 2 ACH50. And my “R-40” wall wasn’t really that – 4” of Icynene in the cavities (4” x R-3.6/in) minus the framing (likely up to 20% of the wall was now just wood) plus the 3” of (aged) R-6.25/inch outside left us with something like R-33 for the assembly. The extra effort to get to R-40? We’d spend that energy somewhere else.



Mechanicals – Heating



Heating / Cooling here

Not exactly how it worked out ...

absolute comfort

Submission Data: RXYMQ48MVJU
4 Ton Outdoor Unit – Heat Pump
VRV-S

Job Name: _____ Location: _____
 Purchaser: _____
 Engineer: _____
 Submitted To: _____ For: Reference Approval Construction
 Submitted By: _____ Date: _____
 Unit Designation: Schedule #: _____ Model No.: _____
Capacities & Efficiencies:

System	Connected with	Nominal Cooling Capacity		SEER	SEER1	Nominal Heating Capacity		COP	Low Heating Capacity		COP	EER
		Btu/h	kW			Btu/h	kW		Btu/h	kW		
RXYMQ48MVJU	Non-Ducted Indoor Unit	47,000	9.4	13.8	32,000	2.76	35,000	2.0	6.10			
	Ducted Indoor Unit	48,000	9.0	13.1	34,000	2.66	36,000	2.0	7.95			
	Mixed Ducted and Non-Ducted Indoor Unit	47,000	9.3	13.5	33,000	2.875	36,000	2.0	7.00			

Operating Range:
 Cooling: 32°F – 115°F DB
 Heating: 37°F DB – 64°F DB
 -3°F WB – 60°F WB

Compressor:
 Type: Hermetically Sealed Scroll
 Quantity: 1
 Capacity Control Range: 25% – 100%
 Motor Rating Output: 3.1 kW

Fan:
 Fan Type & Quantity: Propeller Fan x 2
 Fan Motor Output: 0.870 kW
 Air-Flow Rate: 3,740 CFM
 Drive: Direct Drive

Power Supply:
 Voltage: 208-230V/3Ø
 Maximum Circuit Amps (MCA): 27 Amps
 Maximum Total Amps (MTA): 30 Amps
 Maximum Starting Current (MSC): 24.1 Amps
 Total Disconnect Amps (TDCA): 37 Amps

Refrigerant & Piping:
 Refrigerant Type/Charge: R-410A / 12.8 lbs
 Control: Electronic Expansion Valve
 Liquid Refrigerant Piping: 3/8" Flare
 Suction Gas Refrigerant Piping: 1/2" Flare

Unit Data:
 Max. Number of Indoor Units: 8
 Sound Pressure Level at 2.5: 58 dBA
 Weight: 370 lbs.

