Zero energy housing retrofit

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ABSTRACT: In the face of the two key sustainability issues of global warming and depletion of non-renewable sources of energy, it has proven possible, and even relatively simple, to construct new houses that require little or no non-renewable energy for their operation. However, existing dwellings represent a much more difficult problem. The first difficulty lies in the issue of scale, for example in New Zealand about 20,000 new dwellings are constructed each year, but the existing housing stock comprises around a million units. It would take fifty years for improved new houses to replace the existing ones, and the demolition of the existing dwellings would represent a considerable waste of resources. The second difficulty is the one of technology. It is possible to apply a range of technologies to reduce the energy demand of existing buildings. These include things like increased insulation, improved window glazing, solar water heating, improved lights and low energy appliances. The installation of some of these technologies, particularly those that involve alterations to he building fabric, can be very disruptive in an existing occupied home. In the light of these difficulties, the paper will discuss an alternative approach to achieving the zero energy retrofit of an existing house in New Zealand through the use of a roof-mounted photovoltaic system combined with non-invasive energy improvements. The paper gives detailed costings and measured performance data for the installation and will attempt to draw some policy conclusions.

Keywords: Renewable energy, existing houses

1. INTRODUCTION

Very few houses are ideal from the viewpoint of trying to make more use of renewable energy. Even fewer houses are also ideal in terms of their location, price and the other attributes that prospective buyers consider, and often the right house will not be ideal for retrofitting to reduce the energy demand. Thus, an appropriate strategy has to be adopted for each individual dwelling. Two houses on Waiheke Island, in the Hauraki Gulf, 35 minutes by fast ferry from the Auckland CBD, will be considered in this paper.

2. 20 KARAKA ROAD

This 91m^2 three bedroom house was designed and built by a builder built six years ago, and it meets the requirements of the NZ Building Code. This gave it the following insulation levels, (with the form of construction given in parentheses). Walls, R1.5 (90 mm x 45 mm timber frame with insulation between the studs); Roof, R1.9 (fibreglass blanket laid between the bottom chords of the trussed rafter roof); Floor, R1.3 (timber joists and particle board flooring, with foil faced sisalkraft paper draped between the joists under the flooring, with 100mm sag at the centre. The floor was finished with ceramic tiles to kitchen, dining and living area, and bathroom and separate WC (m^2) and carpet to bedrooms (m^2)); Windows, R0.18 (single glazed in thermally-unbroken aluminium frames). This type of construction is typical of recently built houses throughout New Zealand.

Modelling the house using the ALF3 software developed in New Zealand for New Zealand conditions (Stoecklein and Bassett, 1998) suggested it would use approximately 5,000 kWh per annum for space heating. The average end energy use in NZ households is 11,060 kWh for all fuels used, the majority being electricity. (BRANZ, 2004) This is broken down as follows.

Table 1: Average Energy Use in New Zealand Houses

Home heating	30%	3318 kWh
Stove	6%	664 kWh
Water heating	29%	3207 kWh
Other appliances including lights	35%	3871 kWh

The larger energy requirement for space heating derived from modelling is not unexpected. Recent research has shown that houses in New Zealand are often under heated compared to houses in Europe, Scandinavia and North America in terms of indoor dry bulb temperature. (Isaacs et al 2005) This lack of heating means the biggest single household energy use in the Auckland area, where the climate is milder, is for water heating (ibid.) Energy for this usually comes from use of an electric immersion heater in an insulated cylinder, and in the case of the Karaka

Road house this is located in a cupboard in the central passage through the house. The house was purchased without any white goods and all the light fittings, although fitted with incandescent bulbs, could take CFLs. To complete the picture, Waiheke Island has no reticulated water and sewerage so all rainwater water is collected off the roof, screened and stored in a 25,000 litre plastic tank. Sewage, including all grey water, goes to s septic tank and thence to a drainage field in the bush to the rear of the house. The house sits on the road edge of a classic quarter acre section, of which at least a third is untouched bush.

