# 35

## Renewable Energy Technologies

This chapter introduces methods for determining savings from renewable energy projects. Characteristics unique to renewable energy systems require M&V techniques distinct from those of energy efficiency projects. This document provides a description of M&V options for renewables with examples and recommendations for specific applications. Some renewable energy system may also use M&V methods described in other chapters of this document. This chapter draws on the work of the International Performance Measurement and Verification Renewable Energy Subcommittee, a consensus effort of 135 contributors from 22 countries.

Most renewable energy technologies are well established, but the initial capital costs of these systems tends to discourage their adoption. In addition, they are still considered experimental by many ESCOs, federal agencies, and design professionals. Thus, M&V guidelines are intended for (a) documenting the benefits of federal ESPC projects and serving as the basis for payments in a performance based contract, (b) assisting in the commissioning process and ongoing diagnostics that can help sustain benefits, and (c) allaying the concerns of ESPC participants and to assist them in adopting renewable energy technologies.

### *35.1 Measure Definition*

The term "renewable energy resources" refers to sources of energy that are regenerated by nature and sustainable in supply. Examples of renewable energy resources include solar, wind, biomass (sustainably harvested fuel crops, waste-to-energy, landfill gas), geothermal, small hydroelectric, ocean thermal, wave and tidal energy. Projects covered in this chapter are the installation of devices and/or systems that generate energy (electricity or heat) through the use of renewable energy resouces. Examples of technologies include photovoltaics (PV), active or passive solar water heating or space conditioning, biomass conversion systems (landill gas methane recovery, for example), and wind turbines.

#### 35.1.1 Special M&V Requirements of Renewable Energy Systems

Renewable energy technologies are very diverse in resources used and conversion technologies. Nevertheless, there are several aspects common to all renewable energy technologies that distinguish them from energy efficiency measures. Most notably, renewables supply energy rather than reduce the amount of energy used. Measuring this supply offers a simplified approach to measuring system performance not possible with energy efficiency projects. The supply of renewable energy complements reduction in the load achieved by energy efficiency measures. In most cases, the productivity of a renewable energy system is directly linked to the amount of energy that is consumed, since it is usually not possible to deliver energy in excess of the need. An M&V strategy for renewables often must be able to differentiate between an energy supply and a reduction in the load.

Renewable energy projects are often require a lot of hardware and are therefore capital intensive. An investment term longer than those for efficiency projects is often required. The associated renewables M&V program must verify that benefits are sustained over a longer time period. This would favor M&V

approaches, which may cost more initially, but have lower annual operating costs. Renewables often rely on intermittent resources requiring special procedures to measure effects on the integrated energy system. The capacity to deliver power on demand may be as valuable as the amount of energy supplied over time.

The performance of renewable energy systems is a function of environmental conditions, such as solar radiation and wind speed. While the long-term average of these conditions is reliable, any M&V approach should allocate risk associated with the short-term variation. When a renewable energy system is installed with an existing fossil fuel back-up system, the increased capacity and redundancy can be measured in a carefully structured M&V approach. A sophisticated M&V program may be necessary to credit the generation capacity of a renewable energy system on an integrated system. The following sections demonstrate the differing M&V approaches for renewables and efficiency measures.

The principal barrier to wide-scale implementation of most renewable energy technologies is the high capital cost. The associated opportunity is a low operating cost (low or no fuel cost). High initial cost requires special consideration regarding how other properties of renewables impact financing issues. The lack of widespread information concerning the potential and proper application of renewables is a barrier to broad implementation and also contributes to higher finance rates. Use of a renewable energy system rarely displaces the cost of a conventional system because the conventional system is still required when the intermittent resource is not available. It is also difficult to compare renewables to fossil fuels in terms of cost, performance, emissions, land use impacts, and other criteria because they operate very differently.

Many of the benefits of renewables are external to conventional evaluation and accounting techniques. Renewable energy projects significantly reduce the use of fossil fuel and reap resulting economic and environmental benefits. In addition to the cost of the fuel itself, economic benefits include fuel availability and fuel price stability, which reduce the risk of investing in an energy project. Installation and operation of renewable energy systems also keep money and jobs in the local community, rather than paying for imported energy. The emission of pollutants associated with fossil fuel combustion is avoided, along with the environmental impacts of fuel mining and spills. While the economic benefits generally depend on the amount and cost of energy delivered to the site, environmental benefits often involve consideration of the method in which that energy was generated and delivered. This site-versus-source difference is especially notable in the case of electricity, which can be generated from hydro- or nuclear power, gas, or coal, each with its own environmental impacts and economic value. Diversifying the energy supply and distributing the renewable energy generation around the power transmission system increases grid stability and availability, and reduces outages. Special M&V techniques are required to quantify these benefits unique to renewables.

### 35.1.2 Importance of a Renewables M&V Protocol

An established M&V protocol offers a systematic foundation for providing greater confidence that the predicted economic and environmental benefits of a renewable energy project investment will be realized. This is of principal importance to project investors who bear the financial risk of project nonperformance. Regulatory bodies require a standard method for measuring progress and compliance with energy and emissions requirements in order to implement programs uniformly. Implementation of a more thorough M&V procedure based on the approaches of this section can increase the confidence that estimates of energy generated and other benefits are reliable. This is partially a self-fulfilling prophecy because M&V provide diagnostic information that is often used to improve the performance of a system.

