Volume III

International Performance Measurement & Verification Protocol

Concepts and Practices for Determining Energy Savings in Renewable Energy Technologies Applications

Volume III

August 2003

www.ipmvp.org

International Performance Measurement & Verification Protocol

Concepts and Practices for Determining Energy Savings in Renewable Energy Technologies Applications

Volume III

Prepared by:
IPMVP Renewables Subcommittee

August 2003

www.ipmvp.org

Acknowledgements

10 Gregory Kats (past Chair), Capital-E, USA

11 Steve Kromer, Teton Energy partners, USA

12 Khee Poh Lam, National University of Singapore, Singapore

13 Chaan-Ming Lin, Hong Kong Productivity Council, China

14 Alan Poole, Instituto Nacional De Eficiencia Energetica, Brazil

15 Arthur Rosenfeld, California Energy Commission, USA

IPMVP TECHNICAL COMMITTEE

1 John Cowan (Co-chair), Environmental Interface Limited

2 Venkat Kumar (Co-chair), Johnson Controls

3 Lynn Coles, R. W. Beck

4 Ellen Franconi, Nexant Inc.

5 Jeff Haberl, Texas A & M University

6 Maury Hepner, Crothall Assett Management

7 Satish Kumar, Lawrence Berkeley National Laboratory

8 Fernando Milanez, Global MVO Brasil Ltda, Brazil

9 Demetrios Papathanasiou, International Finance Corporation

10 Steven Hauser, Pacific Northwest National Laboratory

11 Robert Sauchelli, Environmental Protection Agency

12 Steve Schiller, Nexant Inc.

IPMVP RENEWABLES SUB-COMMITTEE

1 Greg Kats (Co-chair), Capital E, USA

2 David Mills (Co-chair), University of Sydney, Australia

3 Andy Walker (Co-chair), National Renewable Energy Laboratory, USA

4 Larry Bean, Iowa Deptartment of Natural Resources, USA

5 Bob Bergman, Colorado Public Utility Commission, USA

6 John Cowan, Environmental Interface Limited, Canada

7 Charles Eley, Charles Eley and Associates, USA

8 Mark Fitzgerald, Institute of Sustainable Power, USA

9 Ellen Franconi, Nexant Inc., USA

10 Charles Gray, National Association of Regulatory Utility Commissioners, USA

11 Jeff Harberl, Texas A&M University, USA

12 Maury Hepner, Crothall Asset Management, USA

13 Anne Grete Hestnes, Norwegian University of Science and Technology Department of Building Technology,Norway

14 Steve Kromer, Teton Energy Partners, USA

15 Satish Kumar, Lawrence Berkeley National Laboratory, USA

16 Kenneth Langer, US Department of Energy, USA

17 Ron Lehr, attorney-at-law, USA

18 Peter Lowenthal, Solar Energy Industries Association, USA

19 Katie McCormack, Center for Resource Solutions, USA

20 Mathew Salkeld, Munro Taylor Energy Systems, Canada

21 Steven R. Schiller, Nexant Inc., USA

22 Arlene Thompson, National Renewable Energy Laboratory, USA

23 Ed Vine, Lawrence Berkeley National Laboratory, USA

24 Satoshi Hirano, National Institute for Resources and Environment, Japan

25 Peter Varadi, Photovoltaic Global Accreditation Program, USA

IPMVP TECHNICAL COORDINATOR

Satish Kumar, Lawrence Berkeley National Laboratory, USA
Email: SKumar@lbl.gov, Phone: 202-646-7953

DISCLAIMER

This Protocol serves as a framework to determine energy and demand savings from a new construction or renewable energy project. IPMVP Inc. does not create any legal rights or impose any legal obligations on any person or other legal entity. IPMVP Inc. has no legal authority or legal obligation to oversee, monitor or ensure compliance with provisions negotiated and included in contractual arrangements between third persons or third parties. It is the responsibility of the parties to a particular contract to reach agreement as to what, if any, of this Protocol is included in the contract and to ensure compliance. IPMVP Inc. strongly urges any person or organization utilizing this protocol to seek legal advice as they deem appropriate for measurement & verification IPMVP Inc. disclaims any liability or responsibility relative to the use of this document. IPMVP Inc. is providing no warranties of any kind associated with the protocol including but not limited to warranties of fitness for a particular purpose.

Chapter 1   Introduction

1.1 Overview

A protocol for measuring performance is required to recognize the actual benefits of renewable energy technologies. These technologies make use of energy sources that are regenerated in nature and thus sustainable in supply. Renewable energy projects are installed all over the world in numerous projects funded by governments, private companies, organizations, and third-party financers.

Renewable energy technologies are highly diverse in terms of resources and conversion technologies. Nevertheless, several things are common to all the technologies that distinguish them from energy efficiency projects. Foremost among these is that all renewable energy technologies supply energy rather than reduce the energy consumed. Measuring this energy supply can often serve as a simplified approach to measuring system performance. The energy production of a renewable energy system that is not connected to a utility is directly linked to the amount of energy consumed by the connected load. Supplies of renewable energy complement the reductions in load achieved through energy efficiency measures. However, a measurement & verification (M&V) strategy for renewable energy may need to differentiate between a reduction in fossil fuel use caused by renewable energy delivery as opposed to one caused by a reduction in the load (by efficiency measures or curtailment).

In addition, the performance of some renewable energy systems is very much a function of environmental conditions, such as solar radiation or wind speed. These conditions are outside the control of project developers and should be taken into account in any M&V approach. An M&V objective always includes a measurement of savings in purchased fuel or electricity, but rarely includes other factors that may be equally important to a project, including savings in first cost (solar photovoltaics are often the least-cost option for small remote loads); reductions in atmospheric emissions; reductions in risk of transporting fuels (fuel spills); employing community industry rather than importing fuel; avoiding fuel supply interruptions or price fluctuations; or other "externalities."

Renewable energy projects are often capital-intensive, often requiring a longer investment term than that of energy efficiency projects. Therefore, an M&V program for renewable energy may need to verify that benefits are sustained over a longer period of time. This situation favors M&V approaches that may cost more initially but have lower annual operating costs.

1.2 Purpose and Scope

The purpose of this document is to describe special M&V considerations regarding renewable energy systems. The scope includes M&V options for renewable energy systems within the IPMVP framework, and includes examples and recommendations for specific applications. Renewable energy technologies include solar, wind, biomass (e.g., sustainably harvested food crops, organic wastes, and landfill gas), geothermal, small hydroelectric, ocean thermal, wave, and tidal energy.

1.2.1 Objectives

From the earliest stages of project development through operation of a completed renewable energy system, M&V may have several objectives:

- To measure existing daily, weekly, and annual demand and/or consumption load profiles to establish the energy use baseline and to ascertain the size of the system, energy storage requirements, and other design characteristics of a project. These load profiles also provide information needed to establish project feasibility.

