A Method for Practical Zero Carbon Refurbishments: A Residential Case Study*

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ABSTRACT

The existing Australian building stock is responsible for around one quarter of our total greenhouse gas (GhG) emissions, and it is being replaced at a very slow rate. We urgently need to retrofit these buildings to reduce our GhG emissions to meet Australia's expectations and international obligations. This paper illustrates a method of finding practical refurbishment options to reduce GhG emissions in a brick veneer residential project home by employing best practice passive solar house strategies. The method uses the second generation residential energy rating software, AccuRate to gauge the effectiveness of each option, and then estimates the cost of those options, including current government rebates. The paper also considers the lessons learnt from the design of the solar photovoltaic system, and considers the advantages of using GreenPower. The case study uses various criteria to rank the strategy results e.g. the star rating (the ceiling R4 insulation increase was two points); the savings of the energy required for comfort; the cost; and the extent of carbon reductions. The case study also shows the dramatic impact of the solar photovoltaic system.

Keywords: existing buildings, greenhouse gases, zero carbon, residential refurbishment case study, photovoltaic system review, AccuRate thermal modeling

INTRODUCTION

The existing Australian building stock is responsible for around one quarter of our total greenhouse gas (GhG) emissions (AGO 1999), and it is being replaced at a very slow rate. We urgently need to retrofit these buildings to reduce our GhG emissions to meet Australia's expectations and international obligations.

Existing buildings provide a great opportunity to dramatically lower GhG emissions since more than 80% of a building's energy consumption occurs during its operation (Lehmann 2008) (J Shiel 2009); many buildings have old services; and over 90% have poor performance envelopes (DEWHA 2008).

The vast majority of peer-reviewed scientists agree on global warming and that it is due to anthropogenic greenhouse gases (IPCC-SPM 2007), (Journet 2008), and all foremost scientific and engineering institutions have also agreed (Scientific Opinion on Climate Change 2010). We are already exceeding some of the worst predictions of the IPCC (Garnaut 2008), (Copenhagen 2009), (BZE 2010).

While much research has been published on energy efficiency and life-cycle analysis (LCA) (DEWHA 2008), (Pears 1998) little research has been done on lowering GhG emissions significantly in Australian residences, especially regarding switching to less-carbon-intensive fuels, and examining non-CO2 GhG emissions.

The methodology used included a house energy audit, an Architect's thermal simulations, a review of "low- and zero-carbon" buildings; investigating thermal modelling tools; surveying literature for residential GhG emissions refurbishments; researching the design of a solar PV system; and modelling and monitoring a house undergoing refurbishment to reduce GhG emissions.

The paper examines aspects of zero carbon and its life-cycle as applied to buildings, and presents a case study of a residential operational zero carbon refurbishment with a solar photovoltaic (PV) system, and that was monitored for temperature and humidity.

ZERO CARBON

The concept of "zero carbon" has developed in the last few years as GhG emissions have become more important. It means "zero carbon dioxide-equivalent emissions", but the boundary conditions are not clear. For an "operational zero carbon" building, the energy produced over a year is equal to the energy consumed with the same fuel source. Un-serviced buildings are already "zero carbon" in operations eg. "daylit barns and sheds" (Cousins 2007:23).

On the other hand, if the scope includes the construction of the building, the life-cycle carbon is evaluated, as presented in the next section.

If the servicing district is included, the infrastructure carbon such as building services (Pepper 2010), and structures are included (Randolph *et al.* 2007), (Twinn 2003), (Sustainability Victoria 2009).

Another complexity is that the fuel source of the services provided such as electricity used by the building must be considered for their carbon. If coal is used to generate electricity, only 30-40% of the energy will be converted to electricity, and much will be lost as heat. There will be some transmission losses as well. So we need to consider the Primary Energy (before losses) contribution, and its corresponding carbon (DCC 2008).

Finally, other household carbon sources may require offsetting by the building renewable system e.g. fluorinated gases for cooling devices, which made up 20% of all energy related CO_2-e emissions from buildings in 2002 (Urge-Vorsatz et al. 2007), and waste and compost methane that has a high global warming potential of 21 times CO_2.

