INTRODUCING SOLAR-POWERED VACCINE REFRIGERATOR AND FREEZER SYSTEMS

A GUIDE FOR MANAGERS IN NATIONAL IMMUNIZATION PROGRAMMES

World Health Organization

unicef

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EXECUTIVE SUMMARY

Refrigerators powered by gas or kerosene have long been considered the best option for storing vaccines in areas with unreliable electricity. Even so, drawbacks with these devices have made keeping vaccines at temperatures within the safe range of +2°C to +8°C both difficult and expensive. Battery-powered solar refrigerators have addressed some of the drawbacks, but the batteries they rely on are expensive and typically have a lifetime of just three to five years. A new refrigerator technology, named "solar direct-drive" (SDD), eliminates the need for batteries, and therefore has the potential to resolve battery-powered vaccine refrigerator problems and help extend the cold chain into areas that might otherwise be underserved.

This document provides managers in national immunization programmes with guidance on how to implement successful solar-powered vaccine refrigerator and freezer systems. The guidance takes into account important new developments in refrigerator technology, and is based on lessons learned during the 30 years since solar refrigerator systems were first used in immunization programmes. The document is organized according to the key stages in the process of implementing successful solar-powered vaccine refrigerator and freezer systems:

- Identify key partners and resources (Chapter 1)
- Ensure that the prerequisites are met (Chapter 2)
- Select the most appropriate equipment for each facility (Chapter 3)
- Procure the selected equipment (Chapter 4)
- Plan the equipment installation (Chapter 5)
- Monitor equipment performance (Chapter 6)
- Maintain and repair the equipment (Chapter 7)

The Annex contains additional resources that can assist managers in implementing solar refrigeration systems.

ACRONYMS

30-DTR	30-day temperature recorder/logger
cMYP	comprehensive multi-year plan
EPI	Expanded Programme on Immunization (WHO)
GAVI	GAVI Alliance (formerly Global Alliance for Vaccines And Immunization)
LED	light-emitting diode
LPG	liquid petroleum gas
PQS	Performance, Quality and Safety (WHO)
SDD	solar direct-drive
SMS	short-message service
SOPs	standard operating procedures
UNICEF	United Nations Children's Fund
WHO	World Health Organization

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GLOSSARY

absorption cycle refrigerator

Refrigerator that uses a heat source such as gas or kerosene to drive the cooling system. A less efficient alternative to *compression cycle refrigerators*, absorption cycle refrigerators are most frequently used in areas with unreliable grid electricity.

autonomy

Time in days that a solar refrigerator, or combined refrigerator and water-pack freezer, can maintain the vaccine load within the acceptable temperature range under low solar radiation conditions (e.g. rain).[1]

battery-powered solar refrigerator

Refrigerators that use solar energy stored in a battery to drive the cooling system, even during periods when solar irradiance is unavailable or limited (e.g. at night or on cloudy days).

climate zone

The highest constant ambient temperature at which a WHO-prequalified vaccine refrigerator can maintain the vaccine storage compartment between +2°C and +8°C. Established during laboratory testing.

compression cycle refrigerator

Refrigerator that uses an electrically powered compressor to drive the cooling system. The electrical supply may come from the grid, a generator or from a renewable source such as solar energy, with or without a battery pack. Provides more reliable and energy-efficient cooling than an *absorption cycle refrigerator*.

cool-down time

The time required for a WHO pre-qualified vaccine refrigerator to cool down to within the acceptable temperature range of +2°C to +8°C, measured from the moment when the appliance is initially turned on. Established by laboratory testing at the ambient temperature of the *climate zone* for which the appliance is prequalified.

cool water-pack

A *water-pack* cooled to a temperature of between +2°C and +8°C before use.

Effective Vaccine Management

The Effective Vaccine Management initiative provides materials and tools needed to monitor and assess vaccine supply chains and help countries to improve their supply chain performance.

flooded battery

A type of battery used to power solar refrigerators. Flooded batteries contain liquid sulphuric acid electrolyte that is potentially dangerous and requires corrective maintenance.

heat of fusion

The amount of heat that must be added to convert a unit of mass of a solid into a liquid at its melting point temperature, or the amount of heat that must be removed to convert a unit of mass of a liquid into a solid at its freezing point temperature.

1 Autonomy is defined in: Solar power system for compression-cycle vaccine refrigerator or combined refrigerator-icepack freezer: PQS performance specification. Geneva: World Health Organization; 2010 (WHO/PQS/E003/PV01.2; http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

holdover time

The time in hours during which all points in the vaccine storage compartment remain between +2°C and +10°C, at the maximum ambient temperature of the climate zone for which the appliance is rated, after the fuel supply has been disconnected.

ice-lined refrigerator

A *compression cycle refrigerator* with an internal lining surrounding the storage that is filled with ice, cold water, or other coolant. When the electricity supply fails, the ice, cold water or coolant keeps the refrigerator cool for a minimum of 20 hours without power.

ice-pack

A *water-pack* that has been frozen to a temperature between -5°C and -25°C before use.

last mile

Refers to the final stage of the supply chain, typically a village health centre.

minimum rated ambient temperature

The lowest constant ambient temperature at which a WHO-prequalified vaccine refrigerator can maintain the vaccine storage compartment between +2°C and +8°C. Established during laboratory testing.

off-grid

A location that is not connected to the national or local electrical grid.

phase-change material

A substance (other than water) with a high *heat of fusion*, which melts and solidifies at a certain temperature and is capable of storing and releasing large amounts of energy. Heat is absorbed or released when the material changes from solid to liquid and vice versa. The phase-change materials used for vaccine transport typically change state at around +5°C. Used in some *solar direct-drive refrigerators* to provide cooling when solar irradiance is unavailable or limited (e.g. at night or on cloudy days).

PQS prequalification

WHO prequalifies a comprehensive range of cold chain equipment, temperature monitoring devices, injection devices and other products needed for safe and effective immunization delivery. A catalogue of prequalified devices is available on the WHO Performance, Quality and Safety (PQS) website.[1]

procurement agency

An organization that purchases required solar equipment, and provides qualified suppliers with details of installation sites.

qualified supplier

A manufacturer or reseller of solar equipment that meets specific criteria.[2]

shading analysis

A means of quantifying the shading that may reduce the amount and duration of solar irradiance a site receives. This is important when checking that a site receives adequate solar power for solar refrigerators to operate effectively.

1 WHO PQS Catalogue [online database]. Geneva: World Health Organization; 2015 http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue, accessed 1 October 2015).

2 A formal definition for 'qualified supplier' can be found in WHO PQS E003/PV01.2 (available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

solar direct-drive refrigerator

A refrigerator that use solar energy to freeze water or other *phase-change material*. This stored energy is then used to provide continuous cooling, even when solar irradiance is unavailable or limited (e.g. at night or on cloudy days).

solar irradiance

The amount of solar energy that arrives at a specific area at a specific time.

solar module

A packaged, connected assembly of solar cells. Also known as a solar panel.

solar array

A set of solar photovoltaic modules (panels) electrically connected and mounted on a supporting structure.

solar service provider

A private organization or a team of technicians managed by the health ministry that provides solar equipment servicing. May also provide services such as pre-installation site assessments, installation, training, and corrective maintenance and repair.

supply chain

A system of organizations, people, activities, information, and resources involved in moving a product from the supplier to end user in a manner that ensures that the product arrives in good condition.

thirty-day electronic temperature logger

A device placed with vaccines, primarily for use in refrigerators. The device logs the temperature and displays alarm violations for the last 30 days (on a rolling basis). Alarm thresholds are pre-programmed by the device manufacturer in accordance with WHO PQS specifications. The term 30-day temperature recorder (30-DTR) is often used interchangeably.

warm water-pack

A *water-pack* typically stabilized at room temperature, up to a recommended maximum of +24°C. Warm water-packs are used for the transport of freeze-sensitive vaccines when the ambient temperature is below 0°C.

water-pack

A flat plastic container, filled with water, which can be used in cold boxes or vaccine carriers as a frozen water-pack (*ice-pack*), a *cool water-pack* or a *warm water-pack*.

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1 INTRODUCTION

1.1. Who is this guide for?

This document provides managers in national immunization programmes with guidance on how to implement successful solar-powered vaccine refrigerator and freezer systems. Its purpose is to help managers decide whether solar power is the most appropriate solution for their context, and if so what must be done to ensure the success of such a system.

This introductory chapter provides an overview of the challenges posed by off-grid vaccine refrigeration, and the options available to meet them. It also provides information on the partners and resources that can help when implementing solar refrigerator or freezer systems.

1.2. How is this guide organized?

The chapters are structured according to the key stages in the process of implementing successful solar-powered vaccine refrigerator and freezer systems. The following table defines each stage and introduces additional resources that are included in the Annexes.

Table 1. Organization of this guide

Chapter	Stage
1	**Identify key partners and resources**
2	**Ensure that the prerequisites are met**
3	**Select the most appropriate equipment for each facility** • Annex A provides a site assessment worksheet that can be used by the person conducting a pre-installation site assessment to capture the key technical details. • Annex B provides a specification checklist to define the equipment required for each facility. • Annex C provides an example specification checklist. • Annex D provides an example budget summary sheet to identify the costs over the project lifetime.
4	**Procure the selected equipment**
5	**Plan the equipment installation** • Annex E provides an installation checklist for technicians to verify that the equipment installation was a success. • Annex F provides a performance checklist that can be used by technicians to confirm that the equipment has operated satisfactorily during the first 30 days of operation.
6	**Monitor equipment performance**
7	**Maintain and repair equipment** • Annex G provides a list of tools and supplies required to perform preventive maintenance of solar equipment. • Annex H provides a checklist of preventive maintenance tasks to be conducted by on-site workers on a daily, monthly, and biannual basis.

1.3. The challenge of vaccine refrigeration in areas without reliable electricity

For the last 30 years, refrigerators powered by gas or kerosene (known as "absorption refrigerators", and described in Section 1.3.2) were considered the most appropriate option to store vaccine in areas without – or without reliable – electricity. However, various drawbacks with these devices can make keeping temperatures within the safe range for vaccines of +2°C to +8°C both difficult and expensive. In the 1980s, battery-powered solar refrigerators (see Section 1.3.3) were introduced as a solution to these problems. But the batteries they rely on failed unexpectedly, had a lifetime of just three to five years, and replacements were expensive and sometimes difficult to obtain.

In recent years a new solar technology has emerged that eliminates the problematic energy storage batteries. Known as "solar direct-drive" (SDD, see Section 1.3.4), this new technology has the potential to resolve many of the problems of off-grid vaccine refrigeration, enabling national immunization programmes to extend the cold chain into areas in the "last mile" that might otherwise be underserved.

Other technologies have also emerged as solutions to the problem of unreliable electricity. Ice-lined refrigerators (see Section 1.3.1) have long been used to provide adequate vaccine storage during extended power cuts. More recently, containers with passive cooling (see Section 1.3.5) that can cool their contents without a direct connection to any combustible fuel or electrical/mechanical source are now offering a potential vaccine refrigeration option at sites where no power is available.

1.3.1. Ice-lined refrigerators

In areas with unreliable electricity, ice-lined refrigerators have long been utilized to provide cooling during extended power cuts. During a power cut, cooling is maintained by an internal cold storage lining surrounding the vaccine storage compartment. The lining is made up of ice- or cold water-filled compartments or frozen ice-packs. When the electricity supply fails, the ice or cold water store keeps the vaccine cool. When power is later restored, the lining is re-cooled or re-frozen. For the last 20 years, ice-lined refrigerators have often proved the most economical choice in areas with unreliable and not excessively expensive electricity.

Standard ice-lined refrigerators can maintain acceptable temperatures with at least 8 hours of electricity per 24 hours and can sustain acceptable temperatures through power cuts of over 20 hours. A second generation of ice-lined refrigerator can operate with just 4 hours of electricity per day and, when fully charged, can sustain acceptable vaccine storage temperatures for several days.

1.3.2. Absorption refrigerators and water-pack freezers

Operating cold chain equipment in areas without grid electricity has long presented a serious challenge. Immunization programmes have addressed the problem by using absorption refrigerators, but there are various disadvantages to using these devices:

- The regular supply of gas or kerosene is expensive for immunization programmes in the long term.
- Supply of gas or kerosene is subject to interruption, and once on site it is vulnerable to diversion for other purposes.
- Absorption refrigeration is less efficient than the compression-cycle technology that is used in electric refrigerators.
- Keeping the temperature within the acceptable range of +2°C to +8°C for vaccines is difficult in absorption refrigerators.[1] There is a high risk of exposing vaccine to freezing temperatures.
- Gas and kerosene refrigerators require frequent maintenance to keep them operating well.
- Operating gas and kerosene refrigerators contributes to local air pollution and an increase in global greenhouse gas emissions.

1 See: Compression and absorption type refrigerators and freezers for vaccine storage. UNICEF (http://www.unicef.org/supply/files/Compression_and_Absorption_Type_Refrigerators_and_Freezers_for_Vaccine_Storage.pdf, accessed 1 October 2015).

In light of these considerations, WHO and UNICEF recommend that in off-grid locations with sufficient solar irradiance, solar refrigerators should be considered.

1.3.3. Battery-powered solar refrigerators and water-pack freezers

Solar refrigerators have been providing cooling for immunization programmes since 1981.[1] However, experience gained over that time has shown[2] that sustained operation of battery-powered solar refrigerators is challenging for a number of reasons:

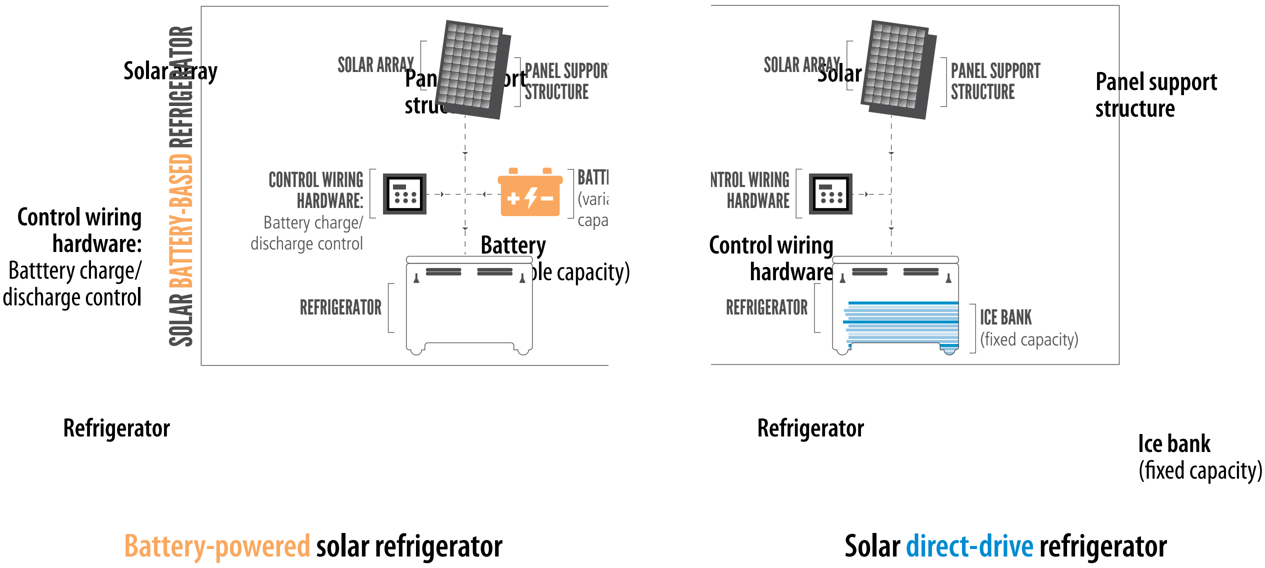
- Batteries that store solar energy often fail after only a few years. They are expensive to replace, sometimes difficult to source, and contain toxic materials that are difficult to dispose of safely.
- Energy from the batteries is sometimes siphoned off for other uses, shortening the life of the batteries and compromising energy needed for cooling.
- Batteries add complexity and the technical expertise required to deal with problems and failures is often lacking in the health centres and communities in which solar refrigerators are placed.
- The capital investment required for battery-powered solar refrigerators is much higher than for absorption and grid-powered options. Battery maintenance and eventual replacement costs add to the overall life cost.

