Renewable energy and energy efficiency guide for rural bungalow operators in Vanuatu

GLOBAL GREEN GROWTH INSTITUTE (GGGI)

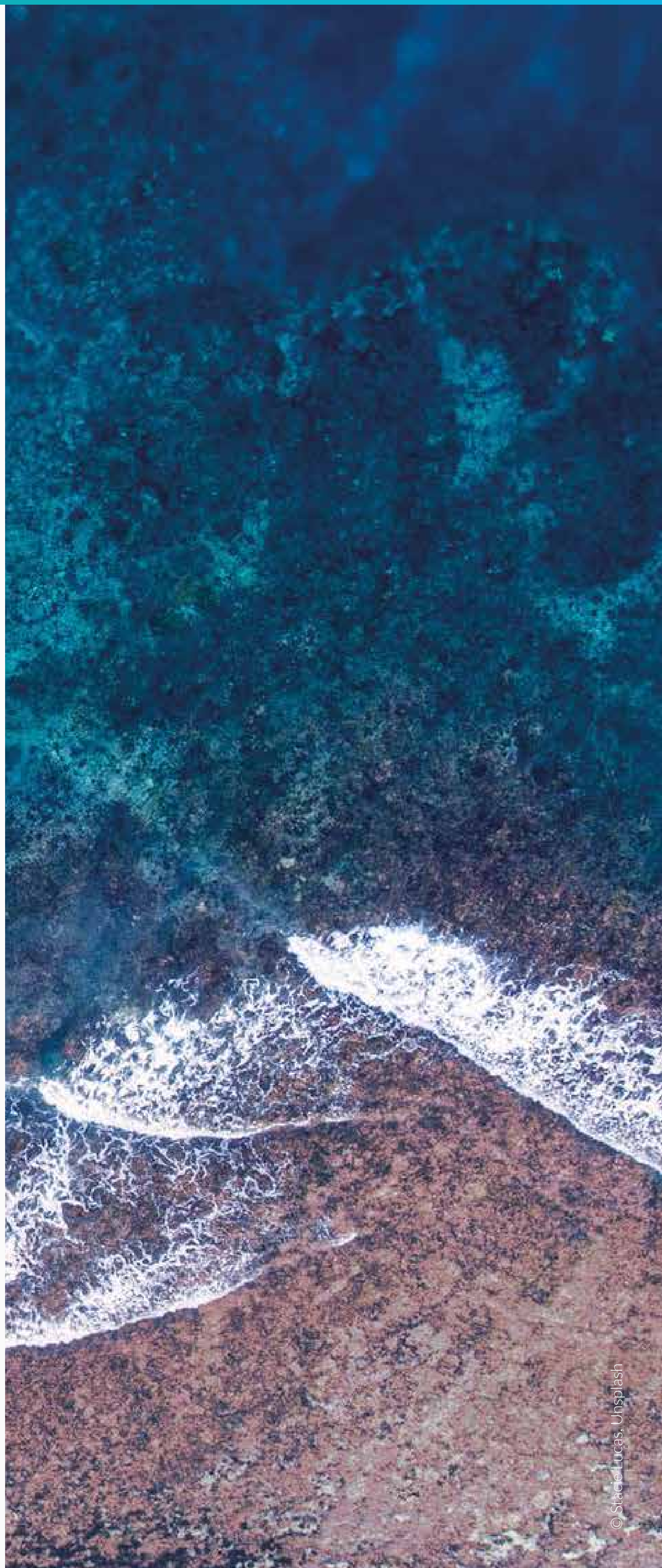
Acknowledgements

THE GLOBAL GREEN GROWTH INSTITUTE **(GGGI)**

and the project team would like to express their sincere appreciation to the Government of Vanuatu, especially, the Directors of the Department of Energy and the Department of Tourism who have provided comments and approved the final report. GGGI also acknowledge the technical contributions made by the local renewable energy suppliers in Port Vila through knowledge and experiences sharing during the workshop held in Port Vila and to also allow the project team to view their RE products at their respective business sites. GGGI would like to further thank the participants from other Vanuatu Government agencies, the private sector and semi-government institutions who have contributed to the validation of this report through a consultation workshop conducted in Port Vila in November 2018.

This Guide was prepared by Sommai Phon-Amnuaisuk, Consultant (GGGI) with support from Paul Kaun, Senior Program Officer, Vanuatu (GGGI) and Christopher Simelum, Investment Officer, Vanuatu (GGGI) with inputs from Katerina Syngellakis, Pacific Regional Representative (GGGI).

The publication of this guide was made possible through financial support to the Regional Pacific NDC Hub from the German Federal Ministry of Economic Cooperation and Development (BMZ), the Foreign and Commonwealth Office (FCO) of the United Kingdom, the Department of Foreign Affairs and Trade (DFAT) of Australia and the Ministry of Foreign Affairs and Trade (MFAT) of New Zealand.



Contents

1 Introduction

2 Choosing RE and EE technologies for bungalows in Vanuatu

3 Best practice guide in operation and maintenance

4 Annex A: Electricity and energy basics

5 Annex B: Solar PV technologies and suppliers for bungalows in Vanuatu

6 Annex C: Sizing your own solar PV systems

7 Best practice checklists for operation and maintenance of energy end-use systems

8 References

Figures

Tables

Acronyms

A	Ampere
AC	Alternating Current
AC	Air Conditioner
Ah	Ampere-Hour
BTU	British Thermal Unit
DC	Direct Current
DoD	Depth of Discharge
DoE	Department of Energy
EC	Energy Conservation
EE	Energy Efficiency
EER	Energy Efficiency Ratio
G	Giga
GDP	Gross Domestic Product
GGGI	Global Green Growth Institute
Hz	Hertz
I	Current
k	Kilo
kWh	Kilowatt-Hour
LED	Light Emitting Diode
M	Mega
m	Meter
MEPS	Minimum Energy Performance Standard
MPPT	Maximum Power Point Tracking
NASA	National Aeronautics and Space Administration
NREL	National Renewable Energy Laboratory
P	Power
PPA	Pacific Power Association
PRIF	Pacific Regional Infrastructure Facility
PSH	Peak Sun Hour
PV	Photovoltaic
PWM	Pulse Width Modulated
R	Resistance
RE	Renewable Energy
SEIAPI	Sustainable Energy Industry Association of the Pacific Islands
SHS	Solar Home System
TV	Television
USD	United State Dollar
V	Voltage
VREP	Vanuatu Rural Electricity Program
VSD	Variable Speed Drive
W	Watt
Wh	Watt-hour
Wp	Watt-Peak

©Jasper Wilde, Unsplash

1

Introduction

1.1 BACKGROUND

Vanuatu's formal economy is dominated by the tourism industry. The total contribution of travel and tourism is about half of the country's GDP, unfortunately only a small portion of this income is distributed to small off-grid tourism operators in rural areas, due to marginal level of services and products offered that have not been able to attract a good number of tourists.

Electricity access has enabled better communications for rural bungalows for bookings and also allowed bungalow operators to offer better services to attract tourists. Realizing these benefits, a number of rural bungalow operators have taken the initiative to invest in solar systems to supplement or even replace the use of petrol/diesel generator sets.

Although the use of renewable energy technologies in rural bungalows, such as pico-solar for lighting and solar home system (SHS), is increasing, the skill level and the know how to operate and maintain these systems out there are unfortunately limited. As a result, electricity generated by these renewable energy systems and costly petrol/diesel generation is not utilized in an efficient manner, leading to high operating costs of these rural bungalows. In addition, poor operation and maintenance have reduced the expected life span of their solar systems.

1.2 ABOUT THE GUIDE

The Renewable Energy (RE) and Energy Efficiency (EE) Guide is a practical handbook with simple guidelines that can help **medium and small-scale rural bungalow operators** to choose and optimize their electricity supply systems through best practices in operation, maintenance, energy conservation and energy efficiency. The Guide provides a range of important considerations and simple calculations when selecting and installing RE and EE systems in bungalows in Vanuatu. The Guide also covers a range of best practices for basic optimization of the solar PV systems, and no-cost/low-cost EE measures for lighting and cooling, which help lower operating costs of the bungalows and maximize lifespan of the solar PV systems. Many of the best practices can be implemented immediately with minimum or no initial investment. The Guide also provides checklists for operation and maintenance of EE systems as well as a basic troubleshooting guide for RE and EE system.

1.3 WHY ARE RE AND EE SO IMPORTANT?

1.3.1 It Reduces Operating Cost

Around 80% of these bungalows use solar energy as their main source of lighting and the remaining use diesel/petrol generators. It is also very common for the bungalows with solar systems installed to use diesel/petrol generators as the backup generation systems, and electricity generation by these diesel/petrol generators is expensive and pollutes our environment. The GGGI study found that these generators are often used just for lighting and small appliance charging. With an average use of 4 hours per day, a diesel generator will cost the bungalow around Vt382,000 (USD 3,500) annually for fuel. Replacing these generators with solar systems and implementing energy efficiency (EE) and energy conservation (EC) measures will not only help bungalow operators to save fuel costs but also provide better services, such as better lighting, for guests.

1.3.2 It reduces climate change risks

GHG emissions, including those from diesel electricity generation, cause global climate change, which in turn affects human habitation and livelihood in many ways such as:

- Rising sea level, causing damages to coastal habitats.
- Increased frequency of extreme weather conditions such as changes to temperature and rainfall, cyclones, droughts, and floods and thereby impacting on agricultural products and threatening food supply.
- Increasing number of tropical-borne diseases impact on human health.

The sea level will rise from thermal expansion and loss of ice mass from glaciers and ice caps due to global warming. The Pacific Islands are extremely vulnerable to rising sea levels. Many islands risk becoming uninhabitable due to salt-water intrusion into fresh water supplies, flooding, and becoming completely submerged.

Climate change is also likely to affect tropical cyclone behavior, and it is likely that fewer tropical cyclones will form as the climate warms, but a higher fraction of those that do will be intense, more damaging cyclones[1].The extremely destructive category 5 cyclone Pam that struck Vanuatu on March 13, 2015 severely affected the provinces of Shefa, Tafea, Malampa and Penama.

1 Tropical Cyclones and Climate Change: Factsheet, Climate Council, climatecouncil.org.au

Cyclone PAM causes not only enormous loses and damages to physical assets, but also loss of income and livelihoods. The total economic value of the effects caused by Tropical Cyclone Pam is estimated to be approximately VT 48.5 billion (USD 449.4 million) which is equivalent to 64.1% of the GDP of Vanuatu[2].

FIGURE 1.1 Damages caused by Cyclone Pam

1.3.3 It Promotes Green Tourism

According to the World Tourism Organization, ecotourism is the fastest growing market in the tourism industry – potentially increasing by 25% to 30% a year. There is now increasing awareness among tourists about climate change and concern for the environment. Many internet-based travel booking agencies like Travelocity, Expedia and, TripAdvisor are responding to tourists demand for eco-friendly travel information and ratings. Energy efficiency in hotels is one of the criteria for obtaining green certification.

1.4 HOW TO USE THIS GUIDE

This Guide is structured to help **medium and small-scale rural bungalow operators** in Vanuatu to choose and operate electricity supply systems and appliances. It involves selection of appropriate solar PV systems and energy efficient lighting and appliances to meet the needs. The Guide also provides basic knowledge in computation of electricity and energy parameters. Basic guides in choosing solar PV systems and appliances are given in **Section 2**, while best practices in operation and maintenance of solar PV systems and appliances are given in **Section 3**. Technical data, calculation and other references are given as Annexes.

2 http://www.ilo.org/suva/public-information/WCMS_368560/lang--en/index.htm

2

Choosing RE and EE technologies for bungalows in Vanuatu

Medium- and small-scale rural bungalows in Vanuatu typically rely on multiple sources of electricity supplies (or power supplies) to operate their lighting and appliances. These power supplies range from small "plug and play" solar home systems (primarily for lighting, phone charging, small fans and small TVs) to larger solar home systems (for larger appliances such as freezers), and small diesel/petrol generators. These different types of power supply lead to a mixed use of direct current (DC) and alternating current (AC) lamps and appliances.

Shown in the figure below are different types of DC appliances connected with DC power supply (typically 12 or 24 VDC) and AC appliances connected with AC power supply (solar inverters and diesel/petrol generators which produce 220-240 VAC).

Solar PV systems for DC and AC appliances in off-grid rural bungalows are not equally efficient due to efficiencies of system components, such as battery, solar charge controller and solar inverter. In general, the solar PV systems for DC appliances are more efficient than the solar PV systems for AC appliances. With 100% solar energy input, off-grid solar PV systems can deliver only around 72% of the input to DC appliances. The off-grid solar PV systems for AC appliances are generally less due to the solar inverter component which converts DC power to AC power, and it generally delivers 3% to 5% less energy compared with the DC system.

FIGURE 2.1 Power supplies and DC and AC appliances in rural bungalows in Vanuatu

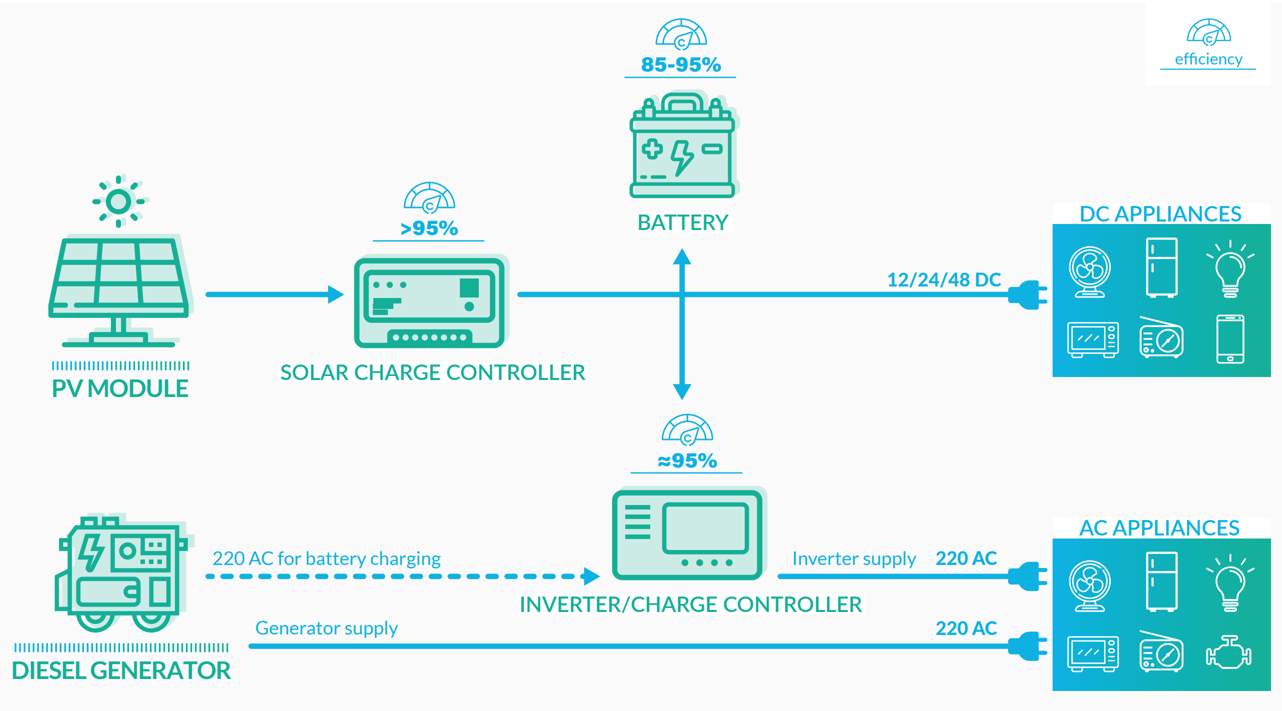
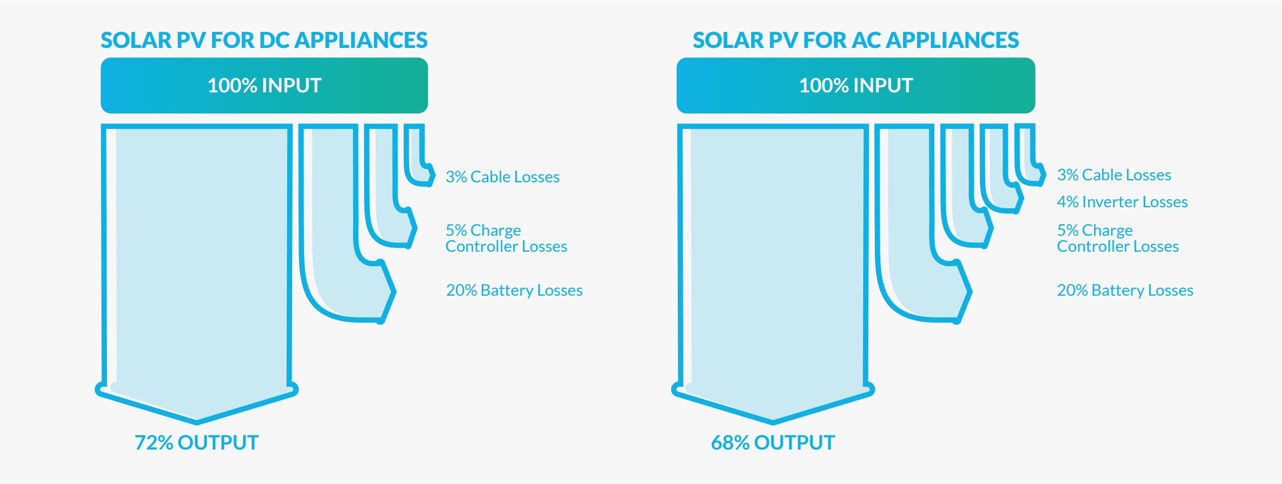