Because the house was relatively new all of the finishes were in very good condition, so non-invasive upgrading to reduce energy use was essential. The house is set down from the road on a sloping site, which means the end furthest from the road is a storey up, and so has a garage underneath at that point. The roof is simple, gable ended, and equal pitch, with one long side facing due north with minimal overshading. This suggested the following should be done, presented below in order of ease of implementation, which also equates to order of cost.

- Fitting low energy lights and appliances (a Gram low energy fridge/freezer and a Bosch washing machine)
- Upgrading roof insulation to R4.8
- Removing the foil under the floor and providing a full fill insulation between the joists with plywood lining under to give R4.8
- Fitting an internal shelf above all window heads and thick lined drapes extending to the floor, or constructing insulated shutters to some windows to give a 24 hour average of R 1.5
- Installing a solar water heater on the north facing roof aiming to reduce hot water load by 70% to 1000 kWh/annum
- Installing photovoltaic (pv) panels on the north facing roof

The first stage, including laundering in cold water using cold water detergent, would reduce the demand for lights and appliances to an estimated 2000kWh/annum. The second two strategies would reduce the space heating load of the building to 2000kWh/annum. This suggested that in terms of impact the solar water heater might be the most effective thing to do, as it would be expected to reduce demand by more than 2000 kWh. However, because the house was new the hot water cylinder was well insulated and not in need of replacement but at 180 litres it was too small to act as fully effective storage for a solar hot water system, where a 300 litre cylinder would be preferable. To install a bigger cylinder would have meant major alteration to the cupboard in the passage, with subsequent damage to the finishes. This work might be better left until the paintwork, and possibly the carpet, needed renewing in a few years time. For these reasons it was decided to do the apparently least desirable energy retrofit first, namely the installation of photovoltaic panels. Because the house was similar in area, number of bedrooms and type as the median New Zealand house it was decided to try to install a pv system that would generate over the year sufficient power to deal with all the electrical needs of the house, assuming that part of the water heating was done by solar energy.

The roof of the house was powder coated Coloursteel corrugated roofing, a standard for NZ houses, with a 60 year life although painting would be required at some point during this. To ensure a long life it was decided to paint the north facing roof slope (using roofing paint that is approved for drinking water collection) before installing the panels. Aluminium bearers were installed on the roof to carry the panels. The Z section bearers have aluminium fixing plates welded to the base, and these sit on the roof with a plastic separating membrane under each plate. The plates are fixed through the roof into the wooden purlins with plastic-sleeved bolts. The bolts and the plastic membrane are used to reduce the chance of electrolytic corrosion between the steel roof and the aluminium. The bearers are 150 mm deep to maximise the gap between the panels and the roof surface so as to allow the greatest possible airflow under the panels to keep them cool in operation. The panels were fastened to horizontal aluminium rails fixed to the bearers and wired separately, so that any overshadowing from future growth of trees around the site would only knock out the panels involved, not the whole array.

The system is rated at 4.4 kW peak and consists of 36 panels (each 120 Watts at 12 volts DC) in two strings running the length of the roof, one at the top and one at the bottom to allow for better air flow beneath the panels. The estimated generation was 5000 kWh/annum. This would cover the reduced lights, appliances and space heating load and the residual load once the solar water heater was installed. The system would thus represent a full renewable energy system for a standard house with the use of minimal and non-invasive energy conservation technologies.

The photovoltaic panels are connected to the electricity grid through a pair of German SMA 'Sunny Boy' inverters, each rated at 2.2 kW. A data logger records the performance of the system in operation. The inverters are installed on the wall of the garage beneath the house. Each inverter serves a string of 18 solar panels and converts the solar energy from 220 Volts DC to 230 Volts AC.

Protocols had to be developed with the line company and with the company that supplied electricity. In the Karaka Road installation the electricity generated by the pv array first supplies the house and any generation over the instantaneous demand is exported to the grid. Electricity can be drawn back from the grid up to the amount put into the grid for any month under an arrangement described by the power company as "net billing". Net billing is not the same as net metering, in which the electricity meter runs in reverse when power is fed back to the grid. With net billing the price paid by the power company for the solar energy fed into the grid is lower than the cost of the electricity purchased for the house. With net metering the price is equal in both directions, as the meter runs in both directions. Net metering has the additional advantage that it is not limited to a monthly calculation of import and export, so an annual energy balance can be achieved between import and export of power. Table 2 shows the charging arrangements for the installation at 20 Karaka Road.

