

Residential Renovation of a Schoolhouse – A Deep Energy Retrofit



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Introduction

Across Canada and the United States there are an exceedingly large number of tired, older solid masonry buildings with sub-standard thermal envelopes and/or major moisture problems. If the bones justify the effort of a major interior renovation, and if the exterior façade and architectural features do not complement the current use, perhaps one should consider an exterior renovation as well. The result may well be surprising! The total wintertime space heating bill for this 'deep energy retrofit' is expected to be in the range of \$ 200 to \$ 250, depending upon winter severity (or about six percent of that of a typical new dwelling of similar size and style)!

Background

A 1963 two classroom elementary school of concrete brick and concrete block construction has been completely renovated to a predominately passive solar dwelling. The school originally had no insulation and had been heated by a fairly massive forced air, oil furnace. When purchased (fall 2005), a marginal amount of fiberglass insulation (about R 5 walls & R9 ceiling) had been installed in some areas. The primary source of heat was a large wood stove, supplemented by a forced air 100k Btu/hr propane furnace. Several rooms were largely unusable, having neither heating nor any insulation!



Figure 1 The schoolhouse before renovation



Figure 2 Inside of schoolhouse early in renovation

The dwelling is located west of Kingston, Ontario at a latitude of 44 deg. N. This is a 7150 F. degree-day heating climate with an extreme winter 'Design Day' temperature of -5.8°F . The original classroom windows faced 30 degrees east of south - far from ideal, but worth solar consideration. The building was gutted, cleaned and the structure rehabilitated. Contractors were then engaged to complete the renovation.

The thermal envelope now encloses a single storey, two bedroom, 1232 sq ft single family dwelling, a 780 sq ft home occupation (studio), 263 sq ft of semi-heated utility/storage, plus a 256 sq ft mudroom/solar heater – for a total usable area of 2531 sq ft. Gross outside area is about 3100 sq ft.



Figure 3 The new addition -- a combined solarium/mudroom



Figure 4 South-southeast facing glazing with triple pane R5.9 windows



Figure 5 Some of the south glazing and paver floors



Figure 6 Masonry Heater

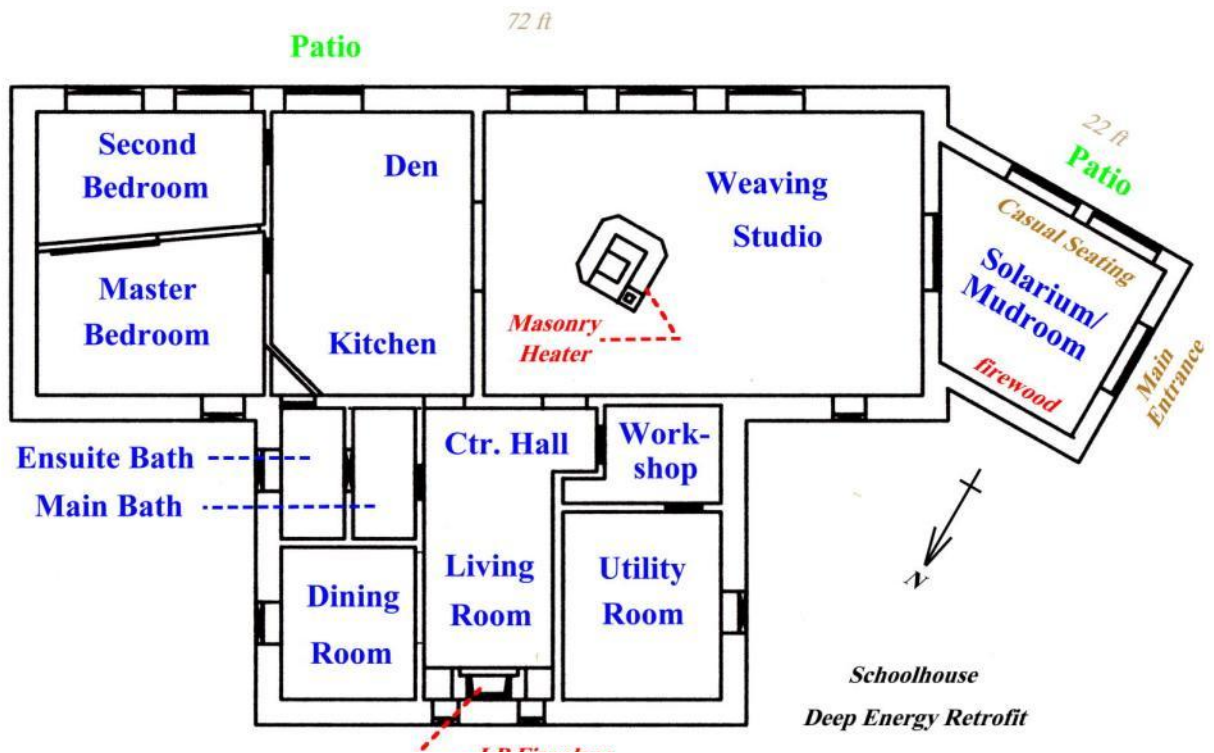


Figure 7 Final floor plan

Design Strategy

The basic goal was to rehabilitate a severely building code deficient dwelling with extremely poor thermal and moisture performance into a quality dwelling where the priority emphasis would be energy efficiency and fire prevention, and the following specific considerations:

- install a relatively high level of quality insulation to reduce winter heating and summer cooling needs,
- satisfy as much of the winter thermal load using passive solar, as feasible, within the constraints of the existing building,
- reconstruct the building envelope in a manner to be exceptionally tight to minimize infiltration,
- provide attractive air quality year round, plus a level of wintertime heat recovery and humidity control,
- satisfy winter heating demand in a redundant manner so as to not be snookered by either (i) the in-availability of individual fuels (propane, firewood, electricity and solar insolation), or (ii) equipment failure,

- make good use of the 200 ton existing building mass in a manner to both (i) significantly temper the temperature swings commonly occurring with passive solar and/or solid wood fuel heating, and (ii) provide considerable thermal storage to counter heating system emergencies,
- design a space heating system with a functional life exceeding that of typical housing and requiring little maintenance,
- provide a quality, rain screen treatment to prevent exterior moisture penetration into the exterior wall assembly,
- rehabilitate the foundation drainage and improve insulation and control of water vapor at the floor slab,
- improve personal comfort by investigating means to reduce the temperature stratification of interior air as may be achieved by: (i) using quality windows, (ii) an attractive level of insulation, and (iii) passively warmed floors,
- make a significant effort to reduce the risk of potential house fire to a level far lower than usual by: (i) giving priority to the selection of non-combustible materials and providing better clearances than normally specified, (ii) selecting quality heating and ventilation appliances and associated components known to provide superior safety, (iii) avoiding high powered mechanical systems susceptible to catastrophic electro/mechanical failure, (iv) selecting components where surface temperatures are low, and unlikely to initiate combustion nor burns to occupants, and (v) developing a redundant heating strategy to ensure that heating units are not put under any stress – even under adverse weather conditions.