Nevertheless, programmes with good management and secure funding that use battery-powered solar refrigerators have reported better vaccine storage temperature control than with absorption refrigeration.

1.3.4. Solar direct-drive refrigerators and water-pack freezers

In recent years a new approach to solar refrigerator design has emerged. This new approach eliminates the need for expensive (and problematic) energy storage batteries used to power solar refrigerators. "Direct-drive" technology uses solar energy to directly freeze water or other cold storage material and then uses the energy stored in the frozen bank to keep the refrigerator cold during the night and cloudy days. These appliances include refrigerators, water-pack freezers and combined refrigerator water-pack freezers and are called solar direct-drive (SDD) because they are wired directly to the photovoltaic generator (Figure 1).

Figure 1. Schematic showing difference between battery-powered (left) and SDD (right) refrigerators



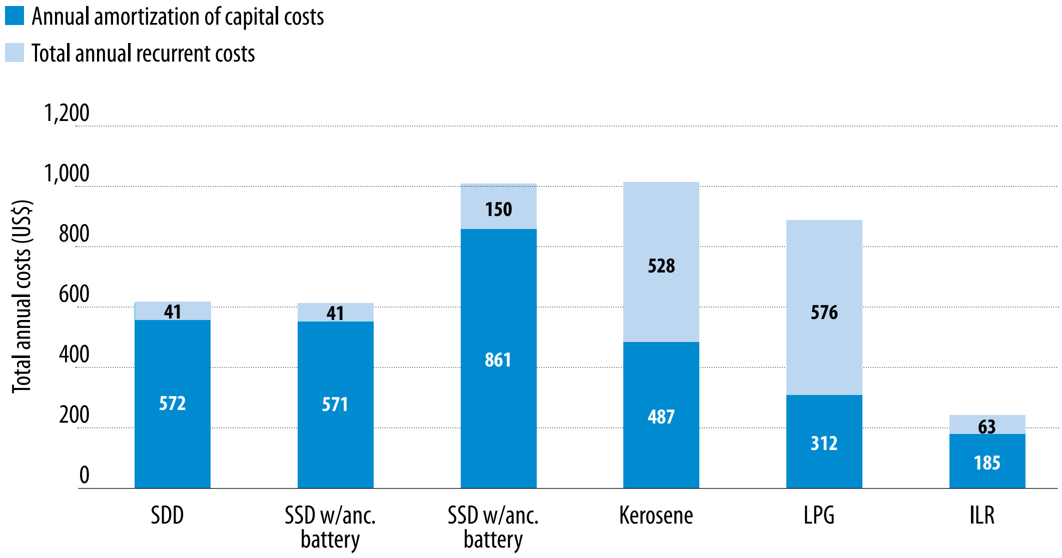
1 Ratajczak AF. Photovoltaic-powered vaccine refrigerator: freezer systems field test results. Springfield (VA): National Aeronautics and Space Administration; 1985 (DOE/NASA/20485-18; http://ntrs.nasa.gov/search.jsp?R=19860002199, accessed 1 October 2015).

2 McCarney S, Robertson J, Arnaud J, Lorenson K, Lloyd J. Using solar-powered refrigeration for vaccine storage where other sources of reliable electricity are inadequate or costly. Vaccine. 2013;31(51):6050 (http://www.ncbi.nlm.nih.gov/pubmed/23933340, accessed 1 October 2015).

There are two categories of SDD refrigerators – those that are entirely battery-free and those that use a smaller, ancillary battery to assist fans and controls. Ancillary batteries used in SDD refrigerators require eventual replacement and project planning must include this cost and consideration. However, the ancillary batteries are much smaller and less costly than those used to power compressor motors in first-generation battery-powered systems.

Because the batteries are historically the most vulnerable component, and the most expensive part that needs regular replacement, removing them has the potential to increase the long-term success of solar vaccine refrigeration. Also, depending on the future cost of electricity and other key inputs, SDD refrigerators may even compete in terms of life cost with other types of refrigerator. This is illustrated in Figure 2, which provides an example of how the annualized life-cost[1] of common vaccine refrigerators may be compared, factoring for both capital costs and operational costs. In this example, the mains-powered ice-lined refrigerator has the lowest annualized life-cost, while the kerosene-fuelled absorption refrigerator has the highest annualized life-cost. The SDD refrigerator would have the lowest life-cost in areas with unreliable electricity and suitable solar irradiance, and where a solar service provider can be funded to provide the necessary support.[2]

Figure 2. Example average estimated annualized cost for purchase, installation, operation and maintenance of PQS-prequalified refrigerator types



Acronyms: SDD – solar direct-drive; LPG – liquid petroleum gas; ILR – ice-lined refrigerator.
Source: Cold Chain Equipment Total Cost of Ownership tool (under development by PATH).

However, many of the shortcomings typically associated with solar refrigeration remain with SDD devices, including the lack of technical expertise likely to be available near the installation site, solar module theft, and ongoing solar array maintenance. Other problems may be even more serious in SDD refrigerators than battery systems, such as the impact of shading of solar modules (careful site selection is particularly important with SDD refrigerators). Careful equipment selection and installation, as well as effective, well-managed temperature monitoring, maintenance and repair are critical to ensure the success of any solar project.

1 Annualized life-cost is the sum of the annualized amortized initial capital costs (equipment, installation and lifetime spare parts), plus annual recurrent costs (fuel maintenance, repairs).

2 This comparison was obtained using the Cold Chain Equipment Total Cost of Ownership tool under development by PATH. Assumptions based on field experience and present-day costs were used to illustrate how operational costs contribute to total life-cost across refrigerator technologies. When complete, PATH will make the model available to enable country-specific comparisons using local costs. Email vxpharmatech@path.org for more information.

1.3.5. Containers with passive cooling

Passive refrigerators cool their contents without a direct connection to any combustible fuel, electrical or mechanical source. Most vaccine carriers and cold boxes are examples of passive cooling where cold or frozen water packs act as the cooling source.

Stationary vaccine containers with long-term storage (from 10 to over 35 days of sustained cold life between recharging) are now a WHO Performance, Quality, and Safety (PQS)-prequalified product option (see Section 1.5.1). These long-term containers can be used in several scenarios, such as at sites where no power is available but where ice can be regularly supplied within its cold life time limits. For example, a functionally off-grid health facility with a long-term container could receive monthly shipments of both vaccine and ice-packs from the district or other facilities with reliable access to ice in the form required by the container. Alternatively, the ice could be frozen on-site with a separate, standalone solar water-pack freezer.

At present, there are few product choices available and only limited field experience with this promising passive refrigeration option.

1.4. Partners

1.4.1. Qualified suppliers

Countries procuring solar equipment directly can obtain technical support from WHO, UNICEF Supply Division or from qualified suppliers who provide equipment and services that meet WHO PQS standards (see Section 1.5.1).

A qualified supplier may be either a legal manufacturer or a reseller, and is experienced in the design, installation and support of WHO PQS-prequalified solar refrigeration systems.[1] Qualified suppliers can also provide a solar power system that is matched to the refrigeration equipment, meets PQS equipment specifications and is suitable for the site-specific climate. A qualified supplier may also offer pre-installation site assessments, installation, training, corrective maintenance and repair services.

It is recommended that countries select a qualified supplier when procuring equipment independently. These suppliers are experienced in providing vaccine refrigerators for developing country immunization programmes, have at least one prequalified solar appliance, and meet WHO requirements for quality supplies and service. Some equipment manufacturers are also qualified suppliers, or alternatively may be able to provide the names of qualified suppliers located nearby. The PQS Catalogue (see Section 1.5.1) provides the contact details for all legal manufacturers of prequalified solar vaccine refrigeration equipment.

The guidance in this document can help countries to gather and present the information a qualified supplier will need to know. A price quotation can then be obtained and the total cost estimate compiled. With this information, countries will be able to determine the full cost of the equipment required.

1.4.2. Solar service providers

A solar service provider that can provide refrigeration and solar equipment servicing is essential to the success of a solar refrigeration system. A solar service provider is capable of pre-installation site assessment, equipment installation, training, corrective maintenance and repair.

1 A formal definition for 'qualified supplier' can be found in WHO PQS E03/PV01.2 (available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

Solar equipment servicing can be provided by a team of technicians managed by the health ministry, by a private organization specialized in solar electricity, or by a combination of both public and private sector actors. This network may already exist within the health ministry or may need to be found in the private sector. Refer to Section 2.3 for more information on identifying a solar service provider.

1.5. Technical resources

The following WHO and UNICEF resources are available to countries implementing solar refrigeration systems:

- WHO PQS Catalogue (see Section 1.5.1)
- UNICEF Supply Division's Cold Chain Country Support Package (see Section 1.5.2)

1.5.1. WHO PQS Catalogue

Any cold chain equipment that is selected should comply with a set of performance standards defined by WHO under its programme for prequalifying cold chain equipment PQS. Prequalified equipment has been tested to standards developed specifically for the vaccine cold chain, with an emphasis on use in developing country settings, and includes all types of vaccine refrigerators, freezers, combined refrigerator/water-pack freezers as well as solar power systems. A list of PQS-pre-qualified equipment is available in the PQS Devices Catalogue, available on the WHO website.[1]

Products in the PQS Devices Catalogue are subjected to post-prequalification review and in some cases performance monitoring to ensure that they are fit for purpose in rough conditions, and to identify future improvements that can be made.

There are several ways in which users can provide valuable feedback on their experiences with PQS-prequalified devices:

- Using the 'Feedback' form on the PQS Devices Catalogue website.
- Providing feedback to UNICEF Supply Division directly.
- Submitting product reviews on the TechNet-21 website.[2]

Based on feedback submitted by users on their experiences with PQS-prequalified devices, the WHO PQS team has published a set of "target product profile" documents. These strategic documents list the principal desired features of a product category intended for future PQS prequalification, and are used to guide manufacturers and other stakeholders in future product development programmes. Target product profiles are available on the PQS Catalogue website, and can be used by procurement agencies when selecting equipment with new features not yet included within the PQS Catalogue.

1.5.2. Cold Chain Country Support Package

In addition to procuring solar refrigerator systems directly (known as "self-procurement"), countries may have the option to procure through UNICEF Supply Division. UNICEF Supply Division has provided the majority of solar vaccine refrigeration equipment in use in developing countries today. The team of dedicated staff members continues to assist countries by providing equipment, conducting quality assurance inspections, and in some cases monitoring field performance. Refer to Chapter 4 for more information on procurement.

1 See: WHO PQS Catalogue [online database]. Geneva: World Health Organization; 2015 (http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue, accessed 1 October 2015).

2 TechNet-21 is a global network of immunization professionals working to strengthening immunization services. Members can share their views on PQS-prequalified products in in the "Reviews" area of the TechNet-21 website (http://www.technet-21.org, accessed 1 October 2015).

UNICEF Supply Division has developed a "Cold Chain Country Support Package" website to support UNICEF country offices and procurement service partners in strengthening immunization supply chains through the procurement of cold chain equipment and services. The website provides information on important technical and commercial considerations in the planning and procurement phases of cold chain implementation projects.[1]

1.6. Pilot projects

When introducing solar-powered vaccine refrigerator and freezer systems, it may be prudent to conduct a preliminary study to evaluate the equipment's performance in the field. Conducting a pilot project should be considered if the country perceives there to be an unacceptable degree of risk in the project. A risk might be perceived if:

- The equipment being purchased has only limited documented field performance (such as certain models of newly-prequalified SDD refrigerator).
- The country is inexperienced in the use of solar refrigerators.
- A very large quantity of equipment will be purchased.
- A significant amount of staff training will be needed.

Introducing solar vaccine refrigerator or freezer systems will involve significant adjustments to cold chain operations and maintenance, requiring planning, budgeting, logistics and staff training. Conducting a pilot project can provide invaluable insights into how best to prepare for the transition, including more precise planning and budgeting information, staff preparedness and familiarity with the new technology.[2] If well-monitored and documented, even a single site installation can provide useful insights into the suitability of a new technology or the logistical ramifications of its introduction. Although conducting a pilot project may involve a delay in national implementation, doing so can help to reduce risks. The decision to introduce new refrigerators on a larger scale can then be based on first-hand experience.

During the early stages of any project involving new technology, it is recommended that countries conduct comprehensive performance monitoring of the new technology.

1 See: Cold Chain Support Package. UNICEF; 2015 (http://www.unicef.org/supply/index_68367.html, accessed 1 October 2015).

2 Pilot projects can prove most effective when they "begin with the end in mind", the "end" in this case being the introduction of the new technology. See: World Health Organization, ExpandNet. Nine steps for developing a scaling-up strategy. Geneva: World Health Organization; 2010 (http://www.expandnet.net/PDFs/ExpandNet-WHO%20Nine%20Step%20Guide%20published.pdf, accessed 1 October 2015).

2 PREREQUISITES

Before beginning the process of introducing solar vaccine refrigerators or freezers, the country should first verify that the following prerequisites have been met:

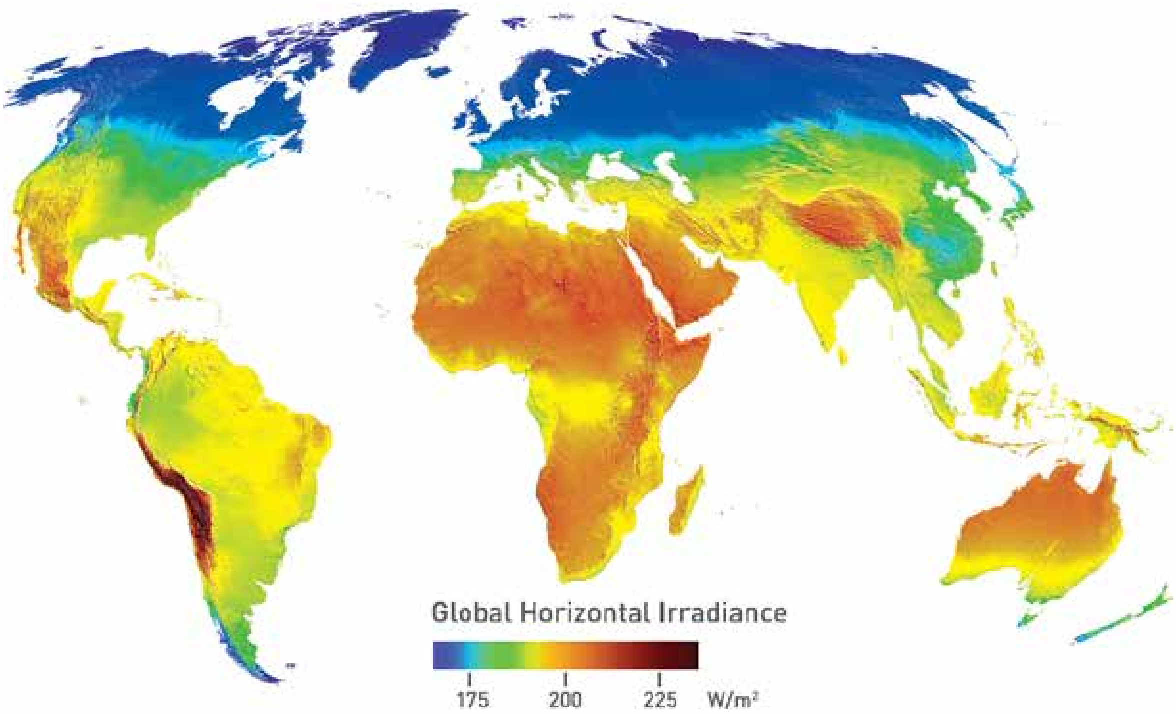
- Sufficient solar energy is available at installation locations (see Section 2.1).
- Solar energy is the most suitable source of energy at installation locations (see Section 2.2).
- A solar service provider is available (or will be made available) to provide all necessary services, including site assessments, equipment installation, training, corrective maintenance, and repair (see Section 2.3).
- Secure and ongoing funding is in place for the lifespan of the equipment (see Section 2.4).