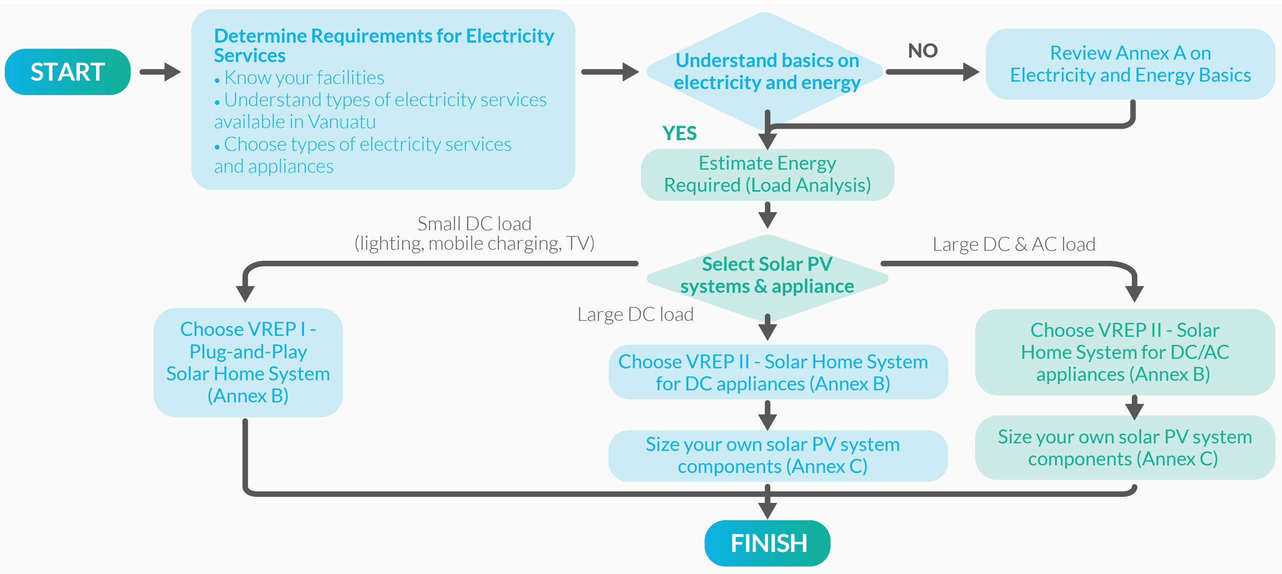
FIGURE 2.2 Efficiencies of solar PV systems for DC and AC appliances



2.1 HOW TO CHOOSE A SOLAR PV SYSTEM?

This Guide primarily focuses on choosing appropriate solar PV systems for DC and AC appliances (e.g., lighting, fan, TV, freezer, etc.) which are commonly used in bungalows in Vanuatu. For rural bungalow operators in Vanuatu, choosing the right solar PV systems begins with an understanding of what electricity services (e.g., lighting, cooling or refrigeration) and types of appliances are required. As mentioned earlier, rural bungalows in Vanuatu typically use both DC and AC appliances to provide electricity services. Once the electricity services and types of appliances are decided, bungalow operators need to understand how much energy will be required for these appliances to operate. The diagram below illustrates recommended steps for bungalow operators in Vanuatu to choose a solar PV system.

FIGURE 2.3 Steps in choosing solar PV systems for bungalow operators in Vanuatu



To be able to follow the abovementioned steps, it is important for bungalow operators to understand basics on electricity and energy parameters and computation. Annex A of this Guide provides basic information on electricity, energy and differences between DC and AC for those who want to review relevant technical parameters and computation.

2.1.1 Type of Electricity Services

Electricity services in this Guide refer to basic lighting, cooling, refrigeration and entertainment services, that bungalow operators aim at providing for their guests. These electricity services are usually delivered through the use of various electrical appliances. Most rural bungalows in Vanuatu have already been providing these basic electricity services, such as lighting and mobile phone charging, for their guests. However, improved electricity services, such as refrigeration (refrigerator-freezer), cooling (fan) and even entertainment (TV), could potentially generate more revenues for rural bungalows.

Rural bungalow accommodation services in Vanuatu are available as a single building facility with multiple rooms, and as multiple detached bungalows with a main building facility for restaurant and other common services. Therefore, it is important for bungalow owners to understand types of electricity services required for their facilities.

The below matrix provides a quick guide on how bungalow operators would choose electricity services for their facilities.

TABLE 2.1 Recommended electricity services for rural bungalows in Vanuatu

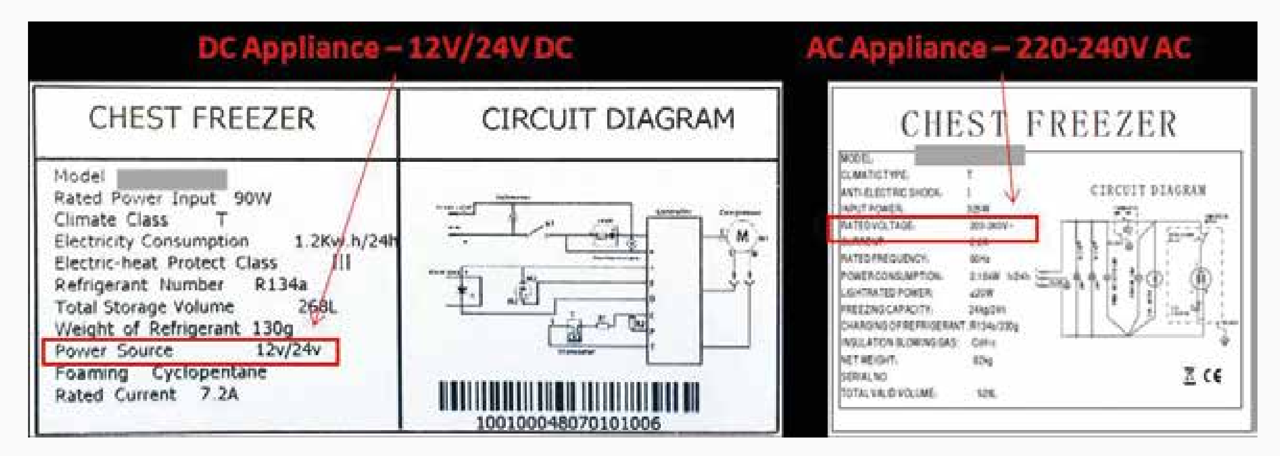
Type of Building Facility	Recommended Electricity Services	Type of Appliances
Detached bungalow	Lighting, Cooling, Mobile Charging	DC/AC lamp, DC fan
Single large bungalow with multiple guest rooms	Lighting, Cooling, Refrigeration, Entertainment, Mobile Charging	DC/AC lamp, DC fan, DC freezer, DC/AC TV
Main building for restaurant and other services	Lighting, Cooling, Refrigeration, Entertainment, Mobile Charging	DC/AC lamp, DC fan, DC freezer, DC/AC TV

2.1.2 How to Identify DC and AC Appliances

Both DC and AC appliances are available in Vanuatu to deliver the electricity services discussed in the previous section. The easiest way to get DC or AC appliances is to check with appliance retailers/suppliers. However, bungalow operators can simply look at the appliances or their packages to identify whether they are for DC or AC power supply, as manufacturers typically provide this information either on the packages or on the appliances. Shown in **Figure 2.4** and **Figure 2.5** are information on DC and AC power supply given for LED lamps and chest freezers respectively. In some cases, frequency of AC power supply in Hertz (Hz.) will be printed after the voltage rating figures, such as 220V 50Hz.

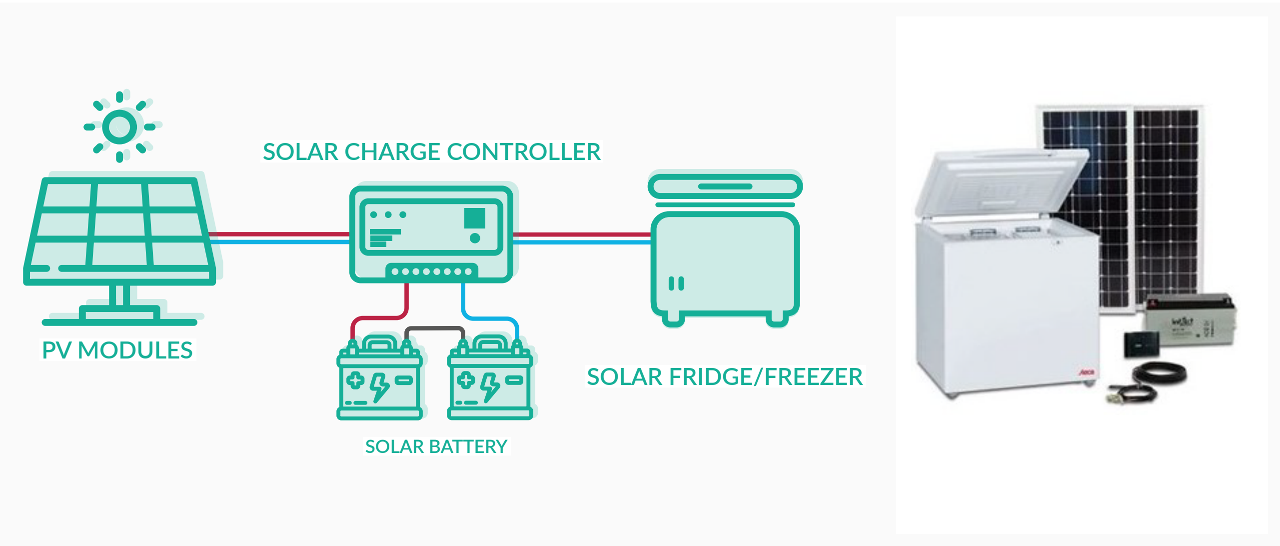
FIGURE 2.4 Information on DC and AC power supply for LED lamps

FIGURE 2.5 Nameplate of DC and AC freezers



For rural bungalows in Vanuatu, a self-contained system where a solar PV system only runs a DC freezer is considered as a viable option. Solar freezers have already been available through local suppliers in Vanuatu[3]. The pilot installation of solar freezers in ten tourism bungalows in rural off-grid areas of Vanuatu shows positive results in improved income earnings and operating cost savings. The Global Lighting and Energy Access Partnership (Global Leap) has published buyer's guides for different types of off-grid DC appliances, and suppliers of high-quality, energy-efficient refrigerators/freezers can be found at http://globalleap.org/resources/.

FIGURE 2.6 DC freezer powered by solar system



3 At least four vendors actively supplying solar freezers in Port Vila are GreenTech, Energy4All, PCS and Savvy Solar.

2.1.3 Understanding Energy Demand

Once types of appliances are decided, the first step in selecting a solar PV system for bungalow operators in Vanuatu is to understand energy used by various appliances in bungalows, and this can be achieved through a load analysis exercise. To determine the amount of energy consumed by each DC or AC load in kilowatthours (kWh), it requires information on the number of watts the load draws and the amount of time it runs (operating hours). Certain loads run daily, while others may run a few time a week, so the operating hours can be per day or per week depending on its usage pattern. The weekly energy consumption can be converted into daily energy consumption using the following equation:

Daily Energy Consumption (in watt-hours) = (Watts × Hours per day × Days per week) / 7 days per week

In addition to common DC/AC loads, such as lighting, fans, TVs and freezers, some small loads, such as chargers for mobile phones, small electronic devices as well as standby loads (e.g., TVs) should be taken into consideration. For bungalows with combined DC and AC loads, it is recommended to keep DC loads separate from AC loads. Analysis of DC/AC loads should be carried out using a spreadsheet as shown in the examples below. The spreadsheet will also enable a quick comparison of EE appliances with standard ones, for example, LED lamps produce the same amount of light as CFLs but they consume less power. Ultimately, the less energy bungalow consumes, the less expensive the solar PV system will be.

EXAMPLE 1 Analysis of lighting loads for small bungalow

Assuming a small bungalow needs 2 light points for general lighting. Wattage ratings of DC lamps in Vanuatu generally range from 2W to 10W, and 2W DC lamps are chosen for this small bungalow. These 2 DC lamps operate at 5 hours per day, 7 days per week. With these operating parameters, daily energy consumption in watt-hours is 20Wh as shown in the computation below.

Load Description	Quantity	Watts	Total Watts	Hours/ Day	Days/ Week	Total Wh/ Day
LED DC lamps	2	2	4	5	7	**20**

Daily Energy Consumption (in watt-hours) = (Watts × Hours per day × Days per week) / 7 days per week
=(4 x 5 x 7) / 7 = 20 Wh

*The total daily energy consumption of **20 Wh** is equivalent to 0.02 kWh (20 Wh divided by 1,000) and the annual energy consumption is 7.3 kWh (0.02 kWh/day x 365 days).*

EXAMPLE 2 Analysis of various DC loads for main bungalow

A main bungalow used as a restaurant and common area for guest needs 4 light points for general lighting, one 24" TV and two 24" pedestal fans. 3W DC lamps are chosen for this main bungalow to serve larger area. Daily energy consumption in watt-hours for each type of DC appliances are shown in the table below.

Load Description	Quantity	Watts	Total Watts	Hours/ Day	Days/ Week	Total Wh/ Day
LED DC lamps	4	3	12	6	7	**72**
24" DC TV	1	15	15	4	7	**60**
24" Pedestal DC Fan	2	15	30	6	7	**180**

*The total daily energy consumption for this main bungalow is **312 Wh** or 0.312 kWh and the annual energy consumption is 113.9 kWh (0.312 kWh/day x 365 days).*

2.1.4 Choosing Solar PV Systems based on DC/AC Loads and Energy Demand

Once the total daily energy consumption is determine, bungalow operators can review the approved solar home systems (SHS) products under the Vanuatu Rural Electricity Program (VREP) Phase I and II, implemented by the Department of Energy (DoE). The solar PV systems approved under VREP I are generally smaller in solar PV rating (below 60W) and sufficient for few light points, mobile charging and one small TV. While the solar PV systems approved under VREP II are larger and available to both DC and AC loads.

Shown in the table below are features of VREP I approved products, however information on daily energy production is not included in the VREP product catalogue. Therefore, it is recommended that the VREP I approved products are chosen based on the requirement of DC appliances and their operation hours. In Example 1 in the previous section, the small bungalow requires 2 DC lamps with 5 operating hours per day each. Considering this, bungalow operators can choose any of the VREP I approved products with PV rating below 20W, i.e., product no. 1, 2, 3 and 4. It should be noted that, for the same operating hours, LED lamps included in a high PV rating general give brighter light than a low PV rating.

TABLE 2.2 Features of VREP I approved products

No.	PV (W)	Light Point	Lamp Operating Hours	Mobile Charging	TV
1	**6.3**	3	5.6	1	
2	**6.6**	4	6.3	2	
3	**10**	4	6	2	
4	**12**	3	5.1	1	
5	**20**	4	6	2	
6	**20**	6	5.3	2	
7	**28**	4	9	2	
8	**30**	4	6	2	
9	**34**	3	16.6	2	
10	**38**	5	6.2	3	1
11	**51**	6	14	2	1
12	**55**	4	18	2	1

Example 2 in **Section 2.1.3** requires different types of appliances with the daily energy consumption of 312 Wh which cannot be serviced by VREP I approved products. However, the recently introduced VREP II approved products offer larger sizes of solar PV systems, including:

- 120 Wp to 160 Wp
- 220 Wp to 280 Wp
- 450 Wp to 550 Wp
- 900 Wp to 1100 Wp

VREP II product can be offered with DC Output only, AC output only or both. As of November 2018, there are 6 pre-assembled SHS products approved by VREP II, as shown in the table below.