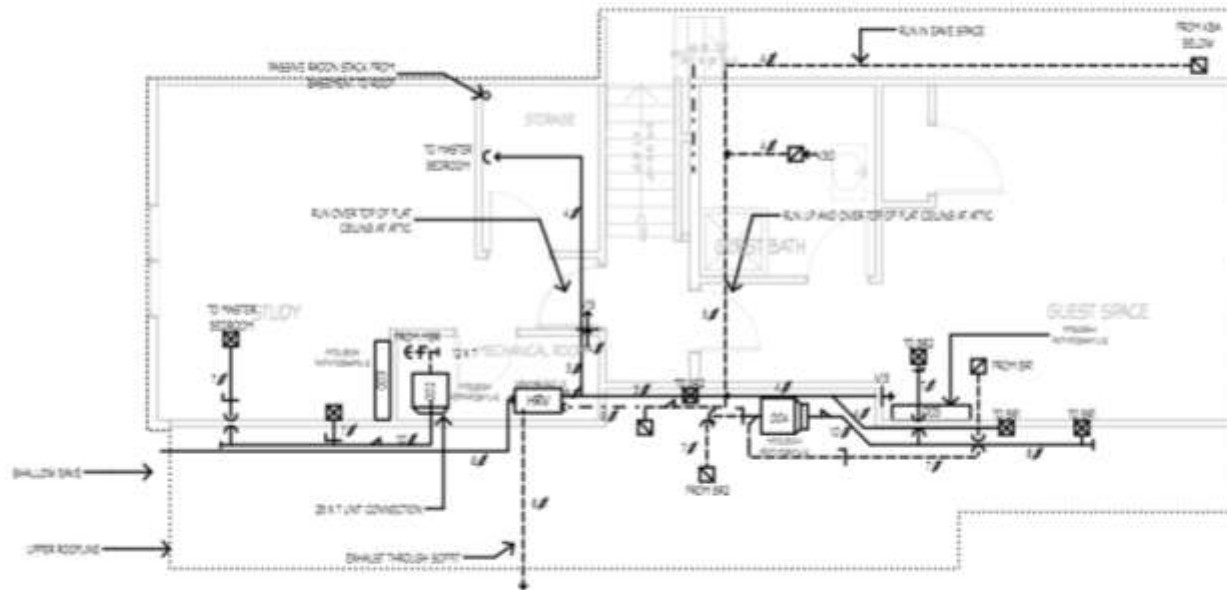
Standard Features:

- Six year compressor warranty
- One year parts warranty
- Heating or cooling operation
- Inverter driven (variable speed) scroll compressor
- VFD controlled outdoor motor fan

On to the Dynamic Systems – We decided early on to go with an air-source heat pump. We have low cooling requirements in Amherst, but as the climate warms, this will change, and low energy cooling is a perk of heat pumps. The Rosses like the low infrastructure needs of a single heat pump with a few indoor heads. Plus, we thought we could do it more affordably than a traditional system.



Mechanicals - Heating



Instead, everything moved to a south-side mechanical room and eave in the attic. It looks crowded on this drawing, and it is. However, the longest run in the house is that exhaust fan from the kids' bathroom in the upper right corner ... and it's just exhaust.

Here's a late-stage mechanical drawing, after feedback from Adam Kohler, PE at Kohler and Lewis, who moved us from a Daikin to a Mitsubishi (based on the availability and capacities of the indoor heads). We tried to minimize run lengths and keep it simple. The house's several zones made the system more complex and expensive than we had hoped – about \$20K for the whole thing, installed.



Mechanicals - Hot Water

Accelera® 300
HEAT PUMP
WATER HEATER

SAVE WATER WISE

- 5 YEAR WARRANTY
- 80 GALLON STORAGE CAPACITY
- REDUCES HOT WATER COSTS BY UP TO 80 %
- COOLS AND DEHUMIDIFIES THE AIR AROUND IT

With no combustion involved in the heating system, we moved rapidly to a no-combustion household. For hot water, we decided to use the new Steibel Eltron heat pump hot water system for showering and washing needs. It's all electric, draws heat from the surrounding air, and should provide COPs near 3 for hot water. We're using data loggers to see how much change it induces in the basement.





Mitsubishi CityMulti Multi-port Air Source Heat Pump (ASHP)

This system is complex – better with short duct runs – and expensive. Other solutions could rely on evenness of temperature within airtight shell, convective distribution to simplify system, reduce upfront costs.



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Amherst, MA

Mechanicals – Ventilation



Our aggressive infiltration standards demanded that we provide fresh air mechanically. We chose the Venmar EKO 1.5 HRV for its low wattage / cfm delivered. Our ventilation needs were low – 4 people in a now 2,900 square foot house, with only occasional use for the attic office and guest space – but the EKO can provide as little as 40 cfm. Plus, at 81cfm, it pledges to consume 32W – more than 2 cfm/watt.



Construction – Walls



Initial layers of polyiso go up



Plywood window bucks go in. (Lifts of polyiso stack in the driveway outside ...)