2.1. Availability of solar energy

More energy from the sun falls on the earth in one hour than the energy used by everyone in the world in one year.[1] While solar energy has been used to power vaccine refrigerators since the 1980s, it is clear that it has the potential to play a greater role in areas that lack reliable electricity.

Many countries receive adequate sunlight to justify the consideration of solar-powered vaccine refrigeration. However, many countries also have microclimates with limited sunlight at some times of the year. For example, most of Colombia receives sufficient solar irradiance for solar vaccine refrigeration, yet mountainous areas and coastal regions may have microclimates with prolonged cloud cover. In cloudy areas of the country, the choice of solar technology will be limited and its implementation will require careful design to ensure adequate performance.

Figure 3. Global mean solar irradiance[2]



1 Learning about renewable energy. National Renewable Energy Laboratory, United States Department of Energy; 2014 (http://www.nrel.gov/learning/re_solar.html, accessed 1 October 2015).

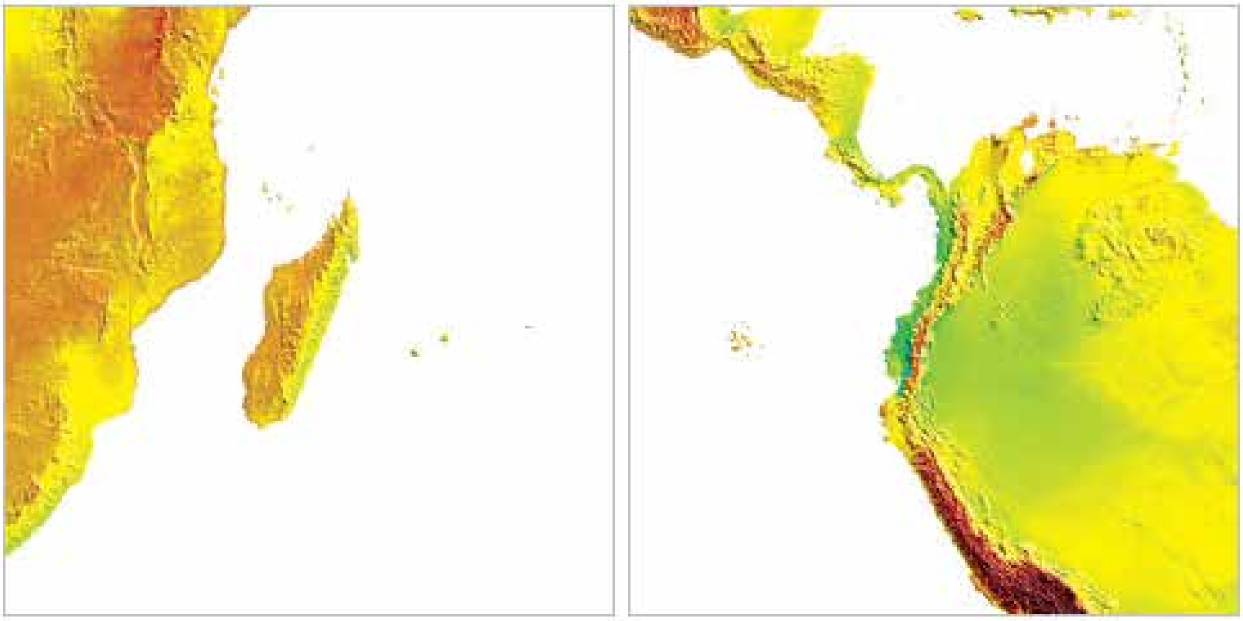
2 Map developed by 3TIER. Copyright 2011 3TIER Inc.

A map of global mean solar irradiance, or sunlight, is provided in Figure 3. This gives a general impression of which areas of the globe may be suitable for using solar energy for vaccine refrigeration. Yellow, orange and brown areas are those with enough sunlight to consider solar refrigeration. Only blue and green areas may be limited in the use of solar refrigeration technologies.

Looking at Madagascar (an island located to the south-east of Africa), we can see that there are two distinct solar irradiance bands (red and yellow), as well as a narrow band of green along the east coast (Figure 4).

In Colombia (located in the far north-west corner of South America; Figure 4), there are at least three distinct bands (green, yellow, and brown). Past solar refrigerator installations in the green area along the country's Pacific coast have experienced prolonged cloudy weather and extremely low solar irradiance. In this situation, careful consideration is needed to ensure adequate performance of solar technologies.

Figure 4. Global mean solar irradiance detail – Madagascar (left) and Colombia (right)

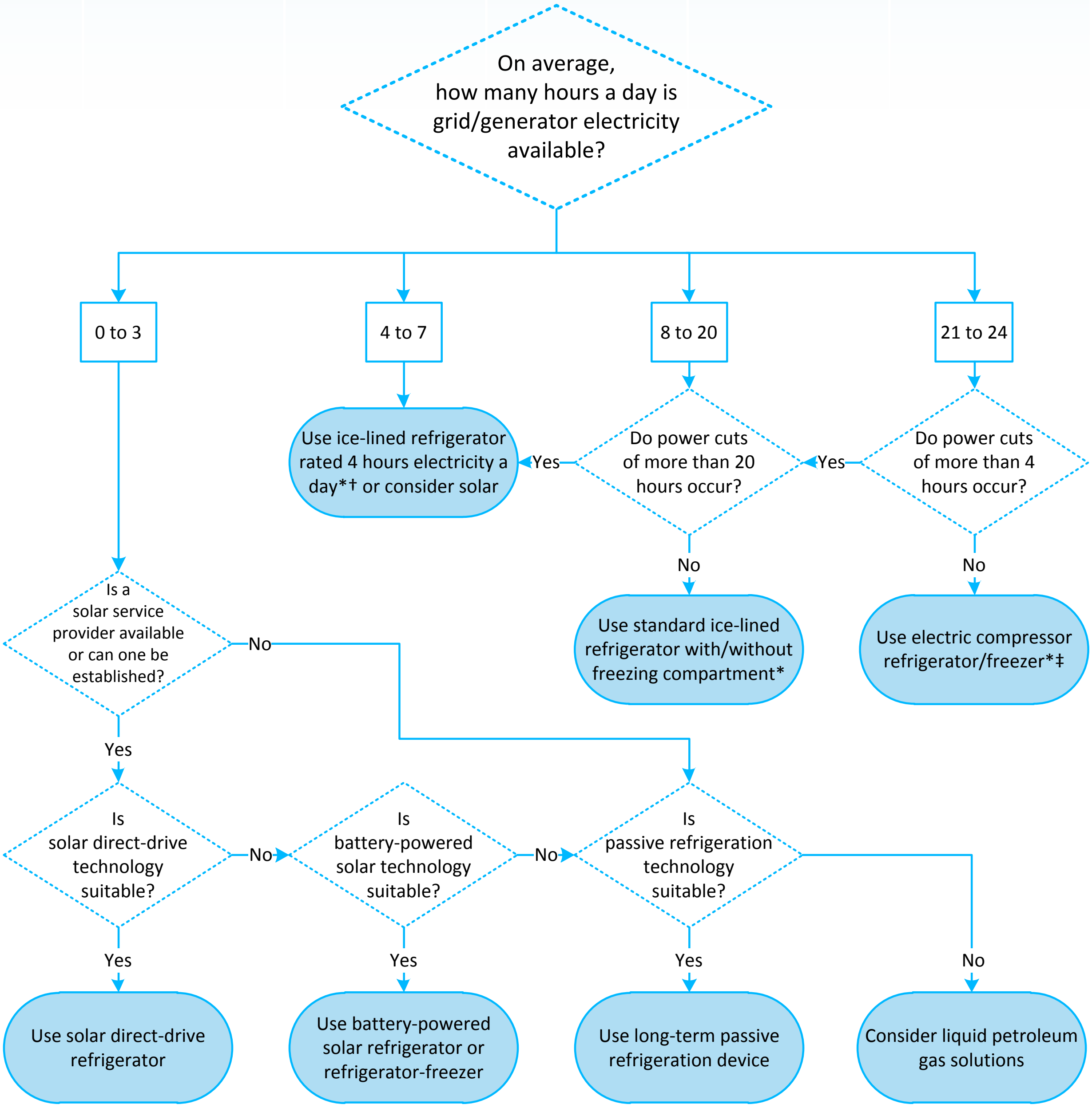


2.2. Suitability of solar energy

Continuous refrigeration is required for vaccine storage and this requires a reliable source of power. When choosing a power source, various factors need to be considered, and it is worth bearing in mind that even in locations with adequate solar energy (see Section 2.1) solar power may not be the best choice for vaccine refrigeration.

The PQS Catalogue (see Section 1.3.1) contains detailed guidance on selecting a suitable energy source for vaccine refrigeration. The following decision tree outlines the factors that will affect the choice of energy source at a given location, and indicates the circumstances in which solar energy may be suitable. Based on the answers to the questions, the most appropriate power source can be identified for each location.

Figure 5. Selecting the most appropriate energy source for vaccine refrigeration



* With voltage regulator

† With adequate holdover time (the time in hours during which all points in the vaccine compartment remain between +2°C and +10°C, at the maximum ambient temperature of the climate zone for which the appliance is rated, after the fuel supply has been disconnected). Refer to the PQS Catalogue for holdover times of ice-lined refrigerators

‡ Do not use domestic refrigerators unless lab tested to PQS standards

More information on selecting a suitable energy source can be found in Section E003.5 of the WHO PQS Catalogue.[1]

1 See: WHO PQS Catalogue [online database]. Geneva, World Health Organization; 2015 (http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/, accessed 1 October 2015).

2.3. Solar service provider

A solar service provider is an essential component in the implementation of a successful solar vaccine refrigerator or freezer system. The solar service provider is an organization whose staff are appropriately trained, and which is equipped and capable of supporting a solar refrigerator or freezer system by providing all necessary technical services, as well as optional non-technical services. The technical services include pre-installation solar refrigerator site assessments, equipment installation, staff training, corrective maintenance, troubleshooting, and repair; non-technical services include assistance with specifications, preparation of bidding documents, bid evaluations, supervision and acceptance of equipment installations, and performance monitoring.

Technical and non-technical solar services, such as trained technicians, can be provided either by a public sector organization (for example, the health ministry) or by private sector organizations (for example, a solar electricity company and consulting services provider), or by a combination of both.

2.3.1. Public-sector solar service providers

A public-sector solar service provider can be part of the ministry of health. Ministry technicians will already be knowledgeable in electricity and cold chain service requirements, and will often be responsible for sustaining equipment operations throughout the country. However, ministry technicians should not be considered ready to support a solar refrigerator or freezer system until they have received specific training from either the manufacturer of a PQS-prequalified solar refrigerator or a qualified supplier, or through a reputable training programme on solar vaccine refrigeration.

If an acceptable in-country service network cannot be found, another option is to create a network by developing the capabilities within the health ministry (or other government agency charged with infrastructure service). This requires training cold chain technicians on specific solar refrigeration capabilities. Staff will need to be equipped with tools and spare parts and supported to carry out the required services. Advice on how to do so can be obtained from UNICEF Supply Division, qualified suppliers, and independent consultants. Once a product has been selected, training can be customized to match country needs. The training is sometimes provided by the refrigerator manufacturer, a qualified supplier or experienced consultants working in coordination with the manufacturer.

It should be noted that a public-sector service network will only function effectively if the appropriate funds are budgeted for the required tools, spare parts, training, transport, lodging, per diem payments and other essential expenses (see Section 2.4).

Providing solar services in Benin

The national immunization programme in Benin developed a national plan for the transition from absorption to solar refrigeration. However, the Ministry of Health was unable to locate any public- or private-sector solar service providers in the country that were prepared for the introduction of solar vaccine refrigerators. As a result, a pilot project was devised to develop capabilities both within the public and the private sectors under the guidance of an independent, experienced solar refrigeration consultant who met the experience criteria of a qualified supplier (see Section 1.4.1).

Equipment was selected and training was customized with the cooperation of two refrigerator manufacturers. The training was then delivered to a combination of public- and private-sector participants, including technicians from the Ministry of Health and two maintenance technicians from a local firm. The training included classroom and field work and concluded with the successful, real-life installation of both a battery-powered solar refrigerator and an SDD refrigerator.

The country has now developed a group of trained technicians from within both the national Government and the private sector to assess sites, install and service solar refrigeration equipment, and to provide essential training for users.

2.3.2. Private-sector solar service providers

Solar equipment manufacturers (or qualified suppliers) can often provide details of the nearest solar service providers. Alternatively, they can be found on the internet (search by inputting the country name followed by "solar energy installers", "solar energy equipment suppliers" or "solar electricity"). Telephone directories often provide contact information for local and national companies not found on the internet.

The experience and quality of private-sector service companies vary greatly. For example, some companies may specialize in solar heating and have limited solar electricity experience When selecting a solar service provider, countries should look for companies that:

1. have in-country offices and in-country staff;
2. provide solar services throughout the region in which the solar refrigerators will be installed;
3. provide solar services for complete solar systems, not just individual components;
4. are experienced in conducting pre-installation site assessments, solar electric system installation, corrective maintenance, troubleshooting and repair;
5. have demonstrated success with previous solar electric contracts, and can provide references from customers who can be contacted;
6. have reliable transportation.

2.4. Secure and ongoing funding

The successful implementation of a solar vaccine refrigeration system requires long-term planning and funding, not just financial and technical support for early-phase activities. Although solar refrigeration systems, and in particular SDD systems, can alleviate many of the performance problems encountered with traditional absorption refrigerators, they still require regular maintenance and timely repair of equipment. It therefore needs to be ensured that these requirements can be met at installation sites throughout the lifetime of the system.

Over the life of the equipment (minimum design life is estimated at 10 years) there will also be ongoing operating and maintenance costs that must also be budgeted annually. Funding must be in place for recurring purchases of spare parts – particularly for expensive replacement batteries, if used – according to a reasonable replacement schedule or plan and with stock points organized throughout the national programme in a rational manner. A well-managed project will plan for ongoing training, performance monitoring, maintenance, repair, and parts replacement. Commitment to funding all of these costs over the life of the project is essential to its success. Without this long-term commitment, it is likely that a solar refrigeration system will not be successful.

3 EQUIPMENT SELECTION

This chapter provides guidance on how to select the most appropriate solar-powered vaccine refrigerator and freezer systems. The process involves the following steps:

- identify facilities that require solar refrigerators and water-pack freezers (see section 3.1);
- identify storage and freezing capacity requirements (see section 3.2);
- assess climate conditions (see section 3.3);
- conduct site assessments (see section 3.4);
- specify required equipment (see section 3.5);
- compile capital and operating costs (see Section 3.6).

The final step in the selection process involves completing a "specification checklist" for each facility that requires solar refrigerators or freezers. These checklists can then be issued to the procurement agency or to qualified suppliers as the basis for issuing a request for quotations (see Section 4.1). A specification checklist template that can be used for this purpose is included in Annex B.

3.1. Identify facilities that require solar refrigerators and water-pack freezers

The identification of facilities that require solar refrigerators and water-pack freezers must be based on national policies and plans, such as a cold chain rehabilitation and extension plan which in turn should be based on an overarching plan such as a national comprehensive multi-year strategic plan (cMYP) for immunization.[1]

If a cold chain equipment inventory for every facility in the area under consideration is not available or is not up-to-date, a new or updated inventory will need to be drawn up. This inventory can then be used to determine the list of facilities that require solar refrigeration, based on the following considerations.

- For facilities where grid/generator electricity is available, the reliability, quality and cost of the electricity at the facility should be determined (see Section 3.1.1).
- For facilities that already have cold storage, the availability, reliability, and volume capacity of cold storage should be determined (see Section 3.1.2).
- For facilities without cold storage, the potential benefits of cold storage should be determined (see Section 3.1.3).