- To serve as a commissioning tool in order to confirm that systems were installed and are operating as intended.

- To serve as the basis for payments to a project developer or energy service company (ESCO) over the term of a performance contract. Payments can be directly tied to measured performance. Alternatively, or perhaps in addition, M&V results could be used to verify a minimum level of performance guaranteed in the contract.

- To provide data that can be used as diagnostics, which continually help to sustain system performance and benefits over time.

- To increase customers' confidence and reduce transaction costs by using a defined, accepted, and proven M&V approach to facilitate negotiations during financing and contract development.

- To secure the full financial benefits of emissions reductions, such as emissions trading. To verify compliance with emissions reduction targets, regulating bodies will need to adopt a protocol for measuring emissions reductions. A protocol common to all projects is required to claim and trade emissions credits.

- To help certify a "green power" program. Although the certification of green power programs, which offer power generated from renewable energy systems to utility customers, is beyond the scope of the IPMVP, the protocols presented here could be used in such a certification process.

Example of an M&V Program: Guaranteed Solar Results

The concept of *Garantie de Resultats Solarieres* (GRS), or Guaranteed Solar Results, has been applied to the implementation of several large water-heating systems. A particular level of energy delivery is guaranteed to the client by a "technical pool" of technical and financial resources that will compensate the client if measured delivery falls short of the guarantee. Energy delivery, key temperatures, and pump status are monitored and reported remotely through telephone lines. The table below lists the guaranteed and measured performance for three GRS projects (Roditi 1999).

Table 6: Annual results of selected GRS projects, 1995 (in kWh)

	Guarantee	Measured
Castres Hospital, Southern France	50,000	54,580
Hipocampo Playa Hotel, Mallorca	106,039	159,693
Heliomarin Centre, Vallauris	133,719	152,119

For project developers, financing entities, and large customers (such as governments), there are additional M&V objectives extending beyond the scope of an individual contract:

– M&V programs can be designed to validate or improve computer simulations or other predictions of system performance, thus reducing project risk and increasing investors' confidence in predictions of project benefits.

– M&V results of existing projects provide developers, investors, lenders, and customers with more confidence regarding the value of future projects than engineering estimates do.

– A protocol would provide a means to pool projects for financing based on their M&V characteristics.

Chapter 2 Baseline Definition and Development

2.1 General Issues

Some issues unique to renewable energy are involved in the establishment of a baseline of energy use and costs for M&V purposes. These include the fact that renewable energy systems deliver energy rather than simply reduce consumption, as noted, and that renewable energy systems are often located in remote areas not served by utilities.

Because renewable energy technologies are used in an energy delivery system, there is no need for a baseline if performance claims are based on delivery rather than savings. However, the M&V options described here can be applied to measure either the energy delivered by a renewable energy system or the resulting utility energy savings for a facility as a whole. It is important to state that these two may not be exactly the same and to specify whether performance claims are based on delivery or on savings.

Metering of delivered energy without a baseline is often the recommended M&V approach for renewable energy systems because it is very accurate, moderate in cost, and measures elements of project performance over which the developer has some control. For example, a solar water heating system may deliver a certain amount of heat, but utility energy savings for the facility would be the amount delivered by the solar system divided by the efficiency of the original water heater. In this case, the developer of the solar project would not have control over the efficiency of the existing water heater, so it is more appropriate to base performance claims on energy delivery rather than on savings.

Renewable energy systems are often cost effective as the only source of power in remote locations where utility power is unavailable. A baseline based on the utility or another type of on-site generation could be arbitrary and rather meaningless in such situations. Nevertheless, savings could be determined from a baseline computed as the energy use or cost that would have been incurred without the renewable energy system.

The impact of demand (kilowatts, kW) of a renewable energy system may be as important as energy (kilowatt-hours, kWh). In order to estimate demand savings, the metered power delivery profile of the renewable energy systems would be added to the measured utility demand profile for a facility to estimate what the demand would have been without the renewable energy system. This requires more sophisticated metering than a simple revenue kWh meter, because it requires that power profiles based on the utility billing period (often 15 minute intervals) be measured and stored for both the renewable energy system and the utility account as a whole. It also requires processing periodically (monthly) to do the algebra and calculate demand savings.

There are distinctions between electrical and heat delivery. Often, heat must be used on-site, but electricity can be fed onto the grid, obviating the need for a baseline.

2.2 Baseline Applications

Savings are determined indirectly by calculating the difference between the baseline energy or demand and the metered energy or demand under similar operating conditions. Metering may be done with a kWh meter, a gas meter, or a run-time meter on a gas or electric appliance. It is important to account for the efficiency of the fossil fuel or electric appliance if only the end use delivery (e.g., the amount of hot water delivered) is measured.

Selecting a method of determining the baseline depends on several factors, including the characteristics and needs of the project, the data available, and whether there is a load before the renewable energy system is to be installed. When only the utility energy is measured and renewable energy delivery is not measured directly, there are four ways to calculate savings relative to a baseline: comparison with a control group; before-and-after comparison; on-and-off comparison; and the calculated reference method (Christensen and Burch 1993).

2.2.1 Comparison with Control Group

Compare metered energy use of loads with renewable energy systems to similar loads (i.e., the control group) that do not have renewable energy systems. The average energy use and cost of the control group establishes the baseline. (Note: A control group can be used only if the number of units is sufficient for a statistically significant result. "Statistically significant" means that the probability of getting the result by random chance is relatively low, less than 5%, for example.)

2.2.2 Before-and-After Comparison

Measure energy use before the renewable energy system is installed and compare it with usage occurring after the system is installed, adjusting for any changes in operating conditions or in the use of the facility that have occurred between the two measurements. The energy use and cost before the renewable energy system is installed establishes the baseline. (Note: The before-and-after method can be used only in a retrofit application in which data have been collected before the renewable energy system was installed and began operating.)

2.2.3 On-and-Off Comparison

Measure energy use while the renewable energy system is on. Then, turn the renewable energy system off by bypassing it. Next, compare energy usage when the system was off with usage when the system was on. The resulting energy use and cost when the renewable energy system is turned off and properly bypassed establishes the baseline (Note: The on-and-off technique can be used only if there is an auxiliary energy system in addition to the renewable energy system, and the auxiliary system can be used in defining the baseline. Also, since a solar or wind resource is intermittent, adequate time is necessary to capture average renewable energy production potential.)

2.2.4 Calculated Reference Method

Determine baseline energy use by using engineering calculations calibrated to actual energy use patterns, and subtract metered energy usage (or similarly calculated post-retrofit energy) to estimate renewable energy delivery. These engineering calculations often assume that the system adheres to applicable codes and standards in selecting hypothetical values for parameters such as

equipment efficiency. (Note: A calculated reference is needed in new construction involving renewable energy, because there are no load data to use in establishing a baseline. See also IPMVP Volume III Part A: Concepts & Practices for Determining Energy Savings in New Construction).

