SUSTAINABILITY FACT SHEET

PHOTOVOLTAIC (PV) DESIGN

Guidelines for Inclusion in New Zealand Homes

Introduction

The aim of this guideline is to promote and provide the information needed to incorporate and make proper use of a robust micro-renewable technology that can significantly offset your electricity needs as well as reduce your environmental footprint: photovoltaics (PVs).

The definition of a robust technology is one that can provide significant benefits to the majority of New Zealand homes while also being both easy and low cost to design, install, use and maintain.

PVs were shortlisted by BRANZ from a wider set of micro-renewable technologies, which included wind and water turbines. Of these three technologies investigated, only PVs made the robust shortlist. The background to this shortlisting process is provided at the end of this guideline (see Supporting Information).

PVs should be integrated into homes that have been designed to be very energy efficient. By reducing energy demand, the effectiveness of this micro-generation technology can be maximised. Ways of effectively reducing energy demand are outside the scope of this guideline, but useful references are provided in Supporting Information.

A glossary of terms is provided at the end of this guideline.

What is a photovoltaic system?

A photovoltaic array is made up of light-sensitive panels that contain solar cells (see Figure 1). The cells consist of layers of a semi-conductor material – typically silicon. Sunlight striking the cells causes electrons to move between the semi-conductor layers, generating direct current (DC) electricity. This DC electricity needs to be transformed into alternating current (AC) electricity for ordinary household needs. This transformation process is carried out by an inverter. From the inverter, electricity is fed into the household switchboard, where it is distributed directly to the outlets/appliances that need it immediately.

Electricity produced by the PV array that is surplus to household needs is redirected to the grid and bought by the energy retailer. In this situation, where no electricity is stored at the house, the PV system is called 'grid-tied' or 'grid-connected'.

The electricity generation capacity of PVs is measured in watts peak (Wp), which is the panel's power output rating under standardised test conditions.

Panels come in output capacity sizes up to 300 Wp and can be connected together in any array size. An array of panels with a 2,000 Wp rating may produce between 4 kilowatt-hours (kWh) and 10 kWh per day on sunny days. New Zealand households use an average of 22 kWh of electricity per day with most residential PV installations ranging between 1–5 kWp of output.

The focus of this guideline is on a typical setup: a grid-tied, 2 kW to 4 kW sized, fixed-roof mounted, crystalline system with no electricity storage ability, where the network buys back the excess electricity.

This setup represents the majority of installed systems in New Zealand. Other PV system variants – such as stand-alone systems with batteries for longer-term electricity storage – are not included here primarily because they are far costlier per unit of energy generated or have specialised application.

Several key considerations must be followed to ensure the success of PVs in the field. This guideline includes the findings of four New Zealand examples, provides much of the information needed to successfully design-in PVs in New Zealand homes.