Table 2: Electricity charges at 20 Karaka Road (31 Dec 05 to 2 Feb 06)

household electricity consumption	13.37 cents/kWh
generation up to monthly household demand	8.45 cents/kWh
generation in excess of monthly demand	3.50 cents/kWh

That part of the solar electricity that is used directly in the home offsets the full cost of imported electricity, but the remainder suffers financial penalties.

In the first year of operation the pv system at 20 Karaka Road generated 5300 kWh/annum. This covered the energy requirements of the house which for various unforeseen reasons had only one occupant. Table 3 shows the costs of the system, and how they were made up.

Table 3: Photovoltaic system costs at 20 Karaka Road

Component	Cost (NZ$)	% of total
PV panels	*47,992.50*	*58.7%*
Inverters	*13,102.21*	*16.0%*
Fixings	1,311.95	
Aluminium rails	1,701.53	
Welding	1,464.68	
Fixings total	*4,478.16*	*5.5%*
Electrician	*16,230.79*	*19.8%*
Total	81,803.66	

The installation is made up of 36 panels each rated at 120 Watts, giving a total installed capacity of 4320 Watts, at a cost of 18.94 cents per Watt, or approx $19,000 per kW installed. Over the lifetime of the system, assuming that it lasts for 40 years, and produces 5,000 kWh per year, the electricity cost based on the capital cost of the system is 41 cents per kWh. Current price of electricity at 20 Karaka Road (as of March 2006) is 13.37 cents per kWh.

The cost of the photovoltaic panels at $81,804 installed does not represent an economic return on money. Moreover, there are no grants of any sort towards such installations in NZ. The house had originally been fitted out for family members but this arrangement fell through so it was then rented as a commercial enterprise. This meant the cost of the photovoltaic system could be written down against tax, something not available to the ordinary householder. This would seem to be the single biggest tax break the government could offer if it wishes to encourage households to install renewable energy systems to help meet Kyoto commitments. The same system would need to apply to all renewable technologies, including solar water heaters.

3. 2 HAURAKI ROAD

This house provides a contrast with the Karaka Road house as it is much older, having been built some 18 years ago, and was in need of some repair and renovation. The house has a total floor area of 196 m^2, and comprises a central section on three storeys, with single storey bedroom wings on either side of this. The western wing contains the main bedroom and bathroom, and the eastern wing comprises two further bedrooms and a bathroom. The two north facing bedrooms open into conservatories on their north elevations. From the room built in the roof of the main part of the house it was possible to determine that the ceiling of the room in the roof had been insulated with fibreglass between the joists. There was also insulation in the flat ceiling above one of the bedrooms and insulation material in the other that had never been properly installed. This suggested that there was insulation in the walls, which turned out to be correct when the lining was stripped off one of the bathrooms in need of alteration. The lower floor consisted of a single space with a concrete slab on ground with concrete block walls to retain the ground with timber frame above. Where the joisted floor was exposed, foil faced sisalkraft insulation draped between the joist had been used. The house was designed so that each of the three parts (the centre and the two wings) had a gable facing north, which meant all habitable rooms apart from one small bedroom, received solar gain from this direction. The house, although lightweight, appeared to be well set up for passive solar design, laid out with the rooms along an east-west axis with the large majority of the glazing on the north elevation. However, the gabled roof design meant there was no large expanse of roof facing the sun.