Space Heating Provisions

Being essentially retirees, we were looking forward to creating a warm, comfortable home – where maintenance was minimal, and operating costs were affordable. The 'Ice Storm' of 1998 got us thinking about minimizing our reliance on specific heating fuels. Rising oil and electricity prices shifted our thoughts towards solar opportunities.

1. By utilizing a quality level of insulation, high efficiency windows, and tight construction practices, the winter 'design day' purchased space heating load is expected to be only about 21 k Btu/hr. This equates to a space heating load of about 270 Btu/hr per degree F. The total annual heating load is expected to be about 60 M Btu. Due to passive solar gains, and recoveries, purchased heating fuel is about 20% of the total space heating need.
2. To reduce both the possibility and implications of mechanical failures, the heating system makes extensive use of high quality and innovative materials in a largely passive or low tech. manner:

- a. The glazing (predominantly triple pane) provides a relatively high insulation R value (typically R5.9) and provides a considerable amount of direct, passive solar heat gain, and
 - b. Rather than using a conventional 'central' heating system, the combined mass of the existing steel ceiling, masonry walls, and the concrete flooring provide (i) readily accessible heat storage to 'average out' daily temperature variations, plus (ii) over a hundred tons of less accessible heat storage to satisfy several weeks of longer term emergency heating needs – yet –
 - c. Have a low need for maintenance and a low risk of equipment failure.
3. In the event of wintertime temporary shortages (ie: several weeks) of electricity, propane, wood or sunlight, the heating system provides
 - a. Redundancy for easily achieving both the severe weather 'design day' heat load, and
 - b. Very little risk of damage due to freeze-up - even if the dwelling is un-occupied and unheated for several weeks.
4. The wintertime heating system is composed of:
 - a. Passive Solar Windows, HRV Recoveries and Internal Gains
 - i. southerly facing windows and four dual patio doors contribute about 50% of the total winter space heating requirement.
 - ii. including the HRV and internal gains, the contribution is 80% of the total seasonal heat load requirement.
 - b. High Mass, Radiant Masonry Heater with Bake Oven
 - i. wood fueled, centrally located in the Studio, providing approximately 7-12 k Btu /hr averaged over the entire day for a single fire per day; (or 15-24 k Btu/hr with two fires per day – an unlikely requirement),
 - ii. the core is high temperature firebrick and refractories, with machined and annealed iron doors manufactured and installed by Norbert Senf/Masonry Stove Builders of Shawville, Que.
 - iii. the custom, cut sandstone facing was provided by Jay Beckwith Masonry of Lansdown, Ont.,
 - iv. masonry heaters are noted for low emissions, high efficiency (~72%), high safety and long operational life,
 - v. the surface temperature of the masonry never becomes sufficiently hot to burn materials or flesh,
 - vi. combustion is typically about 2 hours per load, so over 90% of the day there is neither fire nor high temperature flue gases, drastically reducing the potential for an accidental house fire to occur;
 - vii. one need not open the firebox door during an active fire, ash cleaning and fuel loading is done cold, and at least 9 hours, and more usually, one or more days after the fire has been out!
 - viii. testing undertaken for CMHC has determined that this type of masonry heater is appropriate for modern air- tight house construction - as flue spillage is highly un-likely in comparison with factory manufactured solid fuel appliances.

- ix. combustion involves high temperature with excess air – so smoke, soot and creosote are never a problem!
- x. tests of this unit indicate that it is very difficult to have CO spillage (even when trying to do so!),
- xi. baking bread or cooking dinner in the bake oven on alternate days easily heats the house in mid-winter!;
- c. Direct wall vented propane fireplace in the Living/Dining Room with blower powered ducts to nearby rooms;
 - i. variable 12k-43 k Btu/hr input (Regency P40 - 77% efficient);
- d. 4.1 kW of thermostatically controlled electric baseboard heating (14 k Btu/hr) distributed throughout the dwelling.
 - i. the function of the baseboards is primarily back-up heat in the event of ‘non-occupancy’ of a month or longer.

5. The south yard (having been a ball field) is largely open and generous and has a gentle downward slope. The slope is curved near the dwelling, and with winter snow, tends to act somewhat like a parabolic reflector with the south facing windows at the focus. Mid- day, mid-winter sunlight intensity increases by 50 to 60% when measured indoors!. Even without snow, the passive solar heating system is expected to provide almost the entire fall/spring heating requirement

Summertime Space Cooling Provisions

The close proximity of the Bay of Quinte / Lake Ontario tempers summertime cooling needs, and, along with (i) natural night-time window cross-ventilation, (ii) the solar chimney in the mudroom, and (iii) mature overhanging maple trees, summertime air conditioning is not necessary.

Space Heating Performance Summary

We are very pleased with the first year’s thermal performance of the renovation – both in winter and summer. Almost no purchased heat is required in fall and spring. Between Jan 1 and Feb 28 (mid-winter) we had 22 firings of the masonry heater with an average fuel load of 50.6 lbs. That’s equivalent to a frugal two hour fire every 64 hours! My wife baked bread or cooked supper in the bake oven almost every time the masonry heater was fired. Yummm! Despite summertime temperatures in the mid to high 80s, the interior temperature is a stable 72-73F – with windows continuously open for ventilation. No air-conditioning is required.

A simple thermal energy balance spreadsheet had been developed early in the design process to describe the rather unique nature of the school. As the design process and construction phase continued, this spreadsheet proved to be an effective tool for assessing means to reduce loads and improve gains and recoveries. It has been revised and expanded as newer and more detailed information became available. This spreadsheet may be [downloaded here](#). A detailed log of electricity, propane and firewood usage has been made throughout this first year, and a summary of this log is included at the end of the spreadsheet. The actual measured performance was slightly poorer than that

predicted using 'average' weather data. However, the past winter has been colder than 'average', and the implication of a number of correctable construction difficulties has been assessed. We are confident that the dwelling performs very closely to that predicted in this simulation – and we are delighted.