A LIFE-CYCLE ZERO CARBON MODEL

Henriksen has developed a life-cycle carbon model as part of her research into Temperate dwellings. She used the NatHERS 1st generation thermal modelling tool, and a 50 year LCA approach to calculate energy consumption and carbon emissions (Henriksen 2005). Rather than convert NatHERS required energy to <u>appliance delivered energy,</u> she used a more realistic model to maintain comfortable temperatures to calculate <u>delivered energy,</u> which is converted to the <u>Primary Energy</u> and then to <u>carbon emissions</u> using the NSW grid electricity emission intensity factors (DCC 2008).

Twelve of her low-carbon house models are shown in Figure 1, which shows their life-cycle carbon production. The initial emissions are shown as: <u>embodied carbon for materials</u>, <u>materials transport carbon,</u> <u>site construction carbon</u> and <u>site embodied carbon.</u> Then each set of 5 years, there are <u>operational carbon</u> and <u>component replacement</u>

(renovation) embodied carbon until finally there is demolition carbon and a credit, for the recycled embodied carbon. Note that this operational carbon only takes into account spatial heating and cooling energy, and not any other appliances etc.

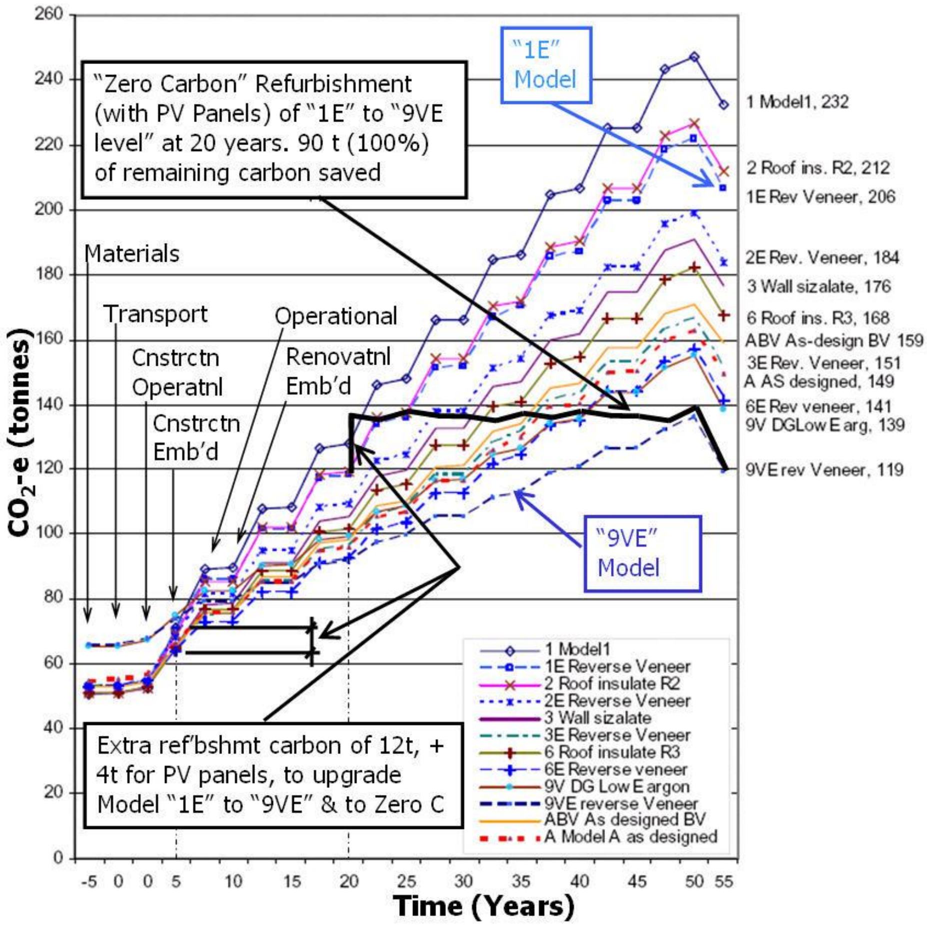
House type "1 Model 1", is 2 storey with 2.4m ceilings, brick veneer/ weatherboard, slab on ground, single glazed Al windows, timber framed roof, 45cm eaves, with standard ventilation levels, sheet metal roofing on foil backed blanket. Models with overall lower slopes have less life-cycle carbon, due to more efficient forms and insulation. All models labelled with "E" (i.e. 1E, 2E etc.) are reverse brick veneer versions of the same model number, and these can be seen in Figure 1 to have lower LCA carbon emissions than their brick veneer counterparts.

