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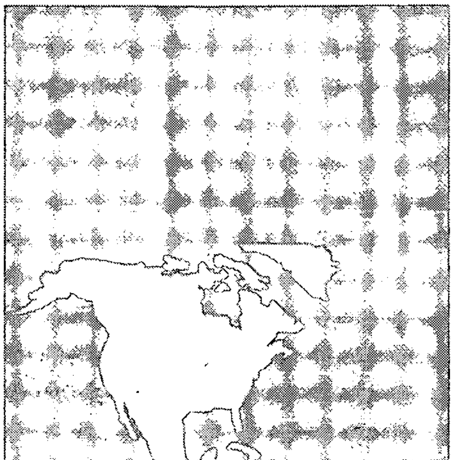
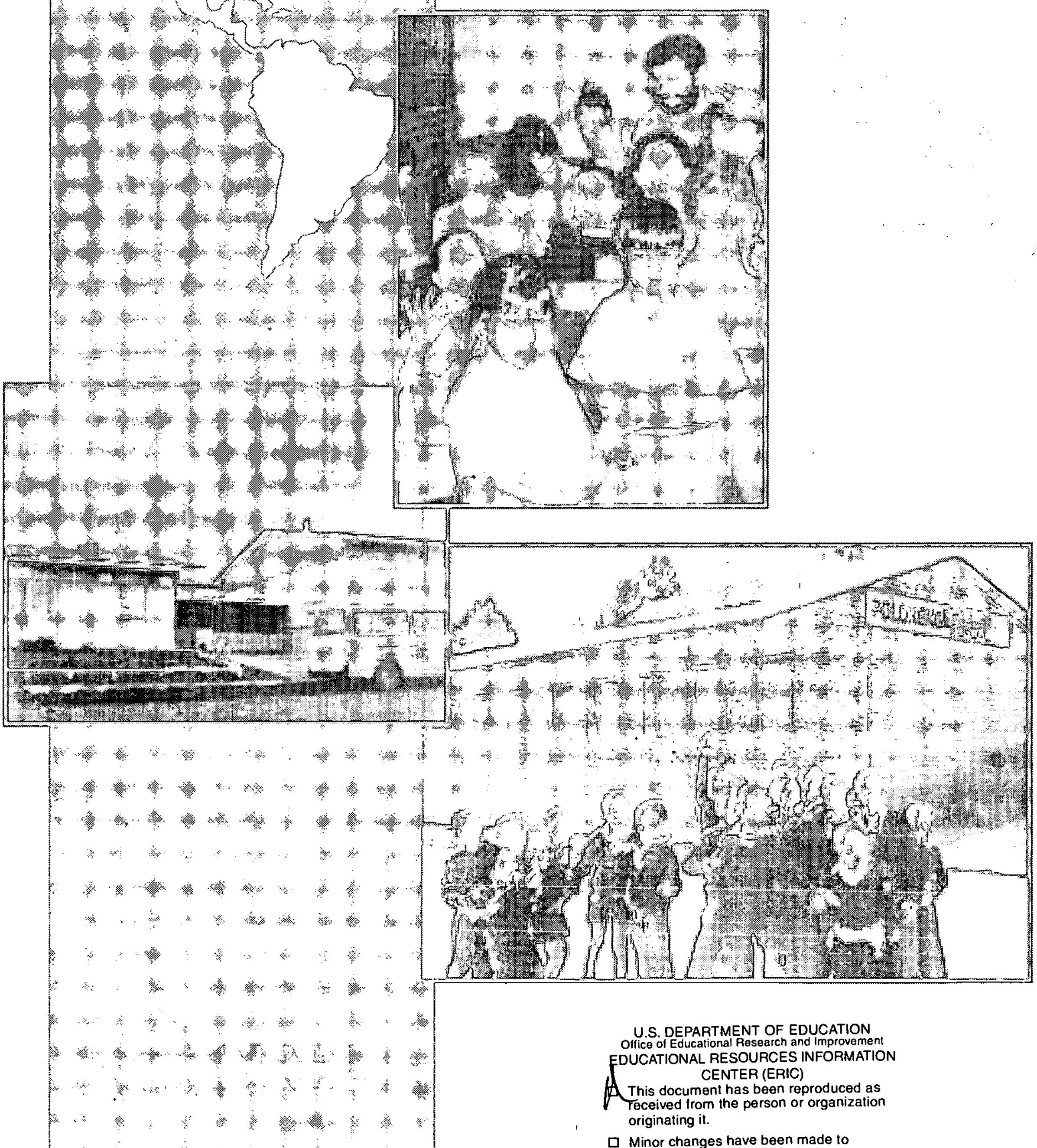
ABSTRACT

Although education in rural communities is an important priority, in many cases, electricity is not available to support rural educational activities. Renewable energy systems present a reasonable solution to support activities such as lighting, computers, telecommunications, and distance learning. There are certain factors and criteria that need to be taken into consideration when choosing the appropriate renewable energy source. This guide complements the National Renewable Energy Laboratory's (NREL) Village Power Program and aims to expand resource opportunities beyond photovoltaic (PV) lighting systems to wind and hydro resources. Guidelines for the selection of systems are also provided. Contents include: (1) "How To Use This Guide"; (2) "Introduction: Definition of Need"; (3) "School Energy Application"; (4) "Solar Thermal Applications and Components"; (5) "Electrical System Components"; (6) "System Selection and Economics"; (7) "Institutional Considerations"; (8) "Case Studies"; and (9) "Lessons Learned". (YDS)

Renewable Energy for Rural Schools





Cover Photos:

Upper Right: Children at a school powered by renewable energy sources in Neuquén, Argentina.
Tom Lawand, Solargetics/PIX008261

Left: Two 1.0 kW wind turbines supply electricity to the dormatory of the Villa Tehuelche Rural School, a remote boarding school located in southern Chile.
Arturo Kuntsmann, CERES/UMAG/PIX08262

Lower Right: Small boys play in the school yard of the newly electrified Ipolokeng School in South Africa.
Bob McConnell, NREL/PIX02890

Renewable Energy for Rural Schools

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FOREWORD

A few years ago, during my tenure as the United States ambassador to the small African nations of Rwanda and Lesotho, I was responsible for administering the Ambassador's Self-Help Funds Program. This discretionary grants program, supported by the United States Agency for International Development (USAID) funds, allowed the ambassador to selectively support small initiatives generated by local communities to make their schools more efficient, increase economic productivity, and raise health standards. These funds were used to purchase equipment and materials, and the communities provided the labor necessary for construction. During this time, I was reminded of my earlier training in a one-room school in rural Bellair, Florida, in the United States. The school, which was without heat and hot water and dependent solely on kerosene lamps for lighting, made me wonder how much more I might have learned had today's advanced renewable energy technologies for rural schools been available to my generation. Following this diplomatic tour, I was asked to serve as chair person for Renewable Energy for African Development (REFAD)—a nonprofit organization dedicated to the application of renewable energy technologies in the rural villages of Africa.

In South Africa, with support from the National Renewable Energy Laboratory (NREL) and the U.S. Department of Energy (DOE), more than one hundred college teachers and representatives from nongovernmental organizations (NGOs) have participated in renewable energy capacity building programs. As a result, several institutions initiated research projects. In Port Elizabeth, the technikon now offers a bachelor's degree in renewable energy studies. In South Africa, the government collaborated with industry and awarded concessionaire funds to implement a country-wide rural electrification program. In several South African countries, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) provided 2-year funding to establish university chairs in renewable energy. In Botswana, REFAD conducted a careful evaluation of the government's 40-home photovoltaic (PV) pilot project. The evaluation showed that the introduction of solar technology to this rural village had a decided positive impact on microeconomic development, health improvements, and school performance—each of which plays an important role in ensuring continued sustainability in rural villages.

Perhaps one of the most satisfying achievements of REFAD's work was the establishment of a "Living Renewable Energy Demonstration Center" in the KwaZulu/Natal region near Durban, South Africa. The major universities and technikons in Durban worked together to establish a KwaZulu/Natal/Renewable Energy Development Group (KZN/REDG) among the NGOs. This group pooled its limited resources to provide renewable energy input to a single community. As a result of the group's action, three schools are being transformed into solar schools. Myeka High School now operates a 1.4kWp hybrid PV/gas system, which powers 20 computers, a television, a video cassette recorder (VCR), the lights in three classrooms and the headmaster's personal computer and printer. Systems are also being installed at Chief Divine Elementary School and Kamangwa High School.