TABLE 2.3 VREP II approved products (as of November 2018)

No.	PV (W)	Light Point	Lamp Operating Hours	Mobile Charging	TV
1	**150**		292	12V/ 114Ah	3 Days @ 60% discharge
2	**150**	325		12V/ 114Ah	3 Days @ 60% discharge
3	**270**		454	12V/ 228Ah	3 Days @ 60% discharge
4	**270**	504		12V/ 228Ah	3 Days @ 60% discharge
5	**275**	148	400	12V/ 185Ah	3 Days @ 80% discharge
6	**275**	592		12V/ 185Ah	3 Days @ 80% discharge

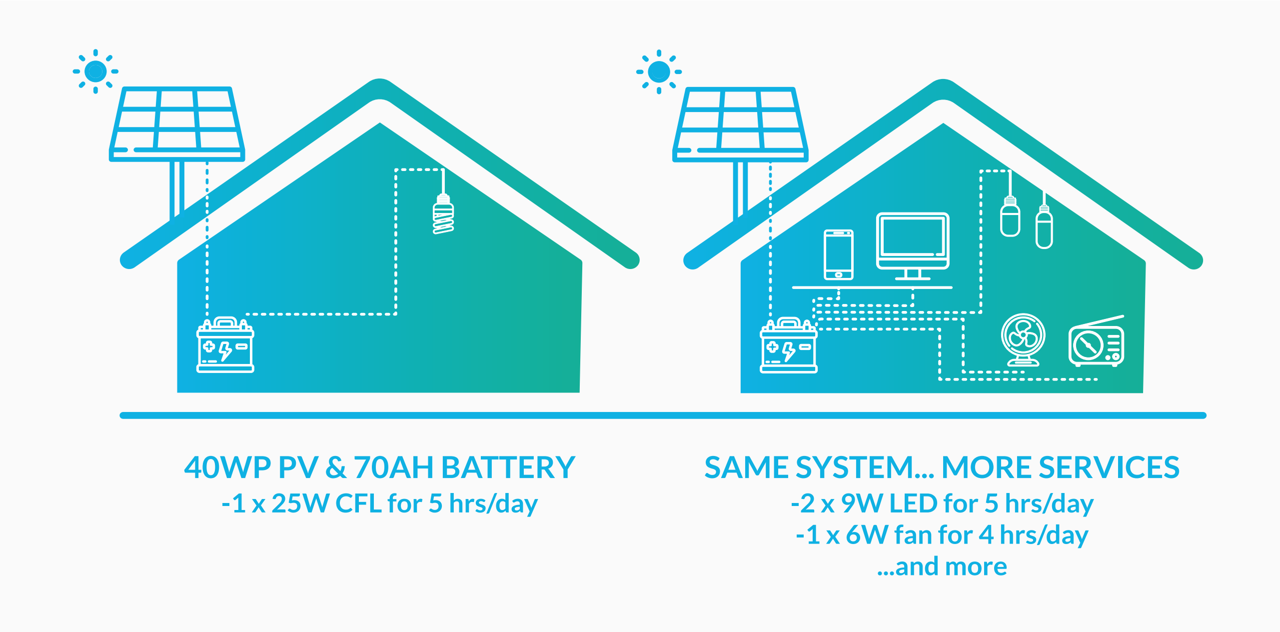
Considering that the total daily energy consumption of DC appliances in Example 2 is 312 Wh, the VREP II approved product no. 2 can be used for this example.

In case, the total daily energy consumption of DC/AC appliances exceeds the capacity of the VREP I and II approved products, bungalow operators can follow the approach for sizing solar PV systems given in Annex C to choose appropriate solar PV systems. It is recommended for bungalow operators in Vanuatu to install a dedicated solar PV system for a critical load to ensure its continuous operation. Intermittent power supply for some specific types of electricity services may result in serious consequences, for example, a long power shortage for a freezer could lead to problems in food safety.

2.2 CHOOSING EE TECHNOLOGIES

Energy Efficiency (EE) is important in off-grid facilities due to limitation and availability of energy supplies, and EE helps provide more electricity services with the same solar systems.

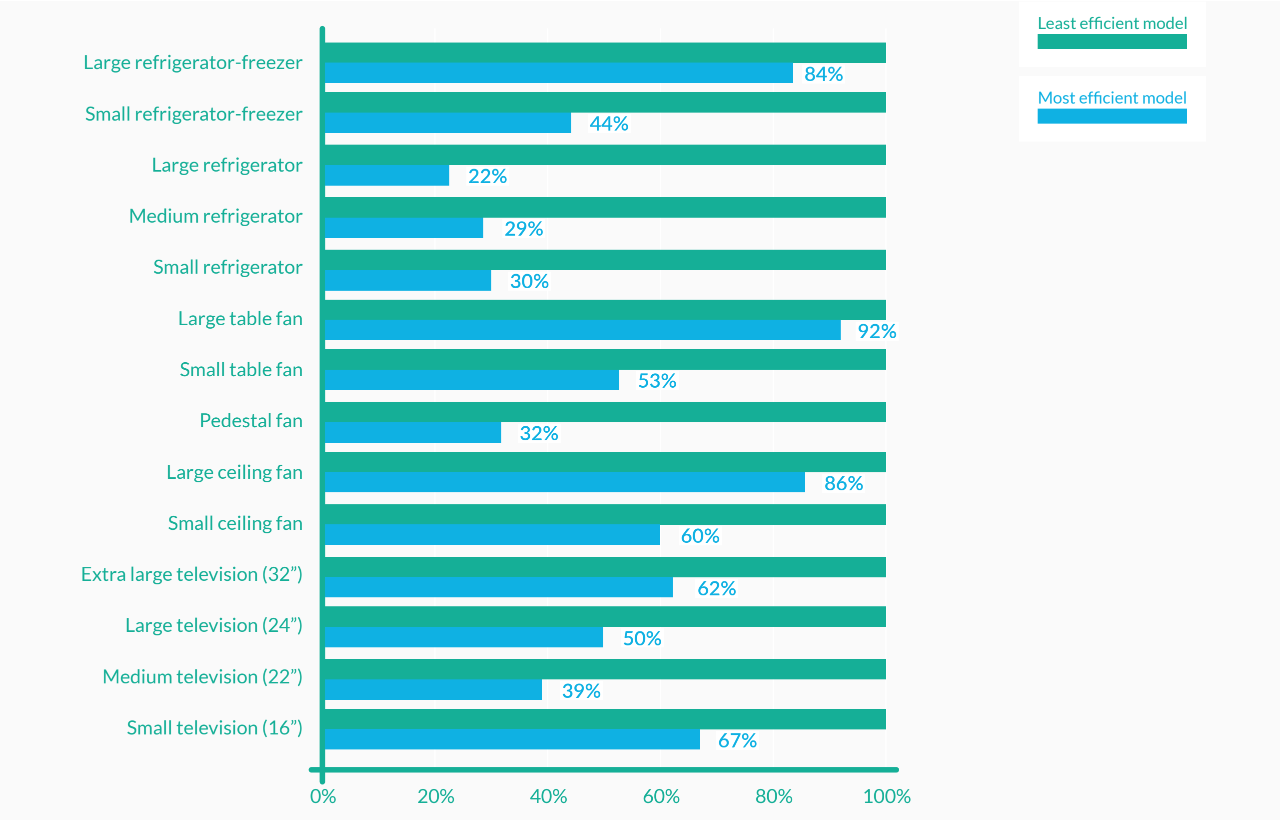
FIGURE 2.7 Enhanced services from energy efficiency in off-grid solar system



2.2.1 Energy Efficient DC Appliances

DC appliances are generally more efficient than AC appliances. However energy consumption (in watts) of DC appliances from different manufacturers and suppliers can be significantly different. The Global Leap Awards program has published various buyer's guide for off-grid DC appliances, and shown in **Figure 2.8** are comparison of power/energy consumption of the least and most efficient models of DC refrigerators/freezers, fans and televisions. It is found that, on average, power/energy consumptions of the most efficient models are about half of the least efficient models. For refrigerators/freezers, the most efficient models can consume only around 30% to 40% of the least efficient models of the same storage capacity.

FIGURE 2.8 Power/energy consumption of the least and most efficient DC appliances

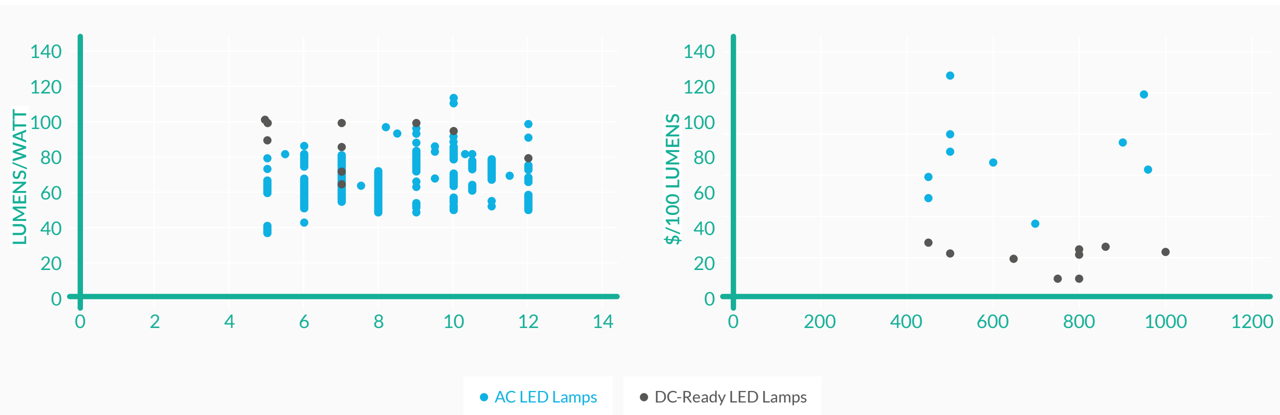


Source: 2017 Buyer's Guide for Off-Grid Fans, Televisions and Refrigerators/Freezers, Global Leap Awards

With a wide range of efficiency of DC appliances, it is recommended that bungalow operators in Vanuatu to check the latest DC appliances available from local and international suppliers, as listed in this Guide, and also review the latest version of the Global Leap Awards Buyer's Guide (http://globalleap.org/resources).

Although DC appliances are more efficient than AC appliances, they are generally more expensive due to the small market size and less market competition. In case of LED lamps, DC LED lamps are 30% to 50% more efficient than AC LED lamps but their costs can be double or triple of the AC counterparts.

FIGURE 2.9 Efficiency and cost comparison of DC and AC LED lamps



Source: DC Appliances and DC Power Distribution: A bridge to the Future Net Zero Energy Homes Conference Paper, LBNL, September 2017

2.2.2 Energy Efficient AC Appliances

AC appliances are generally used in grid-connected facilities, however some of solar PV systems used in the rural off-grid bungalows in Vanuatu have solar inverters which convert DC to AC, and for this reason, small AC appliances are not uncommon in rural bungalows in Vanuatu.

It is important for grid-connected bungalow facilities to understand the energy use profiles to prioritize areas to be focused for EE improvement and investment with EE AC appliances. In grid-connected facilities, energy use profiles vary with services provided, comfort levels and climate conditions. Typically, accommodation facilities in hot and humid climates have the largest energy consumption in cooling (see **Table 2.4**). The energy demands for cooling falls within the range of 35%-50% of total consumption, and hot water usage falls between 7%-18%.

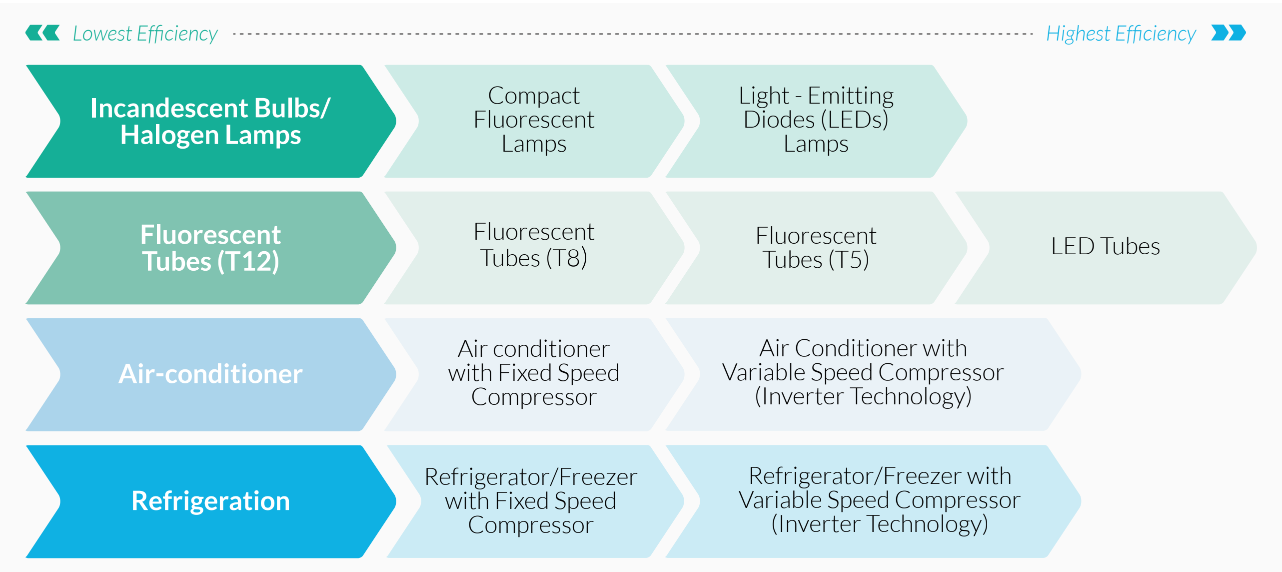
TABLE 2.4 Shares of energy consumption of appliances in hotels in hot and humid climates

Appliances	Share of Energy Consumption
Air Conditioner	35%–50%
Refrigerator/Freezer	5%–6%
Water heater	12%–15%
Laundry (no heat)	1%–2%
Lighting	15%–22%
Pump & fan	10%–18%
Office equipment	4%–6%
Cooking	1%–2%

It should be noted that, for rural off-grid bungalows in Vanuatu, the energy use profiles are likely to be different as refrigerator/freezer appears to be the largest energy end-use rather than lighting.

When replacing old appliances with new ones, bungalow operators should carefully choose those with high efficiency; these will consume less energy and therefore save money in the long run. The diagram below indicates possible EE appliances for bungalows in Vanuatu from least efficient (left) to most efficient (right) technologies.

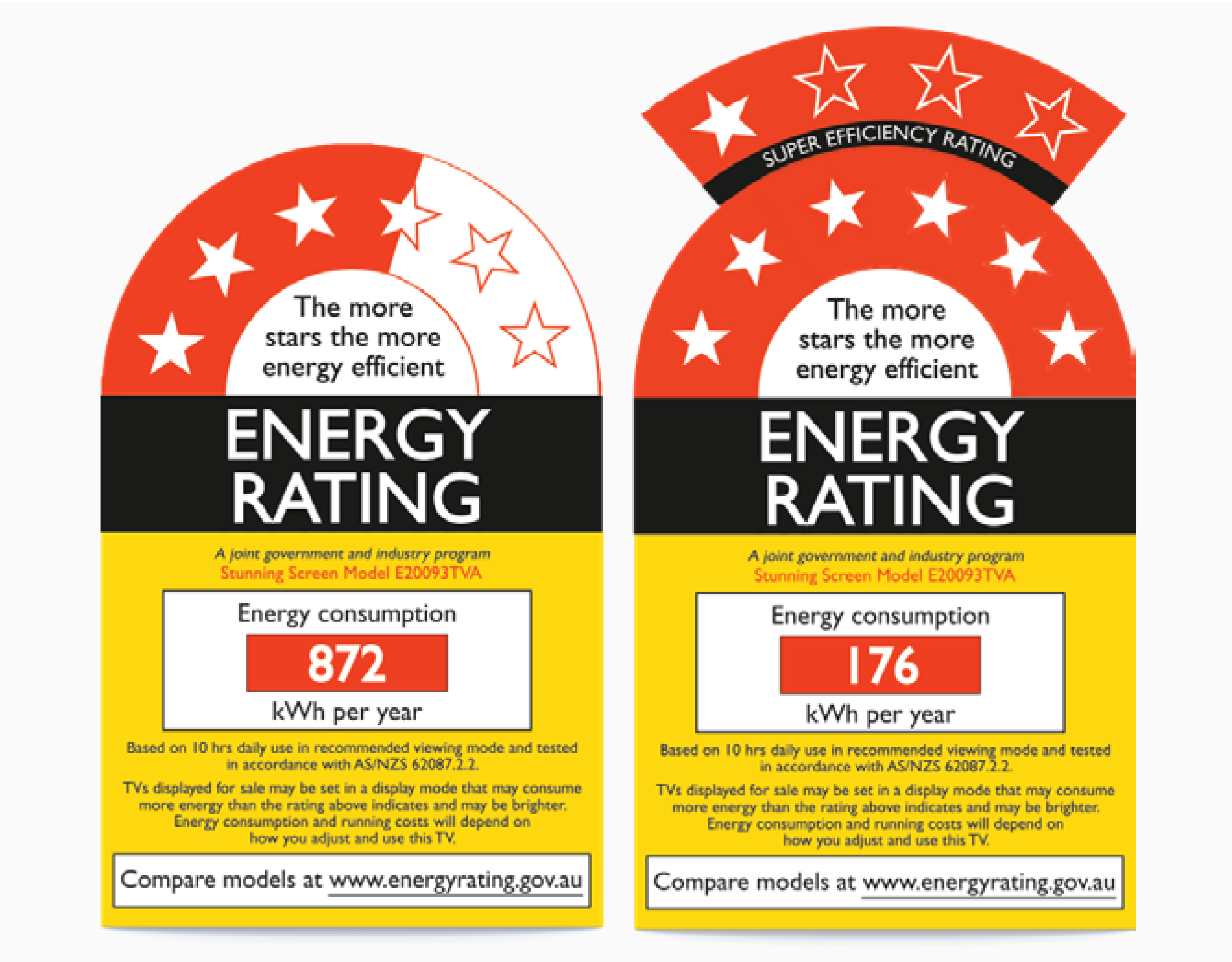
FIGURE 2.10 Energy efficiency technologies from least efficient (left) to most efficient (right)



EE AC appliances can be identified by their energy-rating labels. Different countries use distinct rating systems, and it is therefore important to note how the rating scheme corresponds to the product's efficiency. Vanuatu has begun implementation mandatory MEPS and energy labeling for refrigerators and freezers and air conditioners based on the Energy Rating scheme of Australia/New Zealand since late 2017 (see **Box 1**).

The energy rating labels promoted by the Australia/ New Zealand Energy Rating scheme are common in Vanuatu, and in this system, higher marks indicate higher efficiency. The least efficient products allowed to be sold in Australia are given one just star – whereas the most efficient are given 10.