The line with the lowest slope, a super-insulated reverse brick veneer model "9VE", has efficient windows with a thermal break, produces few emissions and has a total of only 119 tonnes of life-cycle carbon, including embodied energy, demolition and recycling. These results correlate well with other low life-cycle carbon buildings (EHA 2008).

Zero Carbon Refurbishment

A zero carbon life-cycle refurbishment at 20 years is represented also in Figure 1. The heavy full line in Figure 1 represents a "zero-carbon refurbishment house" where modifications were performed on a reverse brick veneer "Model 1E" to:

- Refurbish it to the "super-insulated" standard a "Model 5E", and
- Add a Solar PV array to offset the life-cycle carbon emitted over 30 years.



Source: (Based on Henriksen, 2005: p5:64)

Figure 1 - Carbon Life-Cycle of a Zero Carbon Refurbishment at 20 Years.

Here, 90 tonnes (206t less 120t plus 4t) of carbon emissions were saved in total, as shown finally in Figure 1 – a 30 year life-cycle refurbishment carbon decrease of 100%.

The assumptions are that 1) there are 30 years to demolition, 2) only heating and cooling carbon is accounted for in the operational stages, 3) additional embodied carbon for the refurbishment at 20 years of 12t to refurbish Model 1E to Model 9VE (as shown in Figure 1 as the difference in the initial construction and embodied emissions at "+5 years" for Models 1E and 5E), and 4) an extra 4t for the embodied emissions of the solar PV system itself (assuming approximately 1 year of full operational carbon).

This forms a taxonomy of types of building carbon to assist in choosing the boundary for renewable energy offsets for zero carbon refurbishments, buildings or districts.

CASE STUDY

House Description

Figure 2 shows the case study which is a small 120 m^2 project home located in Newcastle, Australia, in a mild, humid, subtropical climate. The 10-year-old home has two bedrooms plus study and was purchased in 2009 with the intentions of undertaking a high-performance refurbishment, and then installing solar photo-voltaic (PV) panels.

The envelope conditions are slab-on-ground, brick veneer with wall sarking, plasterboard for internal walls and ceiling, no ceiling insulation, colorbond roof with sarking, single-glazed aluminium framed windows and 60cm eaves. There are higher houses on the North Eastern and South Eastern that shade the garage and rear bedroom walls all morning, and about 10% tree shading on the South Eastern side.

The house has town gas which is used for hot water and cooking only, and has no air-conditioning. The living/kitchen wall has 70% glass and is oriented 50 degrees West of North, introducing high heat loads for summer discomfort.

It is occupied by two adults, who work at home, but who use zoning and night purging principles, and use energy efficient appliances e.g. a desk 160W panel heater (Thermofilm 2010).

Case Study Method

The house owners had an energy audit on the house, researched refurbishment strategies (Wrigley 2005), (Stoyke 2007) and engaged an Architect.

The Architect (Hunt, 2010) recommended using AccuRate (Delsante 2005), (Saman et al. 2008), a second generation building thermal modelling program in a design manner, and created a model of the building for thermal simulations of strategies (see Figure 2).