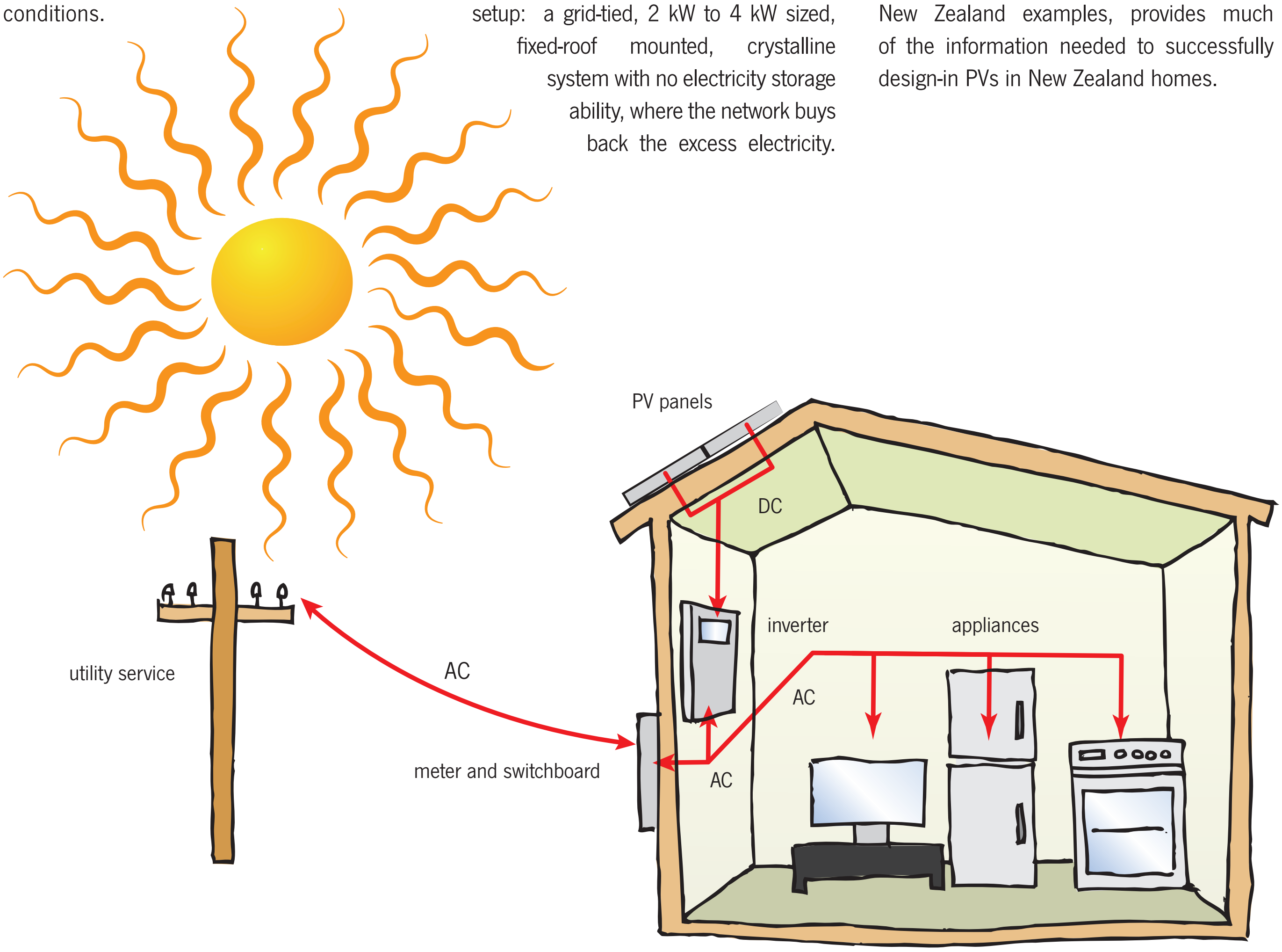

Figure 1: Schematic of typical grid-tied system, showing key components and energy flows (in red lines)

Why use this technology?

Grid-tied PVs are a winner – provided they are properly specified, installed and monitored. They are simple to install, quiet, reliable as the sun, non-polluting, require very little maintenance throughout their lifetime, reduce a home's carbon footprint, may be a good longer-term financial investment, and may add resilience to a home's energy supply. Although particularly well suited to sunny New Zealand climates that have few clouds, PVs are also feasible even in the most southern regions. Internationally, New Zealand stacks up very well in its solar potential, i.e. usability and intensity of sunshine hours.

The rapidly falling price of PV panels (nearing about $1.10 per watt at the start of 2014, down from $1.25 at the end of 2012) and the possibility of New Zealand following international trends in terms of generation buy-back prices, mean that for many situations PVs are a good investment for domestic electricity generation. However, to ensure the best use is made of them, a careful examination of the needs and expectations of the potential buyer, as well as the solar potential of the site, is strongly recommended.

User experiences

PV systems were recommended by all the New Zealand residential users surveyed by BRANZ. This quote is typical of their appreciation:

"The panels provide energy reliably, silently, with little ongoing maintenance"

More survey responses from New Zealand users on key performance issues are found in Table 1.