Builder Holden Construction had never done an exterior insulation job, but the Rosses' Construction Manager, Steve Ferrari, had, at Habitat for Humanity in Springfield. The Holden crew got up to speed quickly. They also quickly fell for the idea of attached eaves, which allow a continuous thermal and air barrier from wall to roof, before we attached the overhangs.



Construction – Walls with Plywood



A missed opportunity: When our local building inspector judged the existing board sheathing inadequate for racking strength, we satisfied her by adding a layer of plywood over the whole exterior. At that moment we should've reconsidered the air barrier and moved to a taped plywood solution all around, like at the College. Plus, we would've tracked down that &#amp;\$&%! tape.



Ross Residence

Amherst, MA

Construction – Applied Eave



Picture from Holden Builders showing the applied eaves, over the first layer of the exterior foam.



Air Barrier – Test 1



We had the windows in, and the first layer of polyiso outside, so we ran the blower door. (CM) Steve had purchased one himself, (Project Manager) Andrew was anxious to show how far we had come / how far we had to go. The Holden team had been doing good work; so we were all anxious to try it out. ... Of course, we weren't ready. The basement leaked like a sieve, and the gaps at the bulkhead were visible as daylight. And the Icynene, which would plug the gaps in the existing sheathing, was still a week away. Result: 2,500 cfm50 – close to Energy Star's 5 ACH50, but we were aiming for 1 ACH50.

Back to work!



Cavity Insulation and Partial Out-sulation



After the cavity insulation went in, comfort increased. The studs are visible here, which would normally scream “thermal bridge!” However, with the continuous exterior foam, we aren’t concerned as much about the framing factor here. After two weeks, we were getting ready for the next blower door.



Basement Walls



Before insulation, here's a hole we carved into a previously concealed crawlspace. What you can't see is that there's a cavity within this brick wall. Having opened it up, we had made it leak – from any brick penetration from the outside, INTO our basement. Sealing this flaw helped us with our next pressure test, too.