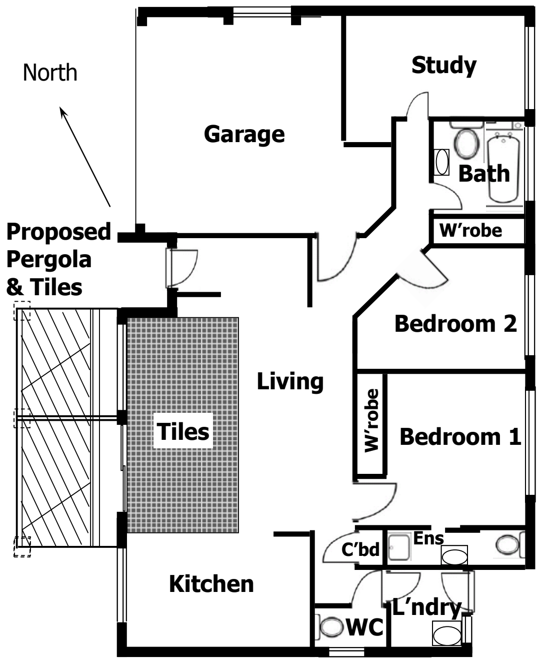


Figure 2 - Plan of Case Study

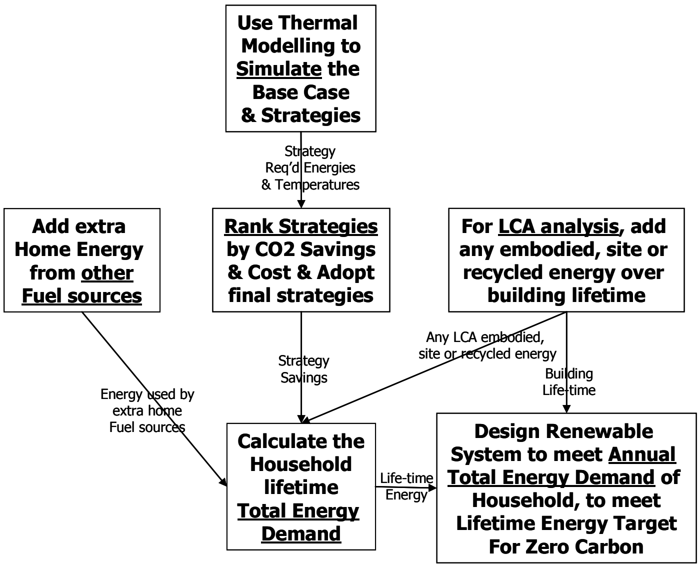


Figure 3 – A Method for Practical Zero Carbon Refurbishments

The Architect found the "required energy" of the case study (i.e. the heating and cooling needed to keep the house comfortable), and determined the room temperatures in "free running" mode (where AccuRate does not add energy to control the inside comfort conditions). He modelled house refurbishment strategies and some combinations.

The simulated temperatures were compared with those monitored during implementation with USB data loggers (DigiTech 2010). Logged results showed that R4 ceiling insulation dropped the Living room temperature by 2-3^{o}C (Shiel 2010).

The reduced spatial energy from the refurbishment strategies (see Figure 5) was factored into the annual total energy demand, along with other site energies and that due to future loads (see the PV System Design and Results sections). The operational carbon approach was used, since the full LCA is extensive, and the refurbishment carbon is low here, and so the LCA steps of Figure 3 do not apply to the Case Study.

PV System Design

The PV System required was to connect to the grid, with the goal of cancelling all operational energy. The small N-W-facing roof was away from street view.

A 30% loading was added to the estimated daily energy load to obtain the final total annual energy demand (see Figure 4). This was assumed to accommodate non-electricity fuel sources (gas for cooking and hot water), and future loads such as charging of electric bicycles.

Confusing quotations prompted more research into the design of the solar PV system. The method to design a system is shown in Figure 4.

RESULTS

Case Study

The initial evaluation indicated that the home had low thermal performance, with an AccuRate rating below average, of 1.9 Stars. It was a "cold house" since of the total of 240 MJ/m2/y "required energy" needed to keep the house comfortable, 147 MJ/m2/y was for heating and 92.9 MJ/m2/y for cooling, and gave focus to heating strategies.

Refurbishment Strategies

Figure 5 shows the required heating and cooling energy saved by each strategy where the energy savings are plotted on the left vertical axis, as a percentage of the case study "required energy". The capital cost (AU$) with zero at the bottom of the chart is plotted on the right axis for each strategy on the x axis. Figure 5 also shows the AccuRate star rating of the building with the new strategy.