Chapter 3   M&V Planning and Processes

To integrate M&V in a project, participants begin with an M&V protocol, formulate an M&V plan, and then implement that plan as part of the project. The protocol for M&V for renewable energy projects is the IPMVP, which defines terms, identifies options, and recommends procedures.

To formulate an M&V plan, the first step is to identify the goals and objectives of the M&V effort, and the second step is to identify the strategies and techniques—the M&V options—needed to achieve those goals and objectives. To borrow a concept from the International Standards Organization, "First state clearly what it is that you do, then state how you measure your success at it." Goals often focus on measuring the benefits of a project or compliance with clearly stated performance claims. They can also involve isolating from one another the effects of various measures and technologies planned for the project. Often, energy efficiency measures and renewable energy projects are implemented together, and one goal of an M&V plan may be to discern the savings attributable to each. The performance claims for renewable energy depend on the particular energy conversion technology, application, and business arrangement between the supplier and the consumer. For example, a renewable energy project may claim to deliver energy (kWh), in which case a simple kWh meter would be sufficient. On the other hand, if the project claims to save electrical demand (kW), a time-of-use meter would be used in conjunction with the utility's revenue meter. Often, the motivesof a project include non-energy benefits, such as reducing noise by reducing generator run time.

Appropriate M&V options can be selected as part of the M&V plan customized to meet the project's goals. The best M&V options for a project depend on the specific conditions of the project, including the method of financing and the technologies chosen. The M&V plan would also describe the criteria for determining whether the performance claims are being achieved.

Implementation of the M&V plan proceeds as the renewable energy system is installed and operated.

Example: Performance Claims

As an example of the many diverse performance claims possible with a renewable energy project, consider a solar ventilation preheating system for a post office in Denver, Colorado. The system is designed to transfer the heat of solar radiation on the building's south wall into preheated ventilation air by means of an 817-square-meter (m^2) unglazed, perforated absorber plate. The supplier claims that the system will perform as follows:

- Deliver 2,800 megajoules (MJ) of solar heat per year
- Save 50 MJ/year in the form of heat recovery from the south wall—the heat, otherwise lost through the south wall, is entrained in the supply air because the absorber plate covers the south wall
- Save 170 MJ/year of heat in the form of heat recovered from the ceiling
- Reduce the interior ceiling temperature from 30°C to 23°C through destratifying the solar-heated air being introduced high in the building, thus

decreasing the use of exhaust fans and saving an additional 2,600 MJ /year of heat

- Improve occupants' comfort by pressurizing the building and reducing incoming drafts.

Although it is tempting to measure only the first claim listed here—direct energy delivery from the system—an M&V plan to verify each claim of economic, environmental, and comfort benefits is often essential to justify an investment in a project.

3.1 Overview of M&V Options

The options for measuring and verifying the energy savings and other benefits resulting from a renewable energy project may be classified into three general categories as follows.

1 Options A & B focus on measuring the performance of specific, easily isolated systems. Renewable energy system applications of these options include photovoltaics, solar water heating, wind power, and biomass combustion. Option B requires full field measurement of energy results, while Option A allows some stipulation of parameters in the final energy computation. Both options may be supported by engineering calculations or component models.

2 Option C measures the change in whole-facility energy use through utility or metering data. This is most suitable for renewable energy systems that are not easily isolated and have significant performance impact, such as passive solar heating and daylighting.

3 Option D relies on detailed, calibrated simulation analysis to determine the performance of a system or whole building that is complex, interactive, and dependent on many operating parameters. This is most suitable to renewable energy systems integrated into the building, such as daylighting and building integrated PV, especially in new construction projects. (See IPMVP, Volume III, Section A, "Concepts and Practices for Determining Energy Savings in New Construction," which treats the special issues of establishing a baseline and measuring performance in new buildings.)

The options are not necessarily listed in increasing order of complexity or cost. Option B deserves special consideration when evaluating M&V options for a renewable energy system because the energy delivery of most renewable energy systems can be measured directly through metering, without using a baseline or energy savings calculations, as required for energy efficiency measures. These options are discussed in greater detail in the next section.

Chapter 4 M&V Methods for Renewable Energy Systems

4.1 Introduction

This section discusses M&V of renewable energy systems within the framework established by the IPMVP. The reader is referred to Volume 1 for the basic requirements of an M&V program, including M&V planning, the four M&V options, statistical sample size, metering and instrumentation, cost vs. accuracy trade-offs, and adherence. The following highlights application of the four M&V options listed in Volume 1 to renewable energy projects.

4.2 Option A: Partially Measured Retrofit Isolation

In this option, the capacity of a system to perform (for example, to deliver renewable energy) is measured in the field, and operating conditions are stipulated. Field measurement may be made continuously or periodically throughout the measurement period. The measurement period can last as long as required to satisfy contractual or legal requirements. Periodic inspections must be conducted throughout the measurement period to ensure that the systems remain as specified and operate as expected.

This can be the least expensive M&V option; it is often suitable for small systems for which the cost savings are not sufficient to justify the expense of instrumentation and analysis. To avoid a conflict of interest, the project developer/ESCO and the customer may retain a third party to conduct inspections and take field measurements.

Example: Solar Water Heating Test

This example describes a short-term test to assess the functionality of a solar water heater based on a single temperature measurement. The outlet temperature of the solar heated preheat tank is measured continuously for a period of one month. This data is compared to a calculated reference (which is based on data typical of "clear sky" conditions), provided that there are at least a few clear days in the month. The comparison provides a useful diagnostic technique to determine whether the system works approximately as expected by the reference calculation. The resultant calculation of savings provides a reasonable ($\pm 30\%$) estimate of actual savings. The method uses a very inexpensive (less than $100) temperature sensor and so is a low-cost metering approach. Mailing a data logger and videotape to the owner upon installation is a way to avoid the cost of a site visit (Burch, Xie, and Murley 1995).

4.3 Option B: Retrofit Isolation

Since renewable energy systems deliver rather than conserve energy, a distinguishing feature over efficiency measures is that performance (energy delivery) can often be measured directly with a meter.

This section describes isolating the renewable energy system by metering the energy delivery from the renewable energy system to the rest of the building, or the rest of a power supply system, continuously for the length of the measurement period. The metered energy delivery of Option B may be the sole component of an M&V plan, but it is very often used with other techniques and combined with other M&V options. Option B differs from Option A of Section 4.2 in that no aspect of system performance is stipulated for Option B. Option

B differs from Option D of Section 4.5 in that the main M&V activity is metering instead of simulation analysis. Option B may be supported by engineering calculations or a component's model to adjust performance for normalized operating conditions.