Ross Residence

Amherst, MA

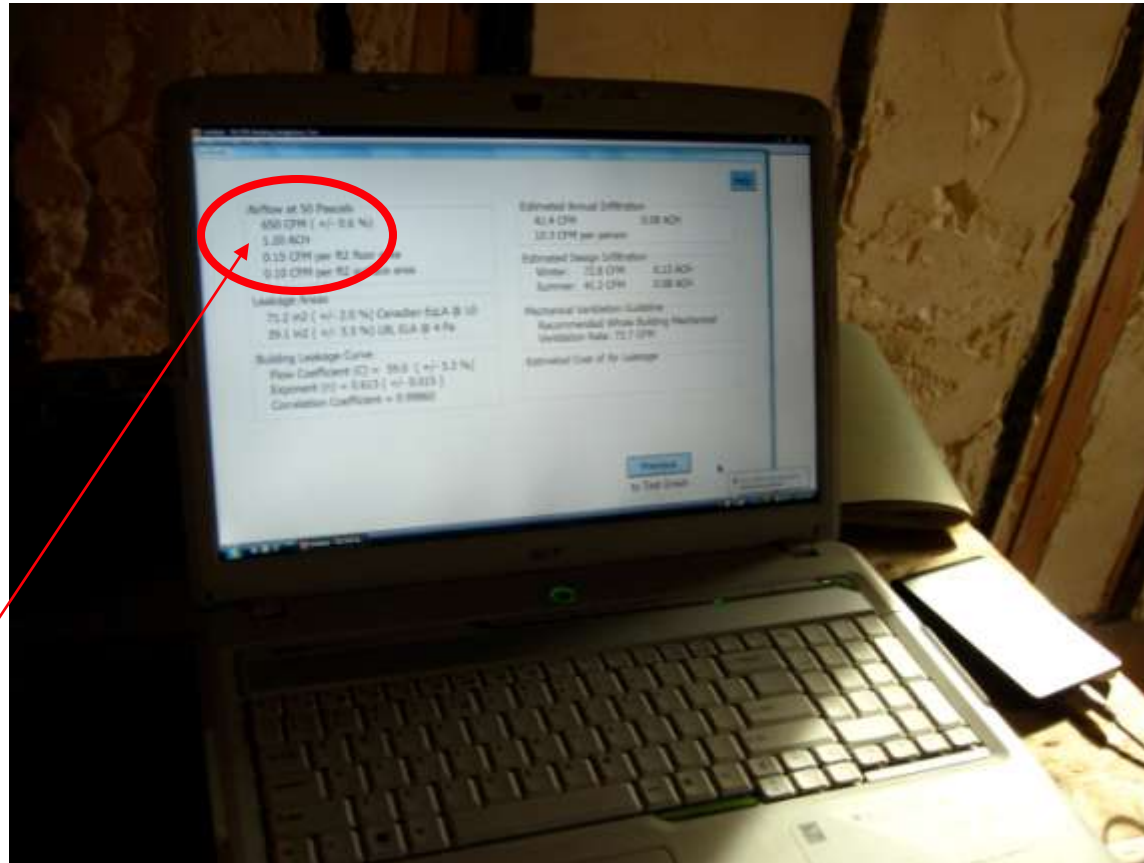
Air Sealing Diagnostics



We ran the test, and the fogger, to find the big leaks. Homeowner Gareth Ross couldn't keep his hands off the foam gun, so we put him to work in a tight eave space behind the upstairs bathroom.



Air Barrier - Test 2 - Success



Before the fog work and Gareth's leak-plugging, we were here. Afterwards, we landed at 558 cfm50. They'd worked hard since the last time to get the place tight. The next blower door would be the last one, at nearly move-in time in June.



Ross Residence Getting Closer

Amherst, MA



PVs to be Added – NOW!

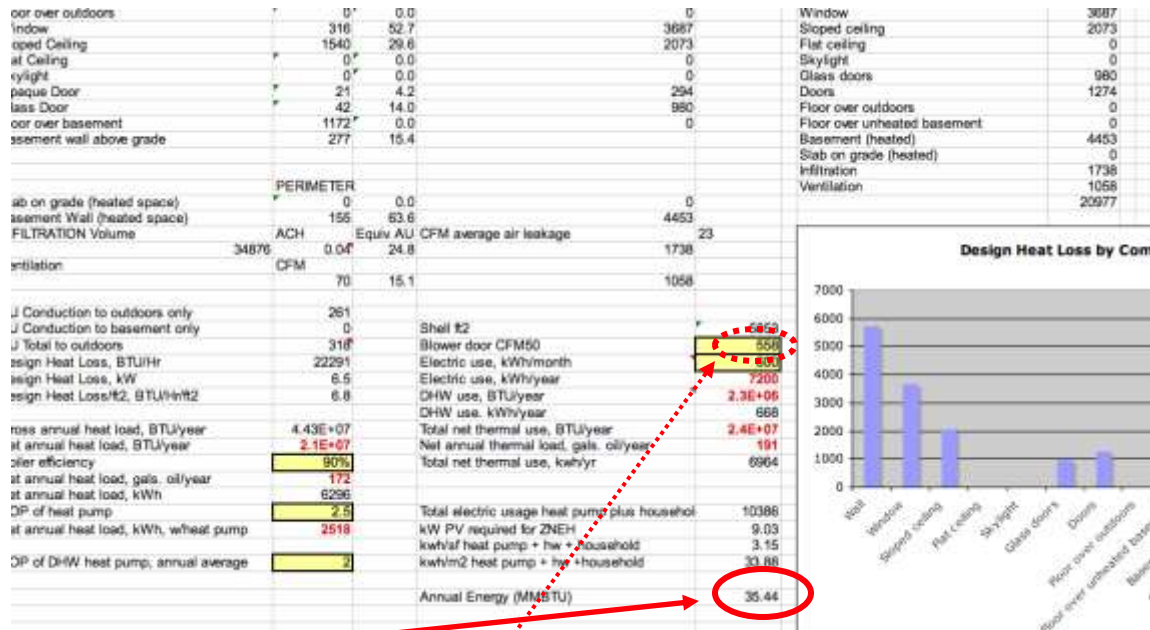
As the last panel goes in: **12.4 kW PV**