3.1.1. Determine reliability, quality and cost of grid/generator electricity at facilities where grid/generator electricity is available

For facilities where grid/generator electricity is available, the reliability, quality and cost of the electricity at the facility should be determined. Note that electricity companies, as well as the government department responsible for energy matters, should be consulted in order to obtain an accurate understanding of the current and future situation (grid extension or service provision using renewable energy such as solar may already be planned, for example).

Reliability

Facilities that receive three hours or fewer a day of grid or generator electricity do not receive enough electricity to operate either an electric compressor refrigerator or ice-lined refrigerator, and solar vaccine refrigerator systems can be particularly suitable in these locations (see Section 2.2). Measuring equipment

1 Guidance to countries on making a cMYP for immunization, using the Global Vaccine Action Plan (GVAP) 2011–2020 as a guiding framework, can be found at: WHO-UNICEF guidelines for developing a comprehensive multi-year plan (cMYP) [website]. Geneva: World Health Organization; 2015 (http://www.who.int/immunization/programmes_systems/financing/tools/cmyp, accessed 1 October 2015).

can monitor and record electricity reliability, but such equipment is rarely used to assess health facilities in the last mile. If the reliability of electricity at a facility is unknown, health facility staff should be contacted to obtain this information. The most important questions to ask are:

- On average, how many hours of electricity does the facility receive a day?
- When power outages occur, what is the maximum duration of the outage?

Quality

The quality of electricity at a facility can be negatively affected by the voltage level or by frequent fluctuations in the voltage level. The recurrent failure of electrical equipment at a facility is a good indication that the quality of electricity is poor. In such locations, voltage stabilizers and/or surge protection can help to protect equipment.[1] Solar refrigerators that are not at risk of failure due to poor quality electricity can also be used in these locations.

Cost

At some facilities where grid/generator electricity is available, the production cost of electricity may be particularly high. In these cases it may be more cost-effective to install solar refrigerators. A life-cost analysis should be carefully undertaken to analyse these costs. PATH's cold chain refrigeration life-cost model (see Section 1.3.4) is one tool that be can be used for this.

Determining electricity availability at district health facilities in Haiti

Haiti has many areas where grid electricity is unavailable or unreliable. Even in urban areas, electricity has been reported to be erratic and in some cases available for only a few hours a month. This is inadequate for even the best ice-lined refrigerators.

Small, peripheral facilities lacking reliable electricity have historically gone without refrigeration, or have used either a single solar or absorption refrigerator. At the district level, facilities requiring larger vaccine storage volumes have relied upon multiple absorption refrigerators.

Dissatisfaction with absorption refrigeration prompted managers to begin the transition to solar refrigeration at the district level. A cold chain equipment inventory was conducted to record the details of all refrigerators in use. The inventory was expanded to inspect for access to electricity and to interview staff regarding the reliability of electricity. (Most facilities do not record the availability of electricity or the quantity and duration of power outages, so this information must normally be obtained by interview.)

Most districts were identified as candidates for solar refrigerators. Later assessment found that most locations do have several local sources for ice, including commercial ice vendors. Therefore, district facilities were identified as candidates for solar freezers or utilization of alternate sources of ice. At least one district site reported sufficiently reliable electricity to allow the use of ice-lined refrigerators (which require at least four to eight hours of power a day) and locally-available freezers for water-pack freezing.

3.1.2. Assess cold storage performance at facilities with cold storage

Facilities that already have cold storage should be assessed to determine the energy sources being used and whether they should be replaced. For example, facilities that use absorption refrigerators should be identified and selected as potential candidates to receive solar refrigerators. Alternatively, if a facility uses a compression refrigerator that is not functioning correctly, it may be because the facility does not have sufficiently reliable electricity. This facility could also be a candidate to receive solar refrigeration.

The performance of existing cold storage can be measured using temperature-monitoring devices such as thirty-day temperature recorders (30-DTRs). Evidence from such data-driven assessment supports sound decision-making on whether the existing cold storage requires repair or replacement.

1 Refer to E001.3 of the WHO PQS Catalogue (available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue, accessed 1 October 2015).

3.1.3. Determine potential benefits of cold storage at facilities without cold storage

Facilities without cold storage should be investigated to determine whether they may benefit from cold storage. The investigation should include an assessment of:

- catchment population;
- unrealized potential catchment population;
- relative benefits of scheduled and unscheduled immunization sessions;
- potential benefit of providing cold storage for other health commodities.

If it is found that a facility may benefit, the availability, quality and cost of grid electricity at the facility should be determined (see Section 3.1.1).

3.1.4. Finalize list of facilities

Having examined every facility in the area under consideration, the list of facilities that are candidates for solar refrigeration can be compiled. For example, if there are 100 facilities in the area under consideration, and the country has decided to make the transition from absorption to solar refrigeration, the list of facilities that are candidates for solar refrigeration can be determined as follows.

Table 2. Example list of 100 candidate facilities for solar refrigeration

Facilities with cold storage	50
Facilities using absorption **(a)**	20
Facilities using compression that receive *more than* 4 hours of grid electricity a day at a more cost-effective price than solar **(b)**	10
Facilities using compression that receive 4 hours or more of generator electricity a day at a less cost-effective price than solar **(c)**	5
Facilities using compression that receive *less than* 4 hours of grid electricity a day **(d)**	5
Facilities using solar **(e)**	**10**

Facilities without cold storage	50
Facilities that might benefit from solar and that receive 4 hours or more of grid electricity a day at a more cost-effective price than solar **(f)**	5
Facilities that receive 4 hours or more of generator electricity a day at a less cost-effective price than solar **(g)**	10
Facilities that might benefit from solar and that receive *less than* 4 hours of grid electricity a day **(h)**	**20**
Facilities that would not benefit from solar **(i)**	**15**

Based on this information, the total number of facilities that may benefit from solar refrigeration is **60**.

Of the facilities with cold storage, the following 30 may benefit:

- Facilities using absorption **(a)** = 20
- Facilities using compression that receive 4 hours or more of generator electricity at a cost that makes it more cost-effective to use solar **(c)** = 5
- Facilities using compression that receive less than 4 hours of grid electricity a day **(d)** = 5

Of the facilities without cold storage, the following 30 may benefit:

- Facilities that receive 4 hours or more of generator electricity at a cost that makes it more cost-effective to use solar **(g)** = 10
- Facilities that might benefit from solar refrigeration and that receive less than 4 hours of grid electricity a day **(h)** = 20

A discussion should be held with the management of facilities with generator-produced electricity to decide whether to continue to run the generator to power an ice-lined refrigerator or switch to solar refrigeration. In cases where a facility is due to be connected to the grid in the near future, instead of investing in solar the management may decide to continue to use generator-produced electricity until the grid connection is made. If the prospect of grid electricity is unlikely, they may decide to switch from generator to solar energy.

Cold chain equipment inventory conducted in pilot region of Benin

The national immunization programme in Benin developed a national plan for the transition from absorption to solar refrigeration. A pilot project was designed to introduce solar refrigerators in a single region in advance of launching a nationwide programme.

A cold chain equipment inventory identified the facilities that use absorption refrigeration and were therefore candidates for solar refrigeration. The inventory listed the facility names, location, latitude and longitude, catchment area, birth rate, and existing equipment. A cold chain equipment inventory is also an opportunity to evaluate the facilities' access to electricity (see Section 3.1.1).

The inventory and electricity availability data enabled the national immunization programme to make an informed decision on the number of facilities that required solar vaccine refrigerators. Location information was also used to plan efficiently for the solar site assessments (see Section 3.4).

3.2. Identify storage and freezing capacity requirements

Once a list of facilities that require solar refrigerators or freezers has been finalized, the vaccine storage capacity and water-pack freezing (or cooling) capacity required for each facility should be determined.

If immunization sessions require water-packs, or if outreach activities are conducted from the facility, then a source of water-pack freezing (or cooling) will be needed. Freezing/cooling capacity is specified in kilograms or litres per day and should include the desired water-pack size to be used (0.3, 0.4, or 0.6 litres).

Vaccine storage capacity can be calculated using the Vaccine Volume Calculator.[1] This Microsoft Excel-based tool, produced by WHO, has been designed to estimate the net storage volume of vaccines per child. The Vaccine Volume Calculator also estimates the number of passive containers needed to transport the necessary quantities of vaccines. This information enables the quantities of water-packs required and their weight to be calculated.

The calculation of requirements for frozen or cool water-packs can also be calculated using the EVM assistant tool.[2] Once the tool is opened and the necessary fields filled in, the software generates a nomogram displaying the total weight of water-packs in kilograms required for each delivery trip.

Given the risk of non-compliance with correct frozen water-pack conditioning, it is possible to use cold water-packs (+2 to +8°C). Depending on the model, the cool life of small vaccine carriers varies from 4.5 to 8 hours, while the cool life of large vaccine carriers ranges from 6 to 18 hours. Therefore, if the duration of a vaccine collection trip or of an outreach activity falls within the cool life of the available vaccine carrier, it makes sense to use cold water-packs instead of frozen ones in order to avoid the risk of freezing vaccines during transport. This is a management decision, as WHO policy only states that vaccines must be transported between +2 and +8°C. Refer to the PQS Catalogue (see Section 1.5.1) for a list of commercially-available appliances with the required water-pack freezing capacity.

1 The Vaccine Volume Calculator and user guide are available at: http://www.who.int/immunization/programmes_systems/supply_chain/resources/tools/en/index4.html (accessed 1 October 2015).

2 Available at: http://www.who.int/immunization/programmes_systems/supply_chain/evm/en/index3.html (accessed 1 October 2015).

3.3. Assess climate conditions

Ambient air temperature can significantly affect the performance of refrigeration equipment. WHO-prequalified refrigerators and freezers are therefore classified according to the maximum and minimum temperature conditions at which they have been tested. When selecting an appliance, countries can use this classification to help ensure that the appliance will function correctly in the particular environment in which it will be installed. The maximum and minimum temperature classifications are described in Table 3.

Table 3. Climate zone and minimum rated ambient temperature

Classification	Description	Definition
Climate zone	The highest constant ambient temperature at which a WHO-prequalified vaccine refrigerator can maintain the vaccine storage compartment between +2°C and +8°C. The three PQS climate zones are: • **Temperate (up to +27°C)** • **Moderate (up to +32°C)** • **Hot (up to +43°C)** Established during laboratory testing.	The mean maximum temperature in the hottest month where the appliance will be located. For example, if the mean maximum is +35°C, the appropriate climate zone is Hot.
Minimum rated ambient temperature	The lowest constant ambient temperature at which a WHO-prequalified vaccine refrigerator can maintain the vaccine storage compartment between +2°C and +8°C. Established during laboratory testing.	The mean minimum temperature in the coldest month where the appliance will be located.

In cold climates, the winter temperature inside a facility can drop below freezing – where heating is absent at night or weekends, for example. In such cases, it is important to select equipment that can operate at low ambient temperatures.

To identify the most appropriate classification for a facility, information on the mean (or average) hottest and coldest monthly temperatures at that location is required. Fortunately, detailed, long-term temperature records for many countries are available online.[1] However, it should be borne in mind that some parts of a country – for example, mountainous regions, deserts or moist coastal regions – may experience very different temperatures than those considered typical. Solar irradiance may also vary greatly within a single country. In many cases, online resources will be able to provide temperature records for at least some locations in a given country. (Note that temperature records are often expressed as average temperatures and these may be used in place of mean temperatures.) In many countries, a national meteorological service/department can provide records of temperature and insolation (either the daily duration of sunshine or the total energy received from the sun on a daily basis) for several measurement points within the country. This resource can help to fill the gaps in meteorological information available online.

If temperature records for the precise location of the facility cannot be found, the temperature records for the location that is closest to the facility can be used.

1 Refer to http://www.weatherbase.com and http://www.wolframalpha.com (accessed 1 October 2015).

Determining climate zones in Benin

India, Kenya and Peru are all examples of countries that have widely varying climates. Geography in each country ranges from tropical coastal regions to high mountains that can receive snow. Air temperatures also vary greatly. Even countries with less dramatic geography must consult temperature records to ensure that the correct information is used to define the climate zone designation.

In Benin, programme managers, manufacturers and consultants were able to quickly confirm the correct climate zone designation by studying national temperature data found in online weather records.[1] The data confirmed that the climate in the north of Benin is different to that in the south. In addition the data confirmed that elevations also differ and that this can affect the climate. Temperature records were found for 14 locations throughout the country, each with over 20 years of records. Comparison was then made of the monthly average temperatures in the north, middle and south of the country, as well as locations at sea level and up to 500 metres above sea level.

Example air temperature data analysis for Benin

Site	Latitude	Longitude	Elevation	Coldest month (average)	Hottest month (average)	Annual temp. (average)
Cotonou	6-21 N	2-23 E	9m	+23°C (July)	+31°C (Feb)	+28°C
Kandi	11-08 N	2-56 E	291m	+17°C (Dec)	+32°C (Apr)	+32°C
Natitingou	10-19 N	1-23 E	460m	+19°C (Nov)	+35°C (Feb)	+30°C
Save	08-02 N	2-28 E	199m	+22°C (Jan)	+35°C (Feb)	+30°C

The data shows that the coastal region near Cotonou and the region near Kandi could use refrigerators with the Moderate (+32°C) climate zone designation. Natitingou and Save have recorded +35°C as the average temperature in their hottest month, and for these regions the designation must be rounded up to "Hot" (+43°C), even though their average annual temperature is just +30°C. The coldest average temperature is +17°C, reported at Kandi. Therefore, a minimum rated ambient temperature of +15°C (or lower) will be acceptable for all locations in Benin.

3.4. Conduct site assessments

Facilities that require solar refrigerators or freezers need to be individually assessed before the solar equipment can be installed. This will ensure that accurate equipment specifications can be drawn up. The purpose of a site assessment is to:

- identify any issues that may prevent the use of solar refrigerators or freezers at the facility;
- identify the specific materials required for the installation, based on conditions at the facility and its dimensions;
- identify any pre-installation work that is required at the facility (for example, roof repair or construction work) and that cannot be completed during installation.

The chosen solar service provider (see Section 1.4.2) should conduct the site assessment by inspecting each site. The solar service provider will be responsible for completing the installation and will therefore know what to look for during the assessment to be able to complete the installation on the next visit. A qualified supplier or an experienced consultant can also provide site assessments.

A solar site assessment worksheet is provided in Annex A. This worksheet can be used by the person conducting the site assessment to capture the key technical details.

3.4.1. Are site assessments necessary?

If the site assessment is conducted thoroughly, with all relevant details carefully recorded at each facility, the installation can be completed in one visit. Although such a site assessment may increase overall project costs, doing so is the best way to ensure that an installation is successful and to minimize the number of (expensive) follow-up visits required.

In some circumstances, conducting site assessments by inspecting every facility may not be possible. If this is the case, a representative number of sites can be selected to determine the approximate equipment requirements. However, each site can have unique features that require adaptations prior to installation, such as the need for an extra-long cable or a pole-mounted array to avoid shading. Because of this, representative site assessments cannot ensure that the equipment required for each site will be provided at the time of installation. This can lead to delays and cost overruns.

Examples of potential project failures that can be prevented by site assessments include the following.

- The shading of solar panels is not assessed in advance. If the solar array is installed in a location that does not receive sufficient energy, the refrigerator will not remain cold.
- Weak (dangerous) roof structures are not accounted for, and therefore cannot be repaired prior to installation. If a solar array is improperly installed on a weak roof then damage to equipment and personal safety is risked.
- Solar array cable length is not measured. The kit-supplied cable may be too short, leading to either a costly return visit, the substitution of improper cable, or placement of the solar array in an incorrect location.
- The mounting structure is not determined. The kit-supplied structure and fasteners may be inappropriate for the site, leading to problems such as reduced performance and increased chances of theft.
- Details of electrical cable entry into the building are not established. The correct hardware cannot be ordered in advance and the wire entry may then be improperly installed, posing a risk to cable durability.