As in all M&V options, Option B involves allocating risk between responsible parties. For projects involving a project developer or ESCO, risk is allocated between the customer and supplier. Using Option B, the supplier is responsible for metered energy delivery. Delivery would depend of course on the functionality of the system, but would also depend on factors beyond the supplier's control such as prevailing weather conditions (sunny, windy), and on fluctuations in the load. Option B is most often employed when the supplier is willing to assume risk of all these factors.

Option B, titled "Retrofit Isolation," is consistent with the standard IPMVP option nomenclature. However, a renewable energy system may be retrofit on an existing building or installed as part of a new construction project. It may also be installed as an energy resource where no specific building is involved (e.g., a wind turbine). For either, the M&V approach described in this section would be the same.

Metering is a core part of an M&V program; however, the way in which metering fits into the M&V plan depends on the specific performance claim. A program can be designed either to directly meter system output (with a thermal energy or electric meter) or to indirectly measure savings or production by subtracting post-installation energy use from baseline energy, after appropriate adjustments are made for changes in conditions.

To determine savings, rather than directly measure energy output, the difference between the base year energy use of a system and the post-retrofit energy use (including auxiliaries) is determined and adjustments made for any change in conditions. The baseyear energy use could be established by the control group, before-and-after, or on-and-off method, as described in Chapter 2.

EXAMPLE 1: DIRECT MEASUREMENT, CENTRALIZED SOLAR HOT WATER HEATER

Figure 41: A monthly bill is issued to a prison for actual energy delivered by a large solar water heating system in Phoenix.

As an example of direct measurement in an Energy Savings Performance Contract, consider a 1,583-m^2 parabolic trough solar water heating system, which was installed at the Phoenix Federal Correctional Institution in Arizona. M&V is critical in this financing arrangement because monthly payments from

the prison to the contractor are based on measured delivery of heat energy, at a cost 90% of that charged by the utility for the same amount of energy.

Energy output is measured directly by two thermal energy meters in series, so that metering can continue if one meter is removed for calibration. Each meter is calibrated to ±5%, so if the two meters disagree by more than ±7% (RMS of 5% and 5%), then the meter with the higher reading is sent for recalibration. The system delivered 1,161,803 kWh of heat in 1999, which displaces the purchase of electricity for domestic water heating by roughly an equal amount of energy.

EXAMPLE 2: INDIRECT MEASUREMENT, RESIDENTIAL SOLAR HOT WATER HEATER

As an example of indirect end-use measurement, consider the monitoring of water-heating loads on a sample of 50 houses (25 with solar water heating and 25 without) at the Kia'i Kai Hale U.S. Coast Guard (USCG) Housing Area in Honolulu, Hawaii. A separate solar water heater 6 m² in area was installed on each housing unit (see Figure 2). Each electric water heater was fitted with a monitoring system to record power consumption every 15 minutes. Figure 3 summarizes data collected as the total water heating power for all 50 sample houses.

Figure 42: Solar water heating systems on USCG housing in Hawaii.
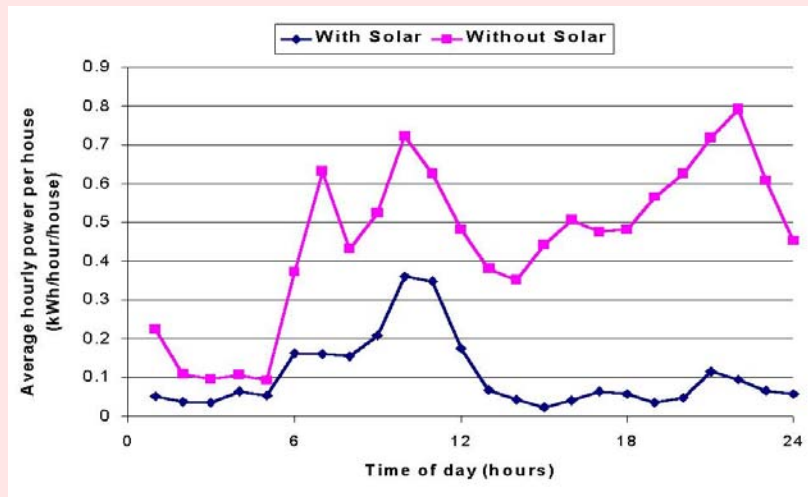

Figure 43: Daily electric water heating profile with and without solar water heating (control group baseline strategy) at US Coast Guard housing in Hawaii.

During a monitoring period from June 11 to July 25, 2002, the houses without solar systems used an average of 11.1 kWh/day for water heating, and those with solar systems used only 2.5 kWh/day. Therefore, the savings were 8.6 kWh/day.

The entire housing area is connected to one utility meter that includes more than the 50 sample buildings. With no installed air conditioning, it is assumed that the facility peak is caused by, and therefore coincident with, the water heating peak. The aggregate peak water heating demand for all 25 houses without solar was 38 kW while it was only 12.2 kW for the 25 houses with solar water heating, for an average demand savings of 1.0 kW per house. The graph of Figure 3 shows an evening demand savings of 0.7 kW, which is the average of the daily peaks, as opposed to the 1.0 kW per house that was the actual demand savings measured when the facility peaked during the monitoring period.

This exemplifies Option B with indirect metering. Incidentally, measured performance was also correlated with measured environmental conditions to calibrate a simulation and estimate $380 annual energy cost savings per house, so this project utilized both Options B and D.

Figure 44: Green Mountain Power 6.05 MW wind farm in Searsburg, Vermont.

Example 3: DIRECT METERING WIND TURBINE VERIFICATION PROGRAM

Figure 6 shows a wind power installation in Searsburg, Vermont, consisting of eleven 550-kW turbines. The project is instrumented to measure environmental conditions, electrical power, and power quality. Detailed reports include performance compared with the power curve of the turbine, power factor, and effect on grid voltage, as well as availability and reasons for forced and planned outages. During the 12-month period from July 1999 through June 2000, the Searsburg wind facility generated more than 13 million kWh of electricity. This represents a 24.6% average annual capacity factor based on 6.05 MW of installed capacity. The system availability was 86.5%, allowing for all scheduled and forced wind turbine outages. Availability for individual turbines ranged between 63.2% and 96.6%. The year of operation was marked by generator replacements for two turbines, destruction of a turbine blade by lightning, and an increased incidence of electrical and generator-related faults. However, the response time to faults remained relatively high.

4.4 Option C: Whole Building Analysis

This option involves the analysis of information available through utility bills or whole-facility metering. After the renewable energy system is installed, the utility bill (which constitutes the measurement) or utility meter reading is subtracted from a baseline with adjustments for changes in use or in the operation of the facility, to determine energy savings. The baseline is determined using one of three comparison techniques described in section 2.1: Control Group Comparison, section 2.2: Before-and-After Comparison, or section 2.3: On-and-Off Comparison.