### 35.1.3 Purpose of M&V in Renewable Energy Projects

M&V may have several objectives from the earliest stage of renewable energy project development through operation of the completed system:

A. Existing daily, weekly, and annual demand and/or consumption load profiles are initially measured to establish the energy use baseline and to use as input to design the size of the system, energy storage requirements, and other design characteristics of the project. These load profiles also provide load information needed to establish project feasibility.
B. Directly after a project is installed, M&V serve as a commissioning tool to confirm that systems were installed and are operating as intended.
C. During financing and contract development, a defined, accepted, and proven M&V approach helps increase customer confidence and reduce transaction costs by facilitating negotiations.
    - For project developers, financiers 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 improving confidence in the ability to accurately predict project benefits, reducing project risk.
    - Actual M&V results of existing projects provide developers, investors, lenders, and customers with more confidence regarding the value of future projects than engineering estimates.
    - A previously defined and accepted M&V protocol can help reduce transaction costs by pooling projects and facilitating negotiations.
D. By helping investors to understand and mitigate risk, a well-established protocol for measuring the benefits of a project will help obtain lower-cost financing for the project.
E. M&V results may serve as the basis for payments over the term of a performance contract. Payments can be directly tied to measured performance, in which case the payment would vary from month to month. Alternatively, or perhaps in addition to this, M&V results could be used to verify some minimum level of performance guaranteed in the contract.
F. Data from a well-designed M&V program provides ongoing diagnostics and helps sustain system performance and resulting benefits over time.
G. An accepted protocol is helpful to secure the full financial benefits of emissions reductions, such as emissions trading. In order to establish compliance with Emissions Reduction Targets, a regulating body will need to adopt a protocol for measuring emissions reductions. A protocol common to all projects would be required for claiming and trading emissions credits.
H. A uniform protocol is useful to certify "Green Power" programs offering power generated from renewables to utility customers.

**EXAMPLE:**
**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. Table 1 lists the guaranteed and measured performance for three GRS projects (Roditi 1999).

**Table 1. Annual results of selected GRS projects, 1995**
**[in kilowatt-hours (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 |

## *35.2 Performance Claims*

An M&V protocol is an agreement adopted between a supplier and a consumer. In a performance contracting arrangement, measuring performance is all-important. It is, in fact, what the consumer is buying. A protocol designed to measure performance must start by clearly articulating the performance of the system that the supplier is claiming to deliver, or "performance claims." The performance claims for renewable energy will depend on the conversion technology, the application, and the business arrangement between the supplier and the consumer. The design of an M&V program should be one which measures and verifies the specific performance claims of the deal. 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."

**EXAMPLE: PERFORMANCE CLAIMS**

As an example of the many and 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:

- 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
- Reduce interior ceiling temperature from 30°–23°C due to destratification caused by the solar-heated air being introduced high in the building, thus saving 170 MJ of heat in the form of reduced ceiling heat loss and saving an additional 2,600 MJ of heat by lowering the temperature of air being exhausted from ceiling exhaust fans.
- Improve occupant comfort by pressurizing the building and reducing incoming drafts.

An M&V plan to verify each claim of economic, environmental, and comfort benefits is often essential to justifying an investment in a project. The cumulative benefit of all these claims exceed savings due to solar delivery alone, illustrating the effect of performance claims on project feasibility.

## *35.3 Overview of Methods*

The options to measure and verify energy savings and other benefits of a renewable energy system may be classified into four general categories:

**Option A: Measured Capacity, Stipulated Performance**[1] – Measured verification of equipment rating and capacity, using engineering estimates based on system specifications to stipulate savings, inspecting the system initially to ensure that equipment was installed according to those specifications, and inspecting the system periodically to ensure the system is operating properly. An example would be verifying solar thermal collector performance values and then using typical year solar insolation values to stipulate savings in water heating.

1 The Solar Rating and Certification Corporation is an independent, non-profit organization that certifies and rates the performance of solar collectors and systems in accordance with the American National Standard for Certification, Third Party Program (ANSI Z34.1-1987).

**Option B: Measured Production/ Consumption** – Long-term measurement of energy delivery over the term of a performance contract directly by using electrical or mechanical meters to measure the system's output or indirectly by determining savings based on analysis of end-use meters. An example would be the use of an electric meter to measure photovoltaic system output. Architectural passive solar systems usually cannot take advantage of Option B.

**Option C: Utility Bill Analysis** – Inferring savings by the statistical analysis of whole-facility energy consumption without end-use metering of the renewable energy system. An example would be comparing natural gas use in a facility before and after a sunspace is added.

**Option D: Calibrated Models** – Predicting the long-term performance of a system by calibrating (renormalizing) a computer model based on data from a short-term test.

These options are not necessarily listed in increasing order of complexity or cost. For example, inspection can be more or less costly than metering, depending on the application. 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, avoiding the determination of baseline and energy savings required for energy efficiency measures.

### 35.3.1 Option A: Measured Capacity, Stipulated Performance.

If the supplier and the customer can agree on the values, energy and cost savings may be stipulated based on an initial performance testing or an engineering calculation of a renewable energy system's performance. Even then, inspections must be conducted to ensure that the systems are installed as specified, operating as expected, and that any statutory or regulatory requirement that the persistence of savings be verified periodically are satisfied. This can be the least expensive M&V option and is often suitable for small systems where the cost savings are not sufficient to justify the expense of instrumentation and analysis. To avoid a conflict of interest, the Energy Service Company

**OPTION A EXAMPLE: RESIDENTIAL SOLAR WATER HEATING**

Option A is good for very small systems, such as residential solar water heating, where the cost of an instrumentation-based M&V program may exceed the cost of the energy system. Energy and cost savings are stipulated based on engineering calculations or ratings provided by the Solar Rating and Certification Corporation (SRCC 1998). For a particular solar collector or residential-scale solar water-heating system, SRCC provides a rating of energy delivery under standard solar resource and temperature conditions. The performance measurements reported by SRCC are used in an engineering calculation or computer model to stipulate performance. Several *good inspection protocols can be used to determine if your system is functioning properly, such as the* Inspection Procedure for Solar Domestic Hot Water Heating Systems *(International Energy Agency 1990)*. During initial inspection:

- Check that the dimensions and ratings of collectors, tanks, pumps, heat transfer fluid, and all equipment match the design specifications.
- Check that workmanship is of acceptable quality.
- Check temperature differences across the collector and heat exchangers.
- Check proper starting and stopping of pumps based on a temperature difference control to confirm proper operation of the system.

