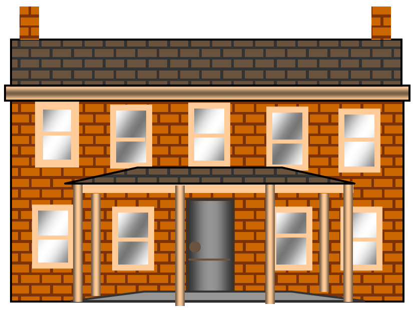
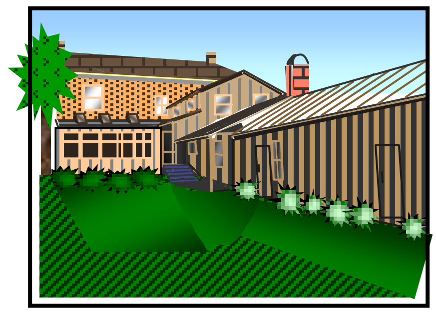
CASE 3. RETROFITTING AN HISTORIC HOUSE

Historic structures present their owners with special challenges. Renovating and retrofitting such structures requires owners with real money and the skills or access to craftspeople with the skills to undertake the renovations. What does one without deep pockets do?

A. The Client's Predicament and Request

Beth lives in a large and stately 4,300 sq. ft. home on a narrow lot in a nearby historic village. The original brick house, built in the mid-19th century, had been added to over the years, the several additions extending down one edge of its corner lot. Beth had earlier insulated the roof of the original house when she turned the unfinished attic into a bedroom.





Above, L to R:
Picture 1. Sketch of original house, roof facing north
Picture 2. Sketch of south-facing side with add-ons. L-shaped configuration is evident.

A modern oil-fired heating system burns 1300 gallons/year to heat hot water for domestic use year-round and for winter heating using cast iron radiators. At the time of our meeting, Beth was facing oil prices exceeding $4/gallon for an annual heating cost of $5,200. Reducing her bill was the reason for calling us in.

As with many owners of historic structures, Beth was unwilling to change the appearance of hers, especially the exterior. Historic houses, poorly insulated to start, are difficult to insulate without undertaking drastic measures. In this case, the original house was brick over stone and timber framing, followed by lath and horsehair plaster and finish coat on the inside. The only feasible approach was to re-do the weather walls from the inside by adding insulation on the inside and then re-plastering. Matching the new wall surfaces, especially papered walls, with the old is problematic, so the renovation could easily extend to all the walls of affected rooms. Since this house is two stories with high ceilings and rooms full of antiques, the prospect of extensive interior work overwhelmed our client logistically and financially.

Windows threw up another challenge. Beth resisted tearing out her old windows with their distinctive wavy glazing and mullions and inserting double or triple-pane replacement windows. Replacing 54 large windows requires deep pockets. Alas, not our client.

At the close of our first visit, Beth asked us to come up with the best ideas to reduce heating costs in four specific areas:

- Insulation options for relevant parts of the house – kitchen, summer kitchen
- Windows – improve insulation in winter months
- Solar energy (passive, active)
- Geothermal (ground source heat pump) system.

B. <u>Our Findings and Main Alternatives</u>

In the table below we summarize our best ideas for reducing heating costs. Detailed analysis follows the table. We placed these ideas in order of their logical consideration. The reason for this order is that you will want to insulate your roof, walls and windows as well as practicable so that you reduce the size (and cost) of the alternative heating system you install – geothermal or solar – and reduce your purchase of fuel oil.

The table includes a column for payback. Payback represents the number of years required to pay back the capital cost of a particular energy improvements out of savings enjoyed from the implementation of that energy improvement.

We emphasize that payback is a useful way to compare alternatives within the same general category. We have used actual cost data where available, but any given project faces unanticipated costs that will increase the payback period. We made assumptions in some cases which we encouraged Beth to check, and urged her to undertake her own payback calculations. With interior storm windows and solar, we assumed these are DIY projects (do-it-yourself). Hiring contractors will increase the payback period.

Beth mentioned she had a budget of $200/month out of which to make improvements. We suggested another way to look at this – as a monthly payment on a loan. If she capitalized her $200/month budget, this would be equivalent to taking out a $23,000 loan at 7% payable over 15 years. Looking at it this way freed up her thinking and allowed her to consider undertaking larger, rather than piecemeal projects.