When you talk with the beneficiaries of these solar projects, you cannot help but be impressed by how much these initiatives are needed by those of us who labor at the grass-roots level in developing countries. When one family returned from Gabarone to Botswana's Manyana Village following the installation of the 40-home PV pilot project, they were asked why they had returned. The father's reply was quite a revelation: "Because Manyana is now a modern city." The defining parameter for determining city status for his family was electrification.

"Renewable Energy in Rural Schools" is an inexpensive, yet comprehensive reference source for all local NGOs and schools that are seeking technical guidance for the integration of renewables as a part of the physical and instructional aspects of their schools. This practical one-stop, hands-on Guide will be welcomed by in-country practitioners, Peace Corps volunteers, and by U.S. colleges and universities engaged in the preparation of students for services in developing countries. I commend the authors for preparing this much-needed document, and I hope that NREL will continue to provide the necessary support for these kinds of initiatives.

Leonard H.O. Spearman, Ph.D,
Chair, Renewable Energy for African Development
Distinguished Professor, Coppin State College

PREFACE

Education of rural communities is an important national and international priority. In many countries, however, the availability of electricity to support rural educational activities is less than adequate. In recent years the development of reasonably priced and reliable renewable energy systems has made it possible to provide electricity and thermal energy for lighting, computers, telecommunications/distance learning, and on-site living accommodations in remote areas. A number of international, national, and local institutions, nongovernmental organizations, foundations, and private companies are supporting the deployment of renewable energy systems in rural communities in the developing world where rural education is a national priority.

Because renewable energy is regionally diverse, choosing the appropriate renewable energy system will be regionally and site dependent. Although photovoltaic (PV) lighting systems have paved the way and are being deployed in many remote communities around the world, other small renewable sources of electricity should be considered. One of the objectives of this guidebook is to expand the remote electricity opportunity beyond PV to areas of good wind or hydro resources. Also, in the near future we expect to see micro-biomass gasification and direct combustion, as well as concentrated solar thermal-electric technologies, become commercial rural options.

The three important factors driving the selection of the appropriate technology are the local natural resource, the size and timing of the electrical loads, and the cost of the various components, including fossil fuel alternatives. This guidebook reviews the considerations and demonstrates the comparisons in the selection of alternative renewable and hybrid systems for health clinics.

The National Renewable Energy Laboratory's (NREL's) Village Power Program has commissioned this guidebook to help communicate the appropriate role of renewables in providing rural educational electricity services. The two primary authors, Tony Jimenez and Tom Lawand, combine the technical analysis and practical design, deployment, and training experience that have made them such an effective team. This guidebook should prove useful to those stakeholders considering renewables as a serious option for electrifying rural educational facilities (and, in many cases, associated rural clinics). It may be useful as well to those renewable energy practitioners seeking to define the parameters for designing and deploying their products for the needs of rural schools.

This is the second in a series of rural applications guidebooks that NREL's Village Power Program has commissioned to couple commercial renewable systems with rural applications, such as water, health clinics, and microenterprise. The guidebooks are complemented by NREL's Village Power Program's application development activities, international pilot projects, and visiting professionals program. For more information on this program, please contact our Web site, http://www.rsvp.nrel.gov/rsvp/.

Larry Flowers
Team Leader, Village Power
National Renewable Energy Laboratory

CONTENTS

HOW TO USE THIS GUIDE

Who is this guide for?

This guide is designed for decision-makers in developing areas responsible for schools, particularly those who are charged with selecting, installing, and maintaining energy systems. Schools are run by many different types of organizations, including government agencies, religious institutions, and many private organizations. This guide is designed to help decision-makers in all these types of agencies to better understand the available options in providing energy to schools.

What is the purpose of this guide?

This publication addresses the need for energy in schools, primarily those schools that are not connected to the electric grid. This guide will apply mostly to primary and secondary schools located in non-electrified areas. In areas where grid power is expensive and unreliable, this guide can be used to examine other energy options to conventional power. The authors' goal is to help the reader to accurately assess a school's energy needs, evaluate appropriate and cost effective technologies to meet those needs, and to implement an effective infrastructure to install and maintain the hardware.

What is in this guide?

This Guide provides an overview of school electrification with an emphasis on the use of renewable energy (RE). Although the emphasis is on electrification, the use of solar thermal technologies to meet various heating applications is also presented. Chapter 1 discusses typical school electrical and heating applications, such as lighting, communications, water purification, and water heating. Information on typical power requirements and duty cycles for electrical equipment is given. Chapter 2 is an overview of solar thermal applications and hardware. Chapter 3 discusses the components of stand-alone electrical power systems. For each component, there is a description of how it works, its cost, lifetime, proper operation and maintenance, and limitations. Chapter 4 includes an overview of life-cycle cost analysis, and a discussion of the various factors that influence the design of stand-alone RE systems for a particular location. Chapter 5 addresses the various social and institutional issues that are required to have a successful school electrification program. Although there is an emphasis on large-scale projects supported by governments or large, private agencies, much of the content relating to maintenance, user training, and project sustainability will be of interest to a wider audience. Chapter 6 describes six school case studies. Chapter 7 summarizes general lessons learned that can be applied to future projects. These are followed by a list of references, a bibliography, and a glossary of terms used throughout this guide

INTRODUCTION: DEFINITION OF NEED

Current State of Rural Schools

A large proportion of schools in the developing world do not have access to basic services, including running water, toilets, lighting, and in some cases, even the pencils and books so necessary to the process of education. Schools in rural communities are generally worse off than those located in urban areas, and those schools located in remote rural areas are least favored of all. They sit at the far end of the table, are often the last to be served from the education budget, and what they do get tends to cost more because they are on the periphery. Communications with these schools are difficult, and they rarely have the infrastructure required to keep things running smoothly. Despite their being last in line for resources, schools in remote areas often fill a larger local role than do schools in urban areas. The school may be the only institution in a given rural area, and serves not only for education, but also for other community activities.

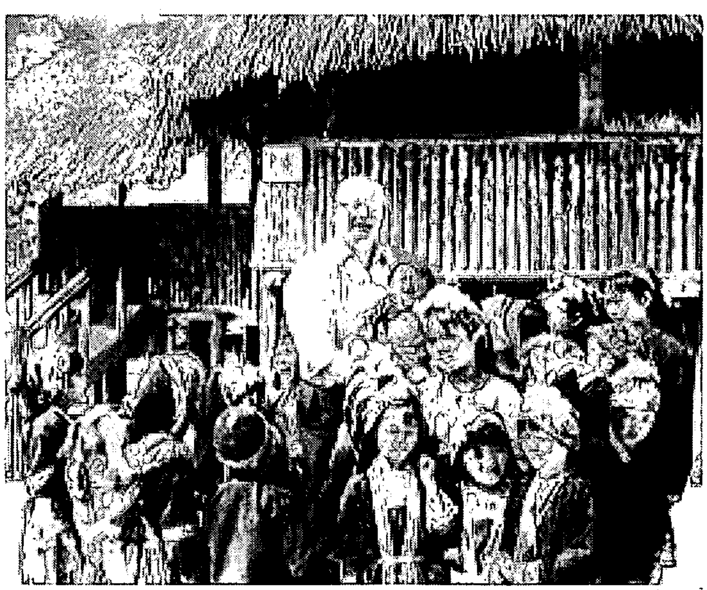

Figure I.1. Children of the Miaozu people in front of their school on Hainan Island.

There is an increasing need for rural populations to improve education so that they may increase productivity and improve their standard of living. It is important to bridge this gap so that the rural areas can become more economically sustainable and reverse the trend of migration from the rural to the urban areas with all the latter's problems.

Renewable energies have a role to play in rural schools. Remote communities are often ideal sites for many RETs (renewable energy technologies) for two reasons: (1) the higher costs of providing conventional energy in these areas, and (2) reduced dependence on fuel and generator maintenance. RETs offer lower operating costs and reduced environmental pollution. This provides long-term benefits, which, if fully evaluated by decision-makers, could impact the choice of technology in favor of RE (renewable energy) systems. However, since RE systems are relative newcomers on the energy-supply side, they are not often given proper consideration for remote school applications. Part of the fault lies in the lack of widely available information about the capabilities and applications of RETs. Part of the problem is due to the reluctance of planners and policy makers to change from accepted practices. They are more comfortable with proven, well-accepted systems, notwithstanding the existing problems and costs of conventional energy systems.