During periodic physical and operational inspections, the operation and condition of the system should be checked to verify sustained performance—all valves in proper position, temperature sensors are not short or open-circuited, and no shading of collectors by new vegetation has occurred. As an inexpensive alternative to a detailed inspection, the solar preheat tank temperature can be checked. If the preheat tank is hot, the solar system is performing at some level.

and the customer may retain a third party to conduct the inspections.

### 35.3.2 Option B: Measured Production/Consumption

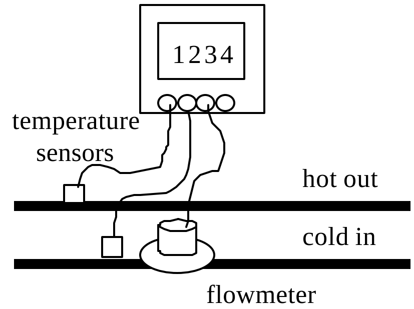

**Figure 1. Thermal energy meter**

Since renewable energy systems deliver, rather than conserve energy, a distinguishing feature over efficiency measures is that the performance (energy delivery) can be measured directly with a meter. Metering can simplify an M&V program; however, the way in which metering fits into the M&V plan depends on the specific performance claims. A program can be designed either to directly meter the system output (with a thermal energy meter or an electric meter) or indirectly meter the gas or electric use and inferring savings by subtracting from the baseline. The numbers of channels and type of measurements taken distinguish metering strategies. A thermal energy meter consists of a flow meter, two temperature sensors, and integrating electronics, as illustrated in Figure 1. The energy delivery of a thermal renewable energy system (i.e., a solar water heater) is calculated automatically by multiplying the mass flow rate by the specific heat of the water and the temperature difference between cold water coming in and hot water going out. Most thermal energy meters also report flow and temperature data, which are useful for diagnostics.

A method developed at the National Renewable Energy Laboratory involves short-term monitoring of only one temperature channel (preheat tank temperature). Data is collected over a period of several weeks, then is reduced to a daily efficiency plot (by assuming clear-sky conditions) and compared to an expected line. This method is very useful for diagnostics to determine whether the system is working approximately as expected. This method gives a reasonable (± 30%) estimate of savings, provided that there are several clear days during the monitoring period. The method uses a very inexpensive temperature sensor (less than $100), representing a low-cost metering approach. Mailing a videotape on installation and the logger to the owner avoids the cost of a site visit (Burch, Xie, and Murley 1995).
It is possible to estimate energy savings indirectly by calculating the difference between the baseline load and the metered auxiliary (electric or gas) energy usage. Auxiliary energy use metering may consist of 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. There are four ways to calculate savings relative to a baseline when only the auxiliary energy is measured (Christensen and Burch 1993):

A. **Control Group** – Compare the metered energy use with similar loads that do not have renewable energy systems.
B. **Before and After** – Measure the energy use before the renewable energy system is installed and compare it with the use after the system is installed.
C. **On and Off** – Turn the renewable energy system off by bypassing it; compare energy use to when the system was on.
D. **Calculated Reference** – Determine baseline energy use by engineering calculations and subtract metered energy usage to estimate renewable energy delivery.

**OPTION B EXAMPLE: INDIRECT METERING**

As an example of indirect end-use metering, consider the monitoring of water-heating loads on a sample of 47 houses (out of a total 285 houses) at Kia'i Kai Hale U.S. Coast Guard Housing Area in Honolulu, Hawaii. Each electric water heater was fitted with a monitoring system consisting of two relays, a voltage divider circuit with potentiometers, and a single-channel data logger to integrate and record voltage every 15 minutes (corresponding to the utility billing period). The potentiometers are tuned so the data logger records a voltage proportional to the power consumption of the heating element that is on. Figure 2 presents a summary of data collected as the total water heating power for all 47 sample houses.

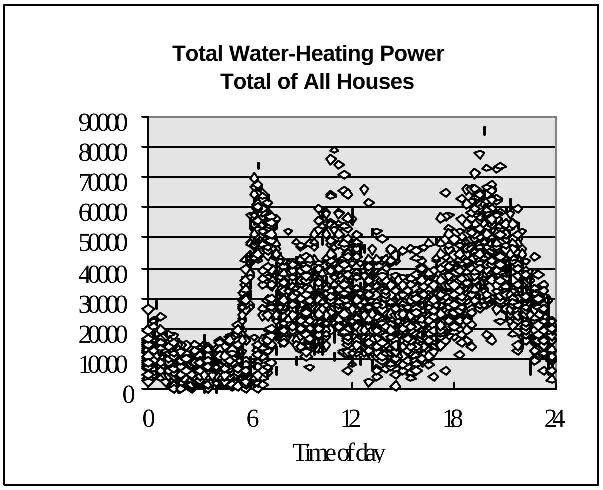


**Figure 2. Power summary data**

The 6 a.m. peak occurs on weekdays, while the noon peak occurs on weekends. The energy use is simply the average energy use for each house type (two-, three- or four-bedroom) multiplied by the number of houses of each type. The entire housing area is connected to one utility meter. The facility water-heating peak is not simply the sum of each house peak because of diversity in the demand. The demand for all 285 houses was estimated by modeling aggregate demand as a curve-fit function of number of houses then extrapolating from 47 to 285 houses.