FIGURE 2.11 Energy rating labels for AC electrical appliances from Australia/New Zealand



Source: www.energyrating.gov.au

The Energy Rating Scheme focuses on a limited range of household appliances and electrical equipment. Some products have energy rating labels, others have MEPS, while others have both. The energy rating labels can be found on air conditioners, refrigerators/freezers and swimming pool pumps, while only MEPS (no energy rating labels) are applied for lighting (incandescent and fluorescent) and electric/gas storage water heaters.

BOX 1 MEPS and energy labeling for AC appliances in Vanuatu

The Department of Energy (DoE) with the technical assistance from the Pacific Community and funding from the Australian Department of Foreign Affairs and Trade (DFAT) developed the Energy Efficiency of Electrical Appliances, Equipment's and Lighting Products Act No. 24 of 2016 which was passed by the parliament on 9th December 2016, and gazetted by State Law on 29th March 2017.

The Energy Efficiency of Electrical Appliances, Equipments and Lighting Products Act was established to regulated and promote energy efficiency of appliances in Vanuatu; to prohibit the importation of inefficient electrical products into Vanuatu, and to stop Vanuatu becoming a dumping ground for unwanted or inefficient appliances from overseas. The Act targets the following AC appliances:

- *Refrigerators and freezers;*
- *Air conditioners, and;*
- *Lighting products (incandescent lamps, linear fluorescent lamps, compact fluorescent lamps and fluorescent lamp ballast).*

DoE is responsible for administering the Act and implementing public awareness to consumers and capacity building for other players.

AC Freezer with Australia/New Zealand Energy Label in Vanuatu

Possible EE options of AC appliances for bungalows in Vanuatu are discussed below.

Lighting

The table below shows types of lighting that vary from low efficiency incandescent lamps to high efficiency Light Emitting Diode (LED) lamps. Light efficacy (lumen/watt) provides information on how efficient the lamps are. Higher light efficacy means that the lamp can provide more light (lumen) per power input (watt). LED lighting is the most energy efficient lights available on the market these days. LED lamps have efficacy up to 110 lumen/watt, while incandescent and halogen lamps have less than 20 lumen/watt. Therefore, switching from low-efficiency lamps to higher efficient ones can reduce an electricity bill by up to 20%. LED lamps also have considerably longer lifetimes. If lamps are turned on for 8 hours per day, incandescent lamps will last around 6 months, fluorescent lamps last around 3.5 years, and LED lamps last up to 17 years!

TABLE 2.5 Types of lighting and their characteristics

Type	Incandescent lamp	Halogen lamp	Compact fluorescent lamp (CFL)	Fluorescent lamp	LED
Light Efficacy [Lumen/ Watt]	7–14	16–18	60–80	80–110	60–150
Rated Watts	40W–150W	5W–500W	2W - 200W	T12 40W T8 32W T5 18W, 28W	3W–40W
Lifetime [hours]	1,000	2,000–4,000	8,000–12,000	10,000	50,000
Cost	$	$$	$$	$$	$$-$$$
Note: $ - Low Cost, $$ - Medium Cost, $$$ - High Cost					

When replacing old lamps with new energy efficient ones, consideration should be given to achieving a light level equivalent to that of the existing lamps or the level recommended by international standards. The light level is measured in lumens. Lux is another luminance unit measured in lumens/m.

Refrigerators/Freezers

New refrigerator/freezer models have better insulation, higher efficiency heat exchanger coils, and compressors. Based on the Australian/New Zealand Energy Star Rating scheme, replacing old refrigerators/freezers with ones that have higher energy ratings will reduce electricity bills by 23% per additional star.

Air Conditioners

Air conditioners (ACs) with inverter technologies consume 30%-50% less energy compared to non-inverter types. Inverter units look the same as typical non-inverter units from the outside, but contain a microprocessor in the compressor, which controls speed and amount of refrigerant flow. Therefore, these systems can vary in speed and energy consumption based on cooling requirements. Non-inverter ACs work at fixed speeds, meaning that the compressor has to stop and start more often and consumes more energy as a result. The easiest way of choosing an AC is to look at its energy-rating label.

ACs employed in accommodation facilities in the Pacific tend to be undersized. As a result, they cannot maintain desired room temperature. This encourages guests to leave their ACs on all the time (even when the room is unoccupied), and results in high-energy consumption. Therefore, proper sizing of the AC units should be an important consideration during retrofitting. When the room can be cooled properly and quickly, it is easier to encourage guests to turn off the ACs when they leave the room. Although the efficient AC units have higher initial cost, their lower energy consumption and decreased operating hours result in lower operating costs.

Table 2.6 shows efficiency comparison between window, split, and split inverter AC units. The window type has the lowest Energy Efficient Ratio (EER - the ratio of the net cooling capacity to the effective power input at any given set of rating conditions). EER can be expressed in watt-per-watt or BTU/hr/W.

Higher EER means that the system uses less power for the same cooling capacity. For a 1-ton window type unit, the EER (W/W) is around 2.63. The EER of old units is often much lower. Changing window type with split type AC with inverter increases the EER from 2.63 to 3.4 and therefore consumes 30% less energy.

AC UNIT CONVERSION

12000 BTU = 3.516 kW

1 Refrigerant Ton = 12000 BTU/hr

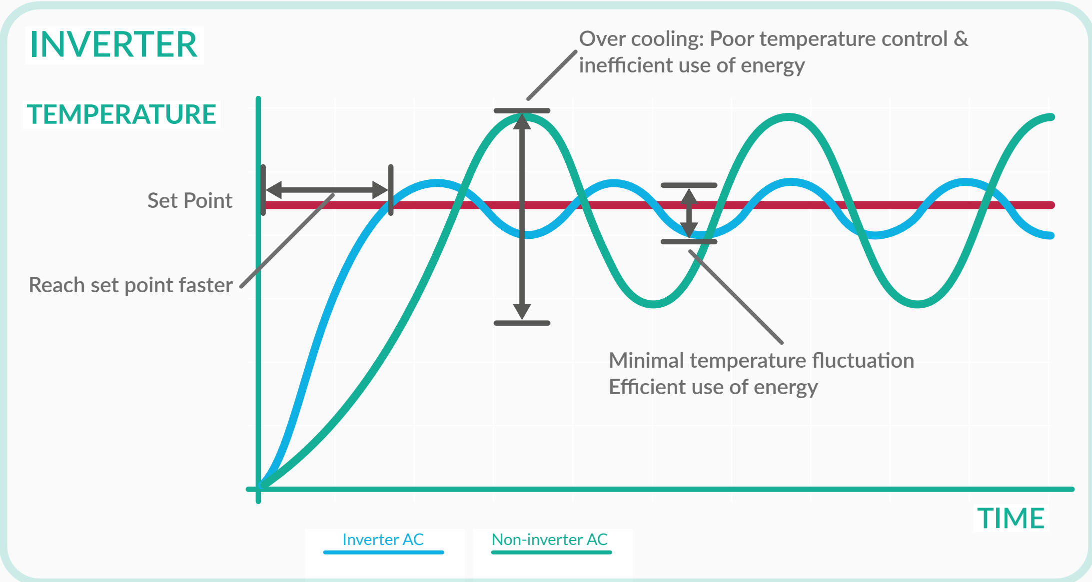
EER (BTU/hr) = 3.412 x EER (W/W)

TABLE 2.6 Comparison of EER (W/W) of AC units

Cooling Capacity	Window	Split	Split Inverter
1 Ton (12,000 BTU/hr)	2.63-3.30	2.80-3.35	3.40 – 4.62
1.5 Ton (18,000 BTU/hr)	2.58-3.11	2.80-3.40	3.30 – 4.51
2 Ton (24,000 BTU/hr)	2.54-3.05	2.80-3.13	3.25 – 3.91

BOX 2 Variable speed compressor air-conditioners

Variable Speed Drive (VSD) compressor air conditioners utilize inverter technologies (also called inverter-type ACs) to vary the speed of the compressors, and deliver precise cooling as required. While in operation, the compressor operates at a high speed to cool the space. As the room temperature approaches the required temperature, the compressor slows down, maintaining a constant temperature and saving energy. Any sudden fluctuation in the temperature will be sensed and instantly adjusted to bring the room temperature back to the set temperature. Inverter-type ACs run continuously at varying speeds, delivering cool air only as needed. Due to this, inverter-type ACs may reach EER up to 4.5 W/W or 15 Btu/hr/W[4].



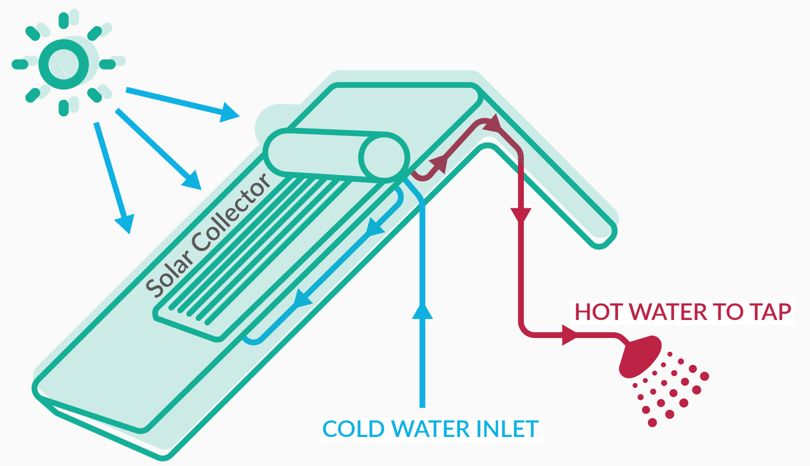
Source: Daikin

4 http://www.daikinac.com/

Solar Water Heater

A solar water heater generates hot water by transferring solar heat to the water or fluids that flow inside the collector. A solar water heater is not an energy efficient model of electric water heater/boiler but rather an alternative which use solar radiation to produce hot water. A solar water heater can be a small system that produces 2-3 litres of hot water per day or a large system for up to several thousand litres per day. Often, hotels in the Pacific use a thermosiphon system with a water tank on top of the collector. Natural circulation of water allows water to flow between the collector and tank without the need for a pump. Larger installations may use a circulating pump, multiple solar water heating panels and a separate hot water storage tank. Payback periods for solar water heaters depend on system cost, water usage pattern, solar radiation, and the cost of the fuel that it replaces. In general, the payback period of a solar water heater system is 3-8 years.

FIGURE 2.12 How a solar water heating system works



3

Best practice guide in operation and maintenance

Solar energy has significant impacts on both supply and demand of energy for bungalows in Vanuatu. Solar systems are the main source of electrical energy in off-grid bungalows, while solar heat gain plays a key role in the energy consumption of cooling and refrigeration loads in buildings. Best practices to maximize solar energy generation and minimize solar heat gain to reduce electricity loads are discussed in this section.

3.1 OPERATION AND MAINTENANCE OF SOLAR PV SYSTEMS

3.1.1 Best Practice in Solar PV Installation

Because solar irradiance directly affects the amount of energy that a PV module produces, it is important to orient the PV module (panel) directly facing the sun, and ensure that any possible shading of the PV module is avoided. Best practices for installation of PV modules are summarized in the table below.

TABLE 3.1 Best practice in solar PV installation

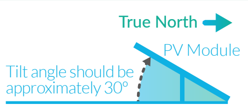
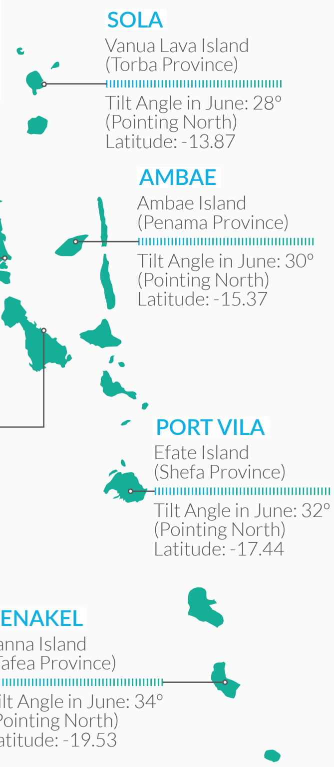
Best Practice	Action/Recommendation
Shading	It is important to keep your PV modules shading free from 9am to 3pm. Full shading reduces energy production, while a small area of shading, such as a leaf falls on the solar module, can cause damage to the solar module. A shaded solar cell can heat up to such an extent where the cell material is damaged.  
Tilt and Orientation	In Vanuatu, the PV modules shall be pointed as close to true north as possible, although local installation conditions such as orientation of rooftop may required adjustments. For solar home systems in Vanuatu, a tilt angle of around 30° will be the most appropriate as this will result in a greater energy daily output in June which has the lowest peak sun hours. In any case, the tilt angle should not be less than 10° in order for rains to run off fast enough to keep the panel surface clean. Panels tilted less than 10° may require frequent manual cleaning.  

TABLE 3.1 Best practice in solar PV installation *(cont.)*

Best Practice	Action/Recommendation
Mounting (Ventilation and Structure)	The efficiency of a solar module decreases as it increases in temperature. It is important to ensure a free flow of air above and below the solar modules. When the solar modules are mounted on the roof, elevation the solar modules off the roof provides gaps for natural ventilation. A gap between the panels and the roof provides natural ventilation. The maximum size of the ventilation gap depends on the quality of mounting frame. Cyclone prone areas obviously require stronger mounting structures. It is not recommended to install solar modules on thatched roof as its structures are unlikely to be sufficiently strong to hold the panels in case of strong wind. A separate on-ground wooden structure is a more prefered option in this case (see figure below). 

3.1.2 Best Practice in Solar PV Maintenance

The amount of current (and power) produced by a PV module is directly proportional to the intensity of the sunlight striking the PV panel. As dirt and dust (as well as leaves and other debris) begin to accumulate on the panel, the intensity of the sunlight striking the panel is reduced, and this can reduce the energy output by nearly 20%. The cleaning can be part of regular system inspection/ maintenance. However the exact schedule of cleaning is dependent on the location of installation and level of cumulative soiling. Regular monitoring the energy output and cleaning the panels whenever the output seems low can be an option for bungalow owners. The cleaning should be carried out when the panels are not too hot, so they will not be damaged with a sudden blast of cool water.

FIGURE 3.1 Dirty solar panel (left) and cleaning of solar panel (right)

3.1.3 Best Practice in Battery Installation

Most of solar batteries available in Vanuatu are maintenance free sealed lead acid batteries. However sealed batteries do not like heat and should be installed away from sun light and heat generating appliances/equipment. Batteries should be stored in a proper container which provides good ventilation and outdoor installation as shown in the figure below is not recommended. In addition, basic preventive maintenance should be regularly carried out including inspection of connection, fuses and circuit breaker, terminal cleaning, and voltage checking.

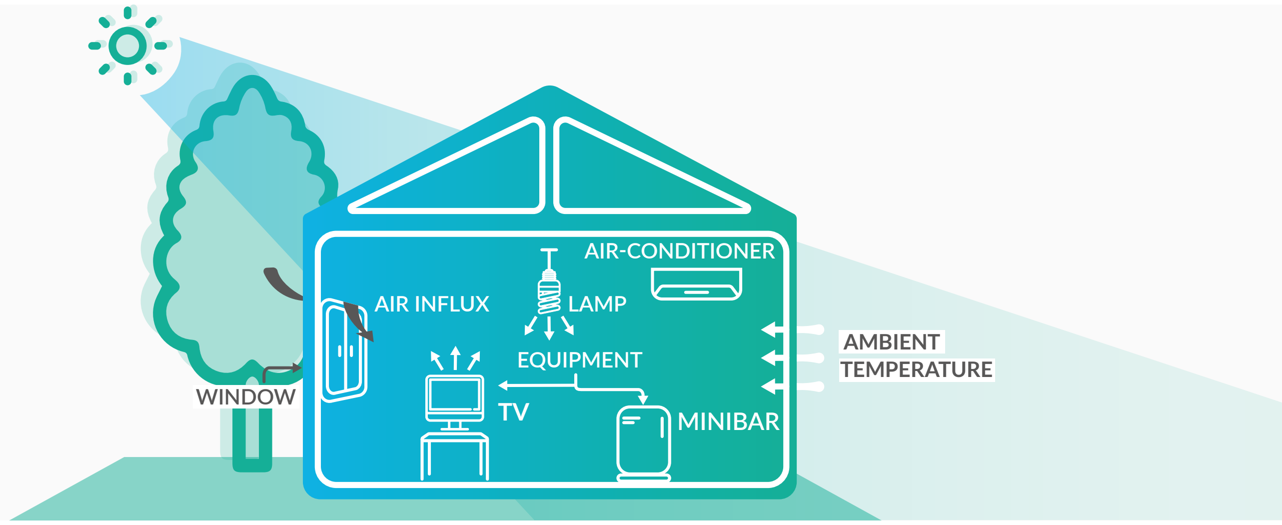
FIGURE 3.2 Outdoor installation of solar batteries (left) and recommended battery box (right)

3.2 OPERATION AND MAINTENANCE OF ENERGY END-USE SYSTEMS

3.2.1 Best Practice in Minimizing Cooling Loads

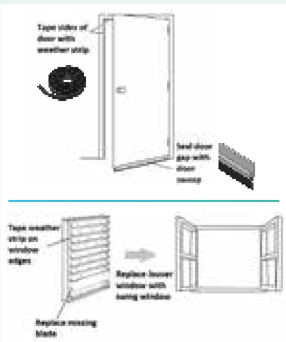
Solar heat gain plays a key role in energy consumption by cooling and refrigeration services in buildings. In addition, air infiltration and heat generated by various electrical appliances used in buildings increase cooling loads and make refrigerators, freezers and air conditioners work harder to deliver the services required (see **Figure 3.3**).