Table. Summary Comparison of Ideas to Reduce Heating Costs

Idea	**Gal oil saved**	**Capital Cost**	**Payback (years)**	**Plusses**	**Minuses**
1. Improve insulation in walls					
2. Interior storm windows:					
Advanced Energy……... Panels	130	$1,800	3.1	Cheap, DIY, 2 layers plastic film	No provision for screens
Innerglass …………….....	130	5,525	9.4	High quality, easy to install	No provision for screens
Window Savers ….….....	130	1,550	2.6	Cheap, DIY, magnetic seal	No provision for screens
Climate Seal ……..…...	130	6,575	11.2	High quality, magnetic seals, screens	
3. Utilize solar energy:					
Winter space heating ….	576	$10,000-20,000	4.1-8.2	Reduce oil use 44% Modest power reqts.	A complicated DIY; contractor advised; still on oil
Domestic hot water……	50	$2,500-4,000	11.2-17.8	Reduce oil use 4% Modest power reqts.	Challenging but feasible DIY; still on oil
4. Install geothermal System	1,300	$20,000	4.1	Get off oil entirely. Modest power reqts.	Complex, so select contractor carefully

Website sources for inner storms shown in table above:
Advanced Energy Panels: http://www.advancedenergypanels.com/Replacement-windows-howitworks.htm
Innerglass: http://www.stormwindows.com/why.htm
Window Savers: http://www.stormwindows.com/why.htm
Climate Seal: http://www.climateseal.com/thermal_window_inserts/thermal_windows.htm

Another inner storm mfgr: http://www.alliedwindow.com/products/res_swim.html

1. Improve Insulation in Key Walls, Ceilings

Beth already had some experience improving insulation in the walls and ceiling of parts of her home. We introduced the idea of improving the board and batten walls of her kitchen and summer kitchen, and the insulation in the roof area above the 2nd floor of the kitchen.

For example, the board and batten walls could be removed, (urethane) foam insulation blown in, foam board placed over this, and then board and batten walls replaced. She could achieve an R=20 wall, a big improvement over your existing uninsulated wall.

Right: Picture 3. Uninsulated board and batten walls that could be retrofitted

Foam is flammable. Since Beth was concerned about arson, we suggested she consider a fire-proof material for the siding. Hardie board, for example, is made from a concrete-like composite, and is durable (http://www.jameshardie.com/homeowner/).

Further investigation is required done to determine costs and payback.

2. Improving Window Insulation

Existing Challenges:

- The house has 54 windows, many of them fairly large (36" x 58").
- Some of the old 3-track storm windows do not work properly, the weights are broken in the old historic windows, and all of it is a nightmare to clean given the adjacency to the quarry and the main road.
- Vandalism and building security.
- Interior storm windows seem desirable, but the challenge is how to do it (without the track)?

Considerations:

- If the exterior storm windows are removed, the historic panes will be more susceptible to damage from vandalism, and they will require greater care and maintenance because they will be directly exposed to weathering from the elements (dust, dirt, snow, rain, etc.).
- Interior storm windows, if removed for spring, summer and fall, must be stored somewhere..
- Improving the R-value of the windows, particularly for the winter months, in order to reduce heating costs.

Options:

Interior Storm Windows**:** Numerous companies make interior storm windows, and they are recommended especially for older and historic homes. Costs per window will vary from the do-it-yourself kits to those custom-made. We compared the products of several manufacturers in the table above.

Payback Analysis: Beth has 25 large windows (most 36" x 58" = 14.5 sq. ft. each) = 362.5 sq. ft of drafty, heat-leaky surface in addition to numerous smaller windows, skylights and all the doors. Manufacturers claim that high-quality inner storm windows (e.g., Innerglass) will yield up to 35%-40%

energy saving over that of a single pane window (double hungs by themselves) if the homeowner does all the windows, doors and skylights. However, Beth already has storm windows, so she would be replacing an existing 2nd pane (the triple tracks) with an improved 2nd pane (interior storms); therefore, your savings will be less – probably only up to half as much (15-20%). Doing only some of your windows – the 25 larger windows – might therefore get you up to 7-10% energy savings. Beth had so many walls with low R values that we wondered whether she would realize that amount in actuality. For the purpose of calculating payback, we used the 10% figure for reduction of fuel oil use (130 gallons) for doing half the windows.

