575: Low energy dwelling: Is it possible to build with low embodied energy and have a passive solar House?

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Abstract

The term low energy dwelling normally refers to the energy required to run a building while it is in use. It would be more useful, however, to look at the use of energy throughout the whole lifecycle of a building. The convention is that passive solar houses normally require thermally heavyweight elements to store and buffer incoming solar energy. Heavyweight materials however tend to have high embodied energy

The Hill of Bandodle, a replacement farm house, was designed with the intention of it using low energy in the construction, use, reuse, remanufacture and recycle stages. This meant, essentially, that materials had to be either thermally lightweight, be very locally sourced or involve little to no processing; preferably all three. Construction methods needed to anticipate the eventual deconstruction and reuse. Thermal comfort needed to be achieved by high levels of insulation, warm surfaces, low infiltration with orientation and design to maximise winter solar gain and minimise summer over heating.
The paper looks at the methodology of construction and choice of materials and considers in the light of the lessons learned if other approaches could have been made in some cases.

Key words; Passive embodied energy, life cycle, detailing.

1. Introduction

Passive low energy standards all relate to energy used during occupation rather than whole life cycle costs for the building including co2 emissions.(1) Whole life Cycle Analysis of buildings looks at the environmental impacts, including global warming potential and water use, from the winning of materials, process, transport and construction through the use and maintenance of a building to its ultimate demolition and hopefully reuse of components. This is sometimes referred to as cradle to grave or better cradle to cradle.
Passive solar housing conventionally requires the use of thermally heavyweight materials to buffer internal solar gains by absorption contributing to heating later when temperatures fall or cooling through night time flushing. It has therefore been argued that reductions in carbon emissions through the use of passive solar heating are more than offset by the use of these heavyweight materials However the making and use of cement emits between 5 and 7% of the worlds carbon emissions (2, 3) together with many other adverse environmental impacts. Nearly all other thermally heavyweight materials are also energy hungry if not quite so intensive as that of cement. Research carried out in Denmark examined three common house types, conventional terrace, solar orientated and 'optimised solar' with large south facing windows .They examined whole life cycle environmental impacts of both heavyweight and lightweight examples of these and found that;
"While the thermal mass in the heavyweight house reduces the environmental impact from the heating demand, the environmental impact from these heavy materials is large enough to wipe out the supposed advantage compared with the lightweight house."(4)..
This paper looks at some of the results of an attempt to construct a dwelling that was low energy in use while also using materials and construction methods with a low embodied energy and environmental impact.

2. Site and Climate

The croft is 250 metres above sea level towards the top of a North facing hill in rural Aberdeenshire. Aberdeenshire Climate tends to be on the cold but dry side. The sun angle is from 10 degrees midwinter to 67 degrees midsummer. The site is sheltered to the South by the remains of the hill and is exposed to the West and North West from where the cold and snow laden wind whistle across from the Atlantic. Windy days are the norm. Trees and rising ground provide some shelter to the East otherwise at the time of construction the site was open fields. There are fine views to East and West and to the North they are exceptional. This is, of course not an ideal starting point for a classic passive solar dwelling but the dwelling replaces the original croft house and planning constraints meant that moving the new house far from the original was not allowed.

Figure 1 winter view North

3. Design

The original croft house is a long low building dug into its site with few windows. This was intelligent and traditional for its time, available technology and context but meant that even in the summer artificial light was needed to read inside. It also meant that each room needed a separate heat source although some heat did percolate upstairs. The open fire in the living room was enjoyed by ourselves and visitors alike. There were no views but there was close contact with the garden.

3.1 Design Aims

- Low embodied energy.
- Local materials. (both for energy and social reasons)
- Materials with low environmental impact during full lifecycle
- A light, sunny house,
- Easy to heat, preferably with wood.
- Passive use of solar energy
- Healthy materials.
- Designed for deconstruction and easy access for repairs and modification.
- Barrier free over most of the ground floor.
- Close association with outside
- Mostly open plan but with some personal areas

3.2 Design Strategy

The strategy was to design a highly insulated envelope around a compact plan with buffering to the North. Overhanging eaves would control summer gains but allow deep penetration from the winter sun with midwinter angle. A sunspace would provide passive heating together with a pleasant place to sit during sunny but cool days and a buffer to some of the extensive glazing. Further thermal buffering would be provided by a thermal store below the sunspace. Further cooling if required would be by cross ventilation and opening roof lights in the ceiling the of Sun Space. Shutters would provide night time insulation to the windows. Technical detailing aimed to provide a breathing wall, minimal material use with access to service areas and provision for non-destructive renewal. The minimal material use had, perhaps, the greatest impact on subsequent performance.