1. The space heating system provides:
 - a. multiple redundancy for accommodating full winter design day space heating load conditions (ie: 70 deg F inside @ - 5.8 deg F outside), and
 - b. the capability to fully satisfy the all-time extreme recorded weather event (an additional 60% heat load) – even without electricity!
2. The passive solar system (including internal gain and recoveries) provides 80% of the seasonal heat requirement, and if all else fails, will usually prevent freeze-up damage over much of the winter.
3. The small (454 litre) propane tank need only be filled once per year – primarily for the kitchen range.
4. Firewood handling is minimal at about 2/3 of a cord per season. The mudroom (adjacent to the main dwelling) provides convenient, ventilated, and protected storage for a full cord.
5. Conventional central heating systems and/or hydronic slab heating are neither appropriate, nor cost-effective heating strategies for this specific dwelling. By the selective elimination of devices prone to failure, and by providing functional redundancy, the risk of damage arising from heating system failure is essentially eliminated.
6. Investment in an attractive level of high quality insulation, not only reduces operating costs but reduces the capital cost of mechanical systems. The fire rated insulation does not support combustion, and is outside the steel and concrete structure, thus poses a low fire risk.
7. We chose to heat with a redundant system involving a relatively expensive masonry heater, propane fireplace and passive solar windows– on the basis of safety, reliability, fossil fuel energy efficiency, aesthetics, and lifestyle. the expected payback period for the full package of insulation and heating system improvements over standard construction levels is 20 years.
Total wintertime purchased space heating is expected to cost about 6% of typical new housing and less than 3% of that required by the original schoolhouse!
8. The space heating requirement of this dwelling is just under 15 kWh per square metre of usable interior area – outstanding performance for custom new construction - but this is a retrofit of a far from ideal older building!

Building Description

The dwelling is comprised of the original schoolhouse, plus a small new mudroom/solarium constructed on the west end. The original school had two classrooms end for end with windows facing east of south. A north wing originally housed a central foyer, washrooms, coat closet and utility room with a massive furnace.

After the renovation, two bedrooms and a kitchen/den occupy the easterly classroom. My wife's weaving studio occupies most of the west classroom. A living room, dining room, two bathrooms, centre hall, utility room and workshop now occupy the north wing. The new westerly addition is a single room functioning as a combination front entrance/vestibule with full air lock, storage for more than a full winter of firewood, coat closet, casual seating area, and solar heater for the main dwelling.

General:

- Municipality: Greater Napanee, Ontario, Canada;
- latitude: 44 deg. N; longitude: 77 deg. W; 190 day heating climate with 7,150 DD64.5F;
- context: rural farmlands adjacent to a tiny village;
- architectural theme: simple farm out-building theme to blend with the rural character;
- overall gross size: 286.6 sq m or 3,085 sq ft, net usable interior space: 235.2 sq m or 2,531 sq ft
- single story over slab-on-grade.

Main Building (original schoolhouse):

- overall gross size: 259.8 sq m or 2,799 sq ft;
- net usable interior space: 211.4 sq m or 2,275 sq ft;
- structure: originally a single story, fire rated elementary school built about 1963;
- original school had two classrooms, end-to-end, with windows facing South30E
- entire building was gutted, cleaned, sanitized and painted prior to reconstruction;
- concrete block foundation wall on concrete footings, approx 7 feet below grade;
- non-insulated concrete slab on grade sub-floor;
- 10 ft 6 inch high concrete block walls with concrete brick facing;
- corrugated 18ga. structural steel 'B' deck ceiling/roof supported by unit masonry walls and structural steel wide flange girders;
- above the original flat steel roof, a previous owner had recently installed a ridge type roof consisting of wood frame trusses bearing on the perimeter masonry walls, and panel steel finish roofing;
- insulation: completely insulated exterior to masonry and steel deck with fire rated, medium density, sprayed-in-place polyurethane, (walls: 7 ½", ceiling: 8" to 9 ½");
- exterior wall facing: stained / back primed, western red cedar board & batten siding;
- to minimize thermal conductance a variant of the 'Larsen Truss' was used:
 - siding is nailed to 2" x 2" (actual size) 2 ft OC horizontal cedar strapping,
 - this cedar strapping is nailed to 2 x 4 (nominal size) SPF vertical studs, and
 - these studs are nailed to 2" x 3" (actual size) cedar nailing blocks, and
 - these cedar nailing blocks are percussion nailed into the masonry wall,
 - the 7 ½" external wall cavity was entirely filled with medium density urethane,
 - rain screen: beneath the siding is a porous polypropylene mesh and Tyvec air barrier



Figure 8 Building the Larsen Truss



Figure 9 Polyurethane foam insulation filling Larsen Truss

- windows: all windows are triple pane, LOF EA2 hard coat #3, #5 glass in fiberglass frames;
- operable windows are awning style, (all doors and windows provided by Stephen Thwaites, P.Eng./Thermotech Fibreglass, of Ottawa);
- sliding door (den): triple pane, LOF EA2 hard coat #3#5 tempered glass, fiberglass frame;
- inside finish: Studio (about 30% of total dwelling area) is painted stucco finish over concrete block walls; and painted exposed steel ceiling and girders,



Figure 10 Painted stucco over block walls and floor pavers

- the remainder, is conventional dry wall on steel studs adjacent to solid masonry walls or the steel ceiling.



Figure 11 Original steel ceiling, stucco walls, and paver floors

- a few partition walls are non-load bearing, dry wall clad wood frame SPF;
- finished 'conditioned' space in the dwelling consists of a relatively small centre hall, living and dining rooms, two small 3pc bathrooms (sink, water closet & tub) plus a larger combined kitchen/den and two mid-sized bedrooms;
- one school classroom has been retained as a generous sized studio – ideal for numerous types of home occupations;
- unfinished 'semi-conditioned' space' consists of a small workshop and a generous utility/storage room, (ie. unheated, but self maintaining above 55F);
- all new plumbing and electrical sub-systems, rehabilitated cased well;
- all new ducted ventilation system, including six port HRV (Nu-Air OP176), mechanical system blowers are low power;



Figure 12 Heat Recovery Ventilator in workshop

- all floors likely to be in sunlight are 20"x20"x1.5" "range red, patterned" concrete pavers placed over 1 ½" type IV extruded foam insulation & 20 mil poly, over the original slab; (thicker foam is preferable, but would necessitate reconstruction of numerous interior masonry doorways)



Figure 13 1.5 inch rigid foam board was used under the hardwood flooring, concrete pavers and slate tile bathrooms.