Calculating payback for several manufacturers for doing 25 largest window:

1. Advanced Energy Panels: $72/window x 25 windows = $1,800 to save 10% of $5,850/yr in fuel oil costs = $585/yr, so payback would be $1,800/585 = **3.1 yrs** @ $4.50/gal fuel oil.
2. Innerglass: $215/window x 25 windows + $150 shipping = $5,525 to save 10% of $5,850/yr in fuel oil costs = $585/yr, so payback would be $5,525 / $585/yr = **9.4 yrs** using oil @ $4.50/gal.
3. Window Savers: $62/window x 25 windows = $1,550 to save about 10% of $5,850/yr in fuel oil costs = $585/yr, so payback would be $1,550 / $585/yr = **2.6 yrs**.
4. Climate Seal: $263/window x 25 windows = $6,575, so payback is $6,575/585 = **11.2 yrs.**

***Exterior Storm Windows*:** Alternatively, Beth could either repair or replace the exterior 3-track storm window system to retain the safety features and minimize degradation of the original windows.

1) Repair info: http://www.thisoldhouse.com/toh/article/0,,476717,00.html
2) Exterior wooden storm windows with screen and glass panel which can be removed or changed from the inside of the house are manufactured by Stark Housejoiners, Inc., but only services the New Hampshire area. http://www.starckhousejoiners.com/stormwindows.htm
3) Storm window replacements:
   a) Gorell (Indiana, PA) http://www.gorell.com/pages/1000_storm_windows.htm
   b) Kaufmann Window & Door (MI) http://www.kaufmannwindow.com/stormwindow.htm?gclid=CIemu-rCkpQCFQQmGgods3iUuQ
   c) The Burch Company (MD) http://www.burchcompany.com/

Total Window Replacement: Beth could replace her existing windows with high quality replacement double or triple pane windows with high e coatings and inert gas filling. These would be east to clean, and have exterior screens built into the windows. Good Canadian windows might cost up to $1,000 each installed. There are cheaper ones on the market, but you get what you pay for. We did not explore this option further as Beth was less interested in this.

3. Solar Options (passive heating, annualized heat storage, hot water heating, photovoltaic)

Beth was particularly keen on using solar to provide heat and electricity because her main house roof faces south. After we did our preliminary analysis, we ended up being not as enthusiastic as Beth. Our preliminary findings follow.

Passive solar heating requires thermal mass to store winter insolation (incoming solar radiation) for release at night. Beth's sunroom, the main with south-facing windows, has insufficient thermal mass to store much daytime heat. It also lacks the nighttime insulation required to retain the heat; that is, heat collected during the day will dissipate at night through the large window area and skylights. Moreover, the room's small size limits its capacity to heat very much of the house. Beth could improve window performance using insulating covers, or improve mass by installing a tile floor, but it will require careful choices to realize decent payback. One inexpensive (compared to window quilts) window insulating option consists of cellular window shades set in tracks to reduce heat losses at night (see http://www.blinds.com for a wide array of choices).

Passive Annual Heat Storage (or Annualized Geo-Storage) is best used in new construction. Here you store summer heat beneath your house for use in the winter (and use the cool earth temperature to cool your home in the summer). Existing homes cannot reasonably be retrofitted with PAHS. One possibility consists of burying and insulating large water tanks (e.g., 10,000 gallons) and using roof-mounted solar hot water collectors to heat the water stored in those tanks for use in the winter. In one calculation we did for another homeowner, we found that the payback was 56 years, well outside the range of feasibility. We calculated that a tank of this size might displace only 50 gallons of fuel oil, not enough in our mind to justify the high cost. The high rock strata on Beth's site made digging a hole for the tank infeasible.

Solar hot water heating can provide hot domestic water and hot water for space heating. A small two-panel system would be sufficient for summer domestic hot water, but many more panels would be required to provide space heating in the winter. If Beth went with a larger system, she would have to cover many of the collectors in summer to prevent their overheating.

Let us start with using solar hot water panels to provide winter heat. Beth's south-facing roof area over the main house (~44'x 25' or 1,100 sq.ft.) might yield 38'x18' or 684 sq.ft. allowing for 3' setbacks from all edges for safety and access. That is enough for two rows of 12 hot water collectors, dimensions 3'x8' (24 total).

As a rule of thumb in the northeast, each square foot of collector area in the northeast displaces 1 gallon of fuel oil for the heating season. Using this in a back-of-the-envelope calculation, Beth would displace 576 gallons of fuel oil, or 44% of your heating requirement. At $4.50/gal, your annual saving is 4.50 x 576 = $2,592. At the 4.1 year payback calculated for geothermal, Beth should be willing to spend $10,627 on a solar system designed to accomplish this. She might be able to install such a system for this money – if she did the work herself and used retrofitted collectors (we know a local source of good quality used collectors requiring retrofitting). A simple two panel hot water system for domestic hot water only would cost around $2,500-$3,000 if she installed it herself and used retrofitted collectors.