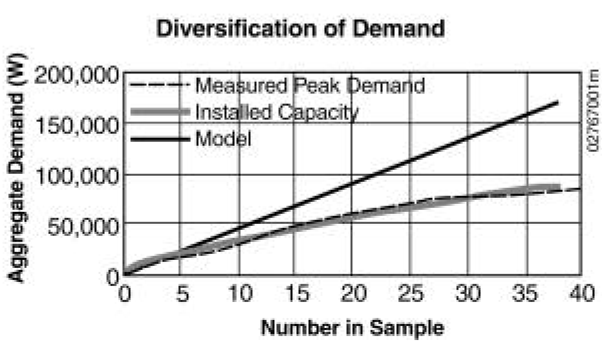


Figure 3 shows the installed capacity (sum of each house's capacity), the measured peak demand, and the model used to extrapolate to the facility water heating peak demand. For a sample size of greater than 25 homes, the aggregate demand is less than half the installed capacity. The result of this monitoring effort was a baseline water-heating energy use of 1,534,000 kWh/year with water heating imposing 370 kW on the facility peak, yielding an annual baseline cost of $143,000/year. Sixty-two of the solar water heaters were installed in 1998, and the instrumentation is in place to measure post-solar energy use using the same method (Walker 1996). This is an example of the "Before-and-After" baselining technique described earlier.

**OPTION B EXAMPLE: DIRECT METERING**

As an example of direct metering in an Energy Savings Performance Contract, consider a 1,583-$m^2$ parabolic trough system valued at $649,000 that was installed at the Phoenix Federal Correctional Institution in Arizona by the Industrial Solar Technology (IST).

Monthly payments from the prison to IST are equal to the monthly solar energy delivery (kWh), as measured by the thermal energy meter, multiplied by the average cost of utility power ($/kWh) and a 90% discount. The average cost of power is calculated from the utility bill each month, so the discount guarantees that the prison will always realize 10% savings over utility power. Use of the average utility rate (currently $0.074/kWh), rather than the incremental energy rate ($0.052/kWh), is based on the performance claim that the system saves demand (kW) in addition to delivering energy (kWh). The system design includes storage control that bypasses the 87-$m^3$ solar preheat tank to save heat for peak shaving, albeit at the expense of monthly energy delivery. Two thermal energy meters are used in a series so that metering can continue if one meter is removed for calibration. Furthermore, each meter is ±5% so that if the two meters disagree by more than ±7% (RMS of 5% and 5%), then the meter with the higher reading is sent for calibration.

The system delivered 1,161,803 kWh (3,964 million Btu) of solar heat from March 1, 1999 to February 29, 2000. Sale of this energy provided $70025.18 in revenue to IST. Using the average utility rate, the prison would have paid $77,805.74 in utility cost during the same period, a net savings of $7,780.56.

### 35.3.3 Option C: Utility Bill Analysis

This option involves analysis of information available through utility bills or whole-facility metering. The utility bill (which constitutes the measurement) is subtracted from a baseline to determine energy savings. The baseline is determined using one of the techniques described earlier in Option B ("Control Group," "Before and After," "On and Off," or "Calculated Reference"). In this case, calculated reference involves identifying driving forces (independent variables) and relating them to the whole-facility energy use through the form of a model. Then, the post-retrofit energy consumption measurement is subtracted from energy consumption (calculated with the model) to estimate savings. Since the accuracy of this method is not better than ±20%, it may be appropriate for applications where renewables contribute a large part of the building load. Measuring all the independent variables needed to model energy usage (i.e., temperature, humidity, solar radiation, and occupancy) generally exceeds the measurements required to directly measure the renewable energy system's output. Despite these drawbacks, this option would be a well-suited M&V approach for renewable energy systems as part of a larger suite of energy efficiency measures. In this case, the load modeling and measurement of the driving functions is done anyway or for measures such as daylighting and passive solar heating that do not lend themselves to metering.

**OPTION C EXAMPLE: DAYLIGHTING**

As an example of utility bill analysis, consider the restoration of inoperative daylighting controls to proper operation at a U.S. National Park Service Visitor Center in Washington, DC. In order to maintain a uniform light level in the space, artificial lighting in the visitor center is adjusted according to the amount of natural light coming through the windows in the east and south walls and through a large central skylight.

Direct power metering of the lighting circuits (end-use metering of Option B) measured an average daily reduction from 50 kWh/day to 34 kWh/day—a savings of 16 kWh/day, or 32%, in the summer. However, the impacts of the daylighting controls on the heating and cooling system cannot be directly measured with Option B. In this case, reference to the overall energy consumption of the entire building (like the utility bill) indicated average savings of 29 kWh per day (based on the “On and Off” baseline option) over the summer months, implying that the additional 13 kWh/day of savings is attributable to the other causes, including reduced load on the cooling system.

Variation over time and wintertime heating effects were not measured in this simple short-term test, but it exemplifies how utility bill analysis can facilitate measuring a renewable energy technology that is integrated into a building system, such as daylighting or passive solar heating (Walker 1995).

### 35.3.4 Option D: Calibrated Simulation Model.

This method offers a tremendous amount of information from a short-term test. A model provides the form of the correlation between measured independent variables and measured system performance. The independent variables (i.e., ambient conditions, such as solar radiation, temperature, and the load) are measured and recorded simultaneously with the system performance over a short time period. Coefficients of the model are adjusted to provide the best fit between the model and the measured performance. The model, so calibrated, then becomes a very valuable source of information. The deviation of model coefficients from their expected value provides information for diagnosing system problems. Running the model with annual weather and load data provides an estimate of annual performance.