After the new Commonwealth Solar incentives were announced, Gareth's finance brain couldn't stop churning over what seemed to be a big upside. If he could roll the PVs into the construction loan – at 5% – he couldn't find any better place to put their household cash than into the PV system. They decided to buy the biggest system that would fit the roof, which they'd already cleared and rebuilt with solar in mind. Suddenly, they were looking at a potentially Zero Energy Home.



Projections for Zero



Projected MMBTU – with plug loads similar to that of their current home: **35 MMBtu/year**
 kW PV required for ZNEH: **9.03 (we think)**
 kW PV installed: **12.4 (this we know)**

Projections are just that, and don't count for much in the zero energy world. For fun, we ran out the numbers based on a peak heat loss, some numbers for incoming solar gains, internal loads based on electric consumption, and the heating degree days for western Massachusetts. With 600 kwh/mo. in plug loads, they reach net zero, presuming it all goes as planned.



Thousand Home Challenge

User Interface - Performance Threshold Calculator for Thousand Home Challenge

yellow shaded cells require user input
blue shaded cells are calculated outputs

Home Description, Basic Inputs		Weather Station Info	
Home's 5-digit zip code	01002	Station linked to zipcode is	MA_CHICOPEE_FALLS_V
Finished floor area (ft ²)	3,245	Preferred weather station is	use zip c
Number of occupants	4	Energy Unit Conversion Chart	
Number of households in building	1	Select Energy Source	Enter annual use
Attached home, % common	0%	Fuel oil (#2) - gal	90.0
		Electricity - kWh	1800.0
		Propane - gal	
		Wood pellets - lbs.	1000.0
		TOTALS	

Option A: 75% Reduction (requires one year pre-retrofit energy bills)

Current gas/fossil/wood use(MMBtu/year)	208	Gas/fossil/wood MMBtu converted to kWh:
Current electric use (kWh/year)	6,000	
Current total energy use kWh/year	66,944	
Threshold gas/fossil/wood use (MMBtu/yr)	52.0	
Threshold electric use (kWh/yr)	1,500	
Maximum total energy use (kWh/yr)	16,736	Gas/fossil/wood MMBtu converted to kWh; Excludes solar

Option B: Calculated Performance Threshold (see Threshold Calculator worksheet)

	if electric heat	if gas/fossil/wood heat	
Gas/fossil/wood (MMBtu/year)	0	35.3	
Electric (kWh/year)	9,026	2,799	
Maximum total kWh/year (net)	9,026	13,145	Gas/fossil/wood MMBtu converted to kWh; Excludes solar
Approximate \$/yr at \$10/MMBtu and 10¢/kWh	\$903	\$633	

Instructions - How to Use this Interface

For any given home, enter appropriate information in the yellow-shaded cells
 The maximum total annual post-retrofit energy consumption for Option A is shown in cell C20
 The maximum total annual post-retrofit energy consumption for Option B is shown in cell C26 or D26 depending on heating fuel