We could get more accuracy by using NREL tables. Beth's latitude is a little shy of 41 degrees, close enough to the NREL station in Williamsport such that we could use this data for her location. At an estimated 27 degrees, Beth's roof is a bit shallow for winter use, but the roof angle happens to correspond closely to the second row of the table. For the 6 months October through March, the average solar insolation is almost 3.1 kWh/m^2 (978 BTUs/sq.ft./day). Multiply by 180 days for the 6 month period yields 176,042 BTUs for the season/sq.ft. For a 24 sq.ft. collector you can collect 4,225,000 BTUs during the season. Assume system efficiency at 50% and this drops to 2,112,000 BTUs of useful heat. Each gallon of fuel oil has 140,000 BTUs, which, in her furnace at 86% efficiency is equivalent to 120,400 BTUs. This has to be further depreciated by her nozzle firing rate (assume 0.85), so you end up with 102,300 BTUs/gal. This is equivalent to 2,112,000/102,300 or 20.6 gallons of fuel oil. For 24 collectors, Beth could save 495 gallons. This is not far off from the 576 gallons obtained using the rule of thumb applied in the previous paragraph.

Winter solar insolation is only available when the sun shines, and between the hours of 10 am to 3 pm. Any extra heat must be stored for release during the night, and such storage will increase complexity and costs, and increase payback beyond what we calculated above. Night-time storage will be particularly important during the cold months of November through February, when solar insolation is lower than the average figure used above. Moreover, Beth's shake roof may not prove workable as a secure, water-proof base for supporting solar collectors, and may require replacing. Additional investigation is required to determine whether Beth could connect the collectors to her cast iron radiators, and whether such connection would be direct, requiring propylene glycol (antifreeze, but different from car antifreeze, which is poisonous) in all lines, or indirect through a heat exchanger, requiring glycol only in the collector loop. A drainback system, if feasible, would be more fool-proof, not require glycol or a heat exchanger, and be cheaper.

Beth could also use solar insolation to heat hot water for domestic use – washing dishes, showers, laundry. There are package systems on the market using 1-2 panels which Beth could install yourself, or have a contractor install. This could be a stand-alone system, and Beth would displace the oil she currently uses to heat on-demand hot water. We can only guess at the gallons of oil she might displace with a roof-mounted solar collector system. We assume 50 gallons. She could install a 2-panel system for $2,500-4,000 as a rough estimate. Hiring a contractor to do this would increase costs and payback.

<u>Photovoltaics</u> for electrical power production is costly. It will not run a geothermal heating system, nor other high amperage-draw appliances (clothes dryer, electric stove). A grid-tied PV system would be more useful at this stage, if she really wanted to invest in it, but these systems are complicated, and would have a long payback when compared to the useful power it would produce. An off-the-grid system would require a battery bank for power storage as well as all the attendant PV system pieces: charge controller, combiner and breaker boxes, inverter, etc. In one off-the-grid system we calculated payback at 75 years. Based on her current electrical use, the capital cost might well reach $125,000, so the first order of business would be to reduce her power consumption (which she might want to do anyway). We did not recommend investing in PV at this time.

4. Ground Source Heat Pumps (Geothermal)

<u>Summary</u>: the option most compatible with Beth's home is one employing a water-to-water ground source heat pump system coupled with vertically-drilled wells. Horizontally laid tubing may be difficult to install due to rock strata lying close to the surface. Key points are as follows:

- Existing water-filled radiators can be used and have been used successfully in at least one local historic home.
- Radiant floor heating in select areas would require further investigation as it is limited by the complexity and large size of the home's floor joists and "add-on" construction. Beth may not require radiant heating if existing radiators work out.
- Domestic hot water could be heated in the summer with the same system using heat extracted from cooling the house, and in the winter through an additional dedicated well and larger heat pump.
- Local geothermal contractors can provide estimates of the cost of the system she would require to meet her home's heating needs.

- Because compressors draw so much current (and power), it is not possible to run this system on solar (photovoltaic, or PV) energy.