FIGURE 3.3 Factors impacting cooling and refrigeration loads in buildings



For the Southern hemisphere, the north side of the building receives solar radiation most of the year. The west side of buildings receives intense heat gain during the afternoon. Various no-cost and low-cost best practices/ measures can be implemented to prevent heat gain from solar radiation and minimize cooling load which can result in significant energy cost reduction.

TABLE 3.2 Best practices in minimizing cooling load

Best Practice	Action/Recommendation
	**North or South** Shade south (northern hemisphere) or north (southern hemisphere) walls of the building with roof overhang or awning.
	**East and West** Planting trees or add vertical shadings on the west side of the building.
	**Southwest (northern hemisphere) or northwest (southern hemisphere)** Vertical fin or wall can effectively shade southwest/northwest walls if the building is not oriented east-west.
	**Roof** Paint building's roof with reflective white paint.
	**Air-conditioned space** Cooling loads on an air-conditioned space can also be reduced by minimizing air infiltration. Outside air can enter the building through cracks, gaps, and openings in doors, windows, walls, and ceilings. Sealing the air leakages will result in lower energy consumption for cooling. Doors and windows can simply be sealed using weather strips and door sweeps. Adjustable louver windows are often used in buildings in the Pacific because they can provide excellent ventilation; however, they have the disadvantage of somewhat higher air leakage than sliding or hinged windows.

3.2.2 Best Practice in Operation of Electronic and IT Equipment

The small loads that are on 24/7 are the so-called phantom loads. Many televisions and entertainment centers draw power even when they are "off," and chargers for mobile phones and small electronic devices and digital clocks incorporated in microwaves can cause major problems. If these small loads are always present, then the solar inverter can never turn off and must always supply power. Therefore, the solar inverter requires a small amount of power to produce a low level of power, causing it to operate at its worst efficiency level. It is strongly recommended these small loads are unplugged from electrical sockets, and by removing these small loads, the solar inverter can go to sleep and wake up (and operate more efficiently) when the larger loads are turned on.

3.2.3 Best Practice in Operation and Maintenance of Lighting

Lighting is an important cost factor. About 15%-22% of the total electricity consumption by accommodation buildings is used for lighting. Good lighting is essential for customers' satisfaction as well as for the health and safety of staff and visitors. With modern LED technologies, lighting energy costs can be reduced significantly by using LED lamps and controllers. The payback period for lighting retrofits in the Pacific is typically short, usually well under two years, due to high electricity cost, and it is considered as one of the most cost-effective measures available to hospitality businesses.

However there are many energy saving opportunities for lighting which require no or minimal investments. Behavior campaigns can yield substantial energy savings, both through the guests and housekeeper behavior. Encouraging housekeepers to use natural light during room cleaning is a simple first step to implement. Summarized below are best practices in operation and maintenance of lighting systems.

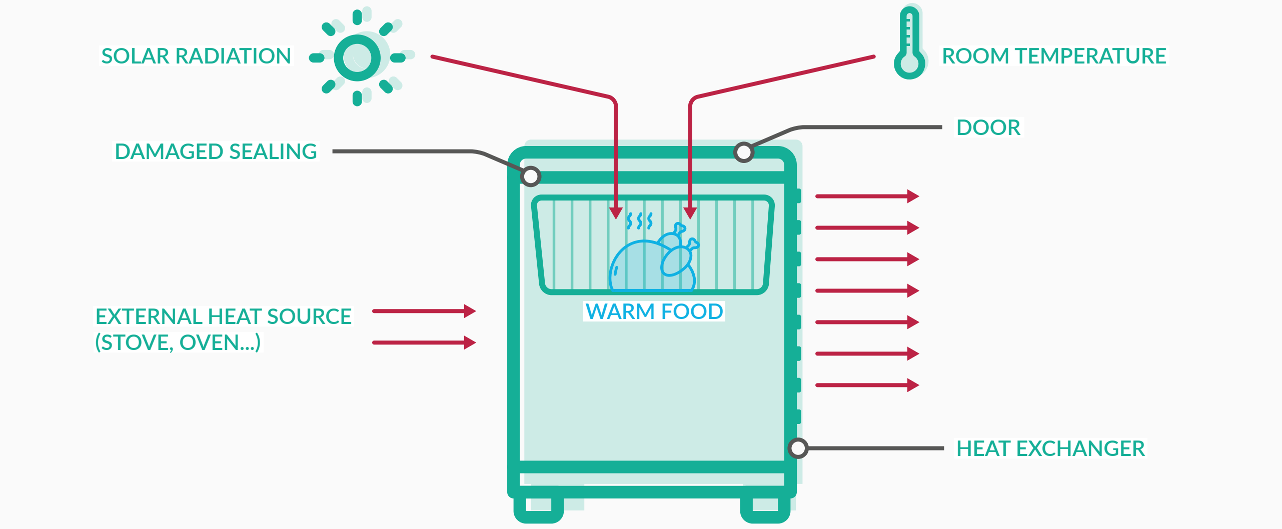
TABLE 3.3 Best practices in operation and maintenance of lighting

Best Practice	Action/Recommendation
Turn off when not in use	Switch off lights in vacant rooms. Put up signs to encourage guest to turn off lights when not in use. Timing controls can be used to reduce night- time lighting, for example, by switching off selected lights along corridor areas and in remote garden areas. Photocells and motion detectors are very effective in areas such as public toilets where the user cannot be expected to turn the lights on and off. However, sensors must be placed to turn lights on as soon as the customer enters the area and, to ensure that the customer does not enter a completely dark room.
Use natural light and light color	Keep the window clean and let natural light in from windows on the south side (for Vanuatu) so that there is light without additional heat. Using light color paint for room interiors can brighten the room and reduce lighting use.
Clean the lights  © IIEC	Clean lamps and luminaires regularly. This can be a part of normal housekeeping. In humid climates, moss and mould can build up on lamps and luminaires and reduce their efficiency as much as 50%.

3.2.4 Best Practice in Operation and Maintenance of Refrigerator/Freezer

For a grid-connected accommodation facility, refrigerators/freezers consume about 5% to 6% of the total electricity consumption. For an off-grid bungalow, the solar PV system for refrigerator/freezer could be the largest solar PV system in the facility. In many cases, refrigeration is badly used, poorly managed and maintained, and there are usually multiple actions for achieving worthwhile savings in consumption and costs. Almost all refrigeration equipment works in the same way. It transfers the heat from the inside to the outside, and it consumes energy to perform this task. The more heat it has to transfer out, the more energy it consumes.

FIGURE 3.4 Factors impacting energy consumption by refrigerators/freezers



Best practices/EE measures in operation and maintenance of refrigerators/freezers are summarized in the table below.

TABLE 3.4 Best practices in operation and maintenance of refrigerator/freezer

Best Practice	Action/Recommendation
Set correct temperature setting	The temperature inside refrigerators is in the range of 2°C to 8°C, freezers usually work with temperatures of around -18°C. This temperature assures freshness of the food for a long time period. Chest freezers are more energy efficient than uprights. To save energy it is important that the temperature settings are correct for the content. Beware of over-cooling. Only 5°C below the required temperature can add 10-20% to the running costs.
Avoid external heat	Keep refrigerator from reach of sunlight and away from hot equipment like ovens and stoves. Place the refrigerator in a cool and shady room. Do not put warm food inside the refrigerator.
Avoid air influx	Keep the air influx to refrigerators/freezers to a minimum. This can simply be achieved by keeping refrigerators/freezer doors opening times to a minimum. The air temperature in the unit can increase by as much as 0.5°C for every second the door is kept open. In older equipment, this will also lead to ice formation and lower energy efficiency. Frequent openings will also mean more frequent defrosting which is a very energy intensive operation that should be kept to a minimum. Make sure that refrigerator is properly sealed. Old refrigerators often have worn seals so that the door cannot be closed tightly. Replacing the seals can reduce energy up to 20%.
Ensure proper ventilation	Blocked condensers can increase operating cost up to 5%. Make sure that the refrigerator is at least 6 inches from the wall and should not be enclosed in unvented cabinetry.
Defrost regularly	Defrosting the ice formed in the refrigerator can save energy. It is strongly recommended to follow defrosting instructions provided by the manufacturer. Do not use any sharp object to remove ice within freezer as it could permanently damage freezer compartment beyond repair.
Clean condenser coils twice a year	Accumulated dust on the condenser coils reduces heat transfer. By cleaning the condenser coils regularly, refrigerators can work more efficiently and consume less power. Use a brush or vacuum to clean the coils; unplug the refrigerator before doing so.
Turn off when not in use	Turn off refrigerators in unoccupied rooms, particularly during low season.

3.2.5 Best Practice in Operation and Maintenance of Air Conditioner

Accommodation buildings can reduce the energy consumed by operating existing equipment more effectively and identifying the best type of air conditioner for their property. Similar to refrigerators/freezers, air conditioners transfers heat from the inside to the outside by using electrical energy. The energy consumption rises with the amount of heat (cooling load) that has to be transferred (see **Figure 3.3** for various factors which impacts cooling load in a building).

In general, air conditioners are classified in three types: window, split, and central. Window types are the most common in the Pacific Islands including Vanuatu. They are generally smaller, and less expensive units, and can be installed without a duct; however, they are the least efficient. Split type room air conditioners have a split fan coil (indoor) and condensing (outdoor) unit, and the two units are connected by refrigerant pipes. The indoor unit circulates and cools the room air. The outdoor unit transmits the heat to the ambient.

Summarized in the table below are best practices in operation and maintenance of room air conditioners.

FIGURE 3.5 Room air conditioning units

TABLE 3.5 Best practices in operation and maintenance of room air conditioner

Best Practice	Action/Recommendation
Turn off AC when not in use	Put signs in your guest rooms to remind guests to turn off AC before leaving the room. Guests often tamper with key tag controls to leave the AC on when they are not in the room to ensure that the room is cool when they return. Place signs to raise awareness of energy and environmental impacts and how they can help.
Make sure that doors and windows are closed when the AC is on	Put signs to remind guests to close doors and windows when air conditioning is on. If windows are frequently open when air conditioning units are operating, explore fitting automatic cut-off switches.
Set temperature setting to at least 25°C	Put signs on the AC thermostats to encourage guest to set the temperature above 25°C. Ensure that housekeepers set thermostat to 25°C Increasing the temperature by 1°C reduces the energy consumption by 6%.
Shut down (turn off lights and AC) parts of the bungalow that are not in use	Arrange for guests to stay in rooms next to each other, or in one part of the building so that unoccupied areas can be shut down.
Avoid heat gain from western sunlight	Use curtains that have the side next to the glass colored white or are made of reflective material to shade sunlight through the window, particularly on the western side. Plant trees on the western side of the building to reduce heat gain from the afternoon sun.

TABLE 3.5 Best practices in operation and maintenance of room air conditioner *(cont.)*

Best Practice	Action/Recommendation
Provide guests with alternate cooling method by using ceiling fan	Use ceiling fans to help distribute cooling throughout the rooms.
Clean the compressor regularly. Accumulated dust on the compressor coils reduce their heat transfer capability	Air-conditioning systems have two coils made of copper tubes with aluminium fins. The evaporator coil or fan coil is located inside the room, while the condenser coil is located outside. **Indoor Coils (Fan Coils)**  • Cut off power to the AC unit, shut off the circuit breaker • Remove the air filters and clean them using small brush or rinse with water • Attach brush to the vacuum cleaner and turn on the vacuum. Run the brush over coils • Replace the air filters **Outdoor Coils (Condenser)**  • Cut off power to the AC unit, shut off the circuit breaker • Remove side panel to access the coil inside, if required • Put plastic cover other parts except coils to prevent them from getting wet • Use water hose to spray water over the coil from inside out • Wipe coils to dry or use air dryer • Replace the side panel • Outdoor coils (condensers) should be shaded to provide the best A/C efficiency and if ground mounted, should not have airflow reduced by contact with hedges or other landscaping components.
Prevent air leakage through window and door gaps	Air leakage through window and door gaps imposes significant amount of energy waste in air-conditioner. Best practice in minimizing air leakage in **Table 3.2** should be implemented.


© GGGI

4

Annex A: Electricity and energy basics

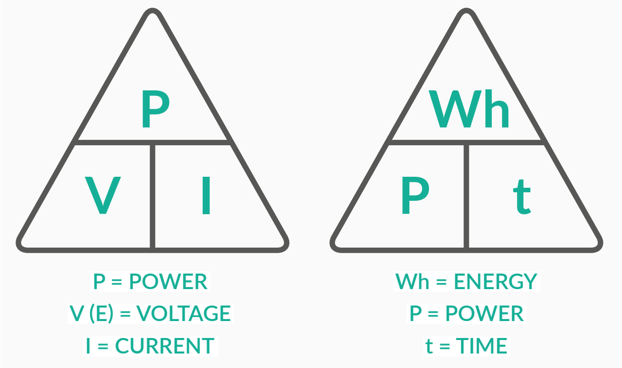
4.1 UNDERSTANDING POWER AND ENERGY

Power and energy are often used interchangeably, however this is not correct, as Power is a rate, measured in watts (W), while Energy is equivalent to how long we use Power or Power x Time, measured in hour (h). The followings are simple definitions of electrical parameters typically used in calculation of Power and Energy.

- **Voltage**: Electrical pressure, measured in volts (V or E)
- **Current**: Electrical flow, measured in Amps (A)
- **Power**: Rate at which electricity is used, measured in watts (W)
- **Energy**: Amount of power used over time, measured in watt-hour (Wh)

Calculation of power and energy uses the metric system, i.e., 1,000 = kilo = k 1,000,000 = mega = M 1,000,000,000 = giga = G, so 1,000 W = 1 kW and 1,000,000 W = 1 MW. The below algebra diagrams show how the above electrical parameters can be calculated.

FIGURE 4.1 Algebra triangles for calculation of electrical parameters



Using the above algebra triangles is simple, for example Power (W) = Voltage (V) × Current (I), while Energy (Wh) = Power (W) × Time (hour). It should be noted that Energy is more often measured with kWh Symbol (1,000 Wh). The triangles can also help us identify the bottom parameters, for example, Current (I) = Power (P)/Voltage (V), and Power (P) = Energy (Wh)/Time (hour).

BOX 3 Calculation of energy used by appliances

You have a 12V 0.5A light bulb that will run for 3 hours per day. You also have a 30W radio that will be on 8 hours per day. How much energy in kWh does the cabin use in a day?

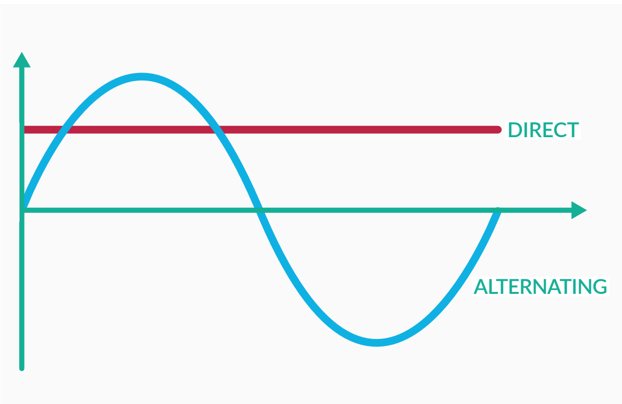
Answer:

- *12V × 0.5A = 6W*
- *6W × 3 hours = 18Wh of energy per day for the lights*
- *30W × 8 hours per day = 240Wh of energy per day for the radio*
- *Total energy = 18Wh + 240Wh = 258Wh/day*

4.2 UNDERSTANDING DC AND AC

AC differs from DC mainly in the sense that the current alternates in flow at a specific interval of time. The process of alternating the direction of current flow can be viewed graphically, as shown in **Figure 4.2.** The sine wave shape of the AC current flow curve indicates the back-and-forth movement of current. In contrary, the DC current flow is represented by a line that remains straight over time.

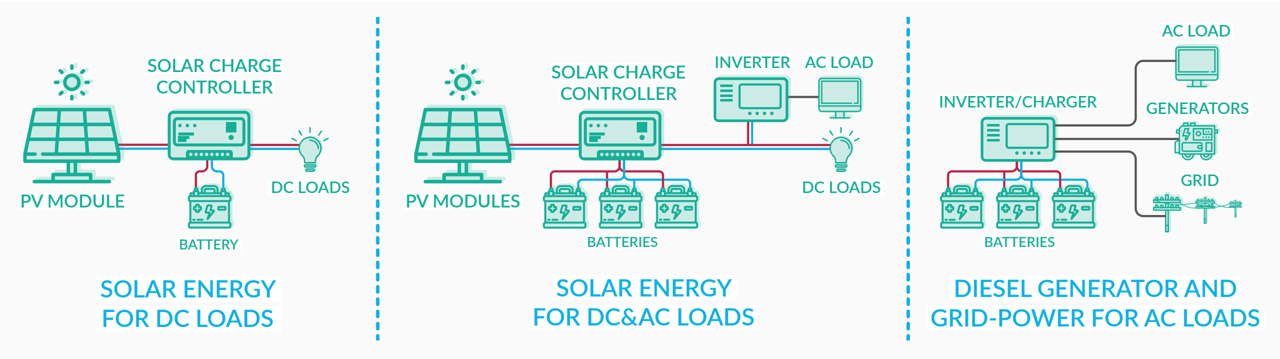
FIGURE 4.2 DC and AC current flow versus time



PV modules create a flow of current described as DC which is also the form of electricity stored by and delivered from batteries. This characteristic is very convenient when charging batteries from PV modules, however it is rather inconvenient when bungalows with DC power systems want to use standard electrical appliances that runs on AC, which is the form of electricity delivered from utilities to grid-connected homes and businesses.