If the baseline is established by a control group, participants may debate and determine by consensus the factors constituting sufficient similarity between the buildings. However, the intent here is to select a control group that is essentially identical to the sample (e.g., identical military housing units with the same use and in the same location).

Since driving forces such as weather and occupancy frequently change, Option C involves routine baseline adjustments. ASHRAE Guideline 14 describes baseline methods appropriate to Option C and PRISM and ASHRAE RP1050 are referenced for software for calculating monthly baseline utility bills based on weather (PRISM 2002).

The accuracy of this method is limited by the numerous variables affecting building energy use. Option C may be most appropriate for applications in which renewable energy contributes a large part of the building load, or when renewable energy systems are installed as part of a larger suite of energy efficiency measures.

4.5 Option D: Calibrated Simulation

Option D relies on comprehensive whole-building or systems models to determine performance and estimate project savings. Option D is commonly used in new construction projects with extensive efficiency and/or renewable energy components in which isolated metering and baseline characterization are difficult. Isolated component metering may be conducted to support simulation calibration as part of Option D. However, it is not the main focus of the M&V activities.

In this method, an estimation of annual energy performance is produced from the results of a short-term test. First, a computer simulation model is used to determine performance based on independent variables and specified operating parameters. To calibrate the model, independent variables (e.g., load, solar radiation, wind speed, and ambient temperature) are measured and recorded simultaneously with system energy performance (e.g., energy delivery) over a time period that includes all operating modes. Next, the parameters of the simulation model are adjusted to provide the correlation between the simulated and measured performance. To provide an estimate of annual project savings, the calibrated simulation is used with independent variables representing load and environmental conditions through the course of a year (e.g., agreed upon operating schedules, Typical Meteorological Year (TMY) weather file for the site).

Challenges in performing calibrated simulations include:

1 Providing the proper inputs such as occupancy and operation patterns, correct weather variables, and system parameters

2 Understanding the limitations of the model

3   Selecting the parameters to vary to calibrate the model and run parametrics

Whole building simulation models that are often used as part of Option D include Energy10 and DOE-2. These comprehensive computer programs account for the interactions between different building systems and energy resources (for example, daylighting would affect both lighting and cooling energy). Often a whole building model is required to determine the thermal or electric load on a renewable energy system serving the building. If the load is known or can be agreed upon, TRNSYS may be used (Univ. of Wisconsin, Madison). In applications where the renewable energy delivery is not limited by the load (such as PV system output that never exceeds the building load, or a wind turbine connected to the utility grid), the whole building analysis is not required and only the renewable energy system is simulated.

EXAMPLE 1: BUILDING INTEGRATED PHOTOVOLTAIC SYSTEM, THE PRESIDIO, SAN FRANCISCO

As an example of Option D, consider a 1,250-W building-integrated photovoltaic (BIPV) system at the Thoreau Center for Sustainability at the Presidio, San Francisco, California (see Figure 5). The monitoring objectives were to verify initial system performance and to predict typical annual performance. Environmental conditions (ambient temperature, wind speed and direction, relative humidity, and insolation) were measured, and the coefficients of a computer model were adjusted to provide the best match with the measured system performance parameters (DC output and AC power output). The system was monitored between January and June 1998 in order to measure performance under the full range of sun angles that it will experience throughout the year.

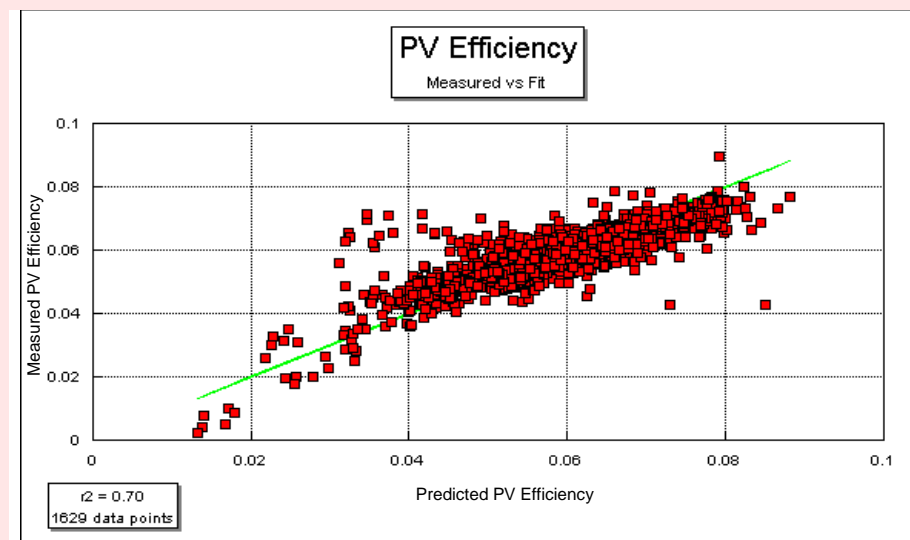**Figure 45: Building-integrated PV system in the Presidio, San Francisco.**

First, a TRNSYS (Klein 1994) shading model was calibrated to correlate the actual plane-of-array insolation with unshaded horizontal insolation, thus accounting for shading by surrounding objects, as well as the reflection off a large, white wall north of the BIPV system. The resulting model of solar radiation provides an R^2 of 0.985.

Second, the coefficients of a model of array DC power output as a function of environmental conditions were adjusted to provide the best fit between the array efficiency model and the measured data. The best fit was found using a model that takes into account the incidence-angle-modifier effects of the glass surface of the modules, the ambient temperature, and the total insolation falling on each of the two sloped surfaces.

Subsequent analysis required combining TRNSYS for the PV and DOE-2 simulations for the building, since the atrium roof provides not only electric power but daylighting through the spacing between the PV cells, which is also designed to admit adequate light into the atrium below. This comprehensive approach quantifies not only electric power from the PV, but also the effects on lighting, cooling and heating requirements of the whole building.

Unlike that of the earlier solar thermal model example, the form of this equation is not determined by a thermodynamic model but rather by a general polynomial. The goodness-of-fit is shown graphically in Figure 6 with an R^2 of 0.70. Power is estimated with a standard deviation of ±22.4 W.

Third, the AC power output of the inverter was measured to perform a third least-squares regression to adjust an inverter efficiency model with R^2 of 0.932. Deviations of the inverter efficiency from expected values indicated a problem with the inverter's maximum-power point-tracking function. Again, the form of this equation is a general polynomial without physical derivation.

Figure 46: Predicted versus measured efficiency of a building-integrated photovoltaic system.