**OPTION D EXAMPLE: PHOTOVOLTAICS**

As an example of Option D applied to a photovoltaic system, consider a 1,250-watt building-integrated photovoltaic (BIPV) system at the Thoreau Center for Sustainability located at the Presidio of San Francisco, California. 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 solar 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 the performance under the full range of sun angles that it will experience throughout the year.

First, a TRNSYS (Klein 1994) shading model is 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 to the 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 of the array efficiency model with 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.

**OPTION D EXAMPLE: PHOTOVOLTAICS (Continued)**

Unlike the solar thermal example model earlier, 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 watts. Third, the AC power output of the inverter was measured to perform a third least-squares regression to adjust an inverter efficiency model with a fit 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.

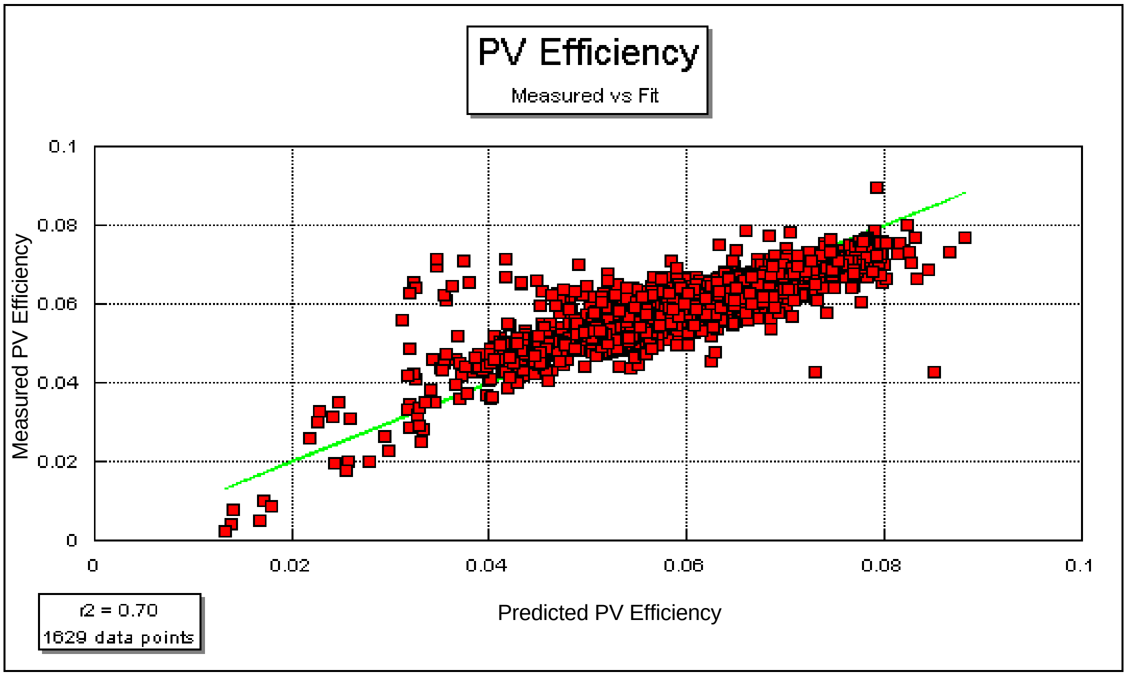


**Figure 6. Measured PV efficiency vs. predicted efficiency**

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 and 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 photovoltaic (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 used as part of the initial commissioning process in order to make sure a system functions as expected.

**OPTION D EXAMPLE: SOLAR WATER HEATING**

As an example of Option D, consider a method of evaluating solar water-heating system performance developed at the National Renewable Energy Laboratory (Barker 1990; Barker, Burch, and Hancock 1990). The instrumentation is illustrated in Figure 4.

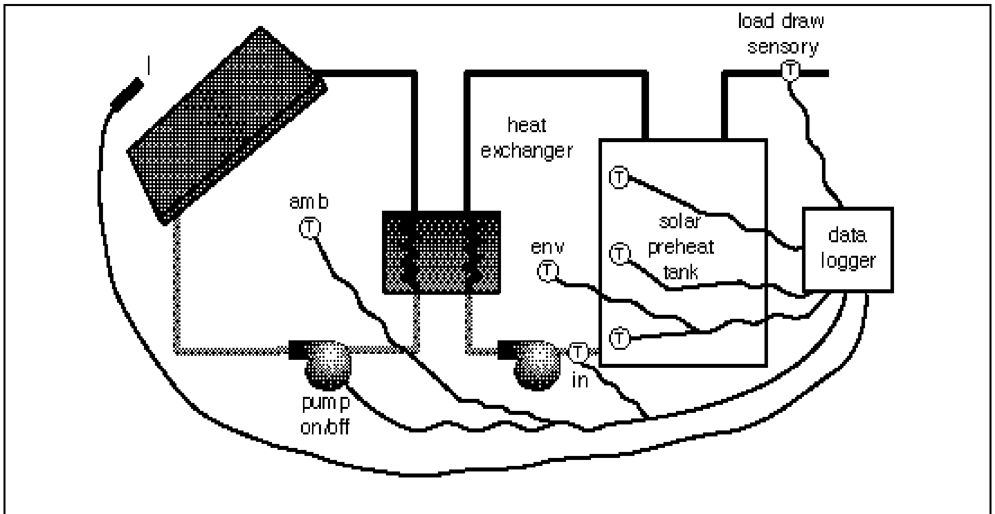


**Figure 4. Short-term test apparatus**

The time period may be as short as one day, but must encompass a sufficiently wide range of conditions. 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:

$$Efficiency = [d_Q/d_t + U_S\,(T_S - T_{env})] \,/\, [I \cdot A_C] \qquad (Eq.\ 1)$$