However, a PV system can provide AC power through a component called "inverter". Inverters take DC power delivered by PV modules and batteries and turn it into a form that the typical household loads can use, which is often AC. Shown in the figure below are different configurations of energy supplies for DC and AC loads for bungalows in Vanuatu.

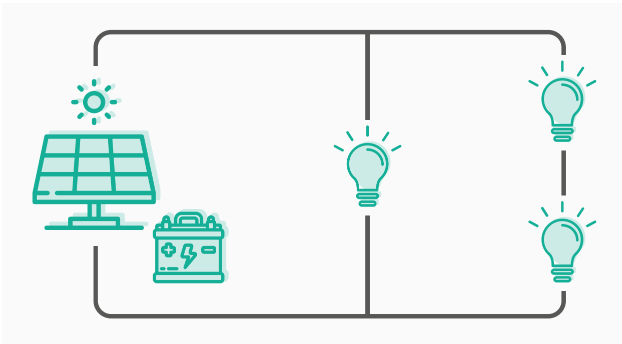
FIGURE 4.3 Solar systems for DC and AC loads in bungalows in Vanuatu



4.3 TYPES OF ELECTRICAL CONNECTIONS (SERIES AND PARALLEL)

Series and parallel connections can be found in both DC and AC electrical systems. In DC systems, series connection connects positive to negative and increase, while, in parallel connections, all the positives are connected to one point and all the negative to another. Lamps on the right are connected in series to each other. A lamp in the middle is connected in parallel with the other lamps.

FIGURE 4.4 Series and parallel connections



4.4 RESISTANCE AND LOSSES

Conductor in any wires and cables has internal "resistance". An ohm is a unit of resistance also symbolized with the Greek symbol Ω. Ohm's law is a relationship between current (I), voltage (V) and resistance (R), and expressed as V = I x R. This means that when current goes up and resistance remains constant, then voltage also increases. When current goes through a wire, there are losses and those losses are consumed by the wire in the form of heat. The losses are known as voltage drop. If the current is increased, so is the voltage drop/loss. The main factors impacting resistance in electrical wiring and cabling generally include size of conductors (crossectional area) and length, as well as jointing and connection of wires and cables.

4.5 BASIC TOOLS FOR MEASUREMENT OF ELECTRICAL PARAMETERS

There are different kinds of tools and instruments for measurements of various electrical parameters discussed in **Section 4.1.** However the two common types of hand-held ammeters are digital and clamp meters, as shown in **Figure 4.5**.

- **Digital Meter:** A digital meter (also called multimeter, due to its multiple functions) can measure voltage (V), current (I) and resistance. This type of meter is usually inexpensive and adequate for basic safety and troubleshooting tasks. When using this type of meter for current measurement, it requires current to flow through the meter, and the meter has to be connected in the electrical circuit. Therefore, it is important to have a good understanding on how the current is flowing through the system, and the proper ways to disconnect and safely measure the current.
- **Clamp Meter:** Clamp meters have a "jaw" on the top that opens when you press a lever on the side of the meter. This type of meter is a better option to measure current as the meter can read the amount of current flowing through the conductor by placing a conductor in the middle of the jaw without becoming a part of the electrical circuit. Some models of clamp meters can also measure voltage, resistance and power, however some simple models can only measure current.

FIGURE 4.5 Digital meter (left) and clamp meter (right)

5

Annex B: Solar PV technologies and suppliers for bungalows in Vanuatu

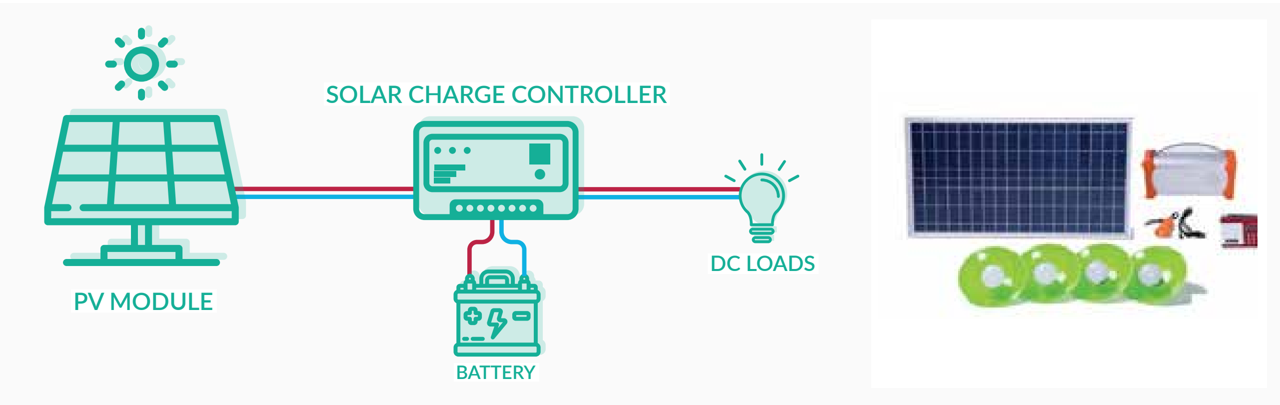
Solar PV technologies have become the most popular RE technologies for bungalows in Vanuatu for many reasons, including affordability, existing experience and expertise in the country, and availability of accredited products and vendors through the existing Vanuatu Rural Electrification Program (VREP) implemented by the Department of Energy (DoE). VREP I approved small "plug and play" solar systems also offer the following features which are appropriate to rural bungalows in Vanuatu:

- **Easy installation and mobility** – Small solar PV systems do not require extra installation areas beyond the bungalow grounds and the systems are easily stored and moved in preparation for natural disasters.
- **Low maintenance** - Maintenance can be extremely expensive in remote islands, and these small solar PV systems require very low maintenance.

Based on the above consideration, Solar PV is the most appropriate RE technologies recommended by the recent GGGI study on business model for the tourism sector in Vanuatu[5]. This RE and EE Guide covers small plug-and-play solar PV systems as well as SHS products for DC and AC loads.

- **Plug and Play Solar Systems:** These solar systems are simple and self-contained that can provide lighting, phone and small appliance charging and power a DC fan and a television. The Vanuatu Rural Electrification Project (VREP) funded by the New Zealand Government through the Pacific Regional Infrastructure Facility (PRIF) and managed by DoE with Implementation Support from the World Bank published a product catalogue of accredited "plug and play" solar systems (5W to 30W) available from VREP accredited vendors in Vanuatu[6]. For an updated list of VREP accredited vendors, please visit the DoE website (https://doe.gov.vu/index.php?r=publication). A wider range of accredited solar systems up to 350W is available from the World Bank Group's initiative Lighting Global website (www.lightingglobal.org/products).

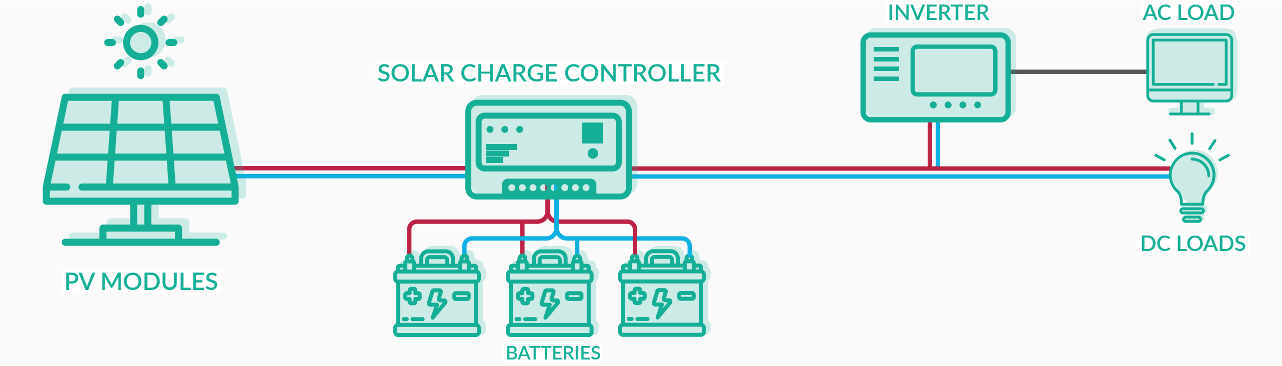
FIGURE 5.1 Plug and play solar systems for bungalows in Vanuatu



- **Pre-Assembled Solar Home Systems:** VREP II Subsidy Implementation Manual (SIM) specifies 4 sizes of solar home systems: 1) 120 Wp to 160 Wp; 2) 220 Wp to 280 Wp; 3) 450 Wp to 550 Wp, and; 4) 900 Wp to 1100 Wp. VREP II SHS can be offered with DC Output only, AC output only or both. The battery system shall provide a minimum three days of autonomy, and the maximum depth of discharge at the end of the required days of autonomy should be 50% for lead acid batteries and the maximum depth of discharge (or the maximum usable capacity) specified by the manufacturer for Li Ion batteries.

5 Vanuatu: Tourism and Renewables Market Assessment and Business Model Development, GGGI, December 2016.
6 https://doe.gov.vu/uploads/pub/VREP-Product%20CatalogueA4-ISSUE4-ENGLISH-v3.pdf

FIGURE 5.2 Solar home systems for DC and AC loads in bungalows in Vanuatu



5.1 SUPPLIERS AND SERVICE PROVIDERS IN VANUATU

Company	Contact Person	Address	Tel/Email	Product/Service
Computer World	Eyal Tendler	PO Box 3253USP Roundabout, Champagne Estate	Tel: 22233 Email: sales@cw.vu	
Ecotech Solutions	Paul Neves, Manager	PO Box 3100, Port Vila	Email: neves@ecotechsolutions.net	Grid connected Solar PV, Solar home systems
Energy4All		Mele Road, PO Box 711, Port Vila	Tel: 25150	Solar home system, Battery, Solar Freezer
eTech (Vanuatu) Ltd.	Losena Bani (5328456), Madeleine Naviti (5328455)	Port Vila Office: PO Box 694 La Rock Terrasse Building, Lini Highway, Port Vila, Vanuatu Santo Office: Level 1, VNFP Building, Main Street Luganville, Santo, Vanuatu	Ph: 26933 / 23800 (next to Medical Centre) Email: solarsales@etech.com.vu Ph: 36977	VREP I and II approved products
Green Power Ltd.	Jin Wong	PO Box 816, Port Vila	Email: greenpower@vanuatu.com.vu	Pico to medium SHS products.
Greentech Ltd	Eric Kerres	PO Box 43, Port Vila	Tel: 25142 / 35740 Email: gm@greentech-vanuatu.com	Solar farm, Solar home systems, Solar Refrigeration and EE lighting products.
Power Solar Communi-cation (PCS) Ltd.	Sallyann Tanabose, Jenifer Natou	PO Box 3553 Kumul Highway Port Vila, Vanuatu	Office: 25945 Mobile: 5573812 Email: info@pcspacific.com, admin@pcspacific.com	VREP I and II approved products
Rapid Electrics		PO Box 875	Tel: 25460/25462	Solar home systems, AC/DC appliances
South Pacific Electrics Ltd		PO Box 905, Port Vila	Tel: 22034 Email: manager@southpacificelectrics.com	Solar PV systems for commercial and residential, and for off-grid
Vate Electrics Ltd.		PO Box 629, Port Vila	Tel: 35010 www.vateelectrics.v	Solar PV systems for commercial and residential, and for off-grid
Savvy Solar	Chales Davies	PO Box 2012, Champagne Estate, Port Vila	Mobile: 7776662, 7364630 Email: savvysolarvanuatu@gmail.com	VREP I and II approved products

5.2 INTERNATIONAL MANUFACTURERS/SUPPLIERS OF DC APPLIANCES

End-Use	Manufacturer/ Distributor	DC Voltage	URL
Cooling & Heating: Ceiling Fans	Nextek	24	https://www.nextekpower.com/fanworks-catalog
	Phaesun	12	http://order.phaesun.com/index.php/loads
Cooling & Heating: Radiant Heating	Warmfloor	24	http://www.warmfloor.com
Cooling & Heating: Air Conditioners	Hotspot Energy	48	http://www.hotspotenergy.com
	GE Innovations	48	http://www.geinnovations.net
Lighting & Lighting Systems	Phocos	10.5-30	http://www.phocos.com
	Lumencache	12/24V PoE	http://lumencache.lighting/
	NuLEDs	12-36V PoE	http://www.nuleds.com/
	Colorbeam	48V PoE	http://www.colorbeamnorthamerica.com/
Refrigeration	Phocos	12/24	http://www.phocos.com
	GE Innovations	12/24	http://www.geinnovations.net
	Norcold	12	http://www.norcold.com
	Sundanzer	12/24	http://www.sundanzer.com
	Dometic	12/24	https://www.dometic.com
Electronics	Alphatronics	12	http://www.alphatronics.de
	TRU-Vu	12/24	http://www.tru-vumonitors.com/
	Niwa	12	http://www.niwasolar.com/Solar-TV/

Source: Table 2, DC Appliances and DC Power Distribution: A bridge to the Future Net Zero Energy Homes Conference Paper, LBNL, September 2017

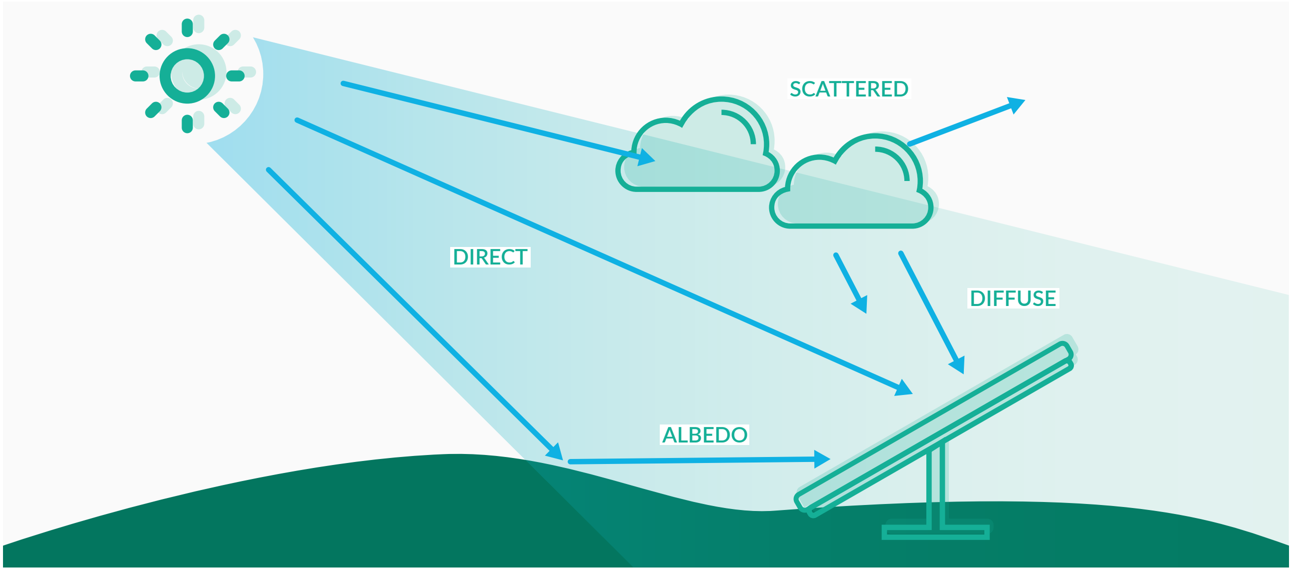
6

Annex C: Sizing your own solar PV systems

6.1 UNDERSTANDING SOLAR ENERGY RESOURCES

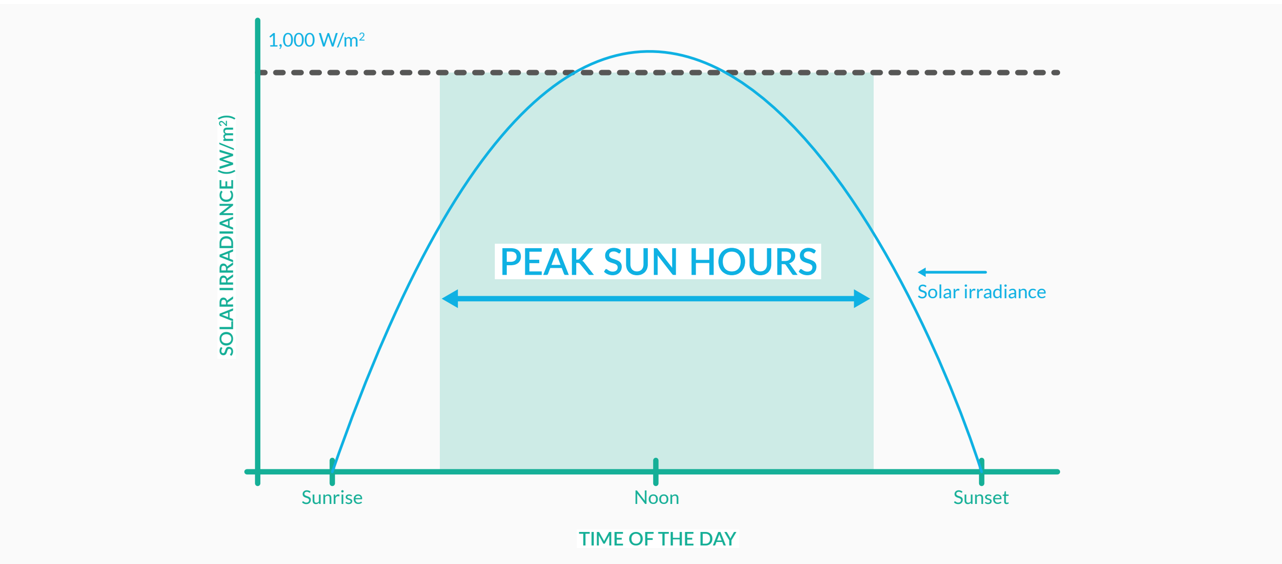
There are three main components of the sun's radiation, direct, diffuse and albedo radiation. Direct radiation comes directly from the sun, diffuse radiation comes from bouncing off of clouds and the atmosphere, while albedo radiation is reflected off something else, such as the ground, a white roof, a tree or a lake. All contribute to the overall radiation on earth and for solar PV systems (see the figure below).