3 Layout

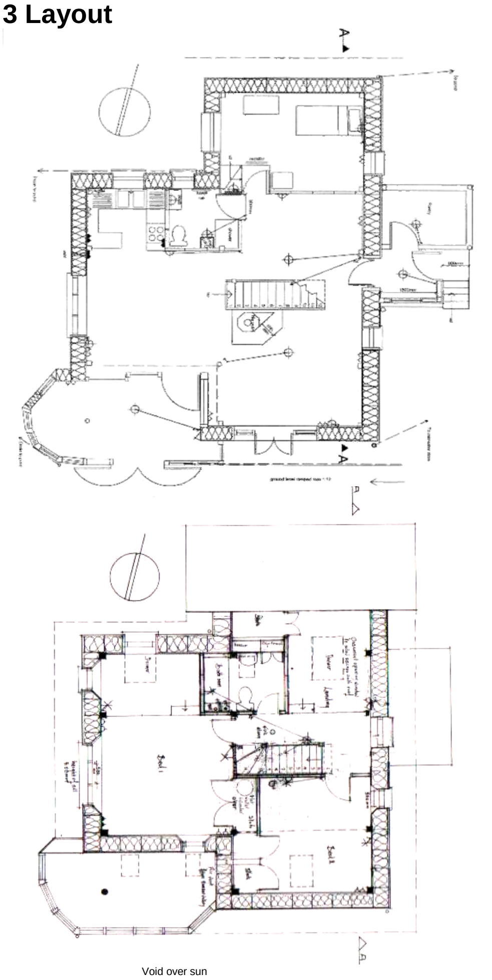

Figure 2 Ground and 1st Floor plans

The new house is more compact on plan than the cottage. Bathrooms, studies and the spare room provide buffering to the North. the spare room being used mostly used during the summer months. The open plan ground floor wraps around the masonry stove. Large glazed doors open onto a double height unheated sun-space. The doors can be used to control heat gains and losses associated with this space. This strategy is working well but requires active management. There was also going to be a pantry off the kitchen/living area to buffer the North West corner but the family demanded the view instead. This is certainly a special view but has made the kitchen area cold especially when Northerlies are blowing and obviously impacts on the whole house. The main bedroom upstairs can also be shut off when there are cold Westerlies allowing the living core to be kept warmer. The door can be then be opened in the evening before bed when the room heats up surprisingly quickly. The pantry has now moved to the uninsulated and unheated porch area where it has almost done away with the need for a fridge in the winter. Convenience requires that there is a small fridge in the kitchen area

4. Construction.

4.1Design for Deconstruction

The principle of design for deconstruction means that elements of the building can be taken apart without damage for maintenance, alteration and ultimate removal at the end of use. The easy removal and reuse of elements such as flooring, linings and even the main frame reduces waste and resource use obviously lowering the lifecycle carbon footprint.

4.2 Frame

The principle was a main oak pegged larch frame supported on concrete block piers. Around the outside of this is wrapped the envelope. The idea was to provide continuity of insulation and wind resisting breather membrane. The piers were to minimise the use of concrete, to allow for the slope of the site and to provide lots of ventilation below the house to remove the risk of radon seepage into the building. It also allows access to the timber structure under the house for examination and any maintenance. The oak pegs can be removed should the building no longer wanted on this site allowing the frame to be reused.
The piers are constructed of bonded dense concrete blocks. These were manufactured ten miles away with cement which came from Dundee. The fuel for the kilns was old tyres. Far from ideal but contributing the lowest carbon emissions we could manage. We had hoped to make the founds from field stones, of which we have many, together with lime mortar but this was vetoed by Building Control.