These three correlations constitute a calibrated composite model, which was fed typical meteorological year (TMY) weather data for San Francisco (NCDC, 1997) in order to estimate the annual energy delivery. This estimate took into account array orientation, shading, and reflection off the south wall, as well as the actual in situ performance characteristics of the array and inverter. The model predicts that under TMY conditions, the system would deliver 716 kWh AC per year without inverter repair and 2,291 kWh AC per year after the inverter is repaired. This technique can be used to predict the performance of a

PV system in a typical year, especially in unusual shading conditions. As used in this case to diagnose the inverter problem, this technique can be employed in the initial commissioning process to make sure a system functions as expected.

EXAMPLE 2: SOLAR WATER HEATING

As an example of Option D, consider a method of evaluating solar water-heating system performance, which was developed at the National Renewable Energy Laboratory (Barker 1990; Barker, Burch, and Hancock 1990). The instrumentation is illustrated in Figure 7.
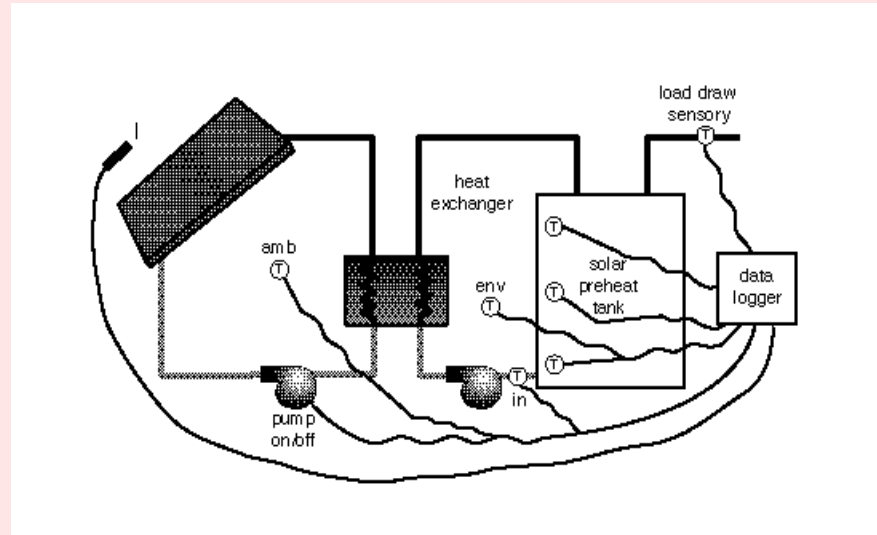
Figure 47: Short-term test apparatus for solar water heating.

The instrumentation measures the energy inputs and outputs over a time period sufficient to calibrate the performance simulation model. The time period may be as short as one day, but it must encompass a sufficiently wide range of conditions (sunny/cloudy, warm/cold). The first law of thermodynamics sets energy collected equal to energy stored plus energy lost from the storage tank. Efficiency as measured in the short-term test,

$$\text{Efficiency} = [dE/dt + U_S (T_S - T_{env})] / [I \cdot A_C] \qquad \text{Eq. 11}$$

is correlated by linear regression with a linear model:

$$\textit{Efficiency} = \tau\alpha - U_C (T_S - T_{amb}) / I \qquad \text{Eq. 12}$$

where:

I = incident solar radiation (W/m^2)

A_C = collector area (m^2)

T_S = average storage water temperature (°C), representing collector inlet temperature

T_{amb} = ambient temperature (°C)

T_{env} = temperature of storage tank location (°C)

dE/dt = time rate of change of energy in storage tank (J/s), as measured by the average of three tank temperatures

U_s = heat loss coefficient of storage tank estimated by cool-down rate (W/m^{2}C).

The term $\tau\alpha$ is an empirical constant representing all the effects of the transmissivity of the cover glass and the absorptivity of the absorber plate. U_C is a term representing all the effects of the thermal loss coefficient of the collector and piping per unit area (W/m^2°C). These two coefficients in the model are adjusted to minimize the difference between measured and simulated performance. The calibrated model is then supplied with an hourly load profile and with ambient temperature and incident solar radiation for all 8,760 hours of the year from typical meteorological year data (NCDC 1997) to predict annual performance. This simple model is isothermal, with the collector and storage all at an average T_S.

This method of calibrating a computer model was used to test the performance of 13 systems in Colorado (Walker and Roper 1992). Figure 8 shows the results of a one-day test on a system with an 8.9-m^2 collector area.
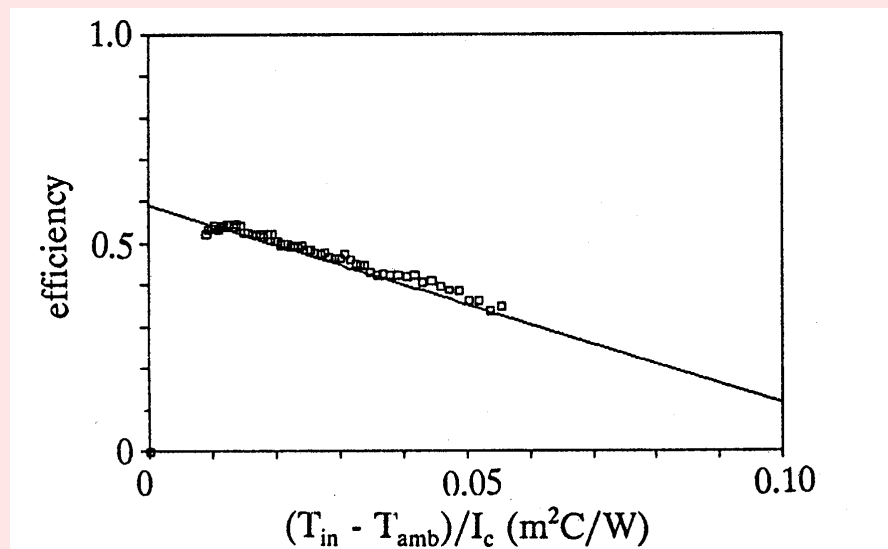
Figure 48: Results from one-day test of a solar water heating system.

The square symbols signify measured data for every 5-minute interval, and the solid line is the best-fit linear regression (the renormalized model). This test was conducted on a clear day, and very good agreement is achieved between the model and the measured performance. The test starts the day with a cool tank, which heats up over the course of the day, providing a wide range of the parameter $(T_S - T_{amb})/I$. The model inputs that were derived consist of $t_a = 0.59$ and $U_C = 4.7$ W/m2 °C. The simulation used Colorado Springs weather data to predict a typical annual energy delivery of 5,388 kWh/year.

Chapter 5   Quality and Cost of M&V for Renewable Energy

M&V programs inherently provide the quality assurance needed in renewable energy projects. M&V costs, however, can vary greatly according to the requirements of a particular project.

The total cost of an M&V program includes the cost of purchasing, installing, and maintaining the instrumentation (including periodic calibration); the cost of the labor involved in designing the program; and the cost of periodically collecting, reducing, and presenting the results of the program. Overly detailed or poorly designed M&V programs can be very expensive, so the amount of money to be spent should be determined by the value of the benefits that result from the M&V program, as mentioned in Chapter 1.