FIGURE 6.1 Solar radiation



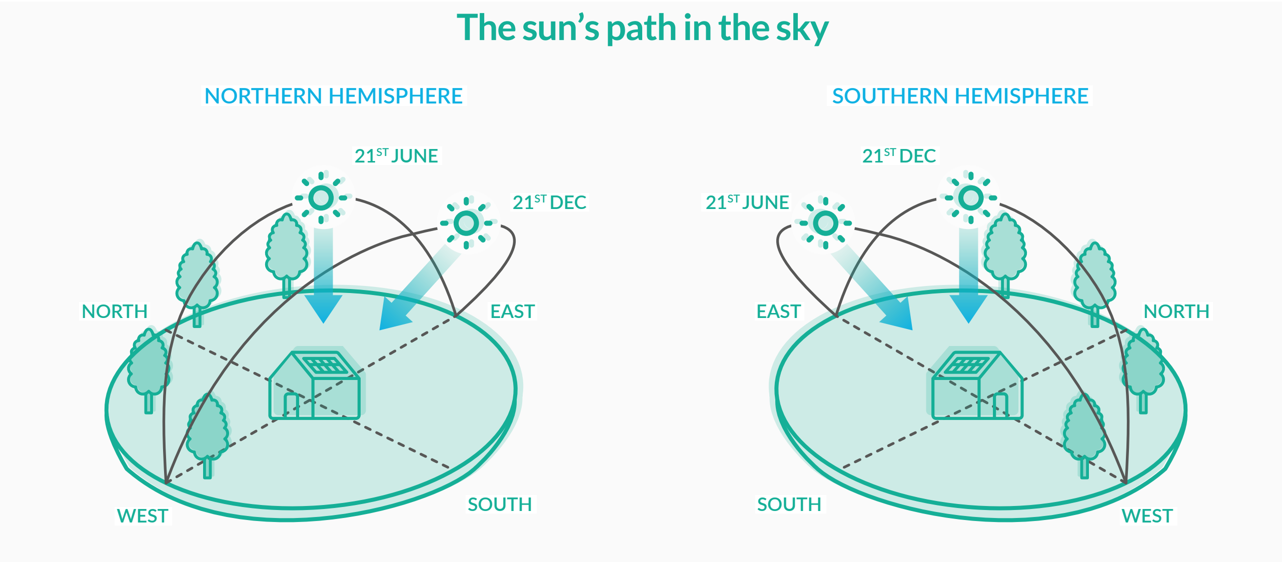
The term for the intensity of the solar radiation striking the earth is irradiance, and it is a measurement of power over an area. The standard units associated with irradiance are watts per square meter (W/ m2), or kilowatts per square meter (kW/m2). Solar irradiance varies throughout the day, from sun rise to sun set, as shown in **Figure 6.2.**

FIGURE 6.2 Variation of solar energy during time of day



Note that the shaded area within peak sun hours (PSH) equals the area under solar irradiance curve. The term peak sun refers to an irradiance value of 1,000 W/m2. The amount of solar energy received at a particular location each day is measured in terms of the energy per unit area per day (kWh/m2/day), and this can be calculated by multiplying number of peak sun hours in a day (hrs/day) with 1,000 W/m2. The term peak sun hours is also called insolation, and both refer to the solar energy received at a site over the course of one day. The number of peak sun hours varies with a number of factors, most notably the time of year and your position on the globe (see **Figure 6.3**).

FIGURE 6.3 Sun's path in the sky



Since PSH or insolation represent the average number of hours per day that a solar module can operate at its rated output, the number can be used to estimate the expected maximum energy output produced by a solar module. For example, a 2 kW solar module installed in a site with a number of peak sun hours of 5 kWh/m2/day will deliver 10 kWh of energy per day, as shown below.

2 kW solar module × 5 peak sun hours = 10 kWh of energy per day

Vanuatu is in the Southern hemisphere, and Port Vila has Latitude of 17.44 South and Longitude 168.19 East. These location coordinates can be used to extract number of PSH from various resources, such as NASA, the World Bank, NREL. Shown in the table below are PSH data of the main islands from the NASA website. It shows that the best month for solar energy generation in Vanuatu is December and the worst month is June. In all the main islands, a tilt angle of around 30° pointing North will give the best PSH in June.

TABLE 6.1 Average peak sun hours per month at different tilt angle in Vanuatu

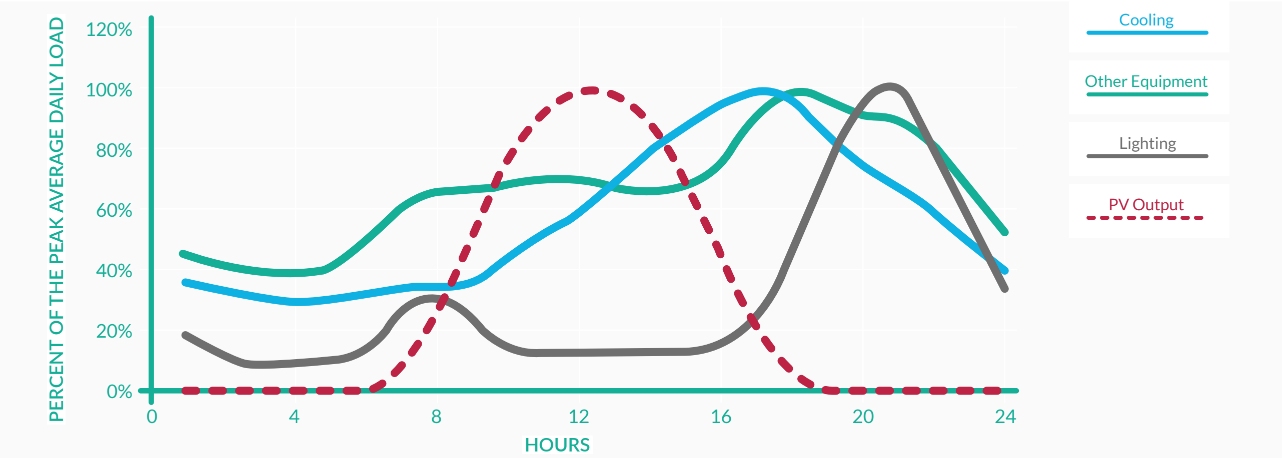
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Vanua Lava Island (Torba Province), Sola													
Latitude: 13.87 South							**Longitude: 167.55 East**						
0° Tilt	6.03	5.58	5.5	4.99	4.42	4.15	4.36	5	5.56	6.13	6.13	6.15	5.33
13° Tilt	6.08	5.42	5.54	5.25	4.85	4.65	4.85	5.37	5.7	6.02	6.15	6.24	5.51
28° Tilt	5.84	4.99	5.3	5.27	5.08	4.98	5.15	5.51	5.56	5.59	5.87	6.03	5.43
Santo Island (Sanma Province), Luganville													
Latitude: 15.51 South							**Longitude: 167.2 East**						
0° Tilt	5.96	5.48	5.35	4.75	4.12	3.77	4.01	4.62	5.31	6.03	6.02	6.34	5.15
15° Tilt	5.98	5.31	5.39	5.03	4.57	4.28	4.52	5.01	5.47	5.92	6.01	6.43	5.33
30° Tilt	5.69	4.87	5.15	5.04	4.77	4.56	4.78	5.12	5.32	5.48	5.68	6.18	5.22
Ambae Island (Penama Province)													
Latitude: 15.37 South							**Longitude: 167.81 East**						
0° Tilt	5.97	5.48	5.35	4.75	4.12	3.77	4.01	4.62	5.31	6.04	6.02	6.34	5.15
15° Tilt	5.98	5.31	5.39	5.03	4.57	4.28	4.52	5.01	5.46	5.91	6.01	6.43	5.32
30° Tilt	5.69	4.87	5.14	5.04	4.77	4.55	4.78	5.11	5.32	5.48	5.68	6.18	5.22
Malekula Island (Malampa Province), Lakatoro													
Latitude: 16.1 South							**Longitude: 167.42 East**						
0° Tilt	6.4	5.82	5.72	4.99	4.26	3.87	4.13	4.82	5.65	6.43	6.38	6.79	5.44
16° Tilt	6.41	5.63	5.78	5.33	4.8	4.47	4.73	5.28	5.84	6.29	6.35	6.92	5.65
31° Tilt	6.06	5.14	5.51	5.35	5.02	4.77	5.01	5.4	5.68	5.8	5.97	6.64	5.53
Efate Island (Shefa Province), Port Vila													
Latitude: 17.44 South							**Longitude: 168.19 East**						
0° Tilt	6.65	5.82	5.68	4.93	4.17	3.76	4	4.72	5.59	6.4	6.52	6.91	5.43
17° Tilt	6.68	5.62	5.75	5.31	4.74	4.4	4.64	5.21	5.81	6.27	6.45	7	5.66
32° Tilt	6.32	5.13	5.48	5.33	4.97	4.7	4.92	5.33	5.65	5.78	6.01	6.67	5.52
Tanna Island (Tafea Province), Lenakel													
Latitude: 19.53 South							**Longitude: 169.27 East**						
0° Tilt	6.79	5.96	5.65	4.86	4.08	3.52	3.93	4.64	5.58	6.52	6.79	7.01	5.44
17° Tilt	6.75	5.75	5.75	5.3	4.76	4.17	4.69	5.23	5.85	6.39	6.31	7.05	5.67
32° Tilt	6.3	5.24	5.48	5.32	4.99	4.42	4.99	5.36	5.69	5.89	5.57	6.63	5.49

Source: https://power.larc.nasa.gov/data-access-viewer/

6.2 SIZING THE BATTERY

Availability of solar energy sometimes does not match the requirements for lighting, cooling and other equipment in bungalows (see the figure below). To enable the solar systems to power electrical loads after sun hours, the battery is required to store electrical energy produced by the PV modules during the day and supply it to the electrical loads at night. The storage is also needed during long period of cloudy weather.

FIGURE 6.4 Load profiles of a residential facility



Source: Adapted from Figure 7 in DC Appliances and DC Power Distribution: A bridge to the Future Net Zero Energy Homes Conference Paper, LBNL, September 2017

The daily energy consumption will be used to calculate the battery requirements. The three important considerations in calculating the number of batteries needed in a standalone off-grid PV systems include: Days of Autonomy; Depth of Discharge (DoD); and Operating Temperature.

Days of Autonomy: This is the number of days a battery bank is expected to provide power to the system without receiving an input from the solar array or when there is little or no sun to recharge the battery. It is a compromise between the time the generator will run in the absence of sun and the added cost of a large battery bank. In case of more days of autonomy there will be larger battery bank and that will be costly. A larger battery bank will need large PV array to recharge the battery bank on a regular basis. Three to five days of autonomy is a good compromise.

Depth of Discharge (DoD): DoD is defined as how much of the rated capacity of battery has been used or the percentage of energy drained from the battery. The battery life is mainly determined by the use cycles of the battery. Similar to a mechanical device that wears out faster with heavy use, DoD determines the cycle count of the battery. The smaller the discharge (low DoD), the longer the battery will last. If possible, avoiding full discharges and charge the battery more often between uses to prolong battery life.

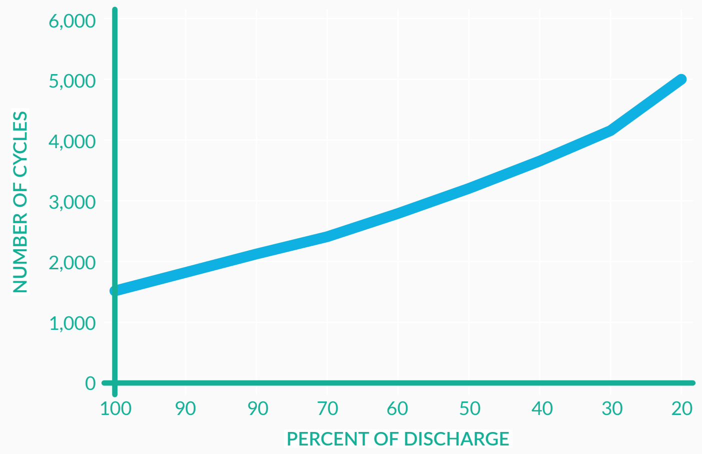
TABLE 6.2 Lifetime of LIPO4 battery versus DoD

Depth of Discharge (DoD)	Discharge Cycles (LIPO4)	Estimated Lifetime (Years) – 365 days operation
100% DoD	~600 Cycles	~1.6 Years
80% DoD	~900 Cycles	~2.5 Years
60% DoD	~1,500 Cycles	~4 Years
40% DoD	~3,000 Cycles	~8 Years

Source: https://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries

Selection of the battery should be a balance between the longevity, cost, and problem of replacing batteries. In the system design 50% DoD is normally used, although actual DoD during sunny weather is often less than 20%. Shown in **Figure 6.5** is an example of number of charge/discharge cycles versus DoD of a battery.

FIGURE 6.5 Number of charge/discharge cycles versus depth of discharge



Operating Temperature: The colder a battery is, the less capacity it can deliver. This is because the efficiency of the chemical reaction occurring inside the battery increases and decreases at different temperatures. However at higher temperatures, the battery tends to shorten life. In general, the battery performs best in moderate temperatures.

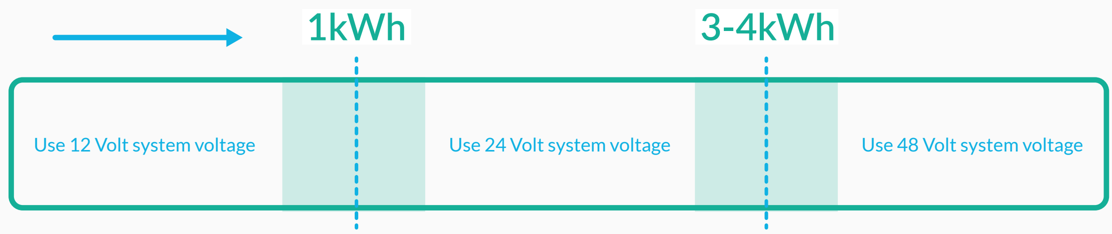
With the above considerations, sizing of the battery can be carried out using the following formula:

$$\text{Battery Capacity (Ah)} = \frac{\text{Daily Energy Consumption x Days of Autonomy}}{\text{DoD x Temp \& Discharge Rate Derating Factor x Nominal Battery Voltage}}$$

The Off Grid PV Power Systems Design Guidelines developed for developed PPA and SEIAPI recommends a minimum of 3 days of autonomy (with no generator as back-up) and 5 days of autonomy is preferred for remote sites because battery life may be significantly increased relative to a 3 day period of autonomy. Long battery life is important for remote sites because battery exchanges are easily the most expensive on-going cost in operating a remote off-grid electricity system. The guidelines also recommended 50% DoD for some residential sized lead acid batteries, and 60% to 80% for lithium ion batteries. As temperature in the Pacific is usually over 20°C (68°F), the guidelines recommend a conservative 5% reduction of the battery capacity (or 95% derating factor).

As for the nominal battery voltage, the recommended battery voltage increases as the total daily energy usage increases. For small daily loads, a 12V system voltage can be used. For intermediate daily loads, 24V is used and for larger loads 48V is used, as shown in **Figure 6.6**.

FIGURE 6.6 Guideline for selection of battery voltage



Source: Off-Grid PV Power System Design Guidelines, The Pacific Power Association (PPA) and the Sustainable Energy Industry Association of the Pacific Islands (SEIAPI), 2018

Using the total daily energy consumption of 312 Wh in Example 2 in **Section 2.1.3**, sizing of the battery using the above formula and recommended factors is shown below.

$$\text{Battery Capacity (Ah)} = \frac{312\ \text{Wh} \times 3\ \text{Days of Autonomy}}{50\%\ \text{DoD} \times 95\%\ \text{Derating Factor} \times 12\text{V Nominal Battery Voltage}}$$

Battery Capacity = 164 Ah

To enable the solar systems to power electrical loads after sun hours, the battery is required to store electrical energy produced by the PV modules during the day and supply it to the electrical loads at night. The storage is also needed during long period of cloudy weather. The main function of the solar charge controller is to charge a battery without permitting overcharge and at the same time, preventing reverse current flow when there is no sun.

In small plug and play solar systems, solar charge controller and battery are bundled as a single unit with built-in multiple sockets and USB ports for lighting and other electrical loads, and mobile phone charging. Rechargeable lithium-ion batteries are normally used in these small plug and play solar systems. For larger PV systems, such as solar DC freezers, solar charge controllers and batteries are separated, and deep cycle rechargeable lead-acid batteries are the most common type.