4.3 Roof

The roof is made up of 350mm ladder trussed purlins constructed on site, spanning across the principle rafters of the frame. These overhang the East and West gables while the principle rafters overhang the North and South walls by a meter providing shading against summer sun and some protection to the timber rain screen cladding. Warmcell insulation was blown between the internal t&g linings and polythene vapour check and the diagonal larch sarking boards overlaid with 'Roofshield' finish is sandstone 'slates'.
Theoretical 'u' value 0.16W/m2K

4.4 Walls

The walls are also 350 ladder trusses with breather membrane on the outside and kraft paper on the inside providing a cavity for the insulation between and around the trusses. The rainscreen is larch, laid vertical board on board these are fixed to diagonal 50x50m battens which provide shear resistance, ventilation and drainage. The alternative would have been battens and counter battens on some kind of sheathing. This would have increased material usage by approximately 90 square metres. Internally horizontal 38mm battens provide a service run behind the Douglas fir t&g linings.
Theoretical 'u'value 0.15 W/m2K
All boards are face nailed allowing relatively easy removal without breaking the tongues. Skirting boards are screwed with the wiring and pipes behind and. where wiring runs vertically to switches or lights there are screwed linings to allow for access for repair or alteration.

4.5Floors

The ground floor consists of joists laid across the principle beams with a hanging frame to provide 400mm of insulation supported by 'Frameshield' and chicken wire. The insulation thus runs between and below the joists reducing thermal bridging. Theoretical 'u' value 0.23 W/m3K
The first floor also consists of joists across the beams but here subsoil from the hole dug for the water cistern was dried and laid between the joist on 'Heraklith' Magnasite boards to provide sound deafening and some thermal weight. Both the ground and first floors are finished in t&g Douglas fir boards.
In all locations where there are cable or pipe runs boards and linings have been screwed to avoid future damage when removal becomes necessary. All boarding is face nailed with screwed boards over service runs as with the timber linings which should lead to easy access and reuse.

4.6 Thermal store

The thermal store of the sun space is 12cubic meters and is made up of the waste glass from three families over two years, slate waste from the roofing, the blocks from an old extension on the cottage, field stones from the croft and finished off with clay/sand subsoil a lime-soil screed and the sandstone 'slates' which were left over from the roofing..

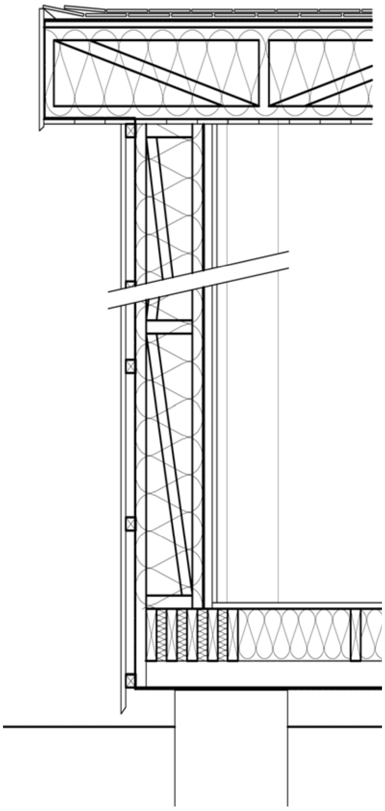

Figure 3; Section through West wall.

4.6 Windows
For the new dwelling we were keen to maintain the garden contact and also introduce lots of light and sunshine. We have therefore installed lots of windows. Most of these are to the South but there are some large ones to the West. There are 3 small ones to the sheltered East along with a large gable window and small North windows in the buffering study areas and bathrooms and the kitchen mentioned above. Approximately 42 percent of the elevations are window. This is well above that recommended for maximum energy efficiency. However that was not the only aim. From mid January until mid-November there is potentially sun in the living area all day. Even on mid winters day there is an hour. Psychologically this is more important to this family than high internal temperatures however after only an hour of sun the internal temp can rise at least 3 or 4 degrees.
60% of the south elevation windows are the walls of the enclosed sun space. This area contains a passive thermal store. The internal air temperature on a sunny day has reached 27 degrees at the beginning of February. This, by opening the intervening door, heats the living area. If the sun is not shining the space is about 4 degrees C above external temperatures which will reduce heat losses if not actually contribute to heat gains.

Windows to the house are all double glazed with soft low 'e', high performance windows from Scandinavia. 'u' values are between 1.8 and 1.4 depending on size; Not high by to-day's standard but good in 2002 when they were ordered.
Glazing to the unheated sunspace walls is double glazed plain float to maximize the solar gain and daylight.