The value of these benefits is determined through negotiations between the customer and the project developer for each project. The objective is for all parties to work together to minimize the total cost of the M&V program while achieving acceptable levels of uncertainty as to savings.

In order to lower project costs, the customer may assume some performance risk by agreeing to periodic and limited (rather than continuous) measurements or by increasing the allowable error in the measurements. Other requirements of a particular M&V program might include verification for emissions credits or other certifications of regulating bodies, as noted in Chapter 1. Total costs will also include the cost of measuring and verifying these kinds of requirements.

Appendix A Definitions

Energy Delivery – Energy delivered by a renewable energy system to a specified point of service over a time period, usually measured in kWh/year or Btu/year.

Externalities – Benefits of a renewable energy system which are "external" to conventional financial analysis or M&V efforts. Examples include reduced atmospheric emissions or mitigated risk of fuel spills.

Reduction in Load – A reduction in the end use of energy by increasing the efficiency of the end use device or by curtailing operation of the device. This is in contrast to energy delivery from a renewable energy system, which also reduces purchased energy.

Site Energy – Energy crossing the boundary of a facility, usually the measured basis of revenue for utilities.

Source Energy – Primary energy used globally in order to deliver site energy. Includes site energy plus losses in generation, transmission, and distribution.

System Performance – General term which may be applied to describe any aspect of operation of a system, such as energy delivery, system availability versus down-time, or economic rate of return.

Appendix B Resources

The objectives and activities of several organizations are closely related to the subject matter of this chapter of the IPMVP. These organizations are listed in alphabetical order below, along with a short description of each one. More information can be found on the World Wide Web; Web addresses are included in each description.

1 Australian Cooperative Research Center for Renewable Energy (ACRE)

The Australian Cooperative Research Center for Renewable Energy (ACRE) in Perth, Australia, seeks to create an internationally competitive renewable energy industry. ACRE brings together excellent research capabilities and market knowledge into a world-class center for the innovation and commercialization of renewable energy systems. One of the principal objectives of the center includes presenting a strategic policy framework to government and energy agencies that can help provide the basis of a viable renewable energy industry in Australia.

URL: fizzy.murdoch.edu.au/acre/

2 American Society for Testing and Materials (ASTM)

The mission of ASTM International-formerly known as the American Society for Testing and Materials (ASTM)-headquartered in West Conshohocken, Pennsylvania, is to provide "the value, strength, and respect of marketplace consensus." ASTM's main functions are (1) to develop and provide voluntary consensus standards, related technical information, and public health and safety services having internationally recognized quality and applicability that promote overall quality of life; (2) to contribute to the reliability of materials, products, systems, and services; and (3) to facilitate regional, national, and international commerce. ASTM's primary strategic objective is to provide the optimum environment and support for technical committees to develop needed standards and related information.

URL: www.astm.org

3 Committee for Standardization (CEN)

The mission of the European Committee for Standardization (CEN), based in Brussels, is to promote voluntary technical harmonization in Europe in conjunction with worldwide bodies and European partners and to develop procedures for mutual recognition and conformity assessment to standards. Harmonization diminishes trade barriers, promotes safety, allows interoperability of products, systems, and services, and furthers technical understanding. In Europe, CEN works in partnership with the European Committee for Electrotechnical Standardization (www.cenelec.be) and the European Telecommunications Standards Institute (www.etsi.fr). CEN's Strategic Advisory Body on Environment promotes developing measurement methods for environmental quality and pollution emissions; standardizing tools and instruments of environmental policy; and incorporating environmental

aspects in product standards. CEN and ISO have parallel procedures for public inquiry and formal votes on international standards.

URL: www.cenorm.be

4 The Electricity Supply Association of Australia Limited (ESAA)

The Electricity Supply Association of Australia Limited (ESAA), based in Sydney, is the prime national center for issues management, advocacy, and cooperative action for Australian electricity supply businesses. ESAA's members consist of both public and private businesses involved in generating, transmitting, distributing, and retailing electricity in Australia together with associate, affiliate, and individual memberships from Australia and overseas.

URL: www.esaa.com.au

5 The International Energy Agency (IEA)

The International Energy Agency (IEA) is an autonomous body, established in 1974 within the framework of the Organization for Economic Cooperation and Development, to implement an international energy program. More than 60 programs currently operate through the IEA; each reflects the need for efficient coordination among international organizations and bodies. Programs are carried out under the framework of an implementing agreement signed by contracting parties, which include government agencies and government-designated entities of the countries involved. Implementing agreements provide a framework for collaborative research projects. Benefits include pooled resources and shared costs, harmonization of standards, and hedging of technical risks (http://www.iea.org).

The mission of the IEA Photovoltaic Power Systems (PVPS) Program, based in the United Kingdom, is to enhance the international collaboration efforts—in particular, research, development, and deployment—by which photovoltaic solar energy will become a significant energy option in the near future. Objectives related to reliable PV power system applications for the target groups (utilities, energy service providers, and other public and private users) include increasing the awareness of PV's potential and value and fostering market deployment by removing the nontechnical barriers.

IEA's SolarPACES Program is looking ahead strategically by cooperating intensively on research and technology development in solar thermal power and solar chemistry. This program is also initiating activities to support project development to tackle nontechnical barriers and to build awareness of the relevance of solar thermal power applications to the current problems of energy and the environment (http://www.solarpaces.org/).

6 International Electrotechnical Commission (IEC)

The International Electrotechnical Commission (IEC), based in Geneva, is the international standards and conformity assessment body for all fields of electrotechnology. The IEC's mission is to promote, through its members, international cooperation on all questions of electrotechnical standardization and related matters, such as the assessment of conformity to standards in the fields of electricity, electronics, and related technologies. The IEC charter embraces all electrotechnologies, including electronics, magnetics and

electromagnetics, electroacoustics, telecommunication, and energy production and distribution, as well as associated general disciplines such as terminology and symbols, measurement and performance, dependability, design and development, safety, and the environment (http://www.iec.ch/).

7 Institute of Electrical and Electronics Engineers, Inc. (IEEE)

The vision of the Institute of Electrical and Electronics Engineers, Inc. (IEEE), headquartered in New York City, is to advance global prosperity by fostering technical innovation, enabling members' careers, and promoting community worldwide. IEEE promotes the engineering process of creating, developing, integrating, sharing, and applying knowledge about electrical, electronic, and information technologies and sciences for the benefit of humanity and the engineering profession. An IEEE effort (SCC21 Committee and Work on Standard P1547) is under way to establish utility interconnection standards important to broad implementation of grid-connected renewable energy distributed generation technologies.