- all new heating system (see Space Heating Provisions);

Mudroom/Front Doorway (west end of Main [original] Building):

- overall gross size: 26.8 sq m or 286 sq ft;
- net usable interior space: 23.8 sq m or 256 sq ft;
- structure: south facing, single storey, newly constructed 2008:
 - 10 inch ICF concrete foundation walls on concrete footing (~ 7 feet below grade);
 - insulated slab on grade floor;
 - 10 inch ICF concrete perimeter walls, about 9 feet high;



Figure 14 Mudroom/Solarium ICF walls



Figure 15 Pouring the ICF walls. 2 inches polyurethane insulation was sprayed over outside of ICF walls



Figure 16 Sun on the new solarium



Figure 17 Mudroom/Solarium "doghouse"

- roof is conventional wood frame rafters with OSB cladding, supported by dual, laminated ridge beams (design is '[sugar shack](#)'), roof is clad with panel steel similar to main structure;
- wall insulation consists of the ICF expanded styrene plus an extra 2" of sprayed-in-place medium density urethane on the outside, and roof rafter cavities are filled with urethane;
- exterior wall facing is similar to that of the Main (original) Building;
- inside finish: painted gypsum dry wall directly over the ICF walls and on the underside of the roof rafters;

- rain screen: identical to Main (original) Building;
- windows: (south clerestory) awning, dual pane LOF EA2 hard coat #3, in fiberglass frames;
- sliding doors: two sets of dual pane LOF EA2 hard coat #3 patio doors, in fiberglass frames;
- French (double air lock) doors: dual pane AFG Ti #3, in fiberglass frames at both ends of the mudroom, with double full view aluminum storm doors (exterior);
- 'Sugar Shack' themed cathedral ceiling and 'dog-house' has two functions:
 - solar heater in winter: collects and 'reheats' passive heat which is harvested by a thermostatically controlled blower for the main house; (additionally there is a separate cold air return near the floor),
 - solar chimney in summer: exhausting hot air from house, thus cooling the house;
- window-less north wall is dedicated to storage of a bush cord of firewood.

Lessons Learned – the Good and Not so Good

A fair amount of effort went into numerous little details. Individually, they tend to be minimally useful – but in total contribute significantly to either minimize heat loss, improve passive solar performance, improve air quality or reduce maintenance.

Windows used in the main dwelling:

All windows in the main dwelling are Pilkington LOF 322 EA2 #3, #5 with argon fill. The '322' means triple pane with two SuperSpacers and 2 low E surfaces. 'EA2' refers to Energy Advantage Two, Pilkington's name for pyrolytic (baked at high temperature) low E coating specifically for cold climate heat retention. The '#3 and #5' refer to the glazing surface with the coating, where surface #1 is the outside surface. The glass properties are SHGC=0.59 with an effective R=6.7 Btu/sqft. For a 1.2m by 1.2m window, the window properties are SHGC=0.51 with an effective R= 5.9. The frames are pultruded fiberglass chosen because of the high strength and thermal expansion characteristic similar to glass.

Note that for low profile, high quality North American windows, the glazing now has a greater R than the frames! This is not necessarily so for European windows because there, a wide profile frame is very common – this of course reduces the glazing size for a particular rough window size.

When ordering passive solar windows, one is cautioned to specify a low E specifically for cold climate heat retention – and demand performance specs. determined by FRAMEplus5.1. Better yet, download the software (free) and calculate the properties yourself for several glass vendors. In our case, we approached about 8 vendors representing perhaps over a dozen manufacturers. All vendors claimed their windows were the very best. The vast majority didn't know what a super-window was, nor what their window performance was! It was rather embarrassing for several 'experts' when after a day or two I could use the software to analyze their windows and tell them how bad their windows actually were!. Only one vendor was thoroughly familiar with current window science – Thermotech, of Ottawa.

Things may have changed in the last 18 months since we ordered our windows, but I doubt whether better window specifications for passive solar are available. There are windows with a higher R value –

but at the expense of solar heat gain. Low iron glass has a high gain but poor R (ok for solar closet, but not to live in!). Note that large passive solar windows encounter a considerable torture test including extreme temperature variations, solar pumping of the seals and an expectation of long life.

'Maple Sugar Shack' design of the mudroom-solarium:

The 'dog-house' ceiling serves several purposes. The increased height increases air temperature stratification. In winter, the hottest air rises into the small 'dog-house' where south facing clerestory windows further raise the air temperature. Mid-winter, mid-day temperatures of 100 to 114 F are common. This air is harvested via a duct down into the Studio. The blower is located within a box over the main doorway. Air filter material in this box keeps dust and insects out of the main dwelling. In summer, by opening both the clerestory windows and door to the house, the chimney effect cools the home, particularly during the night-time.

In actual performance, the duct blower seems somewhat undersized. It can take between three to six hours after sundown for the thermostats to shut down the blower. During that time of course, heat is lost to the roof and glazing of the solarium – heat that could have been harvested to the main dwelling. The ducts are 3" by 10" and the blower is a 160cfm squirrel cage. Something about 50% larger for the duct and blower would have been a better choice.



Figure 18 Mudroom/Solarium



Figure 19 "dog house" with clerestory windows

The glazing in the mudroom-solarium is all dual pane 'hard coat Lo E':

Single pane would have created a greater solar heating effect – but over-night temperatures would be below freezing. Triple pane would reduce the solar heater output significantly. Dual pane seems like a reasonable compromise. Harvested heat is of significance, but the room is quite usable during the daytime in all but perhaps two weeks of winter and over-night temperatures have never dropped below 45 F. Purchased heating has never been supplied to the room. The south exposed clerestory windows are 211 LOF EA2 #3 awnings. The south exposed pair of double sliding patio doors are tempered 211 AFG Tir #3.



Figure 20 Solarium sliding glass doors

A steel rack along the north wall of the mudroom-solarium houses one bush cord of firewood:

This is more than enough for the winter. However, firewood usually contains numerous insects. That is the reason that tight fitting exterior doors were installed between the mudroom-solarium and main dwelling.



Figure 21 This picture shows the one cord firewood rack, and the part remaining in late spring.

Efforts made to minimize non-south window area, yet maximize natural lighting of the interior:

For a passive solar home, one needs to strive to have as high an overall insulation R value as feasible. The R of windows is much poorer than walls so where possible the size and number of non-south windows should be minimized. This was a challenge for our building. It is 'T' shaped. The north wing would receive no direct solar heat, had a large exposed wall and ceiling area, and thus would tend to be cool. We really needed to minimize cold window areas!