Initial Costs (ballpark estimates):

- There are three parts to a geothermal system: the wells, heat pump, heat distribution (radiators in Beth's case).
- For a 4300 sq. ft. house, expect to require 6-7 wells for a closed loop system and 2 wells for an open loop system. This assessment requires more careful analysis by a geothermal contractor.
- For a closed loop system, well costs are currently around $6-7/ft and each well is typically 150 feet deep, so plan on $900-1050 per well plus fuel surcharges or about $6k - $7k to install the wells. An open loop system (2 wells) requires bore casing @ $15-20/ft, so the budget for two wells would be around $7,200 plus fuel surcharges; the costs are similar in both cases. Beth's choice may depend on performance. Open loop may provide more hot water, and this may be an advantage in Beth's older home.
- Including an "on demand" option for providing domestic hot water could add another $1k to the system cost. Some heat pump systems already have this feature included.
- Water-to-water heat pumps could cost $6k - $7k or more if you add the "on demand" feature.
- A ballpark figure for total cost – wells, heat pump and distribution – is $20k, but costs can be reduced if you do some of the work yourself.

Payback:

When payback was calculated in the spring of 2008, Beth was facing the prospect of $4.50 to $5.00 fuel oil. By fall of the year, it had fallen to $2.90. We use $4.50 per gallon in the payback calculation below as we expect the price of fuel to climb once economic recovery occurs.

$$\text{Payback for Geothermal} = \frac{\text{total capital cost of selected geothermal system}}{\text{Energy cost savings per year with geothermal}}$$

1. Energy cost of oil system = oil cost + electrical cost (½ present use x 5 months)
   = $4.50 x 1300 gals + $56 x 5 = $6,130/year
2. Energy cost of winter heat geothermal = $250/month x 5 months = $1,250/year
3. Energy cost savings of geothermal = 6,130 – 1,250 = $4,880
4. Therefore, payback = $20,000/4,880 = **4.1 years** with oil at $4.50/gal (3.6 years at $5/gal, 7.1 years at $2.90/gal)
5. This analysis does not include the additional capital cost of an on-demand domestic hot water option and the cost of running the compressors for the remaining 7 non-winter months.

Advantages of Geothermal:

- If well-done, expect geothermal heating to be 1/2 the cost of heating the home directly with electric. "On-demand" geothermal heating of domestic hot water is about 1/3 of the cost of producing hot water with direct electric heating.
- Lower operating costs: For homes in the 3,000 – 5,000 sq. ft. size, if geothermal is installed in new construction with highly insulated walls and ceilings, power costs could range in the $70 - $100 per month at $0.065 per kwh.

- For older home retrofits, the power cost will more likely be in the $200-$300 per month range. Even if the cost of electricity doubled, this option would cost less than oil heat during the winter months.
- The wells and ground loops are estimated to last at least 50 years.

Disadvantages of Geothermal:

- Without electricity, there will be no water circulation and no heat, but this would be the case with your oil fired furnace which requires electricity to run.
- If Beth purchases a back-up power generator, it must supply *double* the current (amperage) that the heat pump draws in order to get the compressors started.
- Compressors are notorious for breaking down. They often fail when you need them most and you will not have a heating system until they are fixed.
- If under warranty, compressors are usually replaced without charge, but it is an inconvenience to wait for the repair man. A 5 year warranty is fairly standard, and many compressors fail in 2-3 years.
- If not under warranty, replacement compressors could cost $700 or more.
- The system is somewhat complex and there are a number of other parts that can fail including integrated circuitry components which regulate the system.

Specifics to Keep In Mind for Geothermal Systems:

- Oil-fired hot water heat typically heats water to 180^{o}F; a geothermal system can heat water to 120-130^{o}F, so the heat radiating from hot water radiators will be 115^{o}F at best, somewhat cooler than the oil-fired hot water, but what it lacks in intensity, it will make up for in duration and constancy.
- The system must be sized based on tonnage for heating, which requires more capacity than cooling (Beth was not interested in cooling anyway, but she may want to reconsider if she wants to heat summer domestic water by extracting heat from cooling the house).
- Vertical wells are said to be more energy-efficient than horizontal loops because the latter are not deep enough to be unaffected by surface temperatures.
- Finally, and most importantly, the better insulated your house is – walls, windows and doors – the smaller will be the required size (tonnage) of the heat pump component, and the lower the capital and operating costs. Therefore, improve the overall building envelope as much as you can.

C. What Did the Client Do?

When we presented our preliminary findings to Beth in the spring of 2008, we left her with a lot to consider and pursue. We contacted her to ask whether she wanted additional assistance. With the economy taking a dive, and the price of fuel oil dropping, it may well be that the incentives spurring her to action became blunted just as the capacity to put aside money to make improvements shrunk.