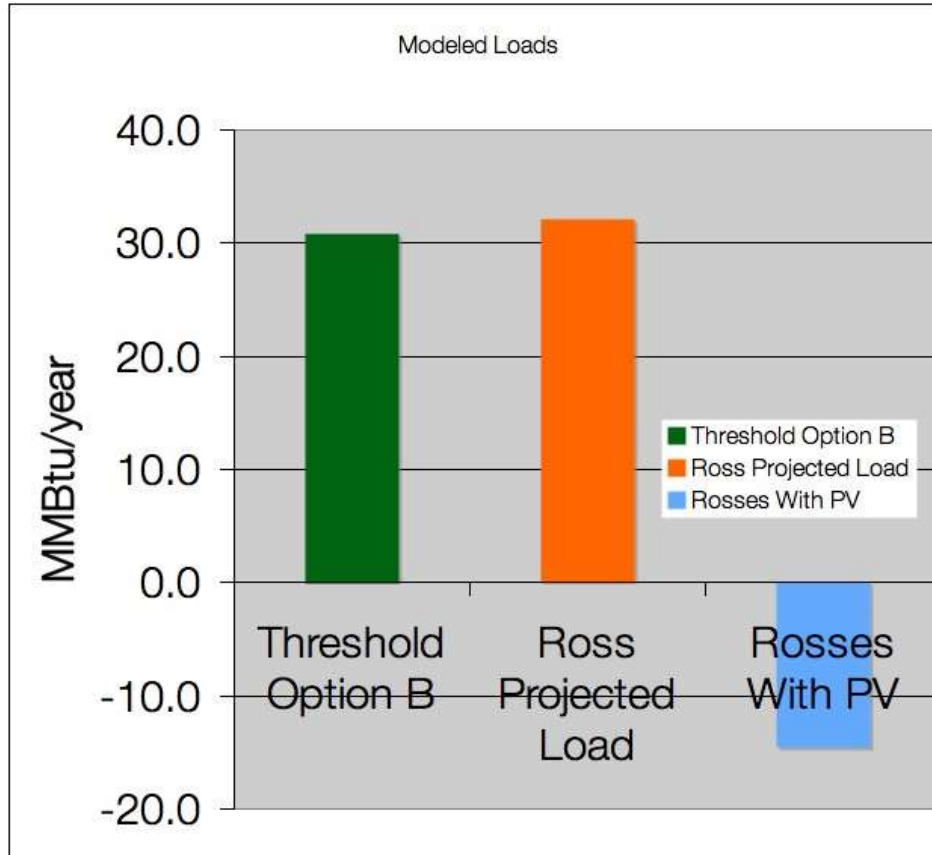
To see how the Option B's Performance Threshold is calculated, see the next worksheet.
 Post-retrofit energy allowances are calculated based on climate, finished floor area, and number of occupants.
 Zip codes automatically link to nearest TMY3 weather data. Over-ride by clicking on cell F8 and selecting a weather station from the drop-down menu.

Threshold for qualification at Thousand Home Challenge - 9,026 kWh/yr (after PV contribution)

The Thousand Home Challenge requires Option B for a significant renovation like this, with no immediate pre-energy use. Therefore, a strict energy budget must be met. This family, even if it doesn't reach zero energy, will certainly meet the rigorous requirements of the Thousand Home Challenge Option B.