The building code has lighting standards including minimum glazing sizes for various residential rooms. In the end we cut the size of all non-south windows generally to a third, and at least in half. To satisfy the Code required: (i) adjusting the definition of some room uses, and (ii) making major efforts to allow natural light from the south wings to flood into the northern areas.

(i) was not an issue because it suited the usual perception of most dwellings – just not our specific intended use

(ii) was achieved using three differing techniques:

- having two oversize doorways between the northern hall/living room and the southerly Kitchen and Studio,
- installing a movable wall panel between the northerly master bedroom and southerly guest bedroom, and
- installing a window in the interior wall between the two bathrooms to let light from the ensuite's east window flood into the main bathroom (main bathroom has no exterior walls).

Bare stucco and/or bare concrete block interior walls:

The Studio walls are Portland stucco over concrete block. The walls of the utility room and workshop are bare painted concrete block. The interior of various cupboards remain concrete block. This was purposely done to make more of the masonry structure accessible to air temperature variations (heat storage). The rough stucco finish in the Studio is quite attractive - resembling vernacular homes of Provence, France.

Concrete pavers were used as an interior finish flooring directly over Type IV XPS foam insulation:

Initially we examined quite a variety of bricks and pavers. We thought the taller ones might store more solar heat. Calculations suggested that we would not be able to supply enough heat to warm them sufficiently. A thickness of about 1 ½" seems ideal for our situation. Exposed to a full day of mid-winter sun, the pavers reach 80 F. Another consideration was whether typical floor loading would cause compression of the foam insulation. We did some calculations and several tests.

Conventional brick pavers would probably result in deformation of the XPS at edges. We tested 20ga. steel sheeting between the foam and bricks and determined that it would correct the deformation problem – but steel prices were skyrocketing. We then tested several paver slabs ranging in size from 8 to 20 inches. A couple of rather attractive 20" x 20" x 1 ½" paver slabs tended to be ideal thermally, and tests confirmed that they were compatible with the strength of Type IV foam. Note that common type III is not adequate for typical floor loads. This testing was by no means scientific. Foam of various types and pavers of various sizes were simply strewn about the most heavily trafficked portions of our old house for a couple of months!

Before we committed to the paver flooring, we undertook a series of tests to determine (i) what types, patterns and colours of pavers to purchase, (ii) cleaning procedures, (iii) the relative attractiveness of various finishing products, (iv) the number of coats required, and (v) how the process might be organized. The result was the following methodology.

Prior to installation the pavers were prepared outdoors. 2 by 8s were spanned over up-ended surplus concrete blocks to create racks at a reasonable working height. We had enough blocks and timbers to support the processing of 75 pavers at a time. The pavers were quickly examined and those with major defects were set aside for an exterior patio (perhaps 3%). They were then washed down with 5% muriatic acid to bring out the deep dyed, variegated red and black colour, thoroughly rinsed, and dried in the sun. The top face and edges were then very lightly sanded with an orbital sander (coarse 50 grit) and dusted. Both faces and all sides of the pavers were given a coat of colourless, oil-based Varathane. When dried, they were stacked ready for installation. There was some variation from the nominal 1 ½" thickness, perhaps 10% were a little thin, while a similar number were a little thick. To ensure an even floor across the main room group, those thick and thin were reserved for the utility room and workshop. The process was continued until all 500 or so paver slabs had been pre-finished.

Actual installation was smooth and simple. A bead of clear silicone caulking was placed mid-way around the perimeter edges and the pavers were dropped into position on the XPS foam in a random orientation. The slabs at the wall edges had to be cut, but that was easy with a diamond chop-saw – but do it outside! The floors were then given five more coats of Varathane.

We actually tested quite a number of floor finishing products – both toxic and somewhat green. The test result using 'Diamond Wood Finish' gloss oil based Varathane seemed to have the best scuff resistance, and by far, enhanced the vibrant colour saturation of the pavers. Water based finishes tended to be a clouded colour after two coats, and looked more like bubble gum after three or four.



Figure 22 Finished paver floor and oak floor.

Alas, we didn't actually succeed in achieving the desired vibrant colour. From week to week, the workmen would never put the tops on opened cans. The Varathane was thus oxidized prior to application. It seems to have dried to a sufficiently tough floor surface – but the resulting colour is a somewhat reddish, muddy brown. It is actually an acceptable colour – just lacking the vibrance that we had planned.

Slate tile was used in the bathrooms:

The tile was thin set applied over two staggered ½” thicknesses of concrete board. Note that concrete board now comes in two varieties: (i) true concrete within fiberglass facings, and (ii) a concrete containing styrene foam bead beneath the fiberglass facings. From the extensive calculations I had made, when the true concrete board is applied over Type IV XPS, there should be no problems with grouting fractures. This is not so with the foamed concrete board nor the softer Type III XPS. The edges of the base of the toilet subjects the floor to major dynamic concentrated loads – fractures in the grout here are just not wanted!

Guess what kind of concrete board the contractors installed in the bathrooms? You betcha. Guess what kind of foam was used in the bathrooms? Well, that we're not sure about. Let's just say I'm tempted to mount a 'No Riling Around' sign on the wall opposite the water closet.

Prefinished oak hardwood was used throughout most areas not exposed to direct sunlight:

During the gutting process we tested the original slab for moisture seepage. The results were iffy in regard to using hardwood. That provided additional incentive to significantly improve foundation/perimeter drainage. Poly was installed over the slab before applying the XPS insulation – but we were still hesitant. The oak flooring we selected had been pre-finished on both the top and bottom, and on all edges – and actually cost less than various brand name products which had a finish only on the top! The oak hardwood has a very slight reddish tint that matches our cherry kitchen cabinets. We're very pleased with the result.

The original slab floor had been poured over a sand base:

No insulation! Early in the design process we examined various heating strategies. Initially we liked the concept of hydronic radiant in-floor heating but the simulations indicated that water temperatures averaging over 90F would be required. To limit heat conduction loss into the ground to reasonable levels, four inches of XPS foam would have been desirable. It is hard to pour a radiant slab less than 3 inches thick without cracking problems. In order to not reconstruct all the steel re-enforced masonry lintels over the interior doorways, we were restricted to a total insulation/flooring assembly no greater than a 3 ¼" thickness.