Site assessments can identify these conditions in advance and enable advance planning to correct them, such as placing orders for site-specific solutions and allowing extra time for the necessary materials and equipment to arrive.

3.4.2. Site assessment preparation

Before a site assessment is conducted, the following arrangements should be made.

- Schedule the visits with both the assessor and the facility. The site assessors will need to interview staff at the facility and gain access to the interior.
- Provide pre-visit support to the assessor. For each facility, the following should be provided:
  - facility details, including address and travel instructions;
  - contact details of all staff to be interviewed;
  - cold chain equipment inventory, if available;
  - any required assessment equipment;
  - vaccine storage, water-pack freezing capacity, and other requirements that have been defined.

If the site assessment and solar service is provided by the ministry of health, then it will be the responsibility of the ministry to arrange transport, access to tools (solar site shading tool, ladders, tape measures, camera, etc.), per diems, travel funds and other logistic considerations.

- Specify the outcomes of the site assessment, including:
  - the return of tools and vehicles (if provided);
  - the submission of completed solar site assessment checklists, including shading assessment;
  - summary of key findings (optional).

Conducting site assessments in Colombia

Four health posts in Colombia were assessed prior to establishing final equipment specifications. The assessor used the solar site assessment worksheet provided in Annex A to prepare for the on-site visits and ensure that all necessary information was gathered during the visit. The results were critical to ensuring that all the required installation equipment had been ordered and that the technicians conducting the installation were fully prepared with the proper tools and supplies. A shading analysis was also essential to ensure that the SDD refrigerators and freezers would receive enough solar insolation to provide the required refrigeration.

The four health posts were located in a sparsely populated region that required several hours of travel between sites (more travel time than actual assessment time – typically, one or two hours – at the health post). Two assessments were completed each day.

The assessor found that two of the four health posts required the solar modules to be mounted on tall poles to provide unshaded solar irradiance from 7 a.m. to 5 p.m., as recommended by the manufacturer.

Not all manufacturers offer a pole-mount option. Special orders were placed for the pole mount structures: galvanized steel poles, a conduit to protect exposed cables, fasteners to attach the conduit, and concrete for setting the poles.

The installation technicians were able to complete the installation to WHO PQS standards in a single trip with no delays. Since then, all systems have been in operation with no reported installation problems, thefts, or temperature alarms.

3.4.3. Data-collection during site assessments

Site assessments can generate a significant amount of detailed technical information. A 'site assessment worksheet' is provided in Annex A that can be used to ensure that all necessary information is gathered during the visit.

A shading analysis is also required to ensure there is adequate solar irradiance for solar direct drive refrigerators and/or to inform the design of battery-powered solar refrigerators. Solar site analysis tools can enable the assessor to quickly and accurately quantify shading. If the assessor finds that one solar array position is not acceptable then the assessor can move about the area until an acceptable location is identified.

3.4.4. Battery considerations

For some facilities, a site assessment may conclude that SDD technology is unsuitable. For example, a facility located in the shade of a mountain or steep valley may not receive enough solar irradiance. In these cases, battery-powered systems that can ameliorate shading problems should be considered.

Battery-powered refrigeration systems are required when SDD refrigeration has been found to be inadequate for any of the following reasons:

- Shading reduces the SDD runtime to less than the minimum required by the manufacturer. Most require the solar array to be unshaded for most, if not all, of the day.
- The autonomy (ability to maintain a temperature between +2°C and +8°C during periods of heavy cloud) provided by SDD refrigeration is insufficient to meet the facility's requirements. Battery capacity can be added to meet these requirements, whereas SDD refrigerators have a fixed thermal storage capacity, which limits their ability to expand their autonomy.
- Quick cool-down time is desired. This may be necessary to facilitate commissioning and acceptance on the same day as installation, or rapid return to service after repair. (SDD refrigerators typically require 5–7 days to cool down before reaching stable temperatures with full autonomy, while battery-powered systems can attain stable temperatures in a few hours.)

3.5. Specify required equipment

The previous steps in this chapter have described how to gather the information needed to specify the type of solar refrigeration equipment required. Once these steps have been completed, the equipment, additional features, and optional items required for each facility should be specified using the 'Specification Checklist' template in Annex B.[1]

If the country is procuring solar equipment directly, the completed checklists should be sent, together with a copy of PQS performance specification E003/PV01.2,[2] to a shortlist of qualified suppliers or published as an open tender as the basis for issuing a request for quotation (see Section 4.1). The qualified suppliers will then review the specifications, provide recommendations of any necessary amendments, and may supply additional details, such as autonomy requirements based on a technical review of equipment requirements using the best available data on site cloudiness. The work of sizing the solar array and/or battery system can be completed by the qualified supplier directly, based on the information provided.

If the country is procuring equipment through an international organization such as UNICEF Supply Division, the checklists can be provided to the international organization or the qualified supplier helping to manage the procurement.

For optimum cold chain performance, it is essential to maintain a stock of spare parts for cold chain equipment, including refrigerators and solar power systems. (This does not include batteries, which have a limited shelf-life and should therefore not be stocked for general replacement.) Spare parts recommendations for prequalified devices per 50 installations are included in the PQS Catalogue (see Section 1.3.1) and equipment suppliers can also provide specific recommendations.

3.6. Compile capital and operating costs

Equipment costs make up only one category of the total solar refrigeration cost. Initially, there will be installation costs. If a solar service provider needs to be created, funding and delivery of training and tools will also be required.

Over the life of the equipment (minimum design life is estimated at 10 years) there will also be ongoing operational and maintenance costs that must also be budgeted annually. Funding must be in place for ongoing purchase of spare parts – including replacement batteries, if used, according to a reasonable replacement schedule or plan and with stock points organized throughout the national programme in a rational manner. A well-managed project will plan for ongoing maintenance, repairs and parts replacements. Commitment to fund all of these costs over the life of the project is essential to its success.

A realistic estimate of all costs will enable countries to evaluate and make informed decisions on the best plan for a solar refrigeration system. This plan should be for at least 10 years (some solar modules now have warranties of 25 years).[3]

To better understand the costs over the project lifetime, a detailed budget should be estimated. An example budget summary sheet is included in Annex F. This can be customized to suit the needs of a programme.[4]

1 This checklist is a reformatted version of the one that appears in Annex 1 of WHO/PQS/PV01-VP2.2 (available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

2 This specification describes the requirements for solar power systems that operate compression-cycle vaccine refrigerators or combined refrigerator and water-pack freezers (available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

3 The Cold Chain Refrigeration Life-Cost Model developed by PATH can provide an indication of likely system costs. Contact PATH for more information.

4 The worksheet was created by the Solar Electric Light Fund (SELF) and has been adapted by WHO-UNICEF with the agreement of SELF.

4 PROCUREMENT

In addition to procuring solar equipment directly (known as self-procurement), countries may have the option to procure equipment through international organizations such as UNICEF Supply Division. The procurement options available depend on the funding source being used and any associated procurement requirements.

This chapter provides a brief overview of the self-procurement process, from issuing and evaluating requests for quotations (see Section 4.1) to negotiating a contract with the chosen qualified supplier (see Section 1.4.1).

4.1. Issuing a request for quotation

Self-procurement is typically implemented in a similar way to procurement through an international organization, but with minor differences that reflect the rules and customs of the countries and organizations involved. Countries considering self-procurement should refer to the WHO *Procurement process resource guide*,[1] which provides a detailed checklist and planning aid for health technology procurement.

To issue a request for quotation, the completed specification checklists (based on the template provided in Annex B), together with a copy of PQS performance specification E003/PV01.2,[2] should be compiled into a tender document that is then:

- Sent to a shortlist of qualified suppliers selected by the in-country project owner (the ministry of health or a nongovernmental organization, for example) in collaboration with the donor.
- Published as an open tender according to the rules and regulations of the country, to which donor requirements can be added if necessary.

The qualified suppliers will then review the specification checklists and submit their bids for the tender, which will provide additional technical information as required, such as the solar array capacity, SDD or battery autonomy, and associated installation and connection hardware. A quotation for the proposed configuration, including spare parts, will be specified, along with any services requested, such as shipping, customs clearance, storage, transport, installation, and training. Comparing several options from more than one qualified supplier is recommended to identify the best solution and cost – even when a specific refrigerator is selected, there may be multiple suppliers from whom quotations can be requested.

All system components included in the qualified supplier's quotation should be PQS pre-qualified. Refrigerators must comply with specification E003/RF04 (battery-powered), E003/RF05 (SDD) or E003/RF06 (SDD with ancillary battery). Solar power systems must comply with E003/PV01.

Once all bids have been received, the country will need to evaluate them. The best choice for a solar refrigerator deployment may not be the cheapest. Other considerations should be taken into account when evaluating a bid, such as:

- equipment warranty offered;
- performance of equipment;
- quality of previous installations conducted by the qualified supplier;
- availability of long-term maintenance;
- technical assistance provided;
- presence of company representatives in the country or region;
- likely long-term running costs of the refrigerator units.

1 Procurement process resource guide. Geneva: World Health Organization; 2011 (http://whqlibdoc.who.int/publications/2011/9789241501378_eng.pdf, accessed 1 October 2015).

2 This specification describes the requirements for solar power systems that operate compression-cycle vaccine refrigerators or combined refrigerator and water-pack freezers. See: WHO/PQS/PV01-VP2.2 (available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

The financial health of the bidding companies and their in-country or regional representatives can be analysed by asking them to submit their certified accounts for the previous three years. This will avoid the risk of awarding contracts to bankrupted companies.

4.2. Negotiating a contract

Once a choice is made, the country should award the contract to the selected qualified supplier. The agreed-upon contract should specify the products and services to be supplied, the agreed price and terms, and should be based on the specification checklists provided and any other supporting documents that the country considers necessary.

Countries should ensure that the contract includes all the equipment they require. As a minimum, this should include:
- solar refrigerators and solar power systems;
- spare parts;
- equipment options such as temperature monitoring devices, maintenance tools and supplies;

The contract should also define the precise terms of equipment delivery (see Section 4.2.1).
In addition to equipment, if required by the country the contract can define services to be provided by the qualified supplier. These can include:
- installation and training services (see Section 4.2.2);
- Maintenance and repair services.

Alternatively, these services can be provided by a private organization as part of a separate contract.

4.2.1. Delivery terms

Once a supply contract is signed, the supplier will proceed with the order. Depending on the terms of the contract, the receiving country or partner may need to engage a freight forwarder and prepare for customs clearance of the shipment.

Manufacturers and suppliers offer delivery arrangements based on international standard definitions known as Incoterms. A new edition of Incoterms was published in 2010 and is being phased in. It is essential to check which version is being used by the supplier. For a full definition of Incoterms, refer to the PQS Devices Catalogue, available on the WHO website.[1]

The manufacturer should mark appropriately all solar equipment before it is shipped to show that it is the property of the health ministry or health department. The manufacturer should also provide a bill of lading if the equipment is sent by sea, or air waybill if they are sent by air, as well as an electronic cargo tracking note, which is mandatory for clearing customs. (Refrigerators with phase-change material linings cannot be sent by air.) Note that shipping costs vary considerably, according to destination. Countries should always confirm freight charges with the supplier before placing an order. Estimated freight charges should be included in budgets, and shipping lead times should be included in project plans.

The safe storage of purchased equipment must begin as soon as the equipment arrives in the country. This is critical to prevent heat damage, for example from overheated shipping containers not adequately protected from sunlight or other sources of heat. The requirements for ensuring speedy customs clearance should therefore be defined in the supply contract to help mitigate these risks. Information about the equipment should be entered into the country's immunization cold chain inventory list as soon as it arrives.

1 Available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/categorylist.aspx?cat_type=device (accessed 1 October 2015).

4.2.2. Installation and training services

If a private organization is providing installation services, the contract with the private organization should include a warranty to ensure that any problems caused by incorrect installation of equipment are promptly resolved by the organization. To ensure that any such problems are resolved, final payment should depend upon the satisfactory performance of the equipment for a specific period after installation. This is known as acceptance testing and can be performed using 30-day temperature loggers to record the temperatures of refrigerators for up to 30 days after installation. If, after the specified number of days, the refrigerators are found to have operated without generating any temperature alarms, the refrigerators can be said to be operating satisfactorily and final payment can be made to the organization.

Temperature alarms can be caused by a variety of factors, not all of which are the responsibility of the equipment installation team. For example, the installation team cannot be held responsible for an interruption in power supply caused by storm damage or theft, misuse of equipment by staff, or faulty or improperly placed 30-DTRs. If a private organization providing installation services incurs additional costs to determine the cause of the temperature alarm, and the cause is subsequently determined not to be the responsibility of the installation service provider, the contract should clearly state who will pay for this aspect of acceptance testing.

If a private organization is providing on-site training as well as installation services, the contract should clearly state the precise training that will be provided. Refer to Section 5.2 for more details.

5 INSTALLATION

Solar refrigeration systems are at risk of early damage and even failure if the equipment is not correctly installed. To ensure correct installation, it is recommended that countries use qualified solar service providers. Alternatively, a specialist organization experienced in solar equipment installation can provide this service. These specialist organizations can either perform the installation themselves, or provide the appropriate training to the Expanded Programme on Immunization (EPI) technicians performing the installation.

If EPI technicians will perform the installation, it is critical to ensure that they have the relevant skills, tools and training to do so. A country's EPI team will normally include experienced refrigeration technicians, but they may not have experience with the most up-to-date solar refrigeration systems. If they do not have this experience, they will need to receive practical training before the installation can take place. Training can take from one day to two weeks, depending on the technicians' skills and experience. All installation work must be carried out in accordance with the qualified supplier's installation instructions, and all on-site electrical installation work must comply with IEC 60364-1.[1]

If a specialist organization will perform the installation, an installation contract will need to be carefully drawn up that clearly states the country's requirements and that holds the organization responsible for ensuring the quality of the installation. The contract should include a warranty to ensure that any problems caused by incorrect installation of equipment are promptly resolved by the organization. Once the installation has been completed, an EPI technician should inspect the installation and only sign-off on the work when it can be verified that the job has been completed satisfactorily.

Solar refrigeration systems should be installed and commissioned in accordance with the PQS Quality Assurance protocol WHO/PQS/PV01-VP2.2, which can be found in the PQS Catalogue.[2] Even when using a specialist organization to perform the installation, countries should work with the organization to ensure they have taken into account these requirements.

This chapter contains information and guidance on:
- preparing for the installation (see Section 5.1);
- delivering staff and technician training (see Section 5.2);
- verifying the installation of equipment (see Section 5.3);
- final acceptance (see Section 5.4).

5.1. Installation preparation

The installation team will need to make a comprehensive plan to prepare for the installation. The procedure for doing so will be the same regardless of who will perform the installation, and should include the following:
- equipment inspection;
- equipment storage;
- sourcing of local materials, equipment and manpower;
- route planning;
- transport to installation sites;
- installation coordination;
- refrigerator and power system installation requirements.

1 See: Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions. Geneva: International Electrotechnical Commission; 2005 (available at: http://webstore.iec.ch/preview/info_iec60364-1%7Bed5.0%7Den_d.pdf, accessed 1 October 2015).

2 See: WHO/PQS/E003/PV01-VP2.2 (available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

Each of these is described in the following sections. In addition, the installation team will need to:
- ensure that users are adequately trained to use the new equipment (see section 7.2.1);
- verify the installation once it has been completed (see Section 5.3).

5.1.1. Equipment inspection
An equipment inspection should be performed by EPI staff as soon as the equipment has been cleared by customs. This will help to confirm that:
- the refrigerator and solar power system order is complete;
- optional equipment order(s) are complete (for example, 30-DTR orders may arrive as a separate shipment and require effort to consolidate with other orders);
- there is no damage to any equipment;
- packing is adequate for further transportation to the installation site.

5.1.2. Equipment storage
The solar equipment should be stored in a warehouse that:
- is secure against theft;
- provides an environment that is dry and will not overheat (maximum temperature: +55°C);
- has loading and offloading capabilities that can handle the equipment.