URL: www.ieee.org

8 International Organization for Standardization (ISO

The International Organization for Standardization (ISO), based in Switzerland, is a nongovernmental, worldwide federation of national standards bodies from 130 countries. The mission of ISO is to promote the development of world standardization and related activities with a view to facilitating the exchange of goods and services and to developing cooperation in the spheres of intellectual, scientific, technological, and economic activity. ISO's work results in international agreements that are published as International Standards.

URL: www.iso.ch

9 European Commission Joint Research Center (JRC)

The mission of the European Commission Joint Research Center (JRC), based in Brussels, is to provide customer-driven scientific and technical support for the conception, development, implementation, and monitoring of European Union (EU) policies. As a service of the European Commission, the JRC serves as a reference center of science and technology for the EU. Close to the policy-making process, it serves the common interest of the member states, while being independent of private or national special interests.

Within the JRC is the Environmental Institute and its Renewable Energies Unit, of which the European Solar Test Installation (ESTI) is one of the work fields. The mission of ESTI is in line with the mission of the JRC: to provide the scientific and technical base for the harmonization of standards within the single market of the European Union. One of the services for testing PV devices and systems includes support to standards organizations. ESTI is actively involved in quality assurance accreditation, both of its own expertise (to EN45001) and in helping industry attain accreditation according to internationally accepted standards (CEC, ISO, and IEC).

URL: www.jrc.cec.eu.int/jrc/index.asp, iamest.jrc.it/esti/esti.htm

10 Global Approval Program for Photovoltaics (PV GAP)

The Global Approval Program for Photovoltaics (PV GAP) is a global, PV industry-driven organization that strives to promote and maintain a set of quality standards and certification procedures for the performance of PV products and systems to ensure high quality, reliability, and durability. Registered in Switzerland, PV GAP is a not-for-profit organization that focuses on certifying the quality of PV systems. PV GAP also concentrates on the enforcement of international standards that promote the integration of quality. This organization works to introduce testing standards into the financing stream. It also seeks to establish international reciprocity of recognition of standards and testing laboratories. PV GAP has developed a professional collaborative relationship with the IEC, based on that organization's long-standing international reputation for quality and its common technical interests with the goals of PV GAP. The International Electrotechnical Commission Quality Assessment System for Electronic Components carries out the certification program for PV GAP.

URL: www.pvgap.org

11 Solar Rating and Certification Corporation (SRCC)

The Solar Rating and Certification Corporation (SRCC) in Cocoa, Florida, is an independent, nonprofit organization that measures, rates, and certifies solar water heating system performance. SRCC's "Solar Energy Factor" ratings allow the comparison of savings provided by many different types of solar water-heating systems and conventional water heaters. SRCC certification has become a code requirement in 12 states across the United States and is being considered as a requirement in other states.

URL: www.solar-rating.org

12 TUV

The primary mission of TÜV Rheinland (TUV) is to protect the health and safety of consumers and the environment by helping industry produce safer and better products. Industry customers work with TUV to achieve product differentiation and a competitive advantage through better methods and technology in research, design, development, manufacturing, and service. Customers comply with applicable regulations or guidelines and, in many cases, go well beyond minimally acceptable standards to achieve "best in class" status.

On its Web site, TUV mentions that the "EU has created an Internet site that provides access to the texts of CEN marking directives, standards officially recognized under those directives, and standards under development with a view to recognition under the same directives."

URL: www.tuv.com, www.newapproach.org

13 Photovoltaics Special Research Center

The Photovoltaics Special Research Center at the University of New South Wales (UNSW) in Sydney, Australia, is a world leader in high-efficiency silicon solar cell research and is involved in major commercialization projects for clean, low-cost, large-scale power generation.

URL: www.pv.unsw.edu.au

14 The Utility PhotoVoltaic Group (UPVG)

The Utility PhotoVoltaic Group (UPVG) has 150 member organizations. It is led by 100 electric service providers from eight countries working together to advance the use of solar photovoltaic power. UPVG is a nonprofit association based in Washington, DC, that receives funding from the U.S. Department of Energy to manage TEAM-UP (Technology Experience to Accelerate Markets in Utility Photovoltaics), a program to put photovoltaics to work in applications that have strong potential for eventual mainstream use. TEAM-UP is helping to create an expanded market for solar electricity. TEAM-UP awards cost-sharing dollars on a competitive basis.

URL: www.upvg.org

15 North American Board of Certified Energy Practioners

It conducts certification examination for PV installers.

URL: www.nabcep.org

Appendix C References

1   Barker, G. 1990. A Short Term Monitoring Method for Active Solar Domestic Hot Water Systems. Master's Thesis. Boulder, CO: University of Colorado at Boulder.

2   Barker, G., Burch, J., and Hancock, E. 1990. "Field Test of a Short-Term Monitoring Method for Solar Domestic Hot Water Systems," ASME/JSME International Solar Energy Conference, National Renewable Energy Laboratory, Golden, Colorado, April.

3   Burch, J., Xie, Y., and Murley, C. 1995. Field Monitoring of Solar Domestic Hot Water Systems Based on Simple Tank Temperature Measurement, NREL/TP-472-7854, National Renewable Energy Laboratory, Golden, Colorado.

4   California Resources Code, Section 2805 (CRC 2805), Article 7, 381.b.3.

5   Christensen, C., and Burch, J. 1993. Monitoring Strategies for Utility Solar Water Heating Projects, National Renewable Energy Laboratory, Golden, Colorado.

6   International Energy Agency. 1990. Inspection Procedure for Solar Domestic Hot Water Heating Systems, Report No. T.3.E.2, International Energy Agency, University College, United Kingdom.

7   NCDC, 1997, Typical Meteorological Year Weather Data, U.S. National Climatic Data Center, Asheville, North Carolina.

8   PRISM, 2002, Princeton University, Program on Science & Global Security, Princeton, New Jersey 08542, USA

9   Roditi, D. 1999. "No Risks, No Worries, Guaranteeing Solar Results," Renewable Energy World (2:2), March.

10 University of Wisconsin, Madison. TRNSYS, FCHART and PV FCHART software. www.fchart.com

11 U.S. Department of Defense. 1998. Energy M&V Reference Handbook Systems Engineering and Management Corporation for Air Force Civil Engineer Support Agency, U.S. Government Printing Office, Washington, DC.

12 U.S. Department of Energy. 1991. National Energy Strategy: Powerful Ideas for America. U.S. Government Printing Office, Washington, DC, 118 pp.

13 Walker, A., Christensen C., and Yanagi, G. 2003. "Time-of-Use Monitoring of US Coast Guard Residential Water Heaters with and without Solar Water Heating in Honolulu, HI," ASME Solar 2003 Congress, March.

14 Walker, H., and Roper, M. 1992. "Implementation of the NREL SDHW Short-Term Monitoring Method," Solar '92: The National Solar Energy Conference, 21st ASES Annual Conference, National Renewable Energy Laboratory, Golden, Colorado, June.

References