This limitation led us to examine several other heating strategies – particularly from a benefit-cost perspective. The thermal simulation model enabled us to test numerous parameters to optimize thermal performance versus cost. In our situation, investing in a superior quality of insulation and glazing was preferable to the installation of a conventional heating system. We settled on a flooring thickness 'budget' that provided 1 ½" to 1 ¾" for the flooring assembly, and 1 ½" for XPS foam insulation.

Intuitively we were not comfortable using only 1 ½" of XPS foam, but the optimization process clearly indicated that increasing the slab insulation to 4" would cost an extra \$ 5000 plus labour, and closer to triple that cost when re construction of the concrete lintels was included.



Figure 23 insulation reduces slab heat loss. Note how Larsen Truss will cover the edge of slab insulation

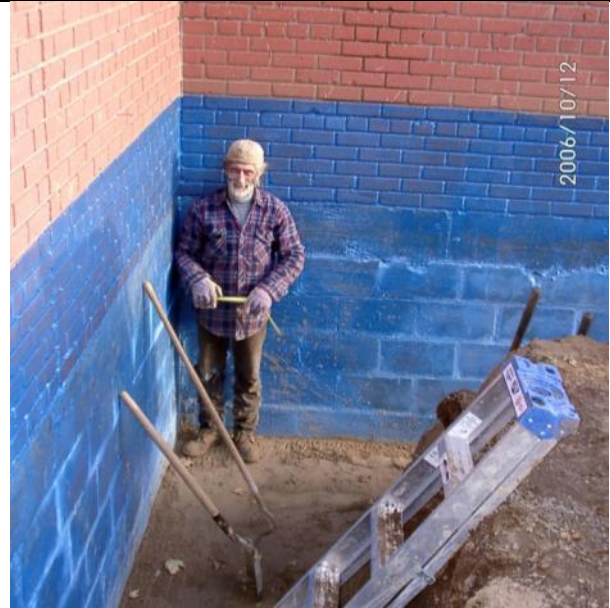


Figure 24 Foundation damp proofing

The benefits of exterior insulation:

In a retrofit, locating the insulation on the exterior maximizes the usable floor area. There are however other significant benefits. It provides a better opportunity to encapsulate the dwelling in a manner with far fewer electrical and mechanical perforations – thereby more easily achieving a very low rate of infiltration. Doing so reduces both the winter heat load and summer cooling load. Infiltration carries significant water vapour and sometimes moisture into and through the wall/ceiling assembly. At the location of the dew point, vapour condenses and a climate for the growth of toxic mold and fungus is formed. This translates into issues of personal health and basic structural integrity. One aspect largely overlooked is that the building structure now resides within a climate controlled environment. Expansion and contraction of structural members is minimal. In our area, outdoor annual temperature swings of 100F are normal. Such temperature swings create stress and strain on structural components. In the case of masonry construction, tension stress is usually relieved by cracking failures, which in turn compromise infiltration and rainscreen performance, which in turn foster frost expansion and more brittle failure. In a nutshell, the lifetime of the structure of an externally insulated masonry building could be measured in centuries rather than decades, and the costs associated with maintenance of the exposed cladding and rainscreen can be to some extent absorbed with costs involving changing trends and styles compatible with building usage.

The use of spray-in-place urethane foam:

Many people avoid urethane as it is considered a less than green fossil fuel product and health concerns were a problem in the past. I would argue it is the best possible use of our fossil resources. In Canada, it no longer contains urea-formaldehyde. Numerous other domestic insulation products do contain this toxin. It is simply the best way to minimize air infiltration, and when properly installed is most unlikely

to foster mold and dew point problems. 2.2 lb per cubic foot foam is expensive, so it is important to make the best of one's investment. One should avoid installation during cold weather. Both the R value per inch and the foam volume per pound is much greater in warm weather. Further, if the base is cold steel or concrete, the initial pass of the foam is instantly cooled producing very little practical insulation. In cold weather, less thickness can be applied in a pass (to avoid large gas pockets), thus for a given thickness, more passes (more installation time) are required - so the cost of both labour and material significantly increase! Yes we knew this, yes we were determined to avoid a cool or cold weather installation – and you guessed it, it didn't work that way!

Implications of the 'Larsen' Truss and its variants:

This is a wall assembly technique developed and patented (I believe) in the '70s in cold Alberta, Canada. The design enables the insulation value of the entire wall assembly to very nearly replicate the R value of the insulation - by almost eliminating the thermal bridging that is typical of insulating stud bays. The technique is somewhat like hanging non-structural wooden 'ladders' vertical, on edge, on typically two foot centers, to the outside of a building structure, and filling the entire cavity with insulation. The rungs of the 'ladders' are typically small rectangular plywood panels. The exterior 'ladder' chord provide a quality medium for fastening the outer rainscreen and horizontal siding.

The area around our dwelling is of rural character with deep historical roots. Vertical board and batten was relatively common in by-gone times, particularly for farm out-buildings. We wanted to quietly fit into the neighborhood. Using a variant of the 'Larsen' technique with board and batten requires strapping the 'Larsen' frames horizontally. Our thermal simulation modeling suggested that an overall R for the wall assembly should optimally be R40. By selecting urethane foam, issues with dew point, frost and mold could be nearly eliminated, and the depth of insulation could be halved, which in turn enabled elimination of the inner 'ladder' chord. We chose 2 x 4 SPF studs as the vertical chord due to availability and hopefully, reasonable straightness. The studs were mounted on blocking nailed to the masonry walls to reduce the thermal bridging (achieving much like the rungs of the 'Larsen' truss). Cedar was chosen for the blocking and strapping due to its better mildew resistance (potentially arising from both the 'rising damp' of the inner masonry walls and infiltration through the outer rainscreen. Custom milling of cedar from our little woodlot enabled the use of conventional nails, achieving a 7 ½" insulation cavity. Using nominal 2 by 2 framing with the stud would have produced a 6 ½" cavity (a slightly inferior R value), and such strapping is somewhat flimsy for the support of solid wood siding.

In unit masonry construction, it is not uncommon to use solid timber buck frames to support windows and doors. For a typical wall, the buck frame might be 7 ½" to 11" wide. When a 'Larsen' truss is used, standard framing is not adequate. In our case, for our large southerly windows to be fully supported on the masonry, a buck frame would need to be 22" wide! All of the new window assemblies are triple pane and weigh about 500 lbs each. That's a lot of weight hanging well out from its support. The adjacent 'Larsen' truss frames are not structural, thus cannot be relied upon to contribute support. In hindsight, a better solution would have been the construction of buck frames from LVL members. To reduce thermal bridging, one could drill large holes in various areas retaining rigidity, and fill them with foam.