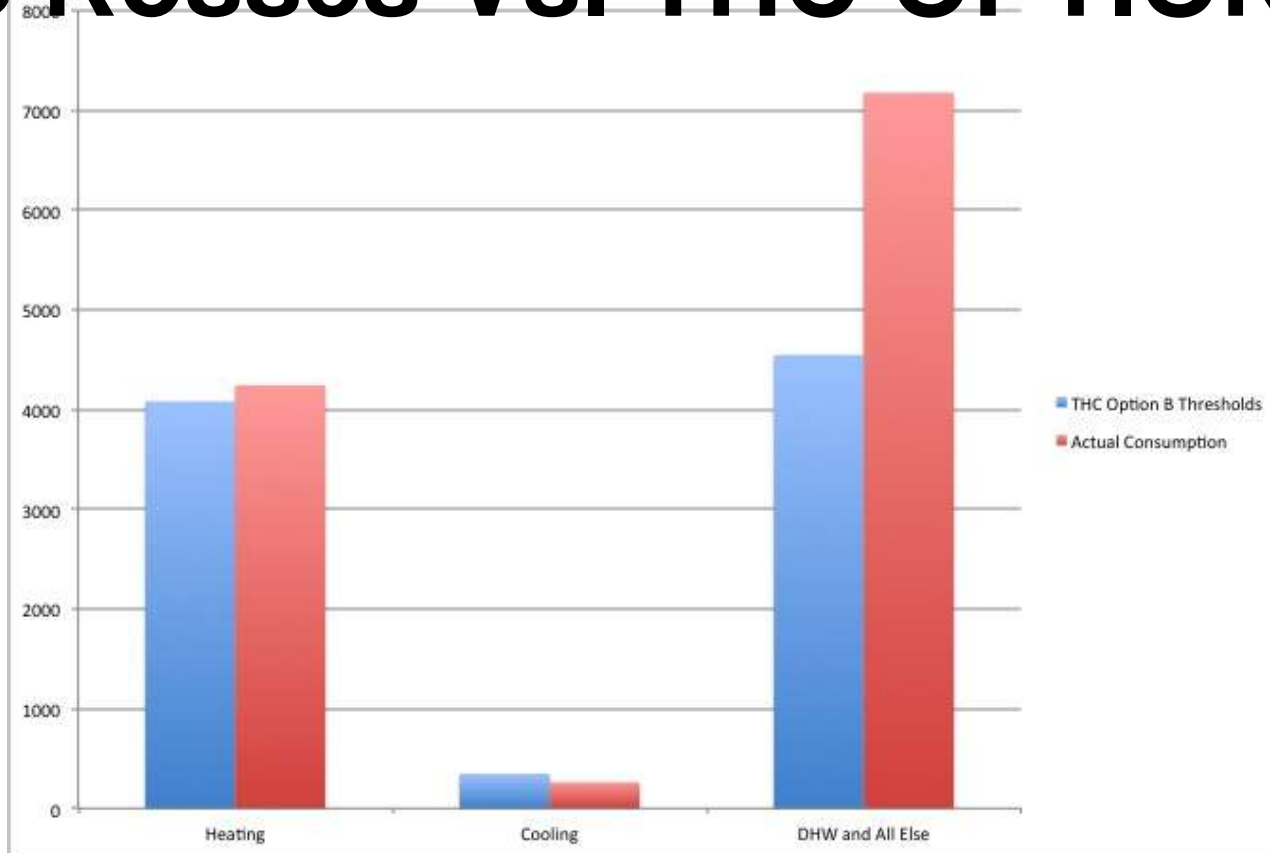
Projected Load Vs. Thousand Home Challenge



Ross projected load includes no significant change in household behavior – 500 kWh/mo. included for plugs/fans. With envelope enhancements alone, the Rosses couldn't make the threshold. If we include behavior modifications and a huge PV system, we begin to see what a producer this house can be.