The main refurbishment strategies adopted were weather-stripping, lined and sealed curtains, R4 ceiling insulation, ceiling fans, temporary double-glazed low E windows, thermal break on the aluminium windows, and pergola with interior dark tiles on concrete to gain thermal mass.

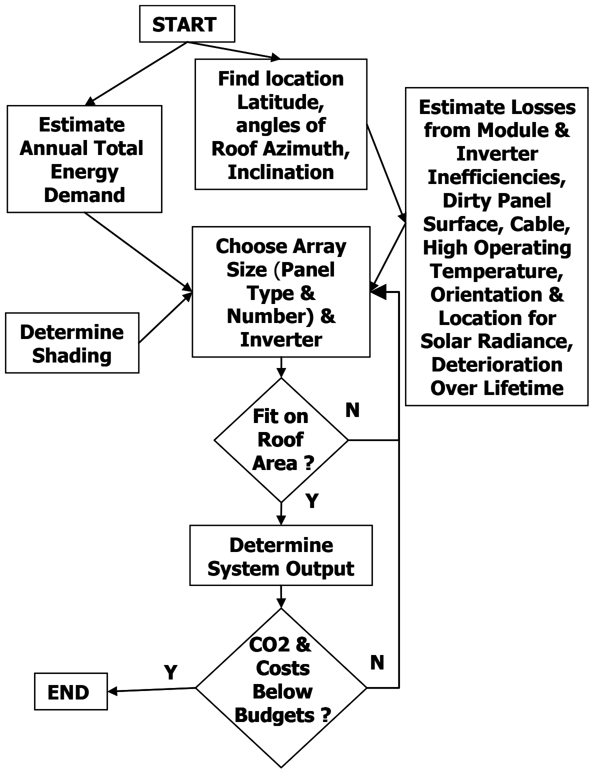


Figure 4 - Zero Carbon PV Sytem Design Method

The cost of these refurbishment strategies adopted was around $12,000 after rebates.