500 lb windows really do need to be set on proper extruded 'sill pans', tilted to drain to the exterior. When maneuvering such a heavy window into place, it is essentially impossible to not tear the critical bottom corners of site fabricated flashing. In summary, for this type of renovation, the detailing of proper window flashing and support needs to be thought out well ahead of time, and executed per the plan without deviation.



Figure 25 Deep window frames to accommodate Larsen Truss



Figure 26 Window frames from the inside

In our case, we additionally have three double sliding patio doors, plus a double 'French' in-swing main door. One of the sliders is triple pane with a large triple pane, overhead glazed transom. They are all heavy, really heavy, but that last one is a killer! In a nut-shell, the traditional buck framing method didn't work for the doors. The glass fibres imbedded in the pultruded fiberglass framing runs longitudinal – there is very little transverse strength. They need to be fully supported!

In the case of 'French' swing doors, the multi-part aluminum threshold cantilevering to the outside must be fully supported – that's another 6" further out from the wall! In the case of sliders, both the sliding screen and outer fixed door are essentially point loads on thin rails, cantilevered out from any conventionally designed buck frame. In our case, the fiberglass frames of all three sliders failed even before they were put to use. To correct the problem, three heavy, welded angle steel brackets were fabricated for each double doorway and back pinned into the poured concrete structure. Angle steel lintels were bolted across the brackets, then fiberglass stakes were used as full length shims and epoxied beneath the thresholds. The fractures in the fiberglass door frames were then epoxied. It's a fix, but others, intending to undertake an exterior insulation retrofit, are cautioned to consider the support problem and install a custom fabricated structural solution prior to installing the doors, to avoid repeating our mistakes.

There are various means to achieve this. The choices depend upon your door geometry, foundation situation, and whether termites and/or carpenter ants need consideration. We used structural steel

pinned back to an outer reinforced concrete bond beam that supports the masonry wall – but this method creates numerous thermal bridges! In new construction, many designers would extend the floor slab cantilevered outwards or consider a wide LVL buck as a doorway support. This would create a very serious thermal bridge! Eliminating the thermal bridge can be achieved by building an outer foundation wall in front of the doorways, well insulated from the inner foundation wall – but both foundation walls must be supported on one monolithic footing. That design solves the thermal bridging problem, but if the outer foundation wall is exposed to the climate, differential thermal expansion may need to be considered. Vinyl or fiberglass door frames can easily fracture long before there is movement of less than an eighth of an inch. Designing adequate support, whilst fully addressing both the thermal bridging and differential thermal expansion issues is difficult, costly and generally fraught with compromise.

Existing domestic hot water (DHW) provisions:

We have extremely hard well water. As a result, considerable precipitation of calcium and magnesium carbonates in the hot water tank is inevitable. The scaling problem is such that discussions of efficiencies of differing fuels and heater designs are irrelevant. One buys the least expensive (electrical) tank possible because it won't last long!.

Lowering the temperature of the thermostats reduces both scaling and thermal losses (ie: reduces electricity cost) somewhat. That was our first priority modification. Late in 2008 our electricity provider replaced our electro-mechanical meter with a 'smart' meter and advised that as of January 2010, rates for peak consumption would effectively double. Our basic electrical power rates are already quadrupled by bill preparation charges, transmission system levies, a massive debt servicing levy, plus taxation. Power here is now effectively 20 cents a kilowatt, doubling the cost of peak usage is outrageous - but alternatives are few. The obvious alternative is to seek ways to reduce consumption.

We monitored our hot water usage for a few weeks and decided that installing a timer on the hot water tank could be worthwhile – if we were willing to adjust our consumption habits somewhat. The timer we purchased is approved for 240-277V and has a 240V mechanical clock mechanism. The timer comes with a pair of adjustable 'on-off' cams. As the duration of the proposed peak and mid-peak hours is wide, a second set of cams may need to be ordered to provide an hour of mid-day top-up heating. We'll see next year. The timer was installed with a switch as follows.

A DPDT/center off toggle switch was mounted to the timer box. The terminals on such switches are usually arranged as two rows of three terminals. Normally there are two hot wires (ie: 240V) and a safety ground powering the tank. These wires are routed to the two centre terminals on the switch (ie: those that 'toggle'). The timer is wired as per the instructions, but a neutral white wire is also brought from the main panel into the timer box. Note that in the timer, one hot lead always powers the clock, while the other is switched by the timer switch. The lead to the clock is connected to two terminals on one side of the toggle switch. In other words, that wire powers the center toggle terminal when either up or down, but not in the center 'off' position. A wire is installed to connect between the 240V

switched by the timer to one terminal on the second row. The white neutral wire is connected to the remaining terminal on the second row. In this manner, the toggle switch selects either a full 240V or 120V or completely off.

Running the hot water tank at 120V consumes ¼ the power. The thermostats still attempt to maintain the set temperature but it will take much longer to bring the tank up to temperature. The result is a lower average water temperature over the day, so thermal losses are lower, and electricity is saved. There will be times during the day when the full temperature is achieved, so Legionella should not propagate. The 'low' ¼ power setting seems fully adequate for two people.

If we have guests, we flip the switch to 'high'. If we are away for a day or two, we set it to off. At the present time the cams on the timer are removed, so it is always on. The hi/low switch seems to save about 3kWh per day or about \$ 18.50 per month at current rates.

We have yet to determine the best operating strategy for the timer when operated in conjunction with the voltage switch. High peak rates commence January 2010.

Intended domestic hot water provisions:

An area has been reserved on the south wall (adjacent to the kitchen/den sliding patio door) for a thermal solar panel. The solar panel could be as large as about 9 feet by 9 feet. If we proceed with solar DHW, it is preferable that it take the form of a home-built installation, but that may depend upon both meeting Code requirements, and satisfying insurance underwriters. I am convinced that a well designed, quality installed, owner-built unit can be more fault resistant (if not fully fail safe) than manufactured units.

I am still considering the pros and cons of various collectors. I like the simplicity of the collector that Gary Reysa has created ([detailed elsewhere on this site](#)). I additionally like the elegance of the 'Copper Cricket' – which I believe is no longer in production (and not likely to be simple to construct). In either case, I favour a vertical, or near vertical panel – even if it must be larger - as it tends to have fewer summertime overheating issues.