All owners were also asked about the initial installation cost of their PV system – i.e. the panels, inverter, wiring, consents, meters and substructure. This information has not been captured here, as the rapidly falling prices of the systems means historic prices are not useful.

Financial considerations (as at the end of 2012)

Determining the financial benefits of PV systems with any degree of accuracy is a challenging exercise, as some variables are important but are very difficult to predict.

Table 1: Key performance indicators of PV systems – from BRANZ interviews in 2011–2012.

House location	Q. What do you really like about the system?	Q. What is the annual maintenance cost?	Q. How reliable is the system?	Q. Would you recommend the system to others?
Auckland	For this setup, it is amazing how little this system needs in terms of repairs. Although the inverter is a sophisticated system, there are no moving parts ... (being) solid state ... technology. Brilliant.	The new modules don't require any maintenance – due to its improved build quality.	Extremely reliable over 5 years. The reliability is further enhanced with the very good sunshine hours that Auckland experiences year round.	Absolutely. Especially now ... mono-crystal is cheap as chips. As long as you follow some sensible guidelines in its installation, you will be able to get your maximum output.
Wellington	Silent, no hassle, no moving parts, low maintenance... Users become very aware of how to use energy effectively. Very important to look at the energy balance.	Minimal	Very reliable. Minimal maintenance needed.	Yes – PV is a good choice for micro-renewables, as it is a solid performer and very easy to live with.
Blenheim	It produces a lot of power – was surprised at how much and for how long they produced power. Installer very competent.	Installer comes around once a quarter for 15 minutes to have a check, as part of his continued (free) service.	Very reliable as far as owners know.	PVs are a very simple technology – good for the average punter. Not much you have to do. No moving parts. Easy because it's simple.

Assuming the PV goal is simply to maximize the financial returns of the system over its lifetime, the key variables become:

- any subsidies provided
- the buy-back rate offered by the electricity retailer
- the size, shading, orientation, and slope of the panel setup
- the amount of electricity the house uses during the day – which determines how much of the utility company's electricity can be displaced
- the fault detection alert systems
- the intended length of dwelling ownership
- and, to a lesser extent:
  - the type of panel used
  - the inverter type.

It is strongly recommended that homeowners consider each of the variables above to gain a realistic appreciation of the issues associated with owning a PV system. Too often, the financial returns quoted by PV designers/installers are based on 'ideal' conditions such as: best possible orientation, no shading, and high buy-back by retailers of electricity. This is usually not representative of reality and therefore over-estimates the actual likely financial returns. The first four key variables above are examined in the following paragraphs.

Subsidies

In terms of financing options, as at the end of 2012, Kiwibank began offering its mortgage top-up and subsidy called Sustainable Energy Loan. This initiative provides up to $2,000 towards the cost of renewable systems, such as PVs. Systems must be supplied and installed by a member of the Sustainable Electricity Association of New Zealand (SEANZ) or Solar Association of New Zealand (SANZ) and come with a 10-year warranty.

Buy-back rates

Typically, the more PV-generated electricity the residents make immediate use of, the greater the financial savings achieved and, therefore, the more cost-effective the PV system is. This is due to the utility pricing structure, which means that retailers typically pay less for the electricity you sell them than the electricity you buy from them.

Size, shading, orientation and slope of panel setup

The size, shading, inclination (Figure 2) and orientation (Figure 3) of the panel setup have a dramatic impact on the PV's output and, therefore, the resulting financial returns. In new homes where the renewables will be integral to the design process, it is likely that 'close to the ideal' situation – i.e. where the panels are well sized, there is negligible shading, and orientation is very close to true north – will be met fairly easily.