6.3 SELECTING SOLAR CHARGE CONTROLLER

The main functions of solar charge controllers are to: prevent battery overcharge; and prevent battery discharge at night through the solar modules. The two common types of solar charge controller available in Vanuatu are: Pulse Width Modulated (PWM) controller and Maximum Power Point Tracking (MPPT) controller.

TABLE 6.3 Main characteristics of PWM and MPPT controller

PWM Solar Controller	MPPT Solar Controller
	
Main Characteristics: • Voltage pulled down to battery voltage • Power capped by battery voltage and rated current of PWM • Cheaper than MPPT	**Main Characteristics:** • Convert voltage input to battery voltage • Increase current when voltage drop to maintain the maximum power point • More expensive than PWM (In Vanuatu, MPPT controller at the same current rating is about 8 times more expensive than PWM controller)

In general, PWM solar controllers are always chosen for small solar PV systems due to their low costs. Sizing solar PV modules and PWM solar controller will be based on current rating of both PV modules and controllers. For MPPT controller, sizing PV modules and controller will be based on energy and power rating. Recommended approaches in sizing PV modules and controllers are discussed in **Section 6.4**.

6.4 SIZING PV MODULES AND CONTROLLER

Sizing of the PV module will take into account the solar irradiation and losses incurred in system components (sub-system efficiency). These include battery, solar charge controller, battery inverter charger and cable. The efficiency values of these components vary depending on manufacturers, however the values shown in **Figure 6.7** and **Table 6.4** are recommended by this RE & EE Guide. It should be noted that the components in Solar DC systems are different from Solar AC systems, as shown in green lines and orange lines in **Figure 6.7**, and the sub-system efficiency factors for DC and AC systems are also different as computed in **Table 6.4**.

FIGURE 6.7 Sub-system efficiency in solar PV system

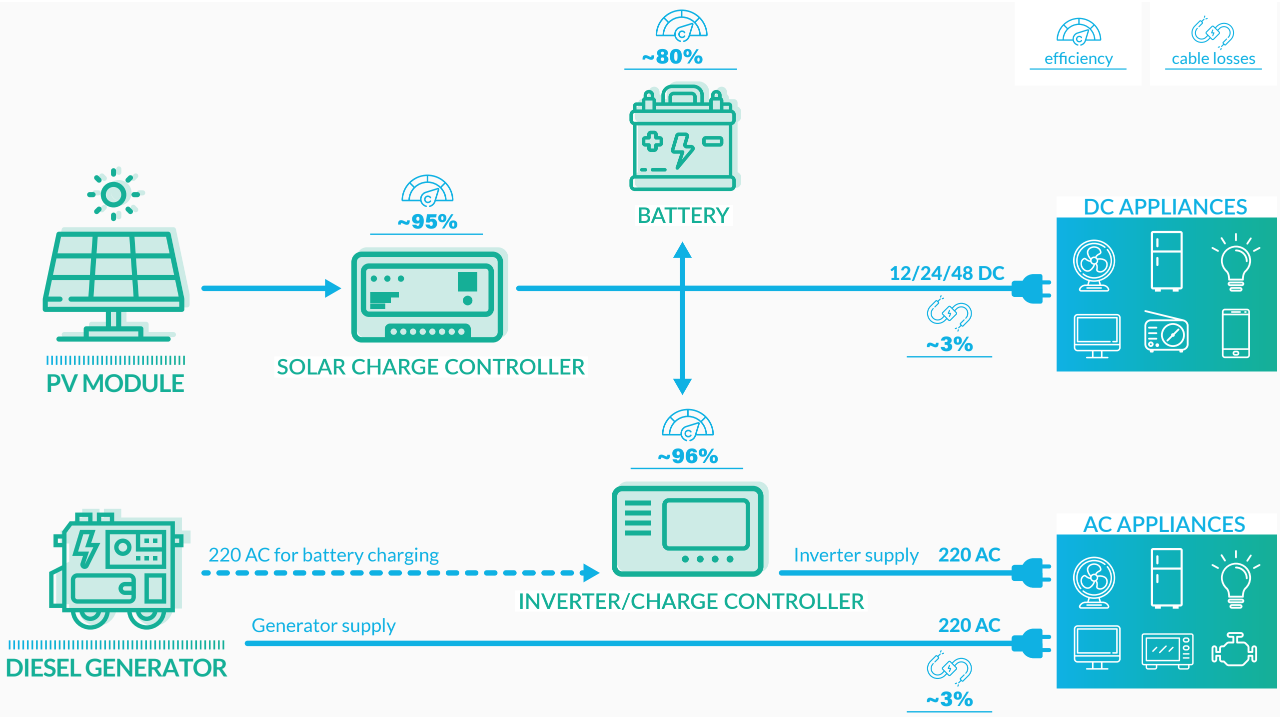
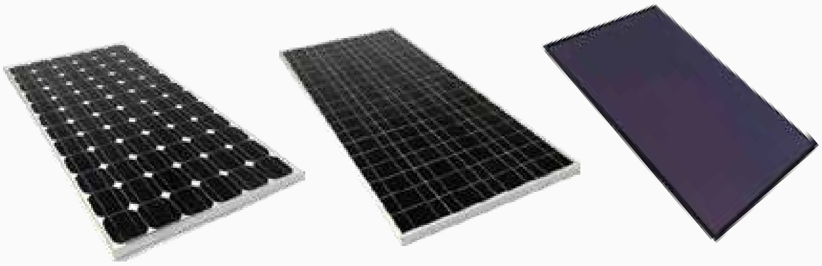


TABLE 6.4 Sub-system efficiency factor

Sub-System	DC System	AC System (Battery)
Battery	80%	80%
Solar Charge Controller	95%	95%
Battery Charger/Inverter		96%
Wire and Cable	97%	97%
Sub-System Efficiency Factor	74%	71%

BOX 4 Common types of PV modules

Commercially available PV modules or PV panels that are currently used for residential and commercial systems include crystalline modules and thin film modules. For the crystalline modules, there are two main types – those containing monocrystalline cells and those containing polycrystalline (multicrystalline) cells. Monocrystalline modules are typically more efficient than their polycrystalline counterparts. Thin film modules have a lower power efficiency which only means they require the most space for the same amount of power, however a thin film module is lighter than a crystalline-based module. PV panels are manufactured in different sizes and can produce power as low as 5 W or as high as 300 W. Higher power panels producing over 50 W are used for commercial and residential applications including grid-tied systems. All accredited plug and play solar systems in Vanuatu use polycrystalline modules.



Monocrystalline **Polycrystalline** **Thin Film**

6.4.1 Sizing PV modules for PWM controller

In case a PWM solar charge controller is selected, sizing PV modules will be based on the computed daily Ah and battery efficiency. Based on the total daily energy consumption of 312 Wh for DC appliances in Example 2 in **Section 2.1.3**, calculation of daily Ah is described below.

Daily Ah = 312 Wh/ 12 V = 26 Ah

Allowing for 80% battery efficiency, the solar array needs to produce following daily Ah:

26 Ah / 0.8 = 32.5 Ah

Assuming this solar PV system will be installed in Port Vila and PSH in June of 4.7 is used, the required PV module derated output current is:

32.5 Ah / 4.7 = 6.9 A

The PPA/SEIAPI guidelines recommend 20% oversize for the Pacific, so the PV module/array shall have the output current:

6.9 A x 1.2 = 8.3 A

When using a PWM solar charge controller, solar modules that have a nominal voltage rating that is appropriate for the battery voltage (in this case 12V), must be used. Assuming the two solar PV modules with the maximum power voltage (Vmp) of around 18V as outlined in the table below will be chosen for this PV system.

TABLE 6.5 Electrical characteristics of 95W and 170W PV modules

Electrical Characteristics	95W PV Module	170W PV Module
Maximum Power Voltage (Vmp)	17.6V	17.9V
Maximum Power Current (Imp)	5.4A	9.5A
Open Circuit Voltage (Voc)	22.2V	22.8V
Short Circuit Current (Isc)	5.71A	9.93A

The output current of each PV module is computed in two steps as follows: 1) Average output current based on Isc and Imp; and 2) Derate output current due to manufacturer tolerance (0.97) and dirt (0.95).

For 95W PV module:

Average module current = (5.71 + 5.4)/2 = 5.56 A

Derated module current = 5.56 x 0.97 x 0.95 = 5.12 A

For 170W PV module:

Average module current = (9.93 + 9.5)/2 = 9.71 A

Derated module current = 5.56 x 0.97 x 0.95 = 8.95 A

With the required module current of 8.3 A, the number of PV modules connected in parallel is computed by dividing 8.3 A with derated module current of 95W and 170W PV module.

Number of 95W PV modules in parallel = 8.3 A/ 5.12 A = 1.62 → round up to 2

Number of 170W PV modules in parallel = 8.3 A/ 8.95 A = 0.93 → round up to 1

Once the PV modules are selected, the PWM solar charge controller will then be chosen based on the array short circuit current and the open circuit voltage of the array. Unless the controller is a model that is internally current limited, it should be sized so that they are capable of carrying at least 125% of the array short circuit current and withstanding the open circuit voltage of the array.

For an array of 2 x 95W PV module:

Isc = 5.71 x 2 = 11.42 A

Voc = 22.2 V

PWM Controller Current Rating = 1.25 x 11.42 A = 14.28 A

For 170W PV module:

Isc = 9.93 A

Voc = 22.8 V

PWM Controller Current Rating = 1.25 x 9.93 A = 12.41 A

6.4.2 Sizing PV Modules for MPPT Controller

Using Example 2 in **Section 2.1.3**, the DC energy supplied by the battery bank = 312 Wh. With the DC sub system efficiency factor of 74%, the total energy required from the PV modules is calculated below:

Energy required from the PV module = 312 Wh / 74% (0.74) = 422 Wh

The energy generated by the PV module can be converted into the required PV output power using number of PSH (insolation), as shown in **Table 6.1**. Assuming the PV system will be designed to produce the daily energy required during the worst month in Port Vila (i.e., June), so the PSH value used is 4.7. Therefore the required output power of the PV array is:

422 Wh / 4.7 peak sun hours = 90 W

The required output power calculated above is referenced as derated output power as it would be affected by modules' orientation, shading, ageing, etc. The Off-Grid PV Power System Design Guidelines published by PPA and SEIAPI recommends that a minimum of 20% oversizing factor for the Pacific Island countries and territories to allow for equalization charging of the battery. This oversizing factor should also effectively cover the ageing of the solar module in the first 10 years. Considering this, the adjusted array output is:

90 W x 1.2 (oversize factor) = 108 W

The above computed array output will be used to determine how many solar PV modules (panels) needed. The Off-Grid PV Power System Design Guidelines recommends that the power output of a solar module should be derated because it will be affected by temperature, dirt, possibly manufacturer's tolerances and/or module mismatches and module ageing, and the derating factor of 0.814 is used in the design guideline[7].

7 The derating factor of 0.814 is calculated based on: derating due to temperature ftemp= 0.883; derating due to dirt fdirt = 0.95; and derating due manufacturers tolerance fman = 0.97. Note that the ageing factor has not been taken into account since it is effectively covered by the 20% oversizing factor.

Assuming the two PV modules in **Table 6.5** will be considered, the derated power output for each PV module is computed as follows:

Derated 95W module power output = 95 x 0.814 = 77 W

Derated 170W module power output = 95 x 0.814 = 138 W

With the adjusted array output of 108 W, the number of PV modules in an array is computed by dividing 108W with derated module power of 95W and 170W PV module.

Number of 95W PV modules in an array = 108 W/ 77 W = 1.4 → round up to 2

Number of 170W PV modules in an array = 108 W/ 138 W = 0.8 → round up to 1

Once the PV modules are selected, the MPPT solar charge controller will then be chosen to match DC power, voltage and current of the array configuration with 125% oversizing factor.

For an array of 2 x 95W PV module:

Total module rating = 95 W x 2 = 190 W

MPPT Controller Power Rating = 1.25 x 190 W = 238 W

For 170W PV module:

Total module rating = 170 W x 1 = 170 W

MPPT Controller Power Rating = 1.25 x 170 W = 213 W

In addition to the power rating, MPPT controller typically will have a recommended minimum nominal array voltage and a maximum input voltage, and the minimum nominal array voltage shall be higher than the nominal voltage of the battery, and the array open circuit voltage shall be less than the maximum input voltage. The maximum DC input current rating shall match the array short circuit current rating as well.

7

Best practice checklists for operation and maintenance of energy end-use systems

7.1 CHECKLIST FOR BUNGALOW OPERATOR/MAINTENANCE STAFF

TABLE 7.1 Best practice checklist for bungalow operator/maintenance staff

Item	Task	Yes	No	Action - if answer is No
	Lighting			
1	Repair broken fixtures	☐	☐	Regularly check for broken fixtures and replace to reduce losses
2	Replace non-working lamps	☐	☐	Regularly check for non-working lamps and if possible install high energy efficient lamps suited for the lighting requirements
3	Install LED lamps	☐	☐	Assess the opportunity to replace old inefficient lamps with LED lamps
4	Add reflectors to increase light level	☐	☐	Consider replacing the luminaires and adding reflectors to enhance lighting levels and reduce the need for further lamps
5	Label panels and switches so lighting can be monitored and control	☐	☐	If possible, label panels and switches to ensure lights are switched off by staff when not required
	Air-conditioner			
6	Clean indoor coils every 3-6 months	☐	☐	If possible, carry out regular cleaning and maintenance of the air-conditioners
7	Clean outdoor coils every 6 months	☐	☐	If possible, carry out regular cleaning and maintenance of the air-conditioners
8	Install insulation strips on room doors	☐	☐	If the rooms have significant losses through the doors, check possibility of installing insulation strips
	Refrigerator/Freezer			
9	Clean condenser coils every 6 months	☐	☐	Depending on the number of refrigerators and staff available, check the possibility for regularly cleaning the coils
10	Seal on refrigerator door is not worn	☐	☐	Check possibility of replacing the seal to reduce losses

7.2 CHECKLIST FOR HOUSEKEEPING

TABLE 7.2 Best practice checklist for housekeeping

Item	Task	Yes	No	Action - if answer is No
1	Use natural light during housekeeping	☐	☐	Regularly check with staff to use natural lighting
2	Turn off lights when guests are not in the room	☐	☐	Assess the opportunity to install key tags or other forms of raising awareness to guests (e.g. labels)
3	Clean light bulbs	☐	☐	Regularly clean light bulbs to ensure adequate lighting levels
4	Turn off air-conditioners when guests are not in the room	☐	☐	Assess the opportunity to install a key tag system or other forms of raising awareness to guests
5	Make sure that refrigerator/freezer door is properly closed	☐	☐	Ensure the staff is aware of the need to regularly check that the refrigerator door is properly closed
6	Make sure that refrigerator is at least 6 inches from the wall	☐	☐	Ensure there is sufficient space at the back of the refrigerator for optimal operation and to allow for regular cleaning of coils
7	Turn off refrigerators in unoccupied rooms	☐	☐	Consider switching off refrigerators in unoccupied rooms

References

Battery University. (2018, October 20). BU-808: How to Prolong Lithium-based Batteries. Retrieved from Battery University: https://batteryuniversity.com/learn/article/how_to_prolong_lithium_based_batteries

Climate Council. (2017). Tropical Cyclones and Climate Change: Factsheet. ClimateCouncil.org.au.

Department of Energy of Vanuatu. (2017, October). Vanuatu. Retrieved from Department of Energy: https://doe.gov.vu/uploads/pub/VREP-Product%20CatalogueA4-ISSUE4-ENGLISH-v3.pdf

GGGI. (2016). Vanuatu: Tourism and Renewables Market Assessment and Business Model Development.

Global LEAP. (2017). 2017 Buyer's Guide for Off-Grid Fans and Televisions. Global LEAP.

Global LEAP. (2017). 2017 Buyer's Guide for Outstanding Off-Grid Refrigerators. Global LEAP.

International Labour Organization. (2015, April 23). Cyclone PAM causes devastating impact on employment and livelihoods. Retrieved from International Labour Organization: https://www.ilo.org/suva/public-information/WCMS_368560/lang--en/index.htm

IPCC. (2007). Climate Change 2007: Working Group I: The Physical Science Basis. IPCC Fourth Assessment Report , 13-15.

IPCC. (2014). Summary for Policy makers. Climate Change 2013: The Physical Science Basis , 26.

Lawrence Berkeley National Laboratory. (2017). DC Appliances and DC Power Distribution: A Bridge to the Future Net Zero Energy Homes. Lawrence Berkeley National Laboratory.

Pacific Power Association (PPA) and Sustainable Energy Industry Association of the Pacific Islands (SEIAPI). (2018). Off Grid PV Power Systems: System Design Guidelines. Retrieved from Sustainable Energy Industry Association of the Pacific Islands (SEIAPI): http://www.seiapi.com/wp-content/uploads/2018/11/Off-Grid-PV-Systems-Design-Guidelines-V2.1-July-2018.pdf

SPTO. (2014). Pacific Regional Tourism Strategy 2015 - 2019. Fiji Islands: SPTO.

World Travel & Tourism Council. (2018). Travel & Tourism Economic Impact 2018 - Vanuatu. London: World Travel & Tourism Council.

The Regional Pacific NDC Hub is implemented in partnership with:

In contribution to:

Follow our activities on
Facebook and Twitter

www. gggi.org