Problems Associated with Existing Energy Delivery Systems

Often, electricity for remote schools is supplied by standard-diesel or gasoline-powered electric generators. In many cases, the school and adjacent buildings form a mini-grid directly connected to the generator. The latter is operated periodically during the day and evening when power is required. In some instances, the generator can be operated continuously, but this is costly, and only happens in rare circumstances. A large problem with standard energy delivery systems is that school personnel require training in the use, operation, and maintenance of the

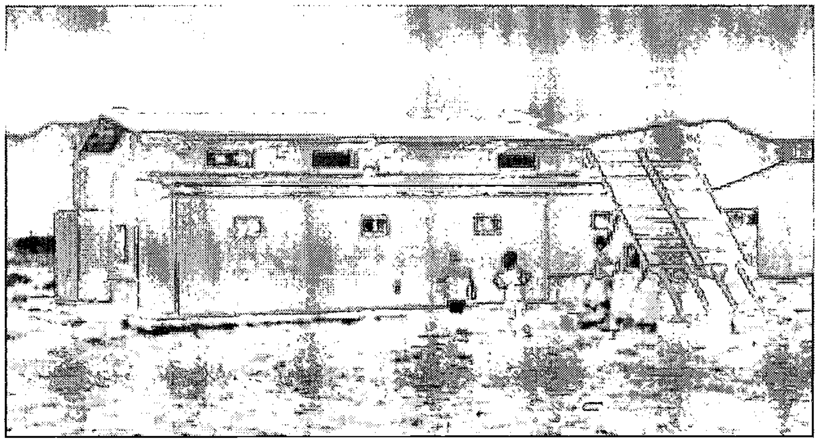

Figure I.2. PV system, including panels, batteries, and regulator box at a school in Collipilli Abajo, Argentina.

system. Most of the people associated with education in rural schools—teachers and custodians—don't have the training, or the experience, to operate equipment of this type. This lesson should be retained when considering the implementation of RE systems. The use of RE systems will not eliminate the training requirement. While simple RE systems require less training than conventional systems, the training requirements increase with increasing system complexity. Thus simple, rugged designs are vital for systems that are destined for use in remote areas.

Problems with conventional systems include:

- Fuel provision
- Fuel cost
- Fuel-delivery system reliability
- Generator spare parts: availability, cost, and delivery
- Generator repair: the availability of a qualified mechanic or technician
- Maintenance and repair costs.

Conventional generators are a mature technology, and when used under the proper conditions, with a proper service infrastructure in place, they can provide years of satisfactory service. Unfortunately, in a significant number of remote rural schools, the generators are often in a state of disrepair, leading to serious consequences that adversely impact the functioning of the school. The lack of electricity exacerbates the already high teacher-turnover rate, which has a negative impact on the quality of education.

The Role of Energy and Water in the Appropriate Functioning of Schools

The applications of energy in remote schools are discussed in Chapter 1. In order for schools to function properly, clean water is necessary for drinking, sanitary cooking, kitchen requirements, and gardening. It is also essential that the students (frequently coming from poor backgrounds, living in houses often devoid of fresh water), learn the use and management of clean-water sources as part of their education. Water and energy are vital components of life—the opportunity to learn about these fundamentals in school should not be missed. For students attending rural schools, it may constitute the only occasion when they can learn about these essential components of modern society. This is a vital opportunity to train the students in basic life skills before sending them back to the often grim reality of rural poverty and deprivation.

CHAPTER 1: SCHOOL ENERGY APPLICATIONS

Chapter Overview

The overall needs of rural schools differ from the needs of urban schools. In many remote rural schools, the teacher, often accompanied by his/her family, lives in residence, either directly in the school building or in an attached building.

This Chapter describes the most common school applications, which are listed below. The Tables in this Chapter give typical power requirements and duty cycles for rural school electrical applications.

- Lighting, water pumping and treatment, refrigeration, television, VCR
- Space heating and cooling
- Cooking
- Water heating
- Water purification
- Radio communications equipment.

Figure 1.2. PV powered lights in a rural school in Neuquén, Argentina.

Lighting (Indoor/Outdoor and Emergency Lights)

Electricity offers a quality of light to which gas or kerosene cannot compare. Kerosene lighting is most common in non-electrified communities. Kerosene is a known safety hazard and contributes to poor indoor air quality. Electric light greatly improves the teacher's ability to

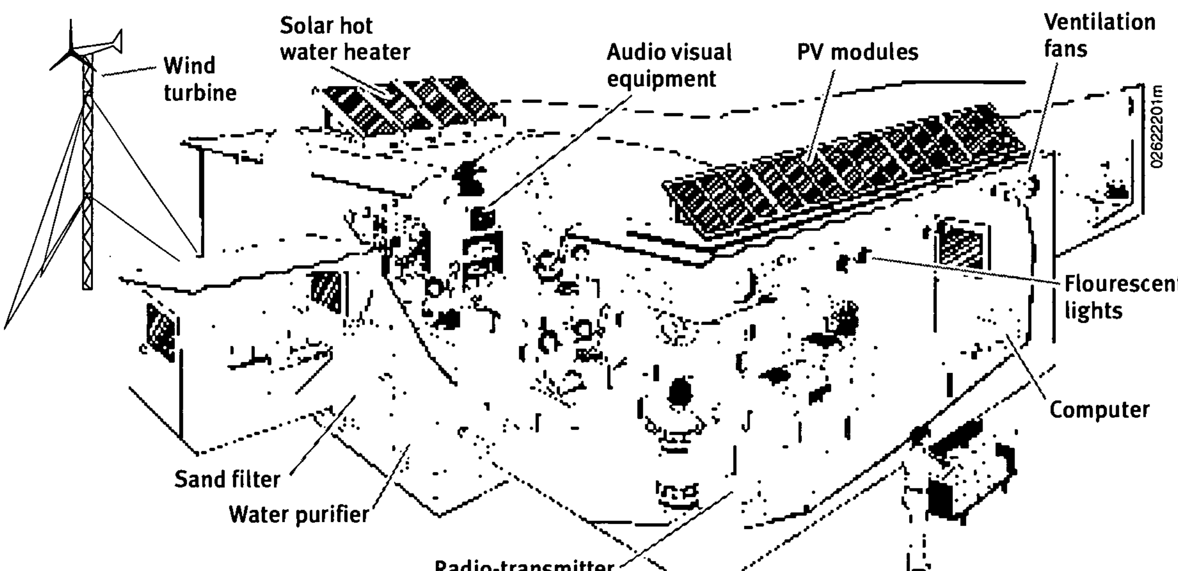

Figure 1.1. School showing potential applications.

Table 1.1. Power Consumption for Lighting

Lamp Type	Rated Power (watts)	Light Output (lumens)	Efficiency (lumens/watt)	Lifetime (hours)
Candle		1-16		
Kerosene lamp		10-100		
Incandescent bulb	15	135	9	850
	25	225	9	850
	100	900	9	850
Halogen bulb	10	140	14	2,000
	20	350	18	2,000
Fluorescent tube	8	400	40	5,000
	13	715	40	5,000
	20	1,250	40	7,500
Compact fluorescent	15	940	72	10,000
	18	1,100	66	10,000
	27	1,800	66	10,000

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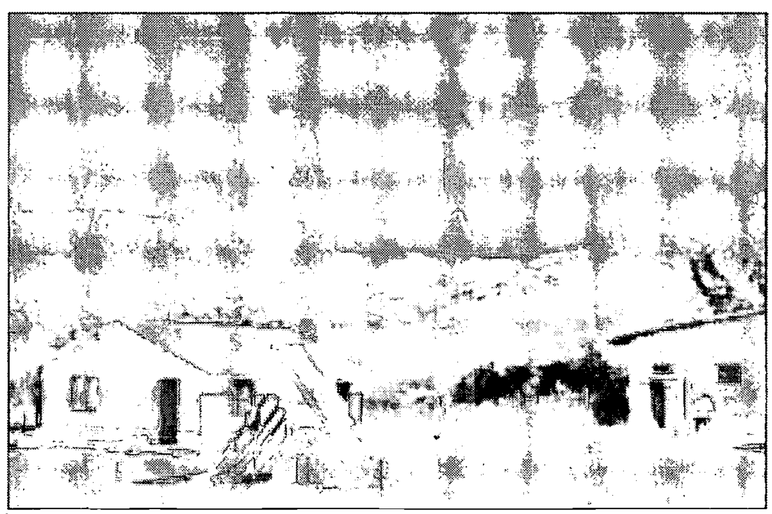
present a variety of subjects in a more appealing way. It also permits the more efficient handling of administrative tasks, and other non-teaching functions. Outdoor light makes the rural school more accessible at night. In non-electrified communities, a school with light becomes a strong community focus. The building can be used at night for training purposes, adult education, cultural events, community meetings, and the like.