The utilisation rate describes how well electricity generation from the PV array matches electricity demanded by a particular house (Figure 4). In typical PV-equipped homes there is a poor match between electricity generation and demand

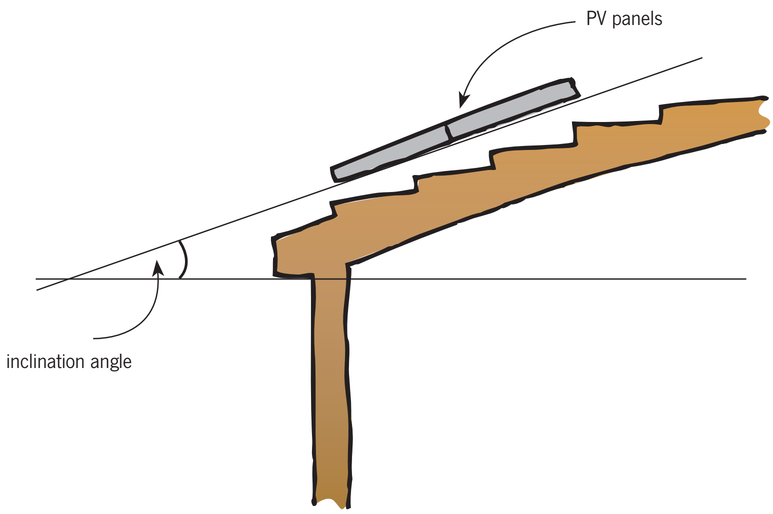

Figure 2: Cross-section of house showing inclination angle

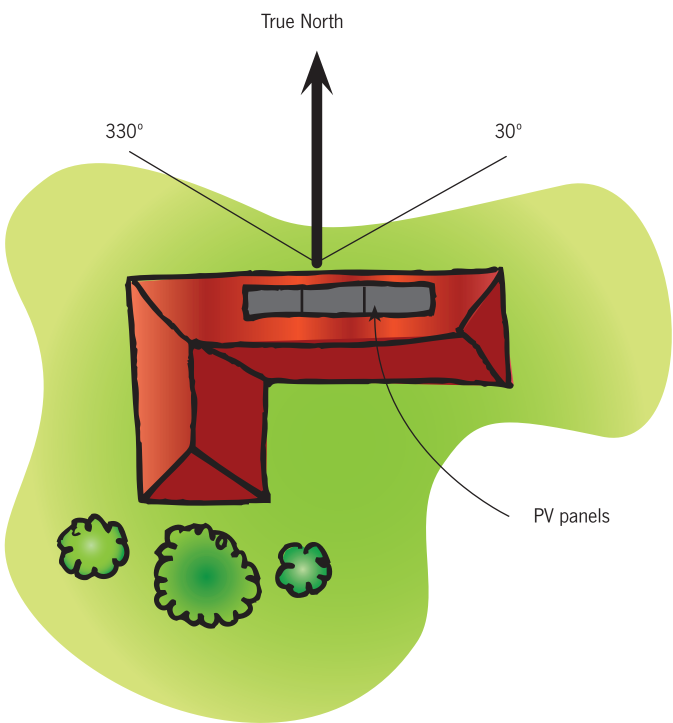

Figure 3: Plan view of house showing PV panel orientation

– since little electricity is needed around mid-day when the sun is shining brightest and PVs are producing the most electricity. Assuming that PVs are installed on more efficient homes with lower appliance loadings, there is less opportunity to 'reassign' heavier appliance loadings to better match generation timings. Exceptions to this could be for time-delayed dishwasher and washing machine usage or where the site-generated electricity can be directly fed into the hot water cylinder element, to top up hot water heating requirements.

The system's owner/user should be able to manage the fault detection systems easily as a result of advances in technology and the user friendliness of the PV controls, monitoring and inverter provided as part of the PV generation package. Some systems even provide smartphone alerts.