PV System

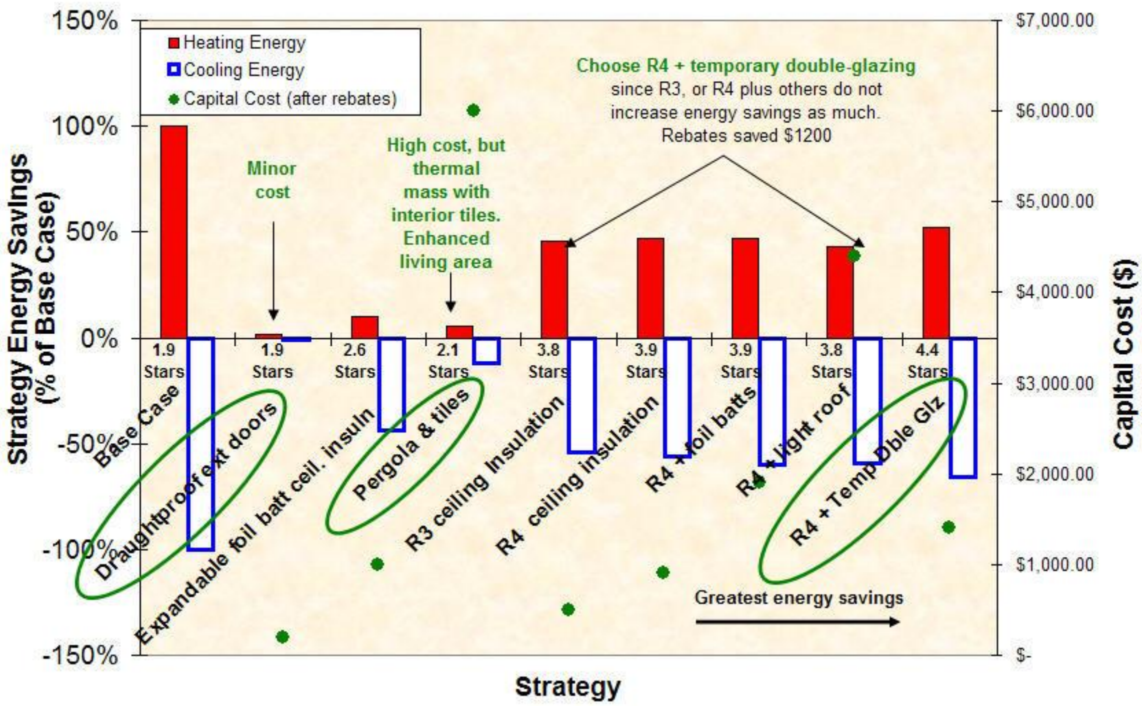


Figure 5 – The Percentage of Spatial Energy Savings, Capital Costs & Star Ratings for Refurbishment Strategy. Chosen Strategies are in Green Ellipses.

The final PV system chosen was a 3kWp (generates a peak of 3 kilo-Watts of power), of SANYO HIT PV Modules, a recent advance of a mono-crystalline layer sandwiched between two thin amorphous silicone layers, with good response at high temperatures. It has an "optimistic" average generation of 10.9kWh/d from the vendor, and cost around $15,000 after rebates and RECS were transferred, and there is an additional $450 is needed for the bi-directional meter. The payback period is around 8 years after entry into the NSW government's 66c/kWh gross feed-in tariff scheme.

The Carbon Budget

Table 1 shows an estimate of the house energy and carbon consumption/ generation before and after refurbishment. The reduction in space heating and cooling was based on the approximate 80% energy reduction for all strategies adopted shown in Figure 5, as well as additional strategies that will be employed e.g. solar hot water.

The gross and net metering connection greatly affects the carbon (see Discussion).

Table 1 - Energy and Carbon Estimates

Item	**Before Refurbishment**		**After Refurbishment**	
	Energy kWh/d	**Carbon t CO2-e/y**	**Energy kWh/d**	**Carbon t CO2-e/y**
PV System Energy Generated*			-10.5	-4.06
Energy Used				
Space Heating & Cooling	2.58	1.00	0.52	0.20
Other Electricity	5.69	2.20	5.00	1.95
Gas (cooking, hot water)	8.90	0.75	3.00**	0.24
Total Used	19.27	4.09	8.52	2.40
Net Used/ (Emitted)			**-2.48**	**-1.67**
*	See Discussion section			
**	Refurbishment includes solar hot water system			

5. DISCUSSION

Zero Carbon Buildings

To create a "life cycle zero carbon building", the aspects of the first two sections "Zero Carbon" and "LCA Zero Carbon Model" would need to be included, as well as the Primary Energy of other site services with fuel sources such as gas, two-stroke fuel or wood, and estimate future energy demand.

Low-, zero- and negative-carbon buildings are one of the main features of sustainable houses (Roaf 2003) (Vale & Vale 2000) with small ecological footprints, (Rees *et al.* 1998). They increase in capital value and have low operating costs with reduced or no utility price rises, since carbon will escalate in price over the coming decades.

Practical Zero Carbon Refurbishment Method

The method for practical zero carbon refurbishments is shown in Figure 3, and explained in the Case Study section.

The energy audit was important to set the baseline for the final energy estimate, and also to identify general improvements.

Thermal modelling considers only the energy (and carbon) from the spatial heating and cooling requirements i.e. only part of the operational carbon. The life-cycle zero carbon refurbishment models presented in Figure 1 only include the carbon from the energy used for spatial heating and cooling in the operational carbon. A full life-cycle carbon method would incorporate the remaining carbon, as shown from the audit in Table 1.

Each strategy was compared for effectiveness using the required energy and temperature impacts, as well as capital costs (see Figure 5), although AccuRate has some deficiencies in free running mode (Kodjamshidi *et al.* 2007), that is used to calculate temperatures.

The amount of energy that a strategy saved is calculated using the AccuRate required energy results, but could have been calculated using Henriksen's Temperate climate approach of air-conditioning hours for out-of-range temperatures, and it also relies on free running mode.