When using a RE system, energy efficiency is key to affordability. Investments in efficient systems generally result in capital and operating cost savings. Table 1.1 shows the light produced by candles, kerosene lamps, and various types of electric lights. The Table also shows the electrical consumption of the various electric lights. What is not shown in the Table is the large qualitative superiority of electric lighting over kerosene and candles.



Tom Lawand, Solargetics/PIX08269

Figure 1.3. PV panels mounted on the ground and on a radio-transmitter tower.

The Table makes clear great efficiency of compact- fluorescent (CF) lights compared to other electric lighting technologies. Compared to incandescent lights, CF lights give four to seven times the light per watt-hour consumed. With an expected service life of up to 10,000 hours, CF lights last up to ten times longer than incandescent bulbs.

Communications—Radio-Telephone, Email, Fax, and Short-Wave Radio

Radio and radio-telephone communications greatly increase the efficiency of school operations in remote locations. Communication is essential for routine operation and management functions, including procurement of supplies and visits by other teachers. Reliable communications facilitate emergency medical treatment and evacuation when a student or staff member becomes suddenly ill.

School communications require very little electrical energy. Stand-by power consumption may be as little as 2 watts (W). Power consumption for transmitting and receiving are higher, on the order of 30-100 W, but this is generally for very short periods of time. For example, many

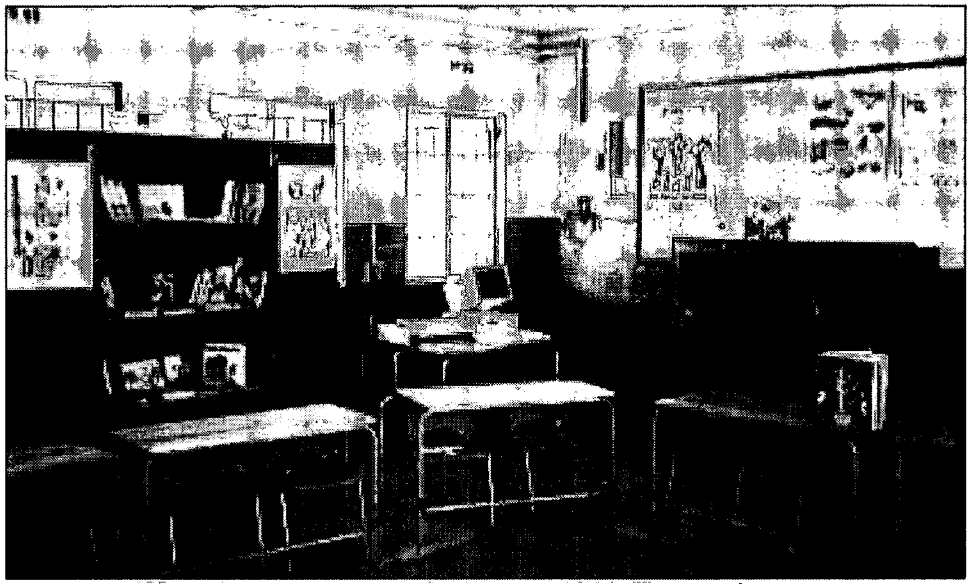


Figure 1.4. The interior of a classroom at the Ipolokeng School in South Africa, showing one of the computers powered by the PV unit on the roof.

rural schools and health clinics have reliable, two-way regional communication by means of very high frequency (VHF) radio with electricity provided by a single 30-W PV module.

Computers

The use of computers, which require small amounts of reliable power, for information transmittal purposes is burgeoning around the world. There are photo-cell powered telephones that use satellites for telephone transmission, permitting access to email services. The availability of a computer system can expose the students to this type of technology. In most rural schools, it may be impossible to envisage the use of this equipment. However, the world situation is changing rapidly and the use of RE-power generating systems offers a wealth of opportunities that were not imaginable some decades ago.

Teaching Aids—VCRs, Televisions, Radios, Film Projectors, and Slide Projectors

Audio-visual equipment can make a significant contribution to the improvement of education in rural areas and the use of these teaching aids is increasing. The energy required to operate small television sets or video-cassette recorders is not excessive (see Table 1.2). These loads can easily be provided by small RE systems.

Water Delivery and Treatment

Water is used for drinking, washing, cooking, toilets, showers, and possibly, gardening. Water may have to be pumped from a well or surface source or it may flow by gravity from a spring. Depending upon the local situation, it may be necessary to pump water to an overhead tank in order to make water available to the school facilities. Rainwater might also be collected from the school roof and stored in a rainwater cistern. Cooking and drinking water may have to be treated if the water is dirty or contaminated with fecal coliforms. In the latter case, solar water disinfection can be used. The provision of some clean, potable water is essential for the operation of any school.

Food Preparation

In many rural schools, snacks and a mid-day meal are often provided. Cooking energy is

Figure 1.5. This young girl in Cardeiros, Brazil can fill her jug from the school water tank thanks to a PV powered pumping system installed 1992. Additional PV systems with batteries power lights, a refrigerator, and a television set for the school.

generally best met by biomass sources (wood, charcoal, biogas, etc.) or by conventional sources—kerosene, bottled gas, etc. In some cases, solar cookers can also be used. The selection of the most appropriate mix of cooking fuels will depend upon the number of students and staff to be fed, the available budgets, the reliability of conventional energy sources, and the management capabilities of the school staff. Even if a school has a generator or a PV or wind powered battery storage system, this energy should not be used for cooking purposes. Cooking requires considerable energy and the use of electricity for this purpose is very inefficient.

Figure 1.6. A PV system at the Laguna Miranda School in Argentina powers lights, a water pump and a radio.

Refrigeration

In some schools, refrigeration is necessary for preserving food and medical supplies. A refrigerator must often be provided to ensure that the family of the teacher enjoys a certain level of comfort. Maintenance of this equipment must be addressed.

There are two main classes of refrigerators, compression and absorption. Compression refrigeration offers great convenience and good temperature control. Vaccine refrigerators are available that use only a small amount of electricity. These refrigerators are very small and very expensive. Larger compression refrigerators tend to have large energy consumption. Planners should purchase energy efficient models if compression refrigerators are envisioned. Manual defrost refrigerator/freezers use significantly less energy than do models with automatic defrost.

Absorption refrigerators use propane or kerosene to drive an absorption cycle that keeps the compartment cold. Due to difficulties in maintaining stable temperatures, particularly with the kerosene models, absorption refrigerators have lost favor for use in storing vaccines. However, tight temperature control is less important for food storage. Unless fuel supply is a problem, absorption refrigerators should be considered for use in off-grid schools. This will reduce the size of the electrical power system and can result in significant capital-cost savings.

Space Heating and Cooling

There is no question that the renewable-energy system might provide space heating, in particular, if the school is located in an area with a cold winter. Generally, this load is handled by using heaters powered by petroleum products such as heating oil and kerosene, or wood or coal. However in some instances, the space-heating furnace might require a small amount of electricity to power the burner or operate fans. In addition, some simple electric fans could be useful, both in winter and in summer, to improve the comfort level within the school. If the school is located in a very warm area, the renewable-energy system probably will not be designed to handle an air-conditioner because the load can be excessive. If some air-conditioning is provided, it should be used sparingly. In addition, maintenance for this equipment must be provided. In dry climates, evaporative cooling may provide a less energy-intensive option.

In most cases, load reduction should be the initial strategy. Ensuring that the building is well insulated and sealed can reduce heating loads.