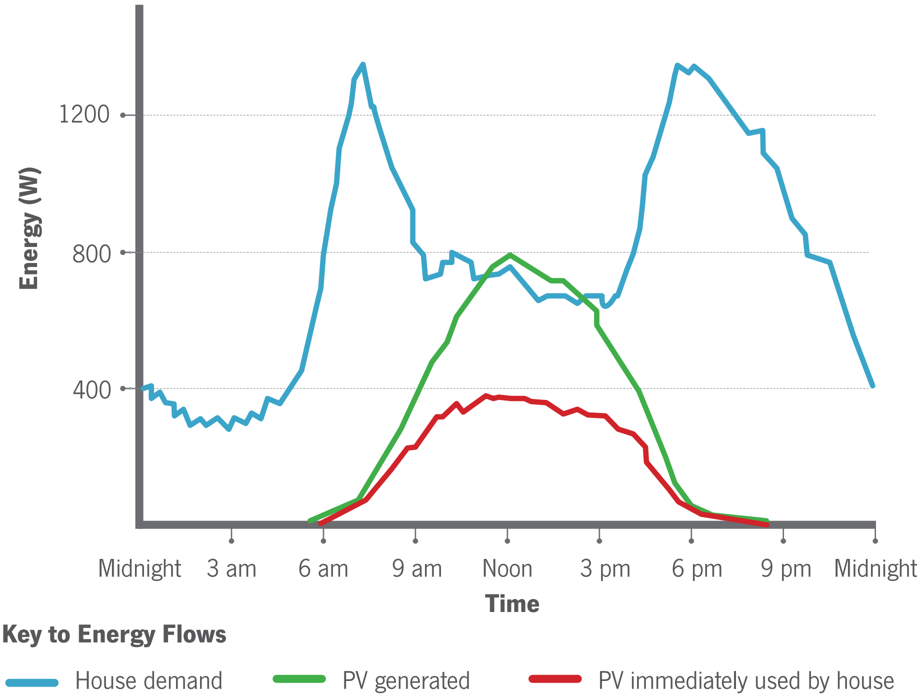

Figure 4: Typical grid-tied home's electricity flows and use

Financial returns

Three grid-tied PV systems (a 2 kWp, 3 kWp and 4 kWp) were modelled for Auckland, Wellington and Christchurch. Three scenarios were examined in terms of initial whole-system setup costs: 'Present' (late 2014), 'Near Future' (estimated two to three years), and 'Far Future' (estimated five to eight years). Present costs were $6,000 for the 2 kWp system, $8,000 for the 3 kWp, and $12,000 for the 4 kWp; 'Near Future' costs were priced at $2,000 less for each system respectively, and 'Far Future costs' at $4,000 less. Present prices were based on late 2014 market rates. Prices exclude the benefit of the Kiwibank mortgage top-up and subsidy. Other variables are detailed after Table 2.

Table 2: Financial implications of a 3 kWp PV array in three New Zealand locations

	Present Scenario Payback in Years		**Near Future Scenario** Payback in Years		**Far Future Scenario** Payback in Years	
Utilisation Rate	*50%*	*25%*	*50%*	*25%*	*50%*	*25%*
Auckland	13.0	12.5	9.7	13.1	8.5	8.3
Wellington	14.0	18.9	10.3	14.2	7.0	9.5
Christchurch	14.5	19.5	10.9	14.6	7.2	9.7
Benefit-cost ratio	**1.0**	**0.7**	**1.3**	**1.0**	**1.9**	**1.4**

Two common economic indicators were chosen: benefit-cost ratio and simple payback period.

Benefit-cost ratio summarizes the overall value-for-money of a project: the higher the ratio, the better the investment. As a rule of thumb, if the ratio is higher than one, then the project is a good investment.

Simple payback period refers to the time required for the return on an investment to 'repay' the sum of the original investment. Although it doesn't account for the risk or the financing of money, it is a useful indicator when used carefully to compare similar investments.

For the 3 kWp system examined (Table 2):

- The benefit-cost ratio for the Near Future and Far Future scenarios is one or more, making for a good financial investment.
- The simple payback period is around 14 years, 10 years and 7 years for the Present, Near Future, and Far Future scenarios, respectively. This is appealing, especially for those who plan to stay in their house for the longer term and would therefore reap the ongoing benefits.
- The higher the latitude, the more solar resource, the faster the payback.