Is correlated by linear regression with a linear model:

$$Efficiency = \tau\alpha - U_C\,(T_S - T_{amb}) \,/\, I \qquad (Eq.2)$$

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) |
| $d_Q/d_t$ | = | time rate of change of energy in storage tank (J/s), as measured by the average of three tank temperatures |
| $U_S$ | = | thermal loss coefficient of the thermal storage tank (W/°C); measured by a cool-down test. |

The term $\tau\alpha$ is an empirical constant representing all the effects of transmissivity of the cover glass and absorptivity of the absorber plate. $U_C$ is a term representing all effects of thermal loss coefficient of the collector and piping per unit area ($W/m^2 \cdot$ °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, ambient temperature, and incident solar radiation from a weather file for all 8,760 hours of the year—from typical year meteorological data (NCDC 1997)—to predict the annual performance. This simple model is isothermal with the collector and storage all at an average $T_S$, although tank stratification could be modeled.

**OPTION D EXAMPLE: SOLAR WATER HEATING (Continued)**

The method described earlier was implemented in a program to test the performance of 13 systems in Colorado (Walker and Roper 1992). Figure 5 shows the results of a one-day test on a system with 8.9-$m^2$ collector area.

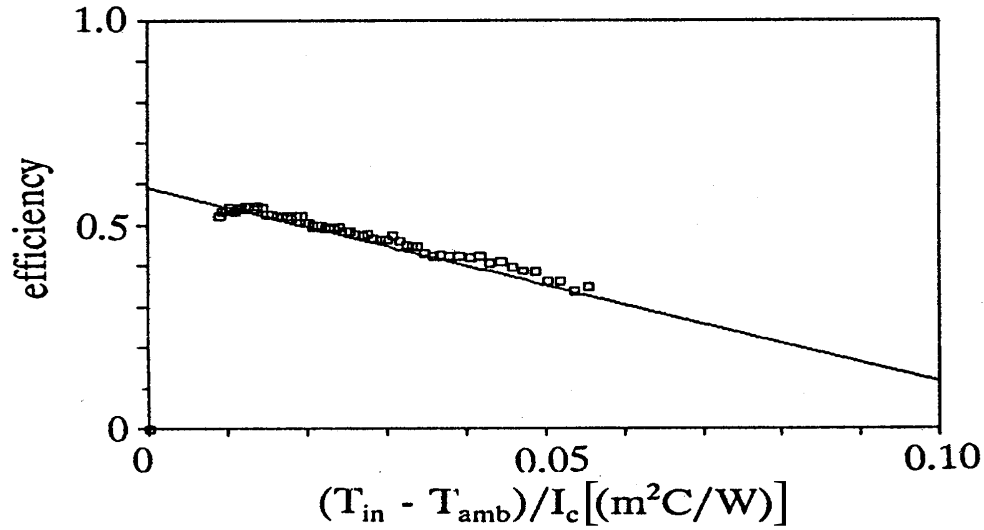


**Figure 5. Results from one-day test**

The square symbols signify measured data for every five-minute interval, and the solid line is the best-fit linear regression (the renormalized model). This test was conducted on a clear day, and there is a very good agreement 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 consists of $\tau_\alpha = 0.59$ and $U_C = 4.7\ W/m^2 \cdot\ °C$. The simulation using Colorado Springs weather data predicts a typical annual energy delivery of 5,388 kWh/year.

### *35.4 Calculation of Savings*

Calculation of savings depends on the type of data collected. If time-of-use data is collected by a sophisticated data acquisition system (personal-computer, for example), then it is feasible to calculate the benefits of the renewable energy system at each utility metering interval (15 minutes). It is often sufficient to calculate savings based on an fixed utility rate which could be stipulated as the average rate, or the average at the part of the rate schedule where the renewables system is expected to have the most impact (a marginal rate). Calculation of savings will depend on the performance claims associated with the project, and should account for parasitic energy used by the renewable energy system and any increased operation and maintenance costs incurred by the Federal agency.

#### 35.4.3 Information on Metering

Determining the electrical output of systems is relatively straightforward. This is because electrical output and parasitic loads can be simply measured with many com-mercially available meters. Measuring thermal output (e.g., hot water from a domestic hot water solar system displacing an electric water heating system) is also straightforward, although not necessarily inexpensive, using commercial Btu meters, water flow meters, or temperature transducers.

Electricity measurements associated with generator output, parasitic loads, power to the project site as well as power to third parties and the utility may be needed. All electrical meters (and related equipment) are usually provided, installed, owned, and maintained by the ESCO or the servicing utility. With the one-for-one replacement approach, meter(s) will typically show the measure's gross output (in kW and kWh) less parasitic use (e.g., pump motors) and sales to third parties or the local utility, as well as any local transformation and transmission and battery storage losses. The goal of this method is usually to measure net generation delivered to the proje ct site. Metering, interconnection (including safety provisions), reporting and other related issues are to be in accordance with current electrical standards and the requirements of the servicing electric utility.

With the net energy-use approach, deliveries to and from the facility should be separately recorded and treated as separate transactions. Note that power may flow into or out of the "plant" at different times and thus detents that prevent reverse registration may be required. For purposes of power delivered to the site, a single meter that records energy supplied to the site is preferred. If a calculated transformer loss value is used, it must be based on certified factory test data for that particular transformer supplied by the manufacturer and acceptable to the ESCO and federal agency.