5.1.3. Sourcing of local materials, equipment and manpower
Local materials may be required to perform the installation. The EPI team must ensure proper handling of local materials and equipment, as well as adequate transportation and check-in of equipment at the equipment storage area.

Local materials may include:
- steel poles;
- wood planks, stakes and wire for bracing poles and forming foundations;
- sand, rock and concrete for foundations;
- water (if used to fill the refrigerator ice-lining, or to mix concrete);
- conduit and fittings not provided by the supplier;
- repair materials for upgrading the facility (roofing, wood, masonry, other);
- other special items noted during the pre-installation site assessment (see Section 3.4).

Special locally-sourced equipment may be required. This can be rented or purchased, and may include:
- a scaffold system for difficult roofs and pole mounts;
- a portable generator for power tools and battery recharging;
- other special tools noted during the pre-installation site assessment (see Section 3.4).

Locally-sourced manpower to assist in performing the installation may also be required.

5.1.4. Transport to installation sites
The installation team will need to arrange for reliable vehicles to transport equipment and technicians to the installation site. These vehicles will need to:
- be in good repair and capable of travelling in the road conditions that will be encountered;
- provide protection from the weather and excessive dust;
- have adequate fuel capacity for the distances that will be travelled;
- have adequate passenger space (if transporting the installation team);
- be suitable for the weight and volume of goods to be transported;
- be prepared to make roadside repairs if necessary.

Experienced drivers who know the local roads and their condition should be hired. During transportation, it is important for the installation team to remain in contact. Cell phones, radios, satellite phones, and messengers should be used as required.

5.1.5. Route planning

While the on-site installation can often be completed in less than one day, travel time can sometimes equal or even exceed this. Careful planning will be needed to minimize travel time, particularly when planning a circuit of several installations during a single trip.

Installation travel time in Haiti

Installations of SDD systems by a crew of three qualified technicians required an average of five hours of on-site installation time, including customized equipment training for users. However, the travel time varied greatly. If the installation site was near the equipment storage area, the travel time could be as short as one hour each way. Travel across the capital city, however, required two or more hours through heavy traffic. Going to a regional city sometimes required up to 10 hours of travel each way. In the most remote areas, travelling required a mixture of motor vehicles, aeroplanes and boats. In cases where overnight lodging was required, a single installation required a round trip of up to three days. It was found that a well-planned circuit of several installations was necessary to economize on travel time.

5.1.6. Installation coordination

The installation team should ensure that all arrangements are made well in advance of the team's departure. The following groups should be fully aware of the arrangements:

- EPI managers;
- project administrators providing funds to pay for expenses;
- installation team-members;
- drivers;
- those responsible for secondary transportation (boat, aeroplane/helicopter, porters, pack animals);
- supervisors/contacts at the installation site;
- local staff who will receive user training from the installers;
- local manpower (if required);
- local authority/community leaders (in some cases);
- hotels (or other sleeping arrangements);
- provision providers (for water, food, local materials obtained on the way);
- security providers (if necessary).

Provision should also be made for secure and safe vehicle loading at the equipment storage location. This should include:

- ensuring that all local materials, rentals, system components and tools are available;
- ensuring that lifting equipment and/or people are on hand to help load and unload heavy items;
- handling equipment carefully while loading and unloading;
- protecting the load from weather damage;
- preparing for emergencies (providing first-aid kits and acid neutralization if using flooded lead acid batteries);
- securing the load against theft;
- securing the load for transport over the anticipated road conditions. Flooded batteries contain sulphuric acid electrolyte that requires personal safety items and material if accidental spills need to be cleaned up.

Ample time should be provided for safe travel to the installation site.

5.1.7. Refrigerator installation requirements

Installation requirements for solar refrigerators differ between battery and SDD technologies, manufacturers, and site conditions. This can significantly affect the time required by the installation team to perform the installation. Some SDD refrigerators, for example, require 5 to 8 days to cool down after installation and a delayed start-up by as much as one day after transportation. This may necessitate a follow-up visit from the installation team. Battery-powered refrigerators, by contrast, allow the refrigerator to be cooled down within a few hours, significantly reducing the time delay from installation to final acceptance, and potentially eliminating the need for a follow-up visit.

5.2. Staff and technician training

On-site staff and technician training can be provided by the installation service provider at the time of equipment installation, or if this is not feasible during a subsequent visit. If offered, the syllabus should reflect the requirements of both:

- health workers who will be using the equipment on a daily basis and performing non- corrective maintenance tasks;
- technicians who will be responsible for corrective maintenance and repair services, both of the electrical and the refrigeration components of the equipment.

The syllabus should also cover the relevant health and safety guidance.

5.3. Installation verification

Once an installation has been carried out, the responsible EPI technician or designated inspector should complete an installation checklist to verify that no serious problems were encountered. An 'Installation checklist' template provided in Annex E can be used for this purpose.[1] Countries can use it as a sign-off document (modified or kept as it is) for inspecting and approving the work of the installation team.

5.4. Final acceptance

Final acceptance (and payment if using a private organization to provide installation services) should depend upon the satisfactory performance of the equipment for a specific period after installation. This is known as acceptance testing and can be performed using 30-DTRs to record the temperatures of refrigerators for up to 30 days after installation. If, after the specified number of days, the refrigerators are found to have operated without generating any temperature alarms, the refrigerators can be said to be operating satisfactorily (and final payment can be made to the equipment installers, if used).

A '30-day performance checklist' is included in Annex F.[2] This checklist can be used by the responsible EPI technician to confirm that the equipment has been correctly installed and has operated satisfactorily during the first 30 days of operation.

1 This checklist is a reformatted version of the one that appears in Annex 3 of WHO PQS E003/PV01-VP2.2 (available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

2 This checklist is a reformatted version of the one that appears in Annex 4 of WHO PQS E003/PV01-VP2.2 (available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

Using 30-DTRs to verify successful installation

UNICEF Haiti contracted an experienced public sector solar electricity organization to install SDD vaccine refrigerators. The contract stated that final payment would only be made if:

- the refrigerators were deemed to have operated correctly (generating no temperature alarms for at least two weeks after the cool-down time); and
- the post-installation inspection and verification proved satisfactory.

Immediately after installation, a 30-DTR was placed in the vaccine storage area of every refrigerator. The lids were then closed and locked so there could be no vaccine or other goods stored in them during the cool-down time (the time required from installation before an SDD refrigerator reaches the correct temperature for use) nor during the acceptance time period.

Once the cool-down time ended and the refrigerators had reached stable temperatures (two weeks after installation), the refrigerators were inspected and found to have operated without generating any temperature alarms. It was therefore decided that vaccine could be safely stored in the new refrigerators and final payment could be made to the equipment installers.

6 TEMPERATURE MONITORING

Effective, well-managed temperature monitoring and recording are a key part of good vaccine storage and distribution practices. These practices help to ensure that:

- new and existing cold chain equipment performs correctly;
- vaccine quality is maintained throughout the supply chain;
- vaccine is not wasted due to exposure to heat or freezing temperatures at fixed storage locations, or during transport;
- when problems arise, they are rapidly detected and corrective action is taken.

The performance of newly-installed cold chain equipment should be validated using temperature monitoring devices such as 30-DTRs that can record the temperature of refrigerators for up to 30 days after installation. This is typically performed as part of final acceptance testing (and payment if using a private organization to provide installation services).

Once new solar vaccine refrigerators or freezers have passed final acceptance testing, they should be incorporated into the system-wide temperature monitoring and recording routine. This is particularly important for new technologies such as SDD refrigerators that have only limited documented field performance. Establishing routine, long-term temperature monitoring can help to prevent avoidable system failures because equipment problems can be resolved at an early stage – a critical step in ensuring their long-term success.

Proper selection, installation, use, and maintenance of solar equipment can be validated with a routine temperature monitoring plan. Monitoring data must be routinely collected, analysed, and linked to a management and supervision plan that will both support health-care workers to properly maintain solar equipment and also provide them with the right technical resources to quickly identify problems when they arise.

It is important to clarify the purpose and expected outcome of a temperature monitoring plan, and ensure that the staffing and financial resources exist to not only collect the monitoring data but also to develop and implement an action plan. Monitoring objectives will depend upon the experience of those running an immunization programme with solar technologies and their level of confidence in a specific solar refrigeration technology. Module VMH-E2-01.1 of the WHO Vaccine Management Handbook provides more information on routine temperature monitoring practices.[1]

In addition to using temperature monitoring devices to validate the performance of newly-installed cold chain equipment, it is also recommended that immunization programmes carry out comprehensive performance monitoring during the early stage of projects involving new technology. This can provide invaluable information about a new solar technology's performance, either to confirm reliable operation in a health-care setting if there is limited evidence from field settings, or to assist a manufacturer in optimizing the performance of prototype technologies.

1 How to monitor temperatures in the vaccine supply chain. Geneva: World Health Organization; 2015 (http://www.who.int/immunization/documents/financing/who_ivb_15.04, accessed 1 October 2015)..

Monitoring the performance of new technology in Senegal[1]

To increase the reliability of vaccine storage in remote locations, the Senegalese Ministry of Health installed 15 SDD refrigerators at health posts in three districts. To evaluate their performance, remote temperature monitors that use SMS messages to send temperature data to a central server were installed in 13 of the refrigerators.

Over the course of a year, the refrigerators were found to have performed reliably with no serious mechanical or electrical problems. According to the temperature data supplied by the remote monitoring devices, cooling performance was steady, even while refrigerators were in regular use and being opened frequently for vaccine storage and removal. With ambient temperatures at times exceeding +45°C, the monitored temperature was found to have remained within the target range of +2°C to +8°C for almost 99% of the cumulative time.

The temperature monitoring revealed some interesting aspects of user interactions with the refrigerators. Early in the study, when reviewing the monitoring data, supervisors and researchers noticed strange temperature profiles for some of the refrigerators. For example, sometimes the temperature would suddenly rise by 5 or more degrees and take some time to return to the normal range. This is different than what would be seen for a normal door opening, where the temperature might rise a few degrees for one reading but be back in range on the next. On investigation, it was found that this temperature behaviour was a result of health workers placing non-vaccine products in the refrigerator. After discussions with the staff at the health posts, compliance increased, and a corresponding improvement in temperature performance of the refrigerators was seen in the data.

1 Source: Direct-drive solar vaccine refrigerators – a new choice for vaccine storage. PATH/World Health Organization; 2013 (http://www.who.int/immunization/programmes_systems/supply_chain/optimize/direct_drive_solar_vaccine_refrigerator.pdf?ua=1, accessed 1 October 2015).

7 MAINTENANCE AND REPAIR

7.1. Maintenance and repair planning

Refrigerators and solar energy generators are complex technologies. Solar vaccine refrigerator systems utilize both of these technologies, and require preventive maintenance, occasional corrective maintenance and repair to function effectively over the long term.

Maintenance planning should begin when solar equipment is first selected (Chapter 3), as the choice of equipment will determine the maintenance requirements. For example, safety equipment and training are required to service flooded or sealed batteries. Consider all of these factors when comparing equipment options.

Maintenance and repair operations can be categorized into:

- preventive maintenance (conducted by on-site workers);
- corrective maintenance and repair (conducted by trained technicians);
- battery replacement (conducted by trained technicians).

The 'Maintenance and repair' module of the WHO Vaccine Management Handbook (currently under development) provides more information on maintenance planning.[1] In addition, the Effective Vaccine Management Standard Operating Procedures (SOPs) provide detailed information on solar refrigeration maintenance tasks that should be performed. Refer to Section 4.6 of 'E5-03.1 Installing and looking after vaccine refrigerators and freezers'. The Effective Vaccine Management SOPs can be downloaded from the WHO website.[2]

7.2. Preventive maintenance

Preventive maintenance includes those activities associated with the upkeep of a machine or power system to protect against normal wear and tear. This type of maintenance requires minimal skills and training, and is usually scheduled for regular intervals (daily, weekly, or monthly). On-site workers who have received appropriate training are responsible for preventive maintenance.

A checklist of preventive maintenance tasks to be conducted by on-site workers on a daily, monthly, and biannual basis is included in Annex H.

7.2.1. Training

Although many preventive maintenance tasks remain the same irrespective of the equipment selected, some tasks may vary depending on the equipment and manufacturer chosen. This makes on-site maintenance training essential. For example, there are no standard presentations on light-emitting diode (LED) indicator lights, and it is vital that users understand the specific messages being transmitted by the LED indicator lights on their equipment. Training that is based on the actual equipment installed is more effective than generalized training.

1 Will be available at: http://www.who.int/immunization/programmes_systems/supply_chain

2 Available at: http://www.who.int/immunization_delivery/systems_policy/evm/en/index2.html (accessed 1 October 2015).

On-site training can be provided by the installation service provider at the time of equipment installation (see Chapter 5). Alternatively, a follow-up visit can be scheduled to provide the necessary training. This may incur additional project costs. However, if the follow-up visit can be scheduled with other planned activities, such as installation verification (see Section 5.3) or final acceptance (see Section 5.4), and health worker are able to attend, then the additional cost can be minimized.

Whichever option is chosen, training plans should be included in the project budget (and the contract if a private organization is used to provide installation services and training).

7.2.2. Supplies and tools

On-site workers often do not receive the supplies and tools they need to conduct preventive maintenance of their solar equipment. To safeguard against this, it is important to ensure that each installation site is provided with the necessary supplies (for example, solar array cleaning tools) and that corrective maintenance staff receive the necessary specialized tools (for example, battery hydrometers and other safety equipment if flooded batteries are used). The EPI team should ensure that the manufacturer or solar service provider provides these supplies and tools as part of the equipment purchase contract.

A list of tools and supplies that are typically required by on-site workers to perform preventive maintenance of solar equipment is provided in Annex G.

7.3. Corrective maintenance and repair

Corrective maintenance and repair is usually conducted by technicians who have received specific training in both refrigeration and solar electric systems. If corrective maintenance and repair services are provided by EPI technicians, the EPI team will need to ensure that in addition to the relevant training these technicians are also provided with the necessary tools, supplies, parts and budget for travel (typically, they do not remain on-site). Without these capabilities, the EPI technicians will not be able to operate effectively.

Corrective maintenance and repair technicians should be capable of troubleshooting (diagnosing) problems and performing minor repairs on-site. Major repairs may require the skills of a repair professional with specialized tools, or the removal of equipment for off-site warranty or repair services.

It is recommended that at least two corrective maintenance visits are scheduled each year (four for systems with flooded batteries). The exact tasks will depend on whether the system is battery based or SDD, and include the following:

- retrain users as needed;
- review system performance (temperature records, alarms, metering/indicators);
- inspect location and condition of refrigerator and solar energy system. Correct as necessary;
- check all fasteners and tighten;
- check all accessible electrical connections, clean corrosion and tighten;
- inspect condition of cabling and conduits and repair as needed;
- inspect array for solar array shading and cleanliness and correct as needed;
- for flooded-battery systems: record specific gravity of each cell, clean terminals, inspect condition of plates, add distilled water as required, apply equalizing charge as needed and check battery enclosure ventilation and lock;
- for sealed battery systems: record open circuit voltage of each battery, clean terminals, apply equalizing charge as needed (and strictly per manufacturer's instructions) and check battery enclosure ventilation and lock.

7.4. Battery replacement

Typical battery life is around five years, but can range from a few years up to 10 years. Most equipment failures in battery-powered systems are due to the battery subsystem (which includes battery, control, overcurrent protection (i.e., circuit breakers or fusing), cabling and safety enclosure).[1] Consequently, timely battery replacement is essential for the sustained operation of any battery-powered system. If a battery is not replaced prior to failure, any sudden failure is likely to subject vaccines stored in the refrigerator to unacceptable temperatures. To reduce the likelihood of battery failure, funding for long-term battery replacement must be included in the project budget (see Section 4.2). Do not utilize battery-powered systems or SDD systems with ancillary batteries unless timely battery replacement can be provided.