The financial implications of two other systems, 2 kWp and 4 kWp, were also examined. These were found to have similar results and trends as for the 3 kWp system. In each of the three modelled cases, the price of selling electricity to the grid (export price) was assumed to be 8 cents per kWh, and the price of buying electricity (import price) was assumed to be 25 cents per kWh. Market expected rates of inflation were used, and

utilisation rates of PV generated energy were assumed to be 25-50%. A 5% discount rate over 20 years was used, which is that typically used for these types of energy saving technologies. As a result of the likelihood of variability in home utilisation rates, two have been used in this financial forecasting model: 25% representing the most common case, and 50% representing the best case scenario. These figures are based on previous BRANZ field monitoring for Beacon Pathway Ltd of a grid-tied energy efficient home, which had a utilisation factor of 25%.

To calculate the return on investment for your specific system, refer to www.pvcalc.org/pvcalc.

Strategies

The following strategies are for those interested in establishing households that generate their own electricity via a small-scale grid-tied PV system connected to a network which buys back the excess power.

Planning

To quickly **estimate the annual PV electricity yield** for any New Zealand location, the BRANZ Photovoltaic Generation Calculator should be used. The only details needed are: solar panel type, location, orientation and roof slope. This estimation assumes no shading. See www.branz.co.nz/toolbox

Having an **unshaded roof area** for the PVs, of a suitable size, pitch and orientation, are the basic requirements for any PV setup. If a suitable nearby roof is not available, then a ground-based array may suffice. If the house/extension has yet to be built, orienting the house to maximize its solar exposure and installing a roof with the correct solar pitch can simplify the process considerably.

At the very start of the investigation, the **current grid pricing** for exporting renewables should be explored and realistic financial returns calculated. Any grid-tied photovoltaic system needs to be agreed to by both the lines company (for the connection) and the electricity retailer (for pricing arrangements).

Design

In terms of the **area required** for a PV array, about 6m^2 is needed per kW installed for the crystalline modules, and module size is usually between 1-4 kWp in capacity.

The **positioning** of the solar array is also critical – both in terms of the inclination (i.e. the slope should be latitude minus 10°) and orientation (i.e. the degrees away from true north). Table 3 shows the drop-off in performance from non-ideal situations. 'Excellent orientation', shaded in red, is the ideal.

Table 3: Performance of PV panels in non-optimum positions (after NZS 4614:1986 *Installation of domestic solar water heating systems*)

		Inclination Angle					
	Direction	0°	20°	40°	60°	80°	90°
West	270°	0.85	0.85	0.80	0.72	0.60	0.53
	300°	0.85	0.92	0.92	0.86	0.73	0.65
	330°	0.85	0.98	0.99	0.93	0.80	0.71
True North	0°	0.85	0.97	1.00	0.94	0.80	0.70
	30°	0.85	0.94	0.95	0.88	0.74	0.65
	60°	0.85	0.88	0.86	0.77	0.65	0.57
East	90°	0.85	0.80	0.73	0.64	0.52	0.46

Excellent orientation (red) | Good orientation (yellow) | Poor orientation (orange)

Although it is possible to install PV modules on all **roof types**, generally, corrugated and trapezoidal long-run metal are the easiest, with timber shingles and tile roofs being more challenging, and membrane-types being the most work. In retrofits, if the roof needs replacing within 10 years, then it is suggested it is replaced at the time the PV system is installed to avoid the cost of removing and reinstalling the PV system.

The placement of a PV array to ensure minimal year-round **shading** between 9am and 3pm is critical for viable PV operation. This is especially true in winter when the sun is lower in the sky and objects such as trees, power poles, dormer windows, chimneys, and TV aerials cast longer shadows.

Solar panels and their **supporting structure** must be installed to meet the requirements of wind and seismic loading, electrochemical corrosion with the different metals in the components, and electrical safety issues, and also allow for a cooling airflow of at least 100 mm behind the panels. Details of these issues is outside the scope of this guideline but will be addressed by the accredited SEANZ installer.

In newbuild homes, **wires from the PV panels to the inverter** can be installed before interior walls are enclosed, reducing installation time and damage to plasterwork, and hiding unsightly conduits. Also, the distances of wire runs can be minimised, reducing costs and increasing system efficiency. In existing buildings, installation is more challenging.