Table 1.2. Power and Energy Consumption for Various Appliances

Appliances	Power (watts)	On-time (hours/day)	Energy/day (watt-hrs)
Lights (compact flourescent)	5–30	2–12	10–360
Lights (tube flourescent)	20–40	2–12	40–480
Communication VHF Radio			
Stand-by	2	12	24
Transmitting	30	1	30
Overhead Fan	40	4–12	160–480
Water Pump (1500 liters/day from 40 meters)	100	6	600
TV 12" B&W	15	1.0–4.0	15–60
19" Color	60	1.0–4.0	60–240
25" Color 15	130	1.0–4.0	130–520
VCR	30	1.0–4.0	30–120
AM/FM Stereo	15	1.0–12	15–180
Refrigerator/Freezer		variable	1,100–3,000
Vaccine Refrigerator		variable	500–1,100
Freezer		variable	700–3,000
Washing Machine[1] (Energy Efficient Models)	100–400	1.0–3.0	600–1,000/load
Hand Power Tools		1.0–3.0	100–800

[1] Energy usage figures do not reflect energy needed to heat the water used in the washer.

Shading and natural ventilation can reduce cooling loads.

Water Heating for Kitchen and Bathing Facilities

Like space heating, cooling, and cooking, the energy use for water heating normally exceeds the potential for power generated by small, electricity-producing RE systems. Hot water is needed for the kitchen and bathroom facilities of the teachers and their families (especially in colder regions). Normally this load can be met with simple solar water heaters or fossil fuel/ biomass-combustion water heaters. The amount of hot water required for the teacher and kitchen is usually small, unless the school has facilities for all students to take regular hot showers, in which case the load can be significant.

Washing Machine

As a labor and timesaving device a washing machine contributes to the quality of life of the teacher and his/her family. If the washing of additional school articles is minimized, then the electric load will not be excessive, especially if energy efficient models are selected. Front-loading washers tend to be more efficient than the top-loading variety.

Kitchen Appliances

Appliances should be selected and used so as to avoid overloading the RE generating system. Such appliances could include items such as mixers and juicers, but should not include electric toasters, irons or electric kettles, as these consume too much electricity.

Workshop

Given the remoteness of the school, and the necessity to undertake minimal repairs, it may be useful to provide electricity to run some simple power tools, such as electric drills, sanders, and portable saws.

CHAPTER 2: SOLAR THERMAL APPLICATIONS AND COMPONENTS

Chapter Introduction

Solar thermal technologies are used for applications in which heat is more appropriate than electricity. This chapter gives an overview of several solar thermal applications and general descriptions of the hardware involved. Solar thermal energy is used to heat air or water using solar collectors. Collectors are shallow insulated boxes covered by a rigid transparent cover made of glass or certain types of plastic. Solar energy is trapped in the exposed space and converted into low grade heat that is extracted by blowing air or circulating water through the collector. A variety of temperatures can be achieved depending upon the construction of the solar collector and the rate of flow of the water or air.

Solar Water Heating

For most hot water applications, 45° to 50°C is sufficient for showering and kitchen use.

A typical solar water heating system consists of a solar collector connected to a hot water reservoir. Active systems use pumps and controllers to circulate a fluid between the collector and the storage tank. Due to their complexity and expense, active systems are generally not well suited for use in remote developing areas. This chapter will focus on cheaper and simpler passive systems. Passive systems are easiest to design in use in warm climates where there are no hard freezes (i.e., temperatures don't typically go below 10°C). These systems can be used in colder climates as well, but in these cases, provision must be made for freeze protection.

Passive systems can be further subdivided into thermosyphon systems and batch systems. In solar thermosyphon systems, a solar collector (located at least two-thirds of a meter below the bottom of the hot-water reservoir) is connected by means of plumbing to create a closed loop with the hot-water tank. Typically, water is heated in pipes in the collector, which consists of a metal absorber plate to which are attached water tubes spaced roughly every 15 cm in an insulated box fitted with a transparent glazing. Water is heated in the collector and rises to the top of the hot-water tank, replaced by colder water from the bottom of the reservoir. During the day, this thermosyphon process continues. It is possible to extract hot water from the tank as needed while the process continues. The advantage of the thermosyphon system is that the heated water can be stored in an insulated container, possibly located indoors. This means the water loses less heat overnight compared to a batch system.

Batch Solar Collector

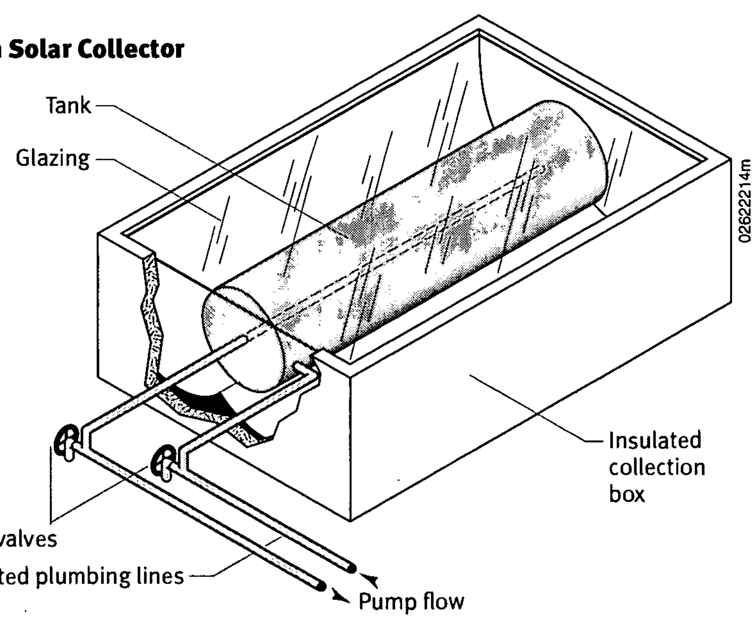


Figure 2.1. The simplest solar water heaters consist simply of a black tank placed in the sun. Collector efficiency can be increased by placing the tank inside inside an insulated glazed box, as shown above.

Table 2.1. Solar Water Heater Efficiencies

System Type	System Efficiency
Active System[1]	50%
Thermosyphon System[1]	45%
Batch System[1]	30%
Batch System (day/evening loads only)	50%

[1] Standard draw, equal weight to morning and evening draws.

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The hot water reservoir must be properly insulated to conserve the heat in the hot water.

A batch type of solar water heater is the simplest design and can be easily constructed. This can consist of a metallic water tank placed horizontally on an insulated base and covered with a transparent cover. Reflectors can be used to increase the radiation incident on the tank. The sun heats the reservoir during the day, and hot water can be extracted for evening showers and kitchen use at the end of the day. In areas where there are clear, cool nights with low, relative humidity, these systems will lose quite a bit of heat, and limited hot water may be available in the early morning hours.

The costs of solar water heating systems vary widely, depending upon whether they are site-constructed with free labor/materials, or are manufactured components /systems purchased from a supplier. Prices might range from $0 (all used/donated materials constructed on site with donated labor) to $200 (manufactured collectors/tanks/systems) per square meter.

To estimate the energy delivered per day, multiply the system collector area times the average system efficiency times the average insolation (typically 3 kWh/m^2 to 7 kWh/m^2 per day,) incident on the collector. Use Table 2-1 to estimate system efficiency.

Solar Space Heating

Before considering solar space heating, it is essential that the building be properly insulated and sealed. Otherwise, using solar air heaters could be wasteful. After that, to the extent possible, passive solar/daylighting strategies should be used. (For pre-existing structures, the opportunities for implementing passive strategies may be limited.) Finally, after insulation, sealing and passive strategies have been examined, simple solar air heaters can further reduce the requirement for fuel oil or wood, which are commonly used for space heating purposes. Solar air heaters are best suited for use in schools that have reasonably good solar radiation regimes in winter. There are several types of solar air heaters, but the simplest and most effective consists of an external transparent glazing covering a shallow collector insulated at the base, and generally containing a dark grill or mesh located in the air space.

For space heating applications, an exit-air temperature from the solar air heater of 30° to 50°C is adequate to contribute to increasing the ambient temperatures within the school building. The size of the solar air heaters depends on the indoor temperature that the school would like to maintain. A small PV panel to operate a simple fan is very useful in increasing the efficiency of heat extraction from the collector. The solar collectors can be mounted on the walls of the building facing the Equator. In this way, they can be used for either natural convection heating and for summer ventilation. These relatively simple systems have few maintenance problems, provided they are fitted with simple filters, especially in dusty areas.

The estimated cost for a simple solar air heater system ranges up to $35.00 per square meter, depending as in the water case, how much donated labor/materials are used.

Solar Pasteurization

Solar flat-plate collectors can be used to pasteurize water. These collectors consist of a black absorber plate in an insulated box covered by a sheet of tempered glass. Water is circulated through the collector for heating and then pumped to a storage tank.

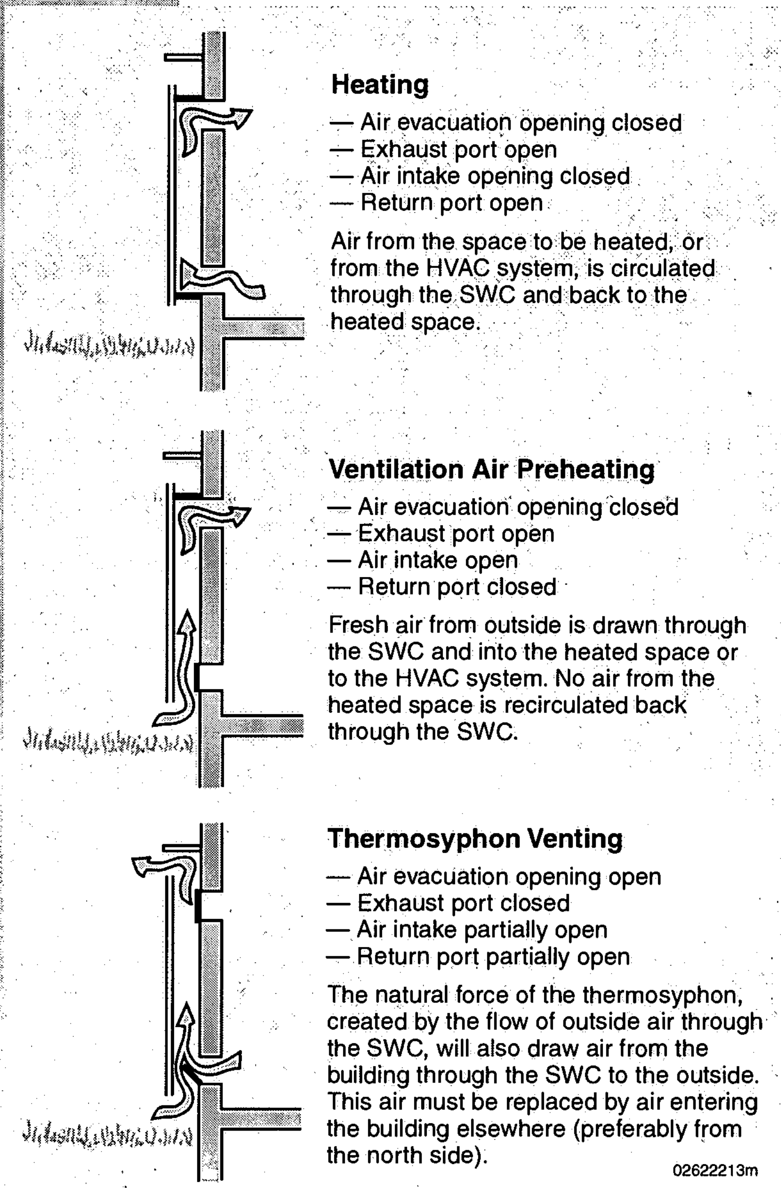


Figure 2.2. Solar wall collector (SWC) operating modes. A solar wall collector may be used for both heating and ventilation as illustrated above.

Water or milk may be pasteurized by heating it to 65°C for 30 minutes. Pasteurization disinfects microbiologically contaminated water by killing viruses, bacteria, and protozoa. However, it will not eliminate chemical pollutants or salts.

Solar pasteurization may also be achieved by placing water or milk containers in a solar cooker—an insulated box covered with glass. Reflectors increase the amount of sunlight directed into the box. In direct sunlight, temperatures sufficient for pasteurization are easily achieved in this manner.

Solar Water Disinfection

As an alternative to pasteurization, solar water disinfection can be used to eliminate bacteriological contamination from drinking water supplies. (Note: This technique only works against bacteriological contaminants, it will not eliminate chemical pollutants or salts.) Clear, but bacteriologically contaminated, water in transparent plastic bags is exposed to direct sunlight for four to six hours. The water can also be placed in thin, plastic transparent bottles, but care should be taken NOT to use bottles manufactured from plastics made with the addition of an

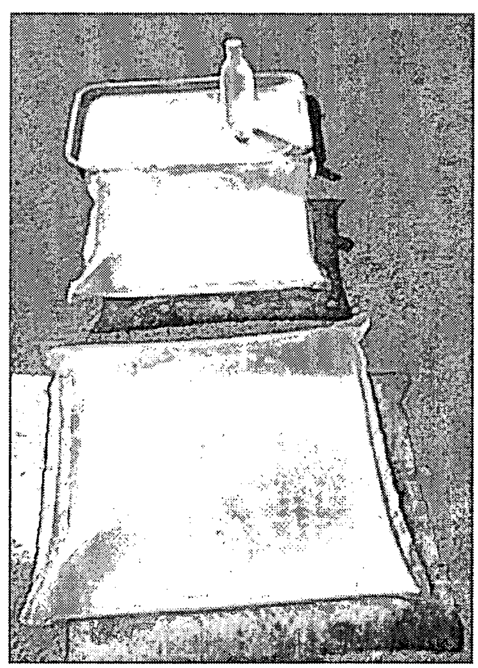

Sanitec, Solargetics/PIX08265

Figure 2.3. Solar water disinfection in the Caribbean.

ultra-violet (UV) wavelength inhibitor (used to ensure a longer life for the bottle when exposed to solar radiation.) These bottles may not prove to be suitable for the solar water disinfection process. The UV rays in sunlight inactivate pathogenic bacteria such as fecal coliforms. There is a synergetic effect with water temperature. Better results are achieved when the plastic bags are placed outside on smooth, dark surfaces that permit an increase in the temperature level of the water. Decontamination takes longer in humid, cloudier regions than in dry and sunny climates. The required materials consist of suitable plastic bags and a thin, dark sheet, preferably of metal resting on a straw mat (to provide some insulation). This technique could be used in isolated schools to produce potable drinking water for the staff and students.

Simple solar thermal technologies, such as pasteurization and solar water disinfection, are effective for treating small quantities of biologically contaminated water. These are good alternatives to boiling water for 15 to 20 minutes to kill bacteria. Often, boiling is not considered because of the inconvenience and the requirement for fuel.

Solar Water Distillation

Distillation is the best single-method for purifying water. It removes bacteria, salts, and pollutants of all types. Distillation is often used to purify brackish water. The simplest stills consist of a sloping transparent cover (usually glass) over a shallow basin filled with 8 to 10 cm of clean saline water. Solar radiation heats up the saline water, causing evaporation. Water vapor condenses on the underside of the transparent cover, where it is collected and stored in containers. This condensed water vapor does not contain dissolved salts or bacterial and viral contaminants, making it drinkable. Depending upon sunlight and temperature, solar distillers can produce 3-6 liters of potable water per day per square meter of collector area. Sizes range from family-sized units of two square meters to community scale units of several thousand square meters. The costs of a solar distiller system vary from $30 to $300 per square meter. In a

CASE STUDY—Solar Stills for Water Supply for Rural Schools

Country: Argentina

Location: Chaco Salteño

Latitude: Tropic of Capricorn

Altitude (average): 350 m above sea level

Climatic conditions: Average insolation: 6 kWh/m^2/day; Average yearly ambient temperature: 21°C

Period of operation during the year: Continuous

Schools provided with solar stills: Los Blancos and Capitan de Fragata Pagé

RE system: Site-assembled solar stills for the production of fresh drinking water

Installation: June 1995

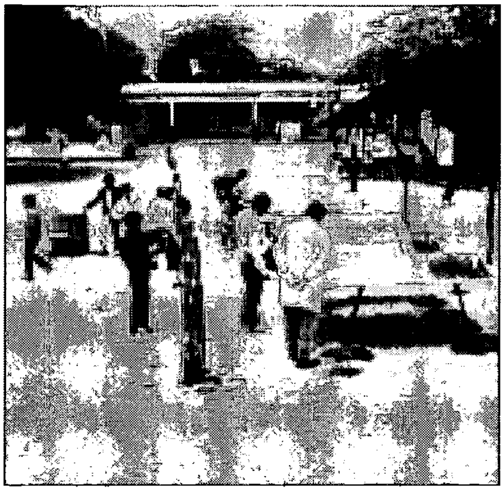
Capacity: 6 greenhouse-type units, each 2.2 m^2 in area producing approximately 50 liters distillate per day

Materials used: Fiberglass basins, glass covers, aluminum frames, Stainless-steel gutters, PVC piping

Feed water: Saline ground water up to 7 g/l salinity

Back-up systems: Rainfall catchment; delivery by tanker truck

Lessons Learned: The maintenance of the stills did not appear to be a major problem. Several of the construction materials selected for the stills could not withstand the high-levels of U.V. radiation and the effects of hot saline brine



Tom Lawand, Solargetics/PIX08271

Figure 2.4. Solar Stills at a school in the Chaco, Argentina.

remotely located school, this technique could be used to produce water that can be used for drinking, cooking and medicinal purposes.

Solar Cooking

Solar cookers can be used under favorable solar radiation conditions to reduce the fossil fuel or biomass energy load normally used for preparing meals. The majority of the energy is used for cooking the mid-day meal. Smaller amounts of energy are used for preparing breakfast and dinner for the staff and hot beverages during the day. Some of the energy demand could be met using simple box cookers. These consist of insulated boxes with a sloping glazed cover and a rear hinged reflector. The cooker is mounted facing the Equator and is generally turned 3 to 5 times a day to face the sun directly, thus, improving its performance. Other types of cookers include concentrating cookers using parabolic reflectors, or steam cookers using a flat plate collector to produce the steam connected to an insulated double boiler. Under reasonable solar conditions, i.e., above 700 Watts/m^2, it is possible to cook a variety of meals. If the school has a large population of students to feed, then solar cooking is not the preferred option. Solar cooking should only be used to reduce the energy demand from conventional sources.

Biomass Cookers

In recent years, improved wood and charcoal stoves have been developed with increased efficiency of biomass use. As wood and charcoal are generally the fuels most readily available in remote developing areas, it is possible to make use of more efficient community-sized stoves for this purpose. It is easily possible to cook meals with a mean-specific fuel consumption of 8 to 10 kilograms of food cooked per kilogram of dry wood.

Bethel Center/PIX08272

Figure 2.5. Solar ovens—household model on right.

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Figure 2.6. Demonstration of improved wood cookstoves at the Renewable Energy Training Center, Nuequen, Argentina.

CASE STUDY—Solar Water Heating in Nepal

Details of School Location

Budhanilkantha School
P.O. Box 1018
Bud Hanilkantha
Kathmandu, Nepal

This school uses solar water heaters to provide hot water for bathrooms.

Specific Conditions of the School

- The school consists of 24 buildings. The orientations of the buildings vary and in general, the roofs are pitched.
- The number of students at the school is 850, with 70 teachers and 150 custodians.
- The school operates for 9 months of the year. The normal occupancy time is from 08:30 to 16:30 hours. It is a full boarding school with all students residing on the Campus. In addition, 55 staff members reside at the school, and there are residents at the school throughout the year, even in holiday periods. The school is not used in the evening for community education purposes.

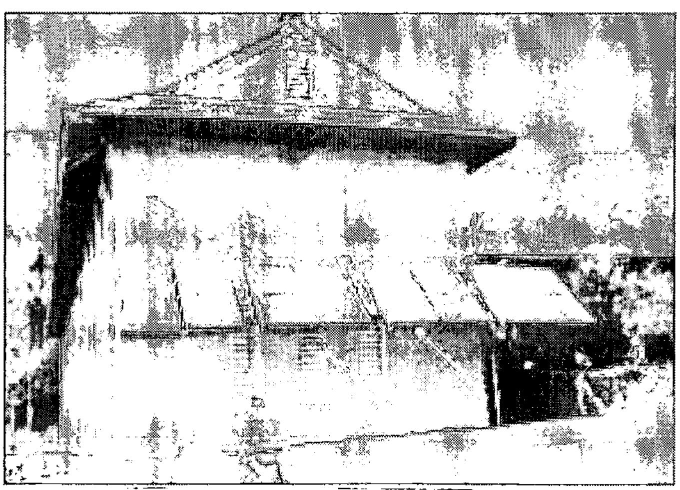

Figure 2.7. This solar water heater has provided hot water to this school in Nepal since 1978.

Energy End Use in the School

- Water Heating–This consists mainly of solar water heating for the student hostels and electric water heaters for the staff quarters.
- Due to its urban location, the school gets its electricity from the grid. The electrical energy consumption (including lighting): Rs 80,000 ($U.S. 1,176) per month. The peak expenditure is Rs 150,000 ($U.S. 2,205) for a month during winter. Note the exchange rate for Nepali rupees at the time of this writing (April 99) is $U.S. 1 = NRs 68.

• Space heating (winter only)—liquid propane gas (LPG) and electricity

• Cooking—communal and familial—electricity and LPG

• Educational aides—

television sets	60
VCRs	30
Computers	30
Printers	10

Type of Renewable Energy System in Operation

Solar Water Heaters:

• Number of solar collectors—40 units.

• Collector types—Most of the installed water heaters use an integrated design, where the collector and storage are in one piece. The more recent installations are thermosiphon types.

• Location—the collectors are fixed on the walls, or on the terrace, and some are ground mounted.

• Equipment manufactured by the following companies—Balaju Yantra Shala; Sun Works; Laxmi Mechanical Solar Works.

• All solar equipment manufactured in Nepal.

• Years of installation—major installation done from 1977 to 1979 and some in the 1990s.

• Present condition of SWH systems—75% of the panels are performing well, including the SWH systems installed in 1977-1979.

• The school paid for the equipment and its installation. The school also handled the financial arrangements of capital investment and pays the operation and maintenance expenses. (Most O & M consists of changing broken glass and repainting).

• Cost of equipment—a 300-liter SWH system costs $500 to $600, including installation—there were extra charges for the plumbing for the supply of the hot water in the buildings.

Micro-Hydro Turbine:

• A demonstration 300-watt cross-flow, micro-hydro turbine provides electricity for lighting.

Operation and Maintenance of the Energy System

• The School Maintenance Department handles the RE systems at the school. Technicians are trained in-house by the Maintenance Department.

• Despite a slight drop in system efficiencies over the years and some leakage, school authorities are satisfied with the performance of the units.

Education and Sociocultural Considerations

• Students are familiarized with the RE systems such solar water heaters, PV cells, and the micro-hydro turbine. They study these systems as part of their courses.

• Due to the introduction of the solar water heating systems, there are many SWH in the local community particularly in the domestic sector. The principal barrier to the spread of this technology has been the affordability and the development of an economic design. There is also a lack of awareness of the technology.

• Although a complete survey has not been undertaken, there are a number of boarding schools in Nepal that have installed SWH systems. A funding and familiarization program would provide local impetus to the installation of more systems in Nepal.

• On the regional and national scale, it should be noted that many small companies manufacture SWH. Typically, the manufacturers do the system maintenance as well.

Acknowledgment:

The information was provided by:

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Kathmandu, NEPAL

CHAPTER 3: ELECTRICAL SYSTEM COMPONENTS

Chapter Introduction

This chapter gives an overview of the main components typically used in RE systems. Diesel and gasoline engine generators are also discussed. For each item, the discussion includes how the component works, proper use, cost, lifetime, and limitations.

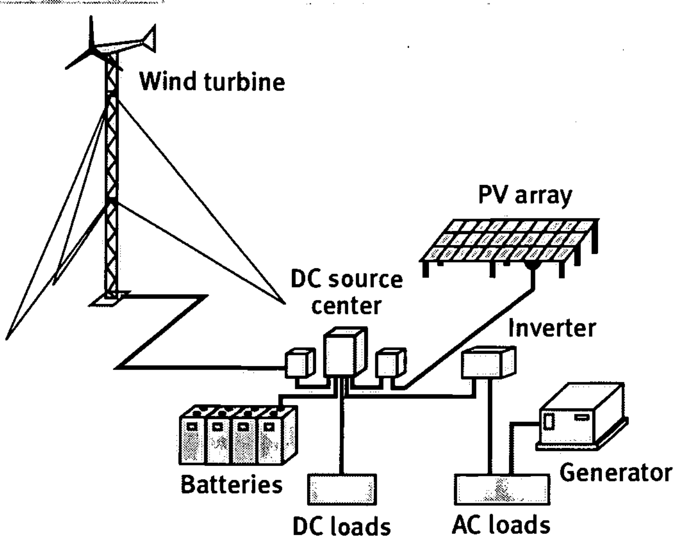


Figure 3.1. Hybrid System Configuration: Generalized hybrid system configuration showing energy generation components (photovoltaic, wind turbine, and generator), energy storage components (batteries), energy conversion components (inverter), and balance of system components (direct current source center and charge controller). Courtesy of Bergey Wind Company

System Overview

Introduction

A hybrid system comprises components that produce, store, and deliver electricity to the application. Figure 3.1 shows a schematic of a hybrid system. The components of a hybrid system fall into one of four categories described below.

Energy Generation

Wind turbines and engines use generators to convert mechanical motion into electricity. PV panels convert sunlight directly into electricity.

Energy Storage

These devices store energy and release it when it is needed. Energy storage often improves both the performance and economics of the system. The most common energy storage device used in hybrid systems is the battery.

Energy Conversion

In hybrid systems, energy conversion refers to converting AC electricity to DC or vice versa. A variety of equipment can be used to do this. Inverters convert DC to AC. Rectifiers convert AC to DC. Bi-directional inverters combine the functions of both inverters and rectifiers.

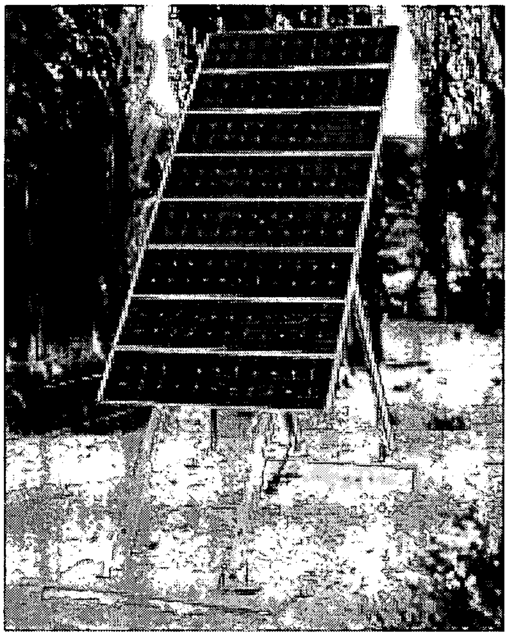
Balance of System (BOS)

BOS items include monitoring equipment, a dump load (a device that sheds excess energy produced by the system), and the wiring and hardware needed to complete the system. Note that the term "BOS" is not strictly defined. In other contexts, energy conversion equipment and batteries may be considered BOS items.

Photovoltaics

Introduction

PV modules convert sunlight directly into DC electricity. The modules themselves, having no moving parts, are highly reliable, long lived, and require little maintenance. In addition, PV panels are modular. It is easy to assemble PV



Tom Lawand, Solargetics/PIX008275

Figure 3.2. Ground-mounted PV panels at a rural school in Neuquén province, Argentina.

panels into an array of arbitrary size. The main disadvantage of PV is its high capital cost. Despite this, especially for small systems, PV is often a cost-effective option, with or without another power source, as the savings of use pays back the initial cost.

PV Module Construction

PV modules consist of individual cells that are wired together in series and in parallel to produce the desired voltage and current. The cells are usually encapsulated in a transparent protective material and typically housed in an aluminum frame.

PV cells fall into three types, monocrystalline, polycrystalline, and thin film (amorphous). Amorphous cells are generally less efficient, and may be less-long lasting, but are less expensive and easier to manufacture.

Performance Characterization

PV modules are rated in terms of peak watts (W_p). This rating is a function of both panel size and efficiency. This rating scheme also makes it easy to compare modules from different sources based upon cost per W_p. The rating is the amount of power that the module will produce under standard reference conditions (1kW/m^2; 25°C [77°F] panel temperature.) This is roughly the intensity of sunlight at noon on a clear summer day. Thus, a module rated at 50 W_p will produce 50 W when the insolation on the module is 1 kW/m^2. Because power output is roughly proportional to insolation, this same module could be expected to produce 25 W when the insolation is 500 W/m^2 (when operating at 25°C).

PV array energy production can be estimated by multiplying the array's rated power by the site's insolation on the panel's surface (typically 1400–2500 kWh/m2 per year; 4–7 kWh/m2/day). The resulting product is then derated by approximately 10%–20% to account for losses caused by such things as temperature effects (panels produce less energy at higher temperatures) and wire losses.

Module Operation

Most PV panels are designed to charge 12-V battery banks. Larger, off-grid systems may have DC bus bar voltages of 24, 48, 120 or 240 V. Connecting the appropriate number of PV panels in series enables them to charge batteries at these voltages. For non-battery charging applications, such as when the panel is directly connected to a water pump, a maximum-point power tracker (MPPT) may be necessary. A MPPT will match the electrical characteristics of the load to those of the module so that the array can efficiently power the load.

Module Mounting and Tilt Angles

In order to maximize energy production, PV modules need to be mounted so as to be oriented towards the sun. To do this, the modules are mounted on either fixed or tracking mounts. Because of their low cost and simplicity, fixed mounts are most commonly used. These type of mounts can be made of wood or metal, and can be purchased or fabricated almost anywhere.

Tracking mounts (either single or dual axis) increase the energy production of the modules, particularly at low latitudes, but at the price of additional cost and complexity. The relative cost effectiveness of tracking mounts versus additional modules will vary from project to project.

Capital and Operating Costs

PV modules are available in a variety of ratings up to 300 W_p. Individual PV panels can be connected to form arrays of any size. Modules may be connected in series to increase the array voltage, and can be connected in parallel to increase the array current. This modularity makes it easy to start out with a small array and add additional modules later.

The costs of a PV array are driven by the cost of the modules. Despite declining prices in the last two decades, PV modules remain expensive. Retail prices for modules bottom out at about $5.50 per W_p. For bulk purchases, prices can go below $4.00 per W_p. Warrantees typically are for 10 to 25 years. Current modules can be expected to last in excess of 20 years. The remaining PV array costs consist of mounts, wiring, and installation. These are typically $0.50–$1.50 per W_p.

PV panels (not necessarily the remainder of the system) are almost maintenance free. Mostly, they just need to be kept clean, and the electrical connections need periodic inspection for loose connections and corrosion.

Wind-Turbine Generators

Introduction

Wind turbines convert the energy of moving air into useful mechanical or electrical energy. Wind turbines need more maintenance than a PV array, but with moderate winds, > 4.5 meters per second (m/s), will often produce more energy than a similarly priced array of PV panels. Like PV panels, multiple wind turbines can be used together to produce more energy. Because wind-turbine energy production tends to be highly variable, wind turbines are often best combined with PV panels or a generator to ensure energy production during times of low wind speeds. This section will focus on small wind turbines with ratings of 10 kW or less.

Wind-Turbine Components

The components common to most wind turbines are shown in Figure 3.3 below. The blades capture the energy from the wind, transferring it via the shaft to the generator. In small wind turbines, the shaft usually drives the generator directly. Most small wind turbines use a permanent magnet alternator for a generator. These produce variable frequency (wild) AC that the power electronics convert into DC current. The yaw bearing allows a wind turbine to rotate to accommodate changing wind direction. The tower supports the wind turbine and places it above any obstructions.

Wind-Turbine Performance Characteristics

A wind-turbine's performance is characterized by its power curve, which relates wind-turbine power output to the hub-height wind speed. Power curves for selected machines are shown in Figure 3.4. Turbines need a minimum wind speed, the "cut-in" speed, before they start producing power. For small turbines, the cut-in speed typically ranges from 3 to 4 m/s. After cut-in, wind-turbine power increases rapidly with increasing wind speed until it starts leveling off as it approaches peak power. The energy