Small, ancillary batteries used in SDD refrigerators are sealed and lower in cost than the batteries used in battery-powered solar refrigerators. They can be more easily transported and handled when compared to the larger, industrial batteries required in a battery-powered system. Nonetheless, ancillary batteries need to be replaced quickly upon failure. One strategy to support sustained operation is a scheduled battery replacement every few years. Qualified suppliers can provide assistance in determining the recommended timeframe for scheduled replacements.

Battery maintenance and replacement in battery-powered solar refrigerators is complex and hazardous, and usually requires:

- funding for battery replacement;
- correct product ordering;
- importation and shipping (in most countries);
- customs clearance;
- safe handling considerations;
- interim storage;
- transport to the installation site;
- a trained technician;
- removal and recycling of the old battery;
- installation and commissioning of the replacement battery.

Battery failure in Senegal

In the Casamance region of Senegal, a battery-powered solar refrigeration project experienced widespread failure after four years when the batteries failed. Without funding to replace the batteries, the refrigerators and solar arrays remained out of service for several years until funding for replacement batteries was secured and the equipment was restored.

This example illustrates that 'equipment failure' may sometimes be due to an administrative failure to plan, fund and act on maintenance and repair needs. It also illustrates that some 'failed' equipment in the field may only require a new battery to be restored to operation.

1 McCarney S, Robertson J, Arnaud J, Lorenson K, Lloyd J. Using solar-powered refrigeration for vaccine storage where other sources of reliable electricity are inadequate or costly. Vaccine. 2013;31(51):6050. doi:10.1016/j.vaccine.2013.07.

7.5. Reusing a solar array

The minimum target for service life of a vaccine refrigerator is 10 years. However, the solar array can generate electricity for 25 years or more. When a solar refrigerator eventually needs to be replaced, it is possible to reuse the existing solar array to power the replacement refrigerator. Reusing the solar array minimizes the cost and complexity of refrigerator replacement. It may also reduce the time required to replace the old refrigerator.

Proper maintenance on an ongoing basis will increase the likelihood of being able to reuse the solar array. To determine whether the array can be reused, the solar service provider may need to assess its condition. If the array is judged to be in reasonable condition, the service provider will assess the power output characteristics of the array and the cable and connectors for compatibility with the new refrigerator.

ANNEXES

Annex A. Site assessment worksheet

Please complete Sections 1, 2, and 3 *before* conducting the site assessment.

1.	**Site assessment details**	
1.1	**Assessment date**	
1.2	**Site assessor(s)**	
1.3	**Site details**	
1.3.1	Name	
1.3.2	Address	
1.3.3	Latitude	
1.3.4	Longitude	
1.3.5	Elevation (metres)	
1.4	**Contact details (1)**	
1.4.1	Name	
1.4.2	Email	
1.4.3	Landline	
1.4.4	Mobile phone	
1.5	**Contact details (5)**	
1.5.1	Name	
1.5.2	Email	
1.5.3	Landline	
1.5.4	Mobile phone	
1.6	**Meeting details**	
1.6.1	Time	
1.6.2	Location	
1.7	**Nearest food and lodging**	
1.7.1	Name	
1.7.2	Address	
1.7.3	Latitude	
1.7.4	Longitude	

2.	Transportation details
2.1	**Start point**
2.2	**Distance to site**
2.3	**Estimated time to site**
2.4	**Phone reception/provider**
2.5	**Road conditions**
2.6	**Security considerations**
2.7	**Waterway crossings**
2.8	**Bridges**
2.9	**Other hazards**
2.10	**Detailed directions**

3.	Site survey and assessment tool list
3.1	**Tools to bring to site assessment** ❑ First-aid kit ❑ Overnight kit ❑ Water / water purification filter or tablets ❑ Food ❑ Sunscreen / hat ❑ Notebook, pencils, pens ❑ Knife ❑ Camera (fully charged) ❑ Cell phone (fully charged) ❑ GPS (fully charged) ❑ Tool belt (hammer, screwdrivers, adjustable wrench, pliers, 30m & 8m tape measures) ❑ Multimeter ❑ Thermometer ❑ Shading analysis tool (e.g. solar pathfinder kit, dome, tripod, extra sunpath diagrams, wax pen) ❑ Compass ❑ Inclinometer ❑ Ladder, safety ropes ❑ Shovel ❑ Rag ❑ Other (specify below)

4.	Facility details		
4.1	**Interviewee**		
4.1.1	Name		
4.1.2	Position		
4.1.3	Contact details		
4.2	**Facility**		
4.2.1	Owned by		
4.2.2	Operated by		
4.2.3	Age		
4.2.4	Condition		
4.2.5	No. of staff		
4.2.6	Time(s) open		
4.2.7	Nightlights		
4.2.8	Guards	❑ Yes ❑ No	If Yes, guard hours:
4.2.9	Lockable storage	❑ Yes ❑ No	If Yes, condition of storage areas:
4.2.10	Security history		
4.3	**Electricity**	❑ None ❑ Grid ❑ On-site generator ❑ Battery back-up ❑ Solar ❑ Hybrid	
4.4	**Availability of grid, on-site generator, or hybrid**		
4.4.1	Hours per day		
4.4.2	Source of information		
4.4.3	Power outage frequency		
4.4.4	Typical outage duration (hours)		
4.4.5	Longest recalled power outage (hours)		
4.5	**Existing vaccine refrigerators**	❑ Yes ❑ No	If Yes, provide details below:
4.6	**Vaccine refrigerator (1)**		
4.6.1	Manufacturer		
4.6.2	Model no.		
4.6.3	Quantity		
4.6.4	Age (years)		
4.6.5	Location		
4.7	**Vaccine refrigerator (2)**		
4.7.1	Manufacturer		
4.7.2	Model no.		
4.7.3	Quantity		
4.7.4	Age (years)		
4.7.5	Location		
4.8	**Vaccine storage volume required (litres)**		
4.9	**Water-pack freezing requirements**		
4.9.1	Required	❑ Yes ❑ No	If Yes, litres per day: If Yes, water-pack size: ❑ 0.3l ❑ 0.4l ❑ 0.6l
4.10	**Future plans for facility**		

5.	Refrigerator placement (if location is known)	
5.1	**Refrigerator details (if known)**	
5.1.1	Manufacturer	
5.1.2	Model no.	
5.1.3	Width (cm)	
5.1.4	Diameter (cm)	
5.1.5	Height (cm)	
5.2	**No. of refrigerators (if known)**	
5.3	**Clearance for ventilation (cm)**	
5.4	**Refrigerator location(s)**	
5.5	**Are all refrigerators in the same room?**	
5.6	**Room name**	
5.7	**Room dimensions**	
5.7.1	Width (cm)	
5.7.2	Diameter (cm)	
5.7.3	Height (cm)	
5.8	**Door width (cm)**	
5.9	**Is room vented?**	
5.10	**If no, how will heat escape?**	
5.11	**Is roof watertight?**	
5.12	**Is floor strong & level?**	
5.13	**Is there any heat gain on refrigerator?**	
5.14	**Building materials**	

6.	Solar array placement (if known)		
6.1	**Solar array plan area**	L (cm): W (cm):	
6.2	**Will multiple arrays be required?**	❑ Yes ❑ No	
6.3	**Quantity of solar arrays (from prescribed quantity or actual quantity)**		
6.4	**Minimum distance from solar array placed north/south of another solar array (cm)**		
6.5	**Solar arrays required**		
6.6	**Array location**	❑ Roof	If ticked — Tilt: Orientation:
		❑ Ground ❑ Pole ❑ Other	
6.7	**Shading assessment**		
6.7.1	Unshaded location		
6.7.2	Dimensions of shaded area	L (cm): W (cm):	
6.7.3	Maximum shaded times and dates for array location		

7.	Photovoltaic array cable	
Record distance from solar array to refrigerator including all bends and obstructions. If manufacturer is known, enter the following details.		
7.1	**Standard output cable length (m)**	
7.2	**Optional cable length (m)**	
7.3	**Distance from solar array to refrigerator (m)**	
7.4	**Special cable length (if needed) (m)**	

8.	Ground cable	
Record distance from photovoltaic array to earth connector connection point including all bends and obstructions. One ground cable can connect multiple solar arrays.		
8.1	**Distance (m)**	
8.2	**Conduit protection**	❑ Yes ❑ No
8.3	**If yes, give length, diameter and fittings**	
8.4	**Soil description**	

9.	Photographs (as needed)	
9.1	**Photographs taken**	❑ Building ❑ Refrigerator room ❑ Solar array site(s) ❑ Roof ❑ Cable concerns ❑ Shading ❑ Other (specify below)

10.	Construction detail sketches (as needed)	
10.1	**Construction detail sketches made**	❑ Refrigerator room dimensions / door dimensions / wall and floor material / details ❑ Array placement details (include full area drawing) ❑ Wire run distance – photovoltaic array cables and ground ❑ Wiring: entry(s) into building, ground detail, and if needed conduit & fittings ❑ Roof detail (if needed) ❑ Other (specify below)

Annex B. Specification checklist

Use this form when the final location of the equipment is known. Complete one copy for each system type.

Solar refrigerator specification checklist for known sites			**Date:**
Country:			
Procurement agency:			
Contact name:			
Address 1:			
Address 2:			
Address 3:			
Address 4:			
Tel:			
Fax:			
Email:			
All system components must be PQS pre-qualified. Refrigerators must comply with specification **E003/RF04** (battery powered), **E003/RF05** (battery-free direct drive) or **E003/RF06** (direct drive, with ancillary battery). Solar power systems must comply with **E003/PV01.**			
SECTION 1: Site			
1.1	*Fields marked * are mandatory. The more precise the other data, the easier it will be for the qualified supplier to design the solar power system to suit the specific site.*	* Country:	
		* Longitude:	
		* Latitude:	
		Nearest city/town:	
		Village or suburb:	
		Site name:	
		Altitude in metres above sea level:	
SECTION 2: Refrigerator and power system			
2.1	**Refrigerator quantity**	Number of units required:	
2.2	**Temperature zone** *Choose the appropriate temperature zone. If winter temperatures are low and site heating is unreliable, specify a freeze prevention circuit.*	Hot zone (+43°C):	☐
		Temperate zone (+32°C):	☐
		Moderate zone (+27°C):	☐
		Cold climate freeze prevention circuit:	Yes ☐ No ☐
		If YES, specify the lowest winter temperature to which the refrigerator will be exposed [1]:	°C
2.3	**Refrigerator model** *Check PQS data sheets for available capacities but do not specify a named model* [2].	Refrigerator only:	☐
		Combined refrigerator & water-pack freezer:	☐
		Minimum vaccine storage capacity:	litres
		Minimum water-pack freezing capacity:	kg/24 hrs
SECTION 3: Power system			
3.1	**Solar power system quantity**	Solar power units required:	
3.2	**Solar power system type**	Either: **Type 1**: with battery set:	☐
		Or: **Type 2**: battery-free direct drive	☐
		Or: **Type 2**: direct drive with ancillary battery	☐
3.3	**Array support details** *The chosen array position must*	**Pitched roof mounting?**	Yes ☐ No ☐
		If YES, give roof pitch in degrees:	

[1] This is the lowest temperature in the room housing the refrigerator, NOT the lowest outside air temperature. In cold climates, temperatures down to -10°C may occur in health facilities that are left unattended and unheated for long periods.

[2] *Note:* Some models are refrigerator only with no ice-making capability.

Solar refrigerator specification checklist for known sites			**Date:**
Country:			
	face as close as possible to South (northern hemisphere) or North (southern hemisphere) and must be completely shade free (including overhead cables) from at least 9:00am to 3:00pm throughout the year. Give orientation in Northern hemisphere as: SE, SSE, S, SSW, SW or in Southern hemisphere as: NE, NNE, N, NNW or NW.	If YES give roof slope orientation:	
		If YES, state roof finish material:	
		If YES, height of building to eaves:	m
		Flat roof mounting?	Yes ☐ No ☐
		If YES, height of building to roof:	m
		If YES, state roof finish material:	
		Wall mounting?	Yes ☐ No ☐
		If YES, give wall orientation:	
		If YES, give mounting height:	m
		Ground mounting?	Yes ☐ No ☐
		Pole mounting:	Yes ☐ No ☐
		If YES, give height of pole:	m
		If YES, choose top or side mount:	Top ☐ Side ☐
3.4	**Array cable** *Measure the true distance[1] from the array to the battery set position as accurately as possible.*	Length of array cable required:	m
		Measured cable length including all bends, and vertical and horizontal lengths and add 10%.	m
3.5	**Ground conductors** *Agree realistic lengths of ground conductor with the qualified supplier.*	No. of lengths of ground conductor:	
		No. of earth connection fitting kits	

[1] True distance is measured along the actual route the cable will follow. Measure vertically, horizontally and with all changes in direction at 90 degrees.

Annex C. Example specification checklist

A facility requiring 50 or more litres of vaccine storage with a limited amount of water-pack freezing can specify the equipment requirements by sending the following specification checklist to the supplier. This includes the minimum information required by the supplier to provide a site-specific solution.
Different manufacturers could fulfil this requirement with the following PQS prequalified equipment:

- SDD combined refrigerator/freezer;
- battery-powered solar combined refrigerator/freezer;
- SDD refrigerator with separate standalone solar direct drive freezer.

Solar refrigerator specification checklist for known sites			**Date:**
Country:			
Procurement agency: Contact name: Address 1: Address 2: Address 3: Address 4: Tel: Fax: Email:			
All system components must be PQS pre-qualified. Refrigerators must comply with specification **E003/RF04** (battery powered), **E003/RF05** (battery-free direct drive) or **E003/RF06** (direct drive, with ancillary battery). Solar power systems must comply with **E003/PV01.**			
SECTION 1: Site			
1.1	*Fields marked * are mandatory. The more precise the other data, the easier it will be for the qualified supplier to design the solar power system to suit the specific site.*	* Country:	**Colombia**
		* Longitude:	**73.10 W**
		* Latitude:	**10.28 N**
		Nearest city/town:	**Sabana Crespo**
		Village or suburb:	
		Site name:	**Health Clinic**
		Altitude in metres above sea level:	**694**
SECTION 2: Refrigerator and power system			
2.1	**Refrigerator quantity**	Number of units required:	**1**
2.2	**Temperature zone** *Choose the appropriate temperature zone. If winter temperatures are low and site heating is unreliable, specify a freeze prevention circuit.*	Hot zone (+43°C):	☐
		Temperate zone (+32°C):	☒
		Moderate zone (+27°C):	☐
		Cold climate freeze prevention circuit:	Yes ☐ No ☐
		If YES, specify the lowest winter temperature to which the refrigerator will be exposed [1]:	°C
2.3	**Refrigerator model** *Check PQS data sheets for available capacities but do not specify a named model* [2].	Refrigerator only:	☐
		Combined refrigerator & water-pack freezer:	☐
		Minimum vaccine storage capacity:	**50** litres
		Minimum water-pack freezing capacity:	**1.6** kg/24 hrs

SECTION 3: Power system			
3.1	**Solar power system quantity**	Solar power units required:	**1**
3.2	**Solar power system type**	Either: **Type 1**: with battery set:	☐
		Or: **Type 2**: battery-free direct drive	☒
		Or: **Type 2**: direct drive with ancillary battery	☐
3.3	**Array support details** *The chosen array position must face as close as possible to South (northern hemisphere) or North (southern hemisphere) and must be completely shade free (including overhead cables) from at least 9:00am to 3:00pm throughout the year. Give orientation in Northern hemisphere as: SE, SSE, S, SSW, SW or in Southern hemisphere as: NE, NNE, N, NNW or NW.*	**Pitched roof mounting?**	Yes ☐ No ☐
		If YES, give roof pitch in degrees:	
		If YES give roof slope orientation:	
		If YES, state roof finish material:	
		If YES, height of building to eaves:	m
		Flat roof mounting?	Yes ☐ No ☐
		If YES, height of building to roof:	m
		If YES, state roof finish material:	
		Wall mounting?	Yes ☐ No ☐
		If YES, give wall orientation:	
		If YES, give mounting height:	m
		Ground mounting?	Yes ☐ No ☐
		Pole mounting:	Yes ☒ No ☐
		If YES, give height of pole:	m
		If YES, choose top or side mount:	Top ☐ Side ☐
3.4	**Array cable** *Measure the true distance[1] from the array to the battery set position as accurately as possible.*	Length of array cable required:	m
		Measured cable length including all bends, and vertical and horizontal lengths and add 10%.	**20** m
3.5	**Ground conductors** *Agree realistic lengths of ground conductor with the qualified supplier.*	No. of lengths of ground conductor:	
		No. of earth connection fitting kits	

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[1] This is the lowest temperature in the room housing the refrigerator, NOT the lowest outside air temperature. In cold climates, temperatures down to -10°C may occur in health facilities that are left unattended and unheated for long periods.