4.8 Construction Plant
The choice of construction meant that the only plant used was a crane for erecting the frame for 2 days and a concrete mixer for another 1.5 equivalent days.

5 Sources of Materials

5.1 Timber
The larch frame came from Aberfoyle close to where the frame was made. It was not possible to find a local firm to make a timber pegged frame. One firm who did show interest backed off because of their engineer's misgivings. The remainder of the larch came from the Ballogie estate, some 10 miles away and Clashendarroch forest, 20 miles from the site. This was milled by a diversifying farmer who lives at the edge of the forest and who transported the timber in reasonable loads to site. Much of the timber for the ladder trusses was recycled; sourced from 'Recyclability' an organization sourcing and its materials from the oil industry by physically and mentally challenged adults The Douglas fir flooring and linings also came from this source. The Douglas fir for all the joists and much of the trusses came from . Unfortunately this relationship broke down.10 miles away and was milled by a small mill only three miles away It was the most sustainable and cheapest source as we bought the timber direct and paid the mill for the labour.

5.2 Insulation
'Warmcell' was blown into the roof cavity. Although the contractor came from Moray the material comes all the way from Wales which is not entirely satisfactory. It suited the detail but maybe there should have been another way to do this. The remainder of the insulation was wool. We had intended to use untreated sheep's fleeces from a local farm. Research has shown they have conductivity only slightly higher than mineral fibre at .04w/mK. Unfortunately only enough were available to do the floor of the spare room and the wall of the sun space. The rest of the walls and floors were insulated with 'shoddy' (cuttings and ends) from the wool mills at Elgin. This was destined for Yorkshire and recycling. Instead they scoured the mineral oil from it and transported it compressed in 40kg bags. The wool then had to fluffed up, stuffed into the cavity in layers and sprayed with borax insecticide. This is certainly low energy but

very labour intensive and threatened at times to hold up progress. It would be easier enough to reuse although disposal would be harder due to the presence of the borax.

5.3 Roof Finish

The roof finish was originally to be planted sedums on an epdm base. Always unhappy about the ecological and energy credentials of the membrane, when we could only get a maximum of a 10 year guarantee for £17000 of work we had a rethink. Recently a new quarry had opened in Halkirk, Caithness and Caithness Slate Products were keen to help. This sandstone 'slate', unlike some others from the area weathers down to a multicoloured finish and from a distance could even resemble the sedums. This kept the planners happy. Stone quarrying is not low energy although at this quarry it is remarkably low tec with the large slabs being lifted by a fork lift and split from the face by a man and two hammers. Caithness is not very local but it is closer than Spain or Wales. It is a very long lasting product and can easily be reused. Overall lifecycle energy costs are quite low.

5.5 Doors

All doors except the French windows are from another dwelling. They did require some resizing and this probably meant that they were marginally more expensive than B&Q because of the labour involved. They were sanded and repainted rather stripped. Research by the Bedzed development shows that overall this is a large saving on embodied energy. [5] They are also much better quality.

6. Heating, ventilation and thermal comfort

We wanted to try and heat the building from one heat source that would also provide a focal point as the open fire in the cottage had done but more efficiently. I was keen that should be wood fired rather than diesel or propane. It should be possible for the croft to be self sufficient in coppiced wood within about twelve years. We decided on a masonry stove. The idea is that a short, very hot firing which heats a large mass of masonry via convoluted flues will then heat the space gently long after the fire has gone out and the stove shut down. An extra water heating element was added both to heat three small radiators in the bathrooms and the spare bedroom. This does not work well. Bathroom ventilation, in line with our requirement for passive technology, was provided by two standard 'Passive vents' controlled by humidistat. They are terminated at the ridge as required by the manufacturers. Since the humidistat opens at 40% RH and internal RH rarely falls below that they are effectively open a bit all the time. This would seem to obviate the need for the window trickle vents that Building Control required us to have.