The following are some suggested metering requirements:
• kWh and demand metering at the point of delivery
• Time-of-delivery metering
• Conduit to accommodate a telephone line for remote meter reading
• Load profile recording equipment at the point of delivery, with graphic recorder or data logger.

Thermal meters (e.g., Btu meters) are required for measuring the net thermal output of certain renewable energy systems, such as hot water generated by an active solar system. Note that metering of thermal energy requires a "net" measurement of flows and enthalpy to and from a system. Placement of the meter should take into account any vented or wasted energy that is produced by the system but not used at the site, as well as distribution and storage losses. Also note that small errors in enthalpy measurements (usually determined by temperature) can introduce large errors in the energy calculations, so meter precision, accuracy, and calibration are especially important.

### 35.4.4 Equation for Calculating Savings

*The general format for calculating savings from renewable energy projects is shown below.*

*Savings to the Federal agency equal:*

(electrcial energy delivered and used at facility) x (electric rate)
+
[(thermal energy delivered and used) x (rates for displaced fuel)/(efficiency of displaced system)]
-
(cost of any fuel or electricity used for parasitic systems)
-
(cost of incremental operations and maintenance)

### 35.5 Notes on Renewable Energy Project M&V

Active solar thermal systems include systems for producing industrial process heat, domestic hot water, and space heating and cooling. For numerous small systems, Option A (site inspections and brief temperature and system monitoring for diagnostics) or Option C (utility bill analysis) would be recommended, whereas for single large systems Option B would be more cost effective (long-term measurement of energy delivery).

Passive solar systems usually involve the performance of a whole building with architectural features such as overhang design and use of thermal mass. As such, this technology is different from other renewable energy measures in that mechanical devices with identifiable energy inputs and outputs are not involved. Thus, passive solar M&V typically involves the analysis of a whole building and it is best to use utility billing analyses and calibrated simulation techniques— options C and D.

With Wind, Photovoltaics and other electricity generation projects, Option B, direct measurement of energy delivery, is preferred due to simplicity, and puts the risk of weather conditions on the ESCO. Alternatively, the risk of weather conditions could be put on the Federal agency by specifying performance characteristics. The performance characteristics of the components in these systems are usually well defined, such as the conversion efficiency of the PV modules or the Btu content of landfill gas, and these parameters could be specified as measures of performance. The complexity of projects is in projecting long-term performance due to variation in the resources (e.g., solar insolation, wind resource, or reserve of methane gas in a landfill) and accounting for any variations between when the resource is available and when it is needed—i.e., the interaction of storage systems and their inefficiencies.

### 35.6 Site Specific Measurement and Verification Plan

M&V plans for renewable energy projects will need to be custom developed by the ESCO and the federal agency since each project is usually unique. The site-specific measurement and verification approach may be specified in the ESPC contract solicitation and/or agreed to after the award of the project. In either case, prior to the federal agency's approval of project construction, the ESCO will need to submit a final M&V plan that addresses the following elements:

• Describe the facility and the project; include information on how the project saves energy and/or provides non-energy benefits and what key variables effect the realization of savings. An accounting-type spreadsheet should be prepared which shows estimated baseline costs and projected performance period costs for categories such as: electricity and fuel purchases (rates, total costs, and consumption), labor, materials, and equipment replacement. Each of these values will need to be verified (baseline) or determined during the pre- and post-installation M&V processes. To determine the savings from renewables projects (particularly demand savings), it is usually necessary to prepare time-of-use analyses for typical days or week, if not for the whole year.

• Indicate how the federal agency's budget will be directly reduced by the implementation of the project (see description of Performance Claims). All payments to ESCOs must come from demonstrable savings to the agency's budget.

• Define the minimum performance standards (e.g., minimum hot water temperatures or voltage over- and under -frequency standards) that are currently in place and those required once the measure is in place. Determine how benefits (or losses) associated with improvements (or reductions) in performance standards will be allocated between parties. Indicate how compliance with performance standards will be verified during the term of the agreement.

• Indicate who will conduct the M&V activities and prepare analyses and documentation.

• Define the details of how calculations will be made and the assumptions that will be made about significant variables or unknowns. For instance: utility rate schedules (including stand-by rates) with and without the new renewables measures and sources for solar or wind resource data. Describe any stipulations that will be made and the source of data for the stipulations. Describe any tracking software that may be used. Show how calculations of savings will be used to determine payments to the ESCO.

• Specify what metering and data logging equipment will be used, who will provide the equipment, its accuracy and calibration procedures, and how data from the metering will be validated and reported, including formats. Electronic formatted data directly from a meter or data logger is usually required.

• Specify what additional management oversight logs will be maintained, the nature and frequency of entries, and the interpretation that is to be assigned to the results. Examples include logging equipment failures, equipment down time, and system outputs.

• Indicate how quality assurance will be maintained and repeatability confirmed. For instance, “The data being collected will be checked every month and provided to the federal agency.”

• Indicate which reports will be prepared, what they will contain, and when they will be provided.

## *35.7 QUALITY AND COST OF RENEWABLES M&V*

The cost of an M&V program consists of the cost of purchasing and installing the instrumentation, maintaining the instrumentation (including periodic calibration) and the labor to design the program, and 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 that should be spent on M&V should be determined by the value of the benefits to be realized by the M&V program. The value of these benefits is determined by negotiation for each project. The objective is to minimize the total cost of the M&V program plus the cost of uncertainty in the savings. The cost of uncertainty would most often be realized by a higher interest rate. In general, the M&V approach and the allowable relative error in an M&V program will be negotiated between parties, with all parties trying to minimize total cost. In order to lower project costs, the customer, in such an arrangement, may assume some performance risk by agreeing to stipulated—rather than measured—values or by increasing the allowable error in measurements. Other requirements of an M&V program might be established by regulating bodies that issue emissions credits or other certifications.