Earlier work on another converted house on Waiheke Island had shown that without any mass other than that provided by furniture and books, rooms with double the insulation of the NZ Building Code could maintain a 7°C difference above ambient with no heating. Given that the lowest winter temperature at night on Waiheke is 7°C, this effectively means no need for space heating in a light weight house (Vale and Vale, 2001). Apart from installing an energy saving fridge/freezer and washing machine and putting CFLs in all fittings, it was decided to exploit the solar gain and upgrade the windows, many of which were in poor order, by replacing them with aluminium faced timber frame windows glazed with low-e double glazing units. This both improved the appearance and use of the house as well as reducing energy demand. The flat areas of ceiling were insulated to R4.5, as was the exposed timber floor, using the same method as proposed for the Karaka Road house. In some places single glazing was left where it formed the entrance to the existing single glazed conservatories. This leaves a few windows that need upgrading using some form of secondary double glazing. As no such system is commonly available in NZ this is still being explored.

The areas of directly north-facing roof were limited to the two very shallow pitched (5 degrees) conservatory roofs. These were made of solid aluminium/insulation sandwich panels, rather than glazed, a fortunate decision as otherwise the spaces would suffer severe over-heating in summer. The roof of the conservatory at the western end of the house was chosen as the location for a solar water heater and 6m^2 of Beasley panels (copper with selective coating, single glazed) were installed. The need to upgrade all the plumbing in the house allowed a new 315 litre insulated solar hot water cylinder to be installed under the house, with pumped connection to the solar panels. The cylinder was fitted with an immersion heater but no automatic switch. Instead there is a read out of the water temperature in the main bedroom, and a relay switch that can be pressed to turn on the immersion heater to top up the cylinder temperature. When the water reaches the set temperature the immersion heater cuts out, and does not come on again until the switch is pressed again. This allows much greater user control off the system. In the first year of operation the switch was used only used 12 times, and only when the water temperature was below 60^{o}C. This means solar is supplying well over 90% of hot water demand. Interestingly, the fact that the solar panels are at a non-optimum tilt of 5 degrees seems to have had little effect on performance. On a moderately sunny day in winter the water temperature reaches 65^{o}C. The panels were deliberately fitted on the existing slope, to avoid the “temporary” look that results from having solar panels bracketed off a shallow-pitched roof.

Electricity consumption for the year of 2005, after the installation of the solar hot water system was 3,200 kWh. Of this consumption, about 2,000 kWh was for lights and appliances, and the remaining 1,200 kWh was for space heating and hot water top-up. This gives an energy demand of 16 kWh/m^2/year.

The eastern conservatory roof was fitted with a 0.8 kWp photovoltaic array, consisting of eight 100 Watt panels. Observing the carport roof, situated on the south side of the building, over the first year it was apparent that a second string of pv panels could be mounted just below the ridge of the carport to catch the sun coming over the top of the house. The plan is to install another 0.8 kWp array, each being passed through a Sunny Boy inverter in the shed at the end of the carport. So far only the first array has been installed. The full 1.6 kWp installation should generate enough power over the year to cover electricity for lights and appliances. Based on the data from the 20 Karaka Road installation, the output should be around 1,900 kWh per year. This will leave 1,300 kWh to be supplied from the mains. This could be provided by a further 1.1 kW of pv panels if a location can be found for these.

4. CONCLUSIONS

What these two projects demonstrate is that there seem to be no obvious technical barriers to zero energy housing retrofit in the New Zealand context. It is normally not appropriate to do a through conversion of an existing house but it is often easy to install some energy conservation technologies and to make more use of renewable energy. At present the lack of incentives makes most of this work unattractive. In addition, there are institutional barriers such as the lack of net metering arrangements for supplying renewable energy to the grid.

It is clear that at first sight the installation of a household renewable energy system makes no sense financially, but if it is compared with other purchases that a household might make it can appear more financially rational. The cost of the pv system for 20 Karaka Road was comparable to the cost of a moderately luxurious car. A car will lose roughly half its value in depreciation over three years (Inland Revenue, 2006), making the purchase of an $80,000 pv system (with a guarantee of 20 years) appear a more rational way of spending the money. Allowing the householder to write down the purchase and installation cost of renewable energy technology against tax, as a business can, would also be an incentive to its uptake.

In the current economic climate, it is not considered irrational to buy an $80,000 car, when a $20,000 car would serve just as well for transport. It may be that one of the most important tasks in the struggle to improve the sustainability of the built environment will be to make the purchase of a photovoltaic system into a status symbol.

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