The house had a theoretical need of 3.5Kw of heating assuming 0.75 air changes per hour. However Bruce Taylor of RGU ascertained that the rates were more in the region of 1.5ac/hr at 50 pascals. The stove is rated at 4Kw. On relatively calm, winter days the house has a comfortable air temperature of about 16 degrees even when external temperatures are well below zero.Surface temperatures are at least 2 degrees higher than this. The higher surface temperatures can be attributed to the soil in the ceiling and timber linings This is at the low end of the winter comfort zone but as a family it suits us and results in lower heat losses. The higher surface temperatures also give a higher effective temperature than the recorded air temperatures. On sunny winter days internal temperatures can rise to 20 degrees C without the use of the stove. On cold days with a northerly wind, however, the stove is not always heating the building satisfactorily. This is probably due to increased ventilation rates within the building due to;

- The lack of buffering from the NW corner.
- Ridge mounted passive vents.
- Drafts through the laps in the membranes. In retrospect they should have been taped. But this was difficult due to the lack of a solid backing in the form of a sheathing board. The laps are large at 200mm but obviously this is not adequate to prevent infiltration. due to pressure differentials opening up the laps..
- Too much ventilation over the surface of the breather membrane behind the cladding pulling heat out of the insulation. At the time of construction 50mm of ventilation and drainage gap was the recommendation. Given the drying effect of the wind at this location I think this could be reduced.
- Too much ventilation under the house. The wind speeds have been reduced since construction by the increasing height and thickness of a native hedge planted to the west of the building together with dry stone walls.

Water heating is via a direct solar panel with the pump run by a PV panel. This supplies almost all the hot water in the summer and on sunny winter days. The stove partially heats the tap water at present and hardly heats the radiators at all. This needs resolving. During the winter we have been using the 3KW immersion heater for about ½ hour/ day Internal temperatures have never risen above 24 degrees C even when external temperatures have been at 28 degrees C in the shade. Shutting off the sunspace from the house helps to maintain the cooler temperatures by isolating the warm surface of the thermal store.

8. Energy Use.

The house has only been occupied since June 2005 and therefore all data is still somewhat raw.

Comparison of electricity consumption between June and December in the original croft house and the same period in the new house shows a very large reduction: The cottage used averaged over three years 6,400 Kwh giving a usage of 36kwh/m2/yr, together with about 2 tonne coal and some wood. The new house averaged over 3 years uses 27kwh/m2/yr or a total of 3,280 kWh. This contributes between 1410 Kg and 3182 Kg of CO_2 depending on the conversion figures used. This figure was extremely hard to ascertain our own supplier resorting to Google when asked for a figure! Approximately 1.5tons of wood is burned per year giving an energy output equivalent of 5160 KWh. At a emissions rate of .025Kg /KWh this gives total output of 129 Kg. gross.(9) Theoretically wood fuel is carbon neutral as growing timber absorbs as much co2 whilst growing as that emitted while burning but some energy is obviously required for transport and processing. Much of our timber is local or from the farm itself so the figure might be lower. In both houses the same old electric cooker, electric kettle, washing machine, fridge and freezer are being used but the new house is larger in both plan and surface area, is more exposed and although not always at optimum comfort levels, nevertheless has higher thermal comfort levels than the cottage.

The higher than expected fuel usage for heating is largely down the very exposed and windy site and the less than optimal wall detail. The low electricity usage is partially attributable to high daylight levels meaning very low usage of artificial light during daylight hours' and no electricity use for space heating beyond the accidental gains from the cooker.

9. Conclusion

The use of locally grown timber from managed forests for the majority of the construction, minimal cement and reuse of onsite 'waste' such as the glass, soil and demolished kitchen, for the small amount of thermal weight, has meant a relatively low embodied energy for the new house.

For a small extra material usage lower ventilation rates could have been achieved by using a sheathing board. This would have probably led to lower fuel usage.

The sun space with its thermal store works well but automated temperature sensitive fan between that and the main space would optimise its ability to heat the house when no one is around to open and shut doors. The buffering of the pantry to the North would have made the whole house easier to heat on windy days. Dwellings have to balance a number of requirements however.

200metres above sea level is not an ideal location to build a passive house. But we knew that anyway. The farm needed a house though.

Electricity usage is well below Passiv Haus standards but space heating at 43 Kwh/m2/yr equivalent [6] is well above, however the fuel is locally sourced timber and is renewable and nearly carbon neutral. Including this element total energy usage is still only 71KWh/m2/yr. Therefore, in the case of this house, in this location it has been possible to construct a dwelling that is relatively low energy in use and construction throughout its lifecycle.

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