I do like Gary's concept for thermal storage, a non-pressurized tank acting additionally as a heat exchanger. In our situation, our primary consideration is determining the most feasible location for the tank and how to best make it totally fail safe. In any event, it will be at least a couple of years before we tackle this job.

Solar hot air garage heater:

The new garage is 32 feet wide. The rear wall faces almost due south. There is an upstairs loft and balcony – but the wall on the lower storey was constructed solar 'ready' for an air heater. The type of garage air heater being considered is that developed by Gary Reysa and additionally [published on this site](#). Steel roof paneling has been installed on the wall for use as the collector. Between the steel

paneling and the wood framing, a layer of high temperature, high density fiberglass insulation has been installed to meet Code and insurance underwriter thermal requirements. Eventually the intention is to over glaze the steel paneling with corrugated plastic and install air manifolds.

This however is not a near term project. The entire garage and loft are totally unfinished – no insulation at all. So while the solar wall is relatively inexpensive and simple, it would be unreasonable unless completion of the finishing and insulation of the entire garage is to be undertaken.



Figure 27 Garage with provisions for solar air heating collector

Handicapped Accessibility:

The renovation of a low-to-the-ground, single storey building provided the rare opportunity to achieve a quality level of handicapped accessibility. My wife and I have noticed all too many friends are having to give up their dwellings or restrict the use of their dwellings, as health concerns make stairs a major barrier. While we did not make the dwelling fully wheelchair compliant, we did ensure that the modifications required to do so were few and minor. Our primary emphasis was ensuring accessibility for the partially dis-advantaged – as the likelihood of it being required was significantly higher.

All too often we hear people say that by building a multi-storey building, it was feasible to consider passive solar. There is no doubt that such construction tends to minimize the area of the thermal envelope, and has the opportunity to more easily flood the interior with passive solar. As a result, numerous people have come to think a passive solar ‘ranch’ is an oxymoron.

Across North America there are numerous existing single storey ranch homes. While almost all are expensive to heat, the very nature of a single storey dwelling is very attractive to both the elderly and

partial accessibility dis-advantaged. I would like to suggest that the technologies and techniques of air sealing, insulation, and windows have come a long way over the last forty years. Ranch homes need not be a heating nightmare. It is not an inexpensive proposition, but a deep energy renovation for many of these dwellings might not only just be feasible – but ideal for the elderly, especially if efforts are made to reorganize the interiors into small multiple units. Let's not forget that it's the elderly who tend to be the least likely to afford crushing energy costs.

Should one wish to consider a deep energy retrofit for a conventional, low mass, stick frame 'ranch' home, if a wide southerly sun exposure exists, one might consider the concept of a rather large sun-space (solarium) inside the dwelling, with a solar closet and thermal store, inside the sun-space. With a little design effort, one just might achieve no cost, zero energy space heating - even in a cold climate!

Final Thoughts and Acknowledgements

This paper is but a concise summary of much research and analysis. The analysis and design of this heating system was extensively integrated into nearly all aspects of the design and construction of the renovation. It has been an iterative process where various tools have been used appropriate to the various levels of design detailing. Major effort was made to optimize numerous aspects of the design, cost and thermal performance.

We initiated the design process with the expectation that contemporary notions of energy efficient design features and equipment would prove to be sound. There were many surprising results. Quite frankly, for this specific renovation, numerous higher profile, commercial products and equipment simply under-perform various low tech. alternatives. Others, investigating the feasibility of renovations or new housing designs are encouraged to thoroughly research their specific situation, - they may well have similar conclusions! They too may find that numerous products are grossly overpriced – vendors justifying this on the basis of potential long term savings (calculated under ideal or surreal conditions), and quickly pointing to governmental subsidies and tax credits. Life-cycle costing tends to paint a more truthful picture. Government incentives seem to significantly involve lobby group manipulation. For example, there are now incentives for the purchase of new 'central' heating systems, air conditioners, dishwashers – even hot tubs and spas - but nothing if one improves efficiency to no longer need or desire them! There are government incentives to contract for 'proprietary building systems' and hire various 'certified' trades people, but it was our observation that their interest seemed more directed to sales of high margin installations, and that their knowledge of performance specifications appeared limited to the dubious printed marketing on the box! There were no incentive programs active at project initiation. As this renovation would be undertaken by the owners with 100% after tax income – significant efforts were made to optimize various building systems.

To all those considering a major energy efficient renovation, be tenacious in your research, complete the detailing of your plans and all financing in advance of setting the meter in motion. Initiate construction timing such that exterior tasks may easily be completed prior to the onset of winter. Exterior wintertime construction is doubly expensive and seldom satisfactory. There will be hiccups, so be on site to help resolve them, you will need faith and perseverance – but the product is pure satisfaction!

Go for it!

I wish to thank my wife, Sue, for her support and patience throughout this project. Together we are indebted to the long standing inspiration of Norman Saunders, William Shurcliff, and Amory Lovins; and to the expertise, patience and consideration provided by Stephen Thwaites, P.Eng., Chief Engineer / Thermotech Fibreglass, Ottawa, (world class window science) and Norbert Senf / Masonry Stove Builders, Shawville, Que., (pre-eminent Canadian fireplace consultant). We also wish to thank the numerous recent contributors to the 'Greenbuilding' web list. We are especially thankful to the following superbly talented people for sharing their experience and wisdom: Professor John Straube, George J. Nesbitt, Keith Winston, Rob Tom, Nick Pine, Gary Reysa, Shawna Henderson, Laren Corie, and Corwyn. In regard to this web list, we regret that we were but 'lurkers' of the digest, and could not actively participate in on-going discussions - our online status being severely restricted to a weekly review of emails from distant hot spot (coffee shops).

The attached Excel 2000 spreadsheet provides details of both the predicted thermal modeling performance and the first winter's actual performance. The spreadsheet has evolved over a three and a half year period - details added as the design and analysis proceeded from preliminary design, right through project completion. As a result, the spreadsheet is very specific to this one particular project, and not easily adapted to other forms of dwelling. That said, the author is confident that the reader could use this spreadsheet as a base for creating something similar for themselves. This spreadsheet has its limitations, and may well still have errors or omissions. Note that the author cannot accept any liabilities what-so-ever from its use.

Best wishes,

Gordon Scale, P.Eng. (retired), Adolphustown, Ontario, Canada
Gordon will answer email questions on the project at: schoolhouse@live.ca



Figure 28 Sue and Gordy