January 9, 2014

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Cc: Rick Fenuccio, Tom Hartman
From: Marc Rosenbaum
Subject: Melpet preliminary heat loss and energy model – results and implications

Approach

I sent BLF&R input spreadsheets for my room-by-room heat loss calculator and my annual energy use model. Building 3,7 and 9 was chosen to model, and I assumed it faces south in an unshaded condition. I set up thirteen cases to model, starting with a base case that roughly approximates code (though we are in an overlap period on the energy code), and adding various upgrades. Cases 2-8 are parametric – only one variable is changed to see how much effect each has on the total. Cases 9-13 are combination cases.

Assumptions

All of the R values used are input as true R values, assuming typical wood frame construction thermal bridging, rather than nominal R values. In Case 1, inputs are:
- R-10 basement wall/slab
- R-16 wall
- R-50 flat ceiling
- R-35 sloped ceiling
- R-3.5 windows, net glazing fraction 70%
- R-5 opaque doors
- R-3.3 glass doors
- Glazing Solar Heat Gain Coefficient (SHGC) 0.40
- Air leakage 0.20 CFM50 per square foot of shell area (CFM50/ssf)
- 120 CFM ventilation air divided amongst the three housing units
- No heat recovery
- Nine occupants using 15 gpd of domestic hot water (DHW) each
- Boston solar data, Martha's Vineyard heating degree days
- 1,200 kWh/month electrical usage for lights/plug loads/appliances
- Minisplit heat pump at a Coefficient of Performance (COP) of 2.3

Parametric cases

The following are the changes made to Case 1, one by one, to see the effects of each upgrade.
Case 2 – R-25 walls
Case 3 – R-5 windows with glazing SHGC 0.56
Case 4 - R-18 basement
Case 5 – 900 kWh/month lights/plug loads/appliances (less heat offset)
Case 6 – Air leakage 0.10 CFM50/ssf
Case 7 – Heat recovery ventilator (HRV) at 70% effectiveness

Case 8 – Heat Pump Water Heater COP 2.35 (adds heating load in heating season)

Results of Parametric cases

Case	Annual heat pump energy, kWh	Savings over Case 1
1	9,957	
2	8,435	15%
3	8,321	16%
4	9,344	6%
5	10,712	-8%
6	9,054	9%
7	8,117	18%
8	10,554	-6%

The most effective upgrades are the HRV; better windows; more wall insulation; and increased air tightness. They also have the largest effect on comfort, by creating higher mean radiant temperatures in the spaces, and by eliminating drafts. Similarly, they have the biggest effect on preventing mold, frozen pipes, ice dams, and pests (of the more-than-two legged type.) Two cases *add* heating energy while saving DHW or plug/light/appliance loads.

The HRV is more effective than generally thought, because of how this was modeled. The base assumption is that there is powered ventilation air, and that the necessary amount roughly follows Building Science Corporation's alternative to the newly released ASHRAE 62.2 Residential Ventilation Standard. BSC increases the required amount of air in a not balanced, not distributed system, such as the common low cost approach of using a bathroom exhaust fan with no dedicated inlets.

Combination cases

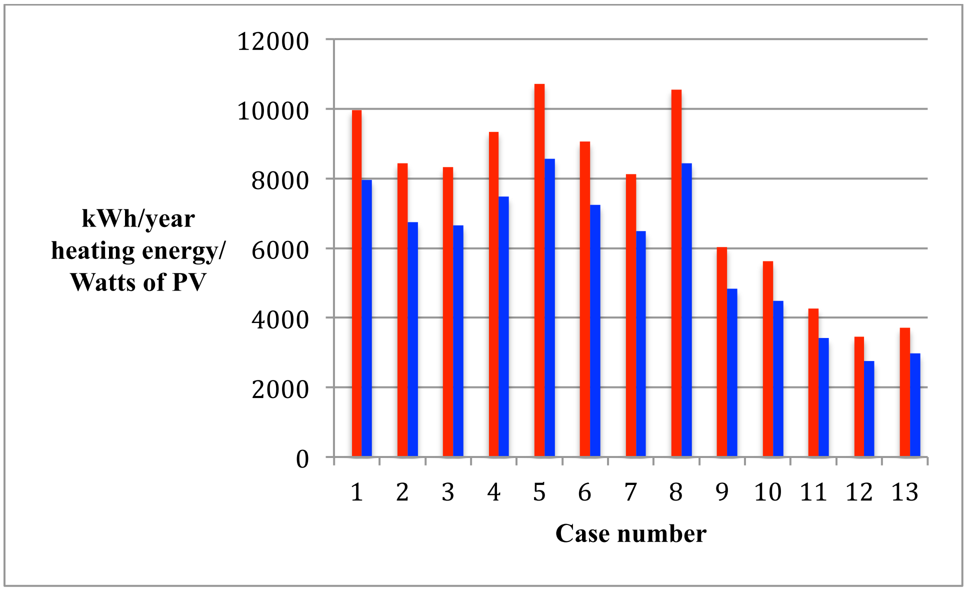
Case 9 – R-25 walls; R-18 basement; 0.10 CFM50/ssf; HRV; HPWH
Case 10 – Case 9 with air tightness 0.05 CFM50/ssf
Case 11 – Case 10 with R-5 windows, SHGC 0.56
Case 12 – Case 11 with R-40
Case 13 – Case 12 with 900 kWh/month lights/plug loads/appliances

Results of Combination cases added (9-13)

Case	Annual heat pump energy, kWh	Savings over Case 1
1	9,957	
2	8,435	15%
3	8,321	16%
4	9,344	6%
5	10,712	-8%
6	9,054	9%
7	8,117	18%
8	10,554	-6%
9	6,034	39%
10	5,615	44%
11	4,269	57%
12	3,446	65%
13	3,718	63%

Case 9 combines the increased wall and basement insulation with increased air tightness and an HRV. It also includes a HPWH, since this is a great strategy although it does impose an additional heating load on the building. Case 10 cuts the air leakage in half again, to a rigorous but achievable target. Case 11 adds the better windows. Case 12 increases the wall insulation to R-40, and the final Case 13 is Case 12 with the lower lights/plug loads/appliances usage.