While houses in the Tropics can be modelled in AccuRate with more advanced passive features such as parasol roofs and better ventilation to provide comfort in more extreme heat and humidity, some still receive a low star rating because of the Accurate cooling algorithm (Aynsley 2007), (Goad 2005).

Greenpower

Purchasing 100% GreenPower is an alternative method of supplying renewable energy to create an operationally zero carbon house, although only the delivered energy is offset, not the primary energy. And of course, it does not cancel electricity price rises.

However, accredited GreenPower from an energy retailer is a convenient way to reduce the carbon footprint. It is especially relevant to those without a suitable site, or those who may not want to, or cannot, invest in a PV system in the long term.

Case Study Refurbishment Strategies

The strategies chosen (see Figure 5) reduced the heating and cooling energy by around 80%, and so this was used to calculate the estimated energy after refurbishment. The "energy required" savings for strategies showed how much they reduced the spatial heating and cooling energy to keep the house comfortable.

The selected strategies are in ellipses in Figure 5. While the pergola is a higher cost option, it adds another lifestyle option to the house and since the thermal mass increase should be of more benefit than indicated by the thermal modelling, it was adopted.

Costings

The solar PV system quotes were analysed for the simple payback period (SPP) and results plotted against the daily energy capacity of the system. The SPP analysis gave a payback period of around 11 years for a 1.5kW system; a maximum payback period of 12 years for a 2kW system; then the line reduced to less than 8 years for a 3 kW system; but then the line tapered rapidly to about 7.3 years for a 5.3 kW system.

The assumptions were that the PV system lasted 30 years; there were 4 inverter replacements; that the NSW gross feed-in tariff rates of 66c per kWh would last for at least 5 years; and there would be a 20% rise in utility prices for the first 2 years; and then 10% for the next two years; and then 5% from then on.

Solar PV System

It was helpful to speak with friends who had bought a Solar PV system, since the energy output from similar modules and the same peak power varied greatly.

The lessons learned from dealings with the Solar PV Vendors, who were attracted by the surge in customers from government incentives were:

- We developed criteria to select the Vendor and system. They were 1) vendor experience that could back up the 25 year warranty – some vendors had only been around for a short time; 2) that they provided good service; 3) that the warranty was on-shore, and 4) that the product was from a well-known manufacturer and easy to get parts in the future;
- Learn the technical aspects to be able to calculate your own realistic annual total energy demand, and take into account all the system losses.
- Ask for specifications since some vendors quoted the wrong models.
- Get a few quotes and do not rush the important zero carbon decision.

The best vendors stocked quality modules; had a detailed method for calculating the energy output of the modules; and included most losses. Note that all ignored the lifetime performance system deterioration, which could be 20% after 25 years.

Carbon and Gross and Net Feed-In Tariff Metering

For a grid-connect system, while the PV system is connected via a gross meter (to obtain the 66c/kWh) the energy will go directly to the grid, and therefore the house will use mostly Primary Energy with large carbon emissions.

However, if the connection changes to net metering in the future, the house will receive the energy first and any excess will supply the grid resulting in much fewer carbon emissions. The majority of these emissions will be due to the Primary Energy required in the evenings.

This was one loss that had not been foreseen, and could mean an additional 30% load factor is needed on the total energy demand to have a truly zero carbon house.

Alternatively, the net meter could be attached initially (the gross meter is not compulsory), although it would take many more years to pay off the system, since certain rebates such as the Renewable Energy Certificates (RECs) may not be paid.

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CONCLUSION

Practical zero carbon refurbishment strategies can be achieved by 1) obtaining a house energy assessment; 2) ranking strategies using thermal simulation for energy savings and temperature impacts and Simple Payback Period to find the impact of the return of the investment against the investment outlay; and 3) offsetting the reduced annual total energy demand with a renewable source such as a solar PV system.

The paper presented a taxonomy of types of building carbon emissions across stages in the building lifecycle as well as spatial scope from refurbishments to districts. This includes operational carbon as part of life-cycle carbon, and infrastructure carbon for services and structures that can be applied to clarify the scope of renewable energy offsets. It also described an affordable zero carbon home refurbishment case study.

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