Establish and **promote good relationships** with the various contractors associated with the installation, such as PV consultants, roofers and electricians. Encouraging the PV installers to work closely with the other trade contractors helps successful project delivery. Good communications between trades results in better allocation of tasks and more economical construction.

Adequate indoor **wall space** to mount the inverter and other associated components is also required in the utility room or next to the electrical panel. Allow at least 1 m^2 of wall space for inverter and switch gear. The mounting area can be on a shelf or wall above the floor, at a height that can be easily read, with no direct sunlight on the unit, and in a position that can be easily accessed in an emergency.

Installation

Installing PV systems presents a number of dangers to the installers and the building itself. Only appropriately qualified people should install PV systems. There are a number of technical Standards relating to the design and installation of PV systems which are mandated by the Electricity (Safety) Regulations 2010. PV suppliers (i.e. the designers and installers) should be **SEANZ accredited** to ensure that outcomes are safe and energy-efficient, and that work meets the requirements of AS 4777 *Grid connection of energy systems via inverters* and AS/NZS 5033 *Installation and safety requirements for photovoltaic (PV) arrays*. Consent may be required for photovoltaic systems that penetrate the roof or are considered by neighbours to affect their property. This is at the discretion of the local council.

Proper **roof mounting** can be labour intensive, depending on the type of roof, accessibility, its angle of inclination and how the mounting brackets are installed and sealed to avoid water penetration and galvanic corrosion. Ask the PV supplier to ensure the best racking system, based on the above factors and the PV panel manufacturer's support requirements. If installing a PV system on a new roof that is covered under warranty, the installer should ensure that adding a racking system with roof penetrations will not void the warranty.

A '**solar ready kit**', provided by some PV component suppliers and volume home builders, is the easiest way for a new house to be easily connected to PV at a later date, while minimising upfront costs. Typically, this service installs the cabling (from inverter to rooftop), inverter backing and essential switching, for a minimal fee. When the owner is ready, it is a very simple task to finish off the system install for the house's PVs to start generating electricity.

Maintenance and monitoring

Very little **maintenance** is required – just wiping panels with a clean, soft cloth when necessary. From time to time, the trimming of nearby trees may also be needed.

The option to have the inverter equipped with **continuous PV system monitoring**, to provide instant feedback on performance and to provide alerts if something goes wrong, is highly recommended for fast remediation. Monitoring now is comparatively easy, low or no cost, and can be integrated with various smart devices, such as smartphones, tablet computers and PCs. Usually, the monitoring systems rely on Wifi and broadband.

Some PV retailers/installers will provide **monitoring services as part of an ongoing contract**; this depends on how engaged the owner wants to be. The type of inverter purchased has implications for the extent of monitoring service possible, so this needs some consideration.

Questions

for homeowner, architect and PV consultant to discuss

A variety of issues can have significant impacts on the financial viability of a PV system. Here are some key issues that need discussing to maximise a system's performance.

1. What implications does the placement of a PV array have, to ensure minimal year-round shading from landscaping and vegetation, over the next 10 years or even 20+ years? What is the risk from neighbouring buildings (or gardens) causing obstructions during this time, and how can the risks be successfully managed?
2. Does the ideal slope of the new house/garage roof have implications for the house/garage design?
3. If the homeowner's needs or budget increase, how easy is it to increase the number of panels adjacent to the existing ones? Is it worth investing in oversized cabling and controls to make upgrades easy? Usually this is as simple as seeing what the next biggest 1 kWp system requires.
4. Some PV arrays might almost completely cover the roofing. If the roofing is metal, this has implications for the way the roof gets rain-washed. In coastal environments, what implications does this have on its longer-term durability and its manufacturer's warranty?
5. Given the panels are likely to be highly exposed, what implications does their placement have on the aesthetics of the whole house?
6. Inverters, which are usually located indoors, can produce a noticeable (rather than noisy) electrical hum; therefore, they should be installed in a location where this will not disturb people. What restriction does this place on its indoor positioning?
7. In terms of maintenance, most PV systems can get away with a half-yearly wiping down of their arrays with a soft cloth. How easy is it for the homeowner to access them safely?