[2] *Note:* Some models are refrigerator only with no ice-making capability.

Annex D. Example budget summary sheet

Site assessments				
Item	**Unit**	**# Units**	**Cost/unit**	**Total ($US)**
Project manager	Days			
Administrative support	Days			
Preparations for site visit	Days			
Tools	Each			
Technician	Days			
Travel: vehicle, fuel, lodging, per diem	Day			
Communications and misc.	Each			
Management	Days			
Other				
			Subtotal	
			Contingency 5%	
			Total	

Specification preparation				
Item	**Unit**	**# Units**	**Cost/unit**	**Total ($US)**
Project manager	Days			
Administrative support	Days			
Communications and misc.	Each			
Management	Days			
Other				
			Subtotal	
			Contingency 5%	
			Total	

Procurement				
Item	**Unit**	**# Units**	**Cost/unit**	**Total ($US)**
Project manager	Days			
Administrative support	Days			
Equipment – refrigerator and solar power system	Each			
Local materials	Each			
Shipping	Each			
Customs clearance	Each			
Transportation to storage	Each			
Storage	Days			
Communications and misc.	Each			
Management	Days			
Other				
			Subtotal	
			Contingency 5%	
			Total	

Optional training – Technician				
Item	**Unit**	**# Units**	**Cost/unit**	**Total ($US)**
Project manager	Days			
Administrative support	Days			
Training materials preparation	Each			
Equipment	Each			
Tools	Each			
Venue expenses: rent, refreshments, AV	Days			
Trainee expenses: travel, lodging, per diem, salary	Days			
Communications and Misc.	Each			
Management	Days			
Other				
			Subtotal	
			Contingency 5%	
			Total	

Installation				
Item	**Unit**	**# Units**	**Cost/unit**	**Total ($US)**
Project manager	Days			
Administrative support	Days			
User training	Each			
Training materials for users	Each			
Technician time	Days			
Communications	Each			
Transportation (motor vehicle)	Days			
Transportation (other than car)	Days			
Food	Days			
Lodging	Days			
Construction drawings (only in special cases)	Each			
Tools	Each			
Local materials (only in special cases)	Each			
Equipment rental (only in special cases)	Days			
Management	Days			
Other				
			Subtotal	
			Contingency 5%	
			Total	

Corrective maintenance (per year)				
Item	**Unit**	**# Units**	**Cost/unit**	**Total ($US)**
Project manager	Days			
Administrative support	Day			
Technician	Days			
Travel: vehicle, fuel, lodging, per diem	Days			
Supplies	Each			
Tools	Each			
Maintenance materials	Each			
Management	Days			
Other				
			Subtotal	
			Contingency 5%	
			Total	

Repairs and parts replacement (per year)				
Item	**Unit**	**# Units**	**Cost/unit**	**Total ($US)**
Project manager	Days			
Administrative support	Day			
Technician	Days			
Travel: vehicle, fuel, lodging, per diem	Days			
Tools	Each			
Battery replacement - prorate to annual cost	Each			
Spare Parts	Each			
Management	Days			
Other				
			Subtotal	
			Contingency 5%	
			Total	

TOTAL BUDGET ESTIMATE	

Annex E. Installation checklist

Note: The installation technician must fill in a copy of this checklist for each completed installation.[1]

Solar refrigerator installation checklist				**Date:**
Country:		**City/town:**	**Site name:**	
Installation technician: Installation company: Address 1: Address 2: Address 3: Address 4: Tel: Fax: Email:				
Note: All checks must be satisfactory before the installation is handed over to the user.				
CHECK 1 – System description				
1.1	Qualified supplier:		Name:	
1.2	Photovoltaic panel:	Make:	Model ref:	
1.3	Panel mounting frame:	Type of support structure (describe)		
1.4	Refrigerator:	Make:	Model ref:	
1.5	Power system:	Direct drive (**RF05/RF06**) ☐	Battery-powered (**RF04**) ☐	
		If 'battery-powered' complete 1.6, otherwise go to **CHECK 2:**		
1.6	Battery powered systems:	Battery set make:	Model ref:	
		Battery type:	Sealed ☐ Flooded ☐	
		Charge regulator make:	Model ref:	
CHECK 2 – Shipment details				
2.1	Was the shipment damaged?		Yes ☐ No ☐	
	If YES, describe damage:			
2.2	Were any components missing?		Yes ☐ No ☐	
	If YES, list missing parts:			
2.3	Were any components under-supplied?		Yes ☐ No ☐	
	If YES, list under-supplied parts:			
2.4	Were any spare parts missing?		Yes ☐ No ☐	
	If YES, list missing parts:			
2.5	Were any spare parts under-supplied?		Yes ☐ No ☐	
	If YES, list under-supplied parts:			
2.6	Have damaged/missing/under-supplied parts been replaced?		Not applicable ☐ Yes ☐ No ☐	
	If NO, describe action taken to complete the installation:			
	Comments:			

1 This checklist also appears in Annex 3 of WHO PQS E003/PV01-VP2.2 (available at: http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

CHECK 3 – Photovoltaic panel installation		
3.1	Panel orientation:	
3.2	Panel slope (measure angle relative to the horizontal):	degrees
3.3	Do shadows fall on the panel between 9:00 a.m. and 3:00 p.m.?	Yes ☐ No ☐
	If YES, the system FAILS and the panel must be moved.	
3.4	Panel support structure: Anodized aluminium:	Yes ☐ No ☐
	Stainless steel:	Yes ☐ No ☐
	Galvanized steel (painted or unpainted):	Yes ☐ No ☐
	Other material (describe):	
	If 'other material', the structure does not comply and must be replaced.	
	Are foundation pads or roof fixings in place and are they adequate?	Yes ☐ No ☐
	Have theft-deterrent fasteners been used?	Yes ☐ No ☐
3.5	Lightning protection:	
	Has the lightning protection circuit been correctly fitted?	Yes ☐ No ☐
	Has the earth electrode been correctly fitted?	Yes ☐ No ☐
	Has lightning protection system been tested for electrical continuity?	Yes ☐ No ☐
3.6	Array cable:	
	Is the solar array cable type correct for the specified application?	Yes ☐ No ☐
	Is the solar array cable protected against mechanical damage?	Yes ☐ No ☐
	Is the solar array cable protected against rodent attack?	Yes ☐ No ☐
	Comments:	
CHECK 4 – Battery installation (where applicable)		
4.1	Battery set and battery set housing: Applicable ☐ Not applicable (go to 5) ☐	
	Accessible for maintenance?	Yes ☐ No ☐
	Protected against the weather?	Yes ☐ No ☐
	Safely located to prevent accidental damage?	Yes ☐ No ☐
	Secured against theft?	Yes ☐ No ☐
	Have battery safety instructions been provided?	Yes ☐ No ☐
	Have battery maintenance instructions been provided?	Yes ☐ No ☐
4.2	Flooded batteries (where fitted): Applicable ☐ Not applicable (go to 4.3) ☐	
	Are battery casings transparent?	Yes ☐ No ☐
	Was the electrolyte (acid) supplied in a separate sealed container?	Yes ☐ No ☐
	Has the battery safety equipment kit been supplied?	Yes ☐ No ☐
4.3	Battery charge regulator:	
	Was the regulator preset in the factory?	Yes ☐ No ☐
	Does the unit have a correctly labelled 'array charging' indicator?	Yes ☐ No ☐
	Does the unit have a correctly labelled 'low battery' indicator?	Yes ☐ No ☐
	Does the unit have a correctly labelled 'load disconnect' indicator?	Yes ☐ No ☐
	Does the unit have an optional acoustic alarm?	Yes ☐ No ☐
4.4	Fuses: 10 no. spare fuses in polythene bag fixed next to fuse box?	Yes ☐ No ☐
	Comments:	
CHECK 5 – Refrigerator		
5.1	Refrigerator or combined refrigerator & water-pack freezer:	
	Casing marked with the correct temperature zone symbol?	Yes ☐ No ☐
	Casing/compressor marked with refrigerant identification?	Yes ☐ No ☐
	Is the thermostat non-adjustable by the user as required?	Yes ☐ No ☐
	Is there an external reading thermometer as required?	Yes ☐ No ☐
	Comments:	

CHECK 6 – Wiring installation		
6.1	Wiring:	
	Has the system been wired in accordance with the qualified supplier's wiring diagram?	Yes ☐ No ☐
	Are all electrical connections concealed and properly protected?	Yes ☐ No ☐
	Has the site installed electrical wiring been tested?	Yes ☐ No ☐
	Comments:	
CHECK 7 – Commissioning tests		
7.1	Commissioning: have all tests been carried out in accordance with the qualified supplier's instructions?	Yes ☐ No ☐
	If YES, describe tests:	
	If NO, explain why tests have not been carried out:	
7.2	Are all system components functioning properly?	Yes ☐ No ☐
	Comments:	
CHECK 8 – Documentation		
8.1	Documentation check:	
	Has a *user manual* been supplied for all system components?	Yes ☐ No ☐
	Are *user manuals* in the correct language?	Yes ☐ No ☐
	Has a *technician's manual* been supplied for all system components?	Yes ☐ No ☐
	Are *technician's manuals* in the correct language?	Yes ☐ No ☐
	Has an *installation manual* been supplied?	Yes ☐ No ☐
	Is the *installation manual* in the correct language?	Yes ☐ No ☐
	Has one complete set of documentation been filed in a lever arch file and given to the procurement agency?	Yes ☐ No ☐
CHECK 9 – Overall conclusions and recommendations		
9.1	Recommendation:	Pass ☐ Fail ☐
	If FAIL, list outstanding work still required:	
	If PASS, the installation can be handed over to the user.	

Installation technician's signature: ……………………………………………………..

Date: ……………………………

Annex F. 30-day performance checklist

Note: The user must complete this checklist for each installation after the first 30 days of operation.[1]

<table>
<tr><td colspan="2">Solar refrigerator 30-day test checklist</td><td colspan="2">Date:</td></tr>
<tr><td>Country:</td><td>City/town:</td><td colspan="2">Site name:</td></tr>
<tr><td colspan="4">Instructions for completing this form:
Complete the form 30 days after the refrigerator was handed over to you.
Send a copy of the form back to
Attach a copy of the temperature record for the whole 30 day test period.</td></tr>
<tr><td>Name:
Position:
Tel:</td><td colspan="3"></td></tr>
<tr><td colspan="3">Have you received training in the use of the system?</td><td>Yes ☐ No ☐</td></tr>
<tr><td colspan="3">Do you have a copy of the user manual for the solar panels, battery set and refrigerator?</td><td>Yes ☐ No ☐</td></tr>
<tr><td colspan="3">Is the system working correctly?</td><td>Yes ☐ No ☐</td></tr>
<tr><td colspan="3">Has the refrigerator temperature stayed between +2°C and + 8°C throughout the last 30 days?</td><td>Yes ☐ No ☐</td></tr>
<tr><td colspan="3">Have you attached a copy of the temperature record for the last 30 days?</td><td>Yes ☐ No ☐</td></tr>
<tr><td colspan="3">Have you checked that all the indicator lights work correctly?</td><td>Yes ☐ No ☐</td></tr>
<tr><td colspan="4">If NO, which of the lights did you see in operation?</td></tr>
<tr><td colspan="4">Comments and questions:
If you have any comments or questions about the equipment or the installer, please write them here:</td></tr>
<tr><td colspan="4">User’s signature: ……………………………………………

Date: ………………………</td></tr>
</table>

1 This checklist also appears in Annex 4 of WHO PQS E003/PV01-VP2.2 (available at:http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue/catdocumentation.aspx?id_cat=17, accessed 1 October 2015).

Annex G. Maintenance tools and supplies

Preventive maintenance tools

Users typically need to be supplied with specific maintenance training and specific tools and supplies. In some cases special long-reach tools or personal access to the photovoltaic array is required to safely reach the photovoltaic array for routine cleaning. In general, the supplies and tools for preventive maintenance include the following:

- soft brush for cleaning condenser fins;
- soft cloth for cleaning;
- mild soap detergent;
- water bucket;
- plastic scraper (for safely removing ice build-up);
- optional for certain appliances: condensate collection pan;
- optional for cleaning photovoltaic arrays with difficult access: long-handle glass cleaning tools and/or ladder.

Technician maintenance tools

In general, the tools required by the maintenance technician include the following:

- first-aid kit;
- paper and pencil;
- thermometer;
- ladder;
- cleaning kit: soft cloth rags, mild soap detergent, water bucket, wire brush, abrasives (emery or sand paper);
- electricians tool kit: wire stripper/crimper, lineman pliers, long nose plier, diagonal pliers, spare fuses and selection of electric connectors/hardware;
- multimeter (bring 2 in case of failure);
- general tool kit: hammer, screwdrivers, wrenches, pliers, socket set, tape measure and selection of fasteners;
- battery operated drill and bits;
- battery operated portable lights (2);
- spare parts kit (per manufacturer's recommendations);
- optional: long handle glass cleaning tool when needed;
- optional: soldering iron and solder (if power available).

If flooded batteries are used, the following tools and supplies are also required:

- safety chemical goggles;
- chemical gloves;
- chemical apron;
- hydrometer;
- battery fill bottle;
- distilled water;
- baking soda;
- wire brush.

Annex H. Maintenance checklist for solar refrigerators and freezers

Maintenance tasks (daily)	
Task	**Check**
Check thermometer on refrigerator for acceptable temperature (+2°C to +8°C)	
Record refrigerator temperature on Daily Temperature Record	
Check other indicators for correct operation (e.g. 30-day temperature recorders for alarms, light emitting diode [LED] lights on refrigerator for correct daytime operation, battery voltmeters)	
Ensure efficient operation: • Open only when needed and close as soon as possible • Do not store personal food or drinks • Load vaccine and ice-packs according to manufacturer's recommendations	
Check refrigerator lid(s) fit tightly and are in position	
If freezer is not completely frozen in the morning wipe away interior moisture	
Check that ventilation of refrigerator is free of blockage	
Report to supervisor any problems that cannot be solved	

Maintenance tasks (weekly)	
Task	**Check**
Disconnect power	
Drain or wipe up refrigerator condensate	
Clean appliance inside, door seals, ventilation grills, condenser and outside	
Defrost as necessary (may be more frequent than monthly)	
Check door seal tightness	
Clean solar array (only if dusty, dirty and/or mould is growing on it)	
Check solar array for shading from plants. Trim plants that shade solar array	
Check solar array for other shading (e.g. new construction). Report to supervisor	
Check wiring for signs of damage (animals, storm, accidents). Report to supervisor	
Reconnect power	
Check for expected operation (e.g. indicator lights, fans operating, cooling as expected)	
For flooded-battery systems: observe electrolyte level through the clear casing and report if electrolyte is below level indicator	

Maintenance tasks (biannual)	
Task	**Check**
Oil hinges (may be more frequent in some locations)	
Request technician to tighten all electrical connections	
Request technician to tighten all mechanical connections	
For flooded-battery systems: request technician to service batteries (i.e. record specific gravity of each cell, clean terminals, inspect condition of plates, add distilled water as required, apply equalizing charge as needed and check battery enclosure ventilation)	

Notes

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