The chart below shows the annual heating consumption of the minisplit heat pump for each case, as well as the wattage of solar electric capacity required to zero this energy out annually.



Case 11 feels like the sweet spot. The R value of 25 can be achieved with 1-1/2 inches of exterior rigid foam. This amount of rigid insulation in Zone 5 allows the use of a Class III vapor retarder in the walls, eliminating the need for polyethylene or a similar material.

Room-by-room heat loss implications of the cases

The level of performance of the building enclosure is intertwined with the choice of mechanical system, especially heating. We have fixed on minisplit heat pumps as the system of choice on all of our projects smaller than large university buildings, because they are reliable, cost-effective to install and operate, need no venting, and are great to combine with solar electricity to make zero annual net energy buildings.

For the lowest cost application in compact superinsulated buildings we have installed a single zone minisplit with a wall cassette in the main living area, and a small amount of electric heat in each bedroom for severe conditions, or for the case where people always keep the bedroom doors closed. In cases where the doors are mostly open, we find the bedrooms running 2-3˚F cooler than the main living space.

In order to implement this strategy I like to see a total heat loss of 15,000 BTU/hour per housing unit and bedroom heat loss not exceeding 2,000 BTU/hour each. These are not hard and fast numbers, they come from a combination of my experience and intuition, as well as an understanding of what the available heat pump equipment is.

The following table shows Case 1 and three of the combination cases. Case 1 doesn’t meet my criteria. Case 11 does, with the exception of the first floor bedroom in Unit C, which has both foundation and roof heat loss. The upgrades in Case 11 over Case 9 are increased air tightness and triple glazed windows, both of which have comfort benefits beyond that shown by the simple BTU/hour number. In the table below, heat loss totals and room heat loss values that meet the criteria are shown in red.

Design loss BTU/hr				
Room:	Case 1	Case 9	Case 11	Case 12
Living Room A	5134	3463	2755	2516
Dining Room A	1980	1310	950	888
Kitchen A	5651	3522	2708	2473
Powder A	222	111	56	56
Stair hall A	936	559	397	377
BR 1 A	3103	2413	1912	1670
BR 2 A	2955	2323	1840	1614
Bath A	863	566	436	368
Unit Total	20845	14267	11055	9961
Living Room B	3359	2361	1799	1712
Dining Room B	2763	1838	1393	1305
Powder B	1015	630	476	429
Kitchen B	1985	1229	888	816

Stair hall B	2578	1785	1365	1287
BR 1 B	3126	2533	1964	1793
BR 2 B	1819	1581	1258	1160
Bath B	791	521	401	338
Unit Total	17434	12479	9544	8840
Living Room C	2578	1855	1390	1312
Dining Room C	3979	2701	2163	2021
Bath 1 C	2179	1269	936	832
Kitchen C	1953	1232	874	825
Stair hall C	4279	2653	2002	1820
BR 1 C	4580	3182	2396	2195
BR 2 C	3143	2792	1931	1683
BR 3 C	2962	2327	1844	1616
Bath 2 C	863	566	436	368
Unit Total	26516	18576	13971	13393

As a result of these numbers and the annual heating energy results, my suggestion is that the building envelope aim for the values listed for Case 11.

Total Annual Energy Results

All of the above report the results of heating loads. To attain zero annual net energy we must consider DHW and plug/lights/appliance loads as well. Once the building is superinsulated and the heating is supplied by a heat pump, the heating load is not the largest load. In this three unit building, if the occupants use the assumed 14,400 kWh/year for plug/lights/appliance loads, and the DHW is supplied by a HPWH, the plug/lights/appliance loads may be double the combined heating and DHW loads.

The table below shows the results of the energy model for the thirteen cases. The last column shows the kW of solar electric capacity needed to allow the building to reach zero annual net energy. Because the largest load is plug/lights/appliance, and that load is varied lower only in cases 5 and 13, the amount of solar electric capacity needed to zero out the building doesn’t change as significantly as it does when only heating energy is considered. In Case 11, heating and DHW energy combined are half of the plug/lights/appliance energy. So occupant education and feedback has to be added into the mix of strategies if zero annual energy is to be attained.

Case	Annual heat pump energy, kWh	Annual HPWH energy, kWh	Annual Plug/Lights/ Appliance energy, kWh	Total annual energy, kWh	kW ZNE @ 1.25 kWh/W
1	9957	6770	14400	31127	25
2	8435	6770	14400	29606	24
3	8321	6770	14400	29491	24

4	9344	6770	14400	30514	24
5	10712	6770	10800	28282	23
6	9054	6770	14400	30224	24
7	8117	6770	14400	29287	23
8	10554	2881	14400	27835	22
9	6034	2881	14400	23315	19
10	5615	2881	14400	22896	18
11	4269	2881	14400	21550	17
12	3446	2881	14400	20727	17
13	3718	2881	10800	17399	14

Renewable Energy System Size

Case 11 results in a requirement of 17 kW of solar electric capacity to zero the building out. This is just under 6 kW per housing unit, so it squares well with experience with compact single family homes aiming for zero net energy. It’s worth noting the amount of aperture this represents. With the most efficient solar electric panels on the market (Sunpower), about 1,000 sf of aperture is required. This is not going to occur solely on the building roofs in this development. I suggest looking at carport roofs along the south side of the property as a possible location to develop this capacity.