Minimum criteria checklist

for designers

For this technology to provide the best results for a typical New Zealand micro-generation setup – i.e. a grid-tied, static, roof-mounted system with no electricity storage capability – some key design issues need to be addressed. These issues are set out below.

- [ ] PVs should be integrated into homes which have been designed to be very energy efficient so that their effectiveness can be maximised.
- [ ] Estimating the financial benefits of PV systems is challenging, as the most significant variable – the buy-back rate of the retailer – is also the most difficult one to predict into the future. If the installation is being carried out for non-financial reasons, then there is a great deal of certainty around performance.
- [ ] Consideration should be given to the following issues:
  - Any subsidies provided, which might be provided by either the government or banks.
  - The physical aspects of the installation, such as the: size, slope, strength, potential for being shaded, and orientation of the roof on which the panels are being installed; potential to install the main cabling within the wall during the new-build process; and size of the wall space needed to mount the inverter and other associated components.
  - The predicted electricity demand of the house. Ideally, user demand should be minimised through behaviour change, more efficient appliance substitution or whole-house thermal improvements. Consequently, the micro-generation capacity would not need to be so substantial or expensive.
  - The monitoring and alert features within the inverter chosen, so that system checks can be easily made and problems quickly rectified over its lifetime.
  - The flexibility of the system so that it is easy to add a panel or two to the existing system. Aspects such as practicality, cost and aesthetics need to be considered for this type of future addition.

These issues should all be discussed at length with your local SEANZ-accredited PV supplier.

Supporting information

These references are specifically chosen to ensure that the designer and user can gain unbiased, independent and relevant information on PVs.

1. The BRANZ Level website, for independent information: www.level.org.nz has a general introduction to the micro-renewables – and covers both grid-tied and off-grid systems overviews.

2. SEANZ (the Sustainable Electricity Association New Zealand): www.seanz.org.nz has resources on training, accreditation, standards and code of conduct. Their *Small scale renewable energy standards guide* provides essential information on the design and installation of small-scale renewable energy systems.

3. The BRANZ Photovoltaic Generation Calculator, which provides a fast and easy method of estimating the annual PV electricity yield for any New Zealand location. See www.branz.co.nz/toolbox

4. Jaques, R. 2013. *Uncommon energy technologies in NZ homes.* Conference paper for 4th International ASA Conference, Hong Kong, November 2013

5. Great 3D shading tools: SketchUp www.sketchup.com

6. Critical standards for industry: NZS 5033 *Installation and safety requirements for photovoltaic (PV) arrays*, and AS 4777 series *Grid connection of energy systems via inverters*.

7. EECA. 2010. *Power from the people: A guide to micro-generation*. Downloadable from www.eeca.govt.nz

Glossary of terms

AC (alternating current)
An electric current that periodically reverses its direction. Most household electricity supply is AC.

array
A group of solar panels wired together.

base load power
The lowest continuous power demand that must be met by the network. It includes the standby power (i.e. power drawn by an appliance when it is not in operation, such as to power clocks in microwave ovens) and appliances which operate continuously (e.g. phone chargers and security systems).

DC (direct current)
Electric current that moves in one direction only. DC current is the current produced by PV cells.

grid-tied or grid-connected
A generation system that is connected to the local electricity network, and can export excess electricity into the network.

inverter
The electrical device that converts DC electricity from generation sources such as photovoltaics into AC electricity that can be used by modern appliances.

kilowatt-hour (kWh)
The accumulated amount of energy used or produced. A PV array that has a rated capacity of 1 kilowatt will produce 1 kilowatt-hour of electricity in 1 hour of operation (under standard conditions).

panel
A group of photovoltaic cells wired together as one unit, as a sheet.

watt (W)
A standard measure of power. Used to rate the production capacity of PVs, and also the electricity requirements (or demand) of appliances, etc.

watts peak (Wp)
The power output generated by a PV module under standardized test conditions.

This factsheet is part of a BRANZ series on the best performing, unusual space conditioning and micro-renewables technologies for the New Zealand situation.