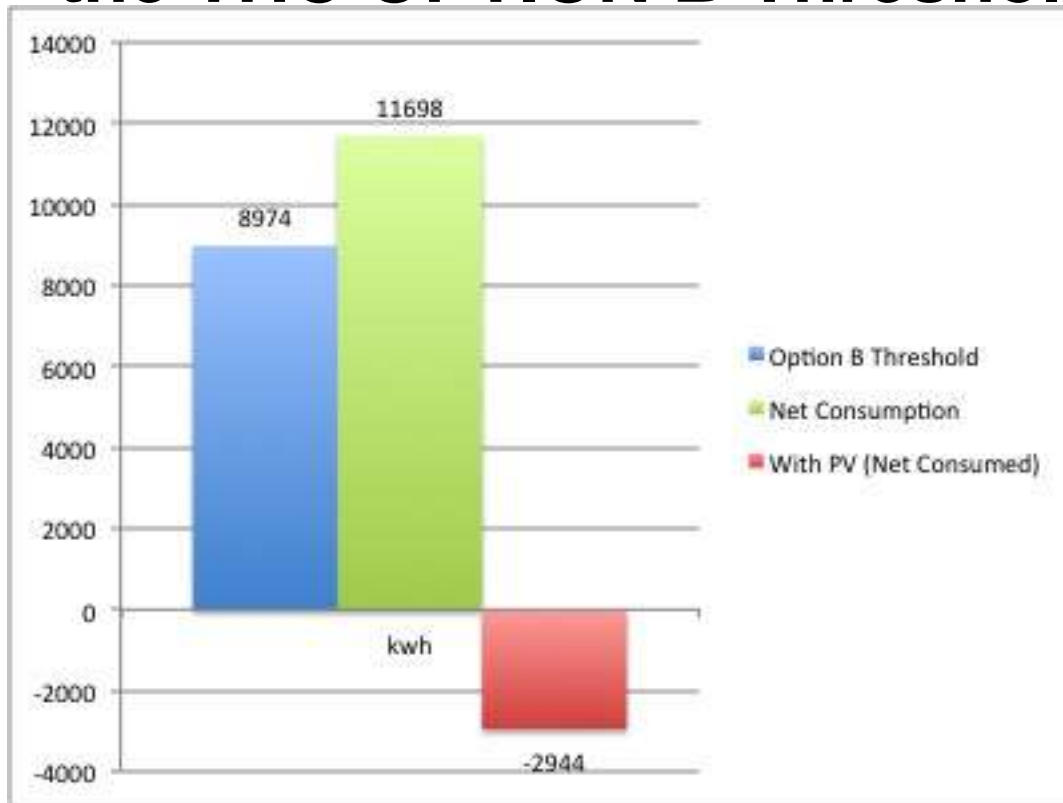
The Rosses Vs. THC OPTION B



Against THC targets, the Ross envelope performed reasonably – slightly higher heating energy, slightly lower cooling energy. The hot water & misc. electric loads (MELs) were high ~600kwh/mo.



Household Energy Use & Net Compared to the THC OPTION B Threshold (kWh/year)



With the incorporation of the PV system, the MELs are easily handled, & the house becomes a net exporter of energy, - 2,940 kWh in the last sampled year (2010-2011).

The green bar is actual consumption Nov. 2010-Oct. 2011 (excluding PV).

THC OPTION B Threshold Assumptions: Single-family detached, 3,245 ft² finished floor area, 4 occupants, electric heat, Chicopee Falls, MA weather station



Lessons Learned

The Rosses moved in during June of 2010, and the learning will continue as we watch their house over the coming years. For now, however:

1. Watch continually for no-cost opportunities to upgrade, as when we had to go to all plywood skin. Don't be afraid to reexamine earlier thinking – and its implications.
2. The devil is in the details, as with our missing primer for a taped exterior air barrier. Stay involved, and stay on top of it. The wrong tape meant our roof air barrier failed, and we had to change from all cellulose in the roof cavity to a spray foam flash coat and cellulose. That tape cost us real money.
3. Be diligent. The first blower door test was a shock to all of us, at 5+ times higher than we'd targeted. However, the crew worked with that in mind, and C&H prepped a list of likely problem areas, too. Together, we found nearly 2,000 cfm50 of leakage before the next test. The final test result was 625 cfm50. It got better, then worse, as real doors and windows were installed, HRV vented, etc.

Learn. Plan. Do. (Repeat.)



Anecdotally, Passive Survivability is Good



During the 2011 October snowstorm, the house was without power (grid-tied PV being no help in a grid-based outage) for 2 ½ days. The indoor temperature, despite outdoor temps in the 20s, started at 70°F, and never dropped below 67°F in the living room.



Design and Construction Team

Project Manager: Andrew Webster, Coldham & Hartman Architects (Amherst, MA)

Energy Consultant: Marc Rosenbaum, P.E. – Energysmiths (Meriden, NH)

Construction Manager: Steve Ferrari – FCM Smartbuild (Northampton, MA)

General Contractor: Holden Builders (Bernardston, MA)

Structural Engineer: Ryan Hellwig, P.E. (Northampton, MA)

Mechanical Engineer: Adam Kohler, P.E. – Kohler & Lewis (Keene, NH)

Photovoltaics: PV Squared (Greenfield, MA)