## *35.8 Other activities*

Several organizations have objectives and activities related to M&V for renewables. A short description of each organization follows. More information on these organizations can also be found on the World Wide Web (Web addresses are included in each description).

Much of the information is this chapter is repeated from the Renewable Energy section developed for the International Performance Measurement and Verification Protocol. www.ipmvp.org.

The mission of the American Society for Testing Materials (ASTM) in West Conshohocken, Pennsylvania, is to provide the value, strength, and respect of marketplace consensus standards. 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 the 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. **<http://www.astm.org/>**

The vision of the Institute of Electrical and Electronics Engineers, Inc. (IEEE), based in New York City, is to advance global prosperity by fostering technical innovation, enabling members' careers, and promoting community worldwide. The 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 underway to establish utility interconnection standards important to wide-scale implementation of grid-connected renewable energy distributed generation technologies. **<http://www.ieee.org/>**

The Solar Rating and Certification Corporation (SRCC) in Cocoa, Florida, is an independent, nonprofit organization that certifies and rates the performance of solar energy equipment. SRCC's "Solar Energy Factor" ratings allow the comparison of savings between many different types of solar water-heating systems and conventional water heaters. SRCC's certification criteria help to improve the quality, reliability, and durability of the systems carrying SRCC certification. Because of these important and distinguishing features, SRCC certification has become a code requirement in 12 states across the United States and is being considered as a requirement in other states.
**<http://www.theenergyguy.com/SRCC.html>**

The International Organization for Standardization (ISO), based in Switzerland, is a non-governmental 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 facilitate the exchange of goods and services and to develop cooperation in the spheres of intellectual, scientific, technological, and economic activity. ISO's work results in international agreements that are published as International Standards. **<http://www.iso.ch/>**

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 parallel procedures for public inquiry and formal vote on international standards.
**<http://www.cenorm.be/>**

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/>**

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 is the organization to carries out the certification program for PV GAP. **<http://www.pvgap.org/>**

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. **<http://www.jrc.cec.eu.int/jrc/index.asp>**

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 to internationally accepted standards (CEC, ISO, and IEC). **<http://iamest.jrc.it/esti/esti.htm>**

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. **<http://www.tuv.com/>**

On their 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." These texts can be viewed and searched at **http://www.newapproach.org/.**

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 the strong potential to develop into mainstream use. TEAM-UP is helping create an expanded market for solar electricity. TEAM-UP awards cost-sharing dollars on a competitive basis. **<http://www.ttcorp.com/upvg/>**

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 of electricity in Australia together with associate, affiliate, and individual membership from Australia and overseas. **<http://www.esaa.com.au/>**

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. There are more than 60 programs currently operating through the IEA—each of them reflects the need to efficiently coordinate between 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 offer the 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 their market deployment by removing the non-technical barriers. **<http://www.caddet-re.org/html/pvpsp.htm>**

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 non-technical 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/>**

The Photovoltaics Special Research Center at the University of New South Wales 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. **<http://www.pv.unsw.edu.au/>**

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. **<http://fizzy.murdoch.edu.au/acre/>**

## REFERENCES

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.

Barker, G.; Burch, J.; Hancock, E. (April 1990). "Field Test of a Short-Term Monitoring Method for Solar Domestic Hot Water Systems." Prepared for the ASME/JSME International Solar Energy Conference, April 1990. Golden, CO: National Renewable Energy Laboratory.

Burch, J.; Xie, Y.; Murley, C. (1995). *Field Monitoring of Solar Domestic Hot Water Systems Based on Simple Tank Temperature Measurement.* NREL/TP-472-7854. Golden, CO: National Renewable Energy Laboratory.

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

Christensen, C.; Burch, J. (1993). *Monitoring Strategies for Utility Solar Water Heating Projects.* Golden, CO: National Renewable Energy Laboratory.

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

National Climatic Data Center. (1997). *Typical Meteorological Year Weather Data.* Asheville, NC: U.S. National Climatic Data Center.

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

Sarkar, A.; Wolter, N. (Fall 1998). "Environmental Externalities from Energy Sources: A Review in the Context of Global Climate Change." *Strategic Planning for Energy and the Environment* (18:2); pp. 55–63.

Solar Rating and Certification Corporation (SRCC). (1998). *Directory of SRCC Certified Solar Collector and Water Heating System Ratings.* ANSI Z34.1-1987. Washington, DC: SRCC.

United States Department of Defense. (1998). *Energy M&V Reference Handbook Systems Engineering and Management Corporation for Air Force Civil Engineer Support Agency.* Washington, DC: Government Printing Office (GPO).

United States Department of Energy. (1991). *National Energy Strategy: Powerful Ideas for America.* Washington, DC: GPO, 118 pp.

Walker, A. (1995). *Federal Energy Management Program Report: White House Visitor Entrance Building Daylighting Analysis.* Golden, CO: National Renewable Energy Laboratory.

Walker, A. (1996). *Federal Energy Management Program Report: U.S. Coast Guard Kiai Kai Hale Housing Areas I & II Domestic Water Heating Baseline.* Golden, CO: National Renewable Energy Laboratory.

Walker, H.; Roper, M. (June 1992). "Implementation of the NREL SDHW Short-Term Monitoring Method." Prepared for Solar '92: The National Solar Energy Conference, 21st ASES Annual Conference, June 1992. Golden, CO: National Renewable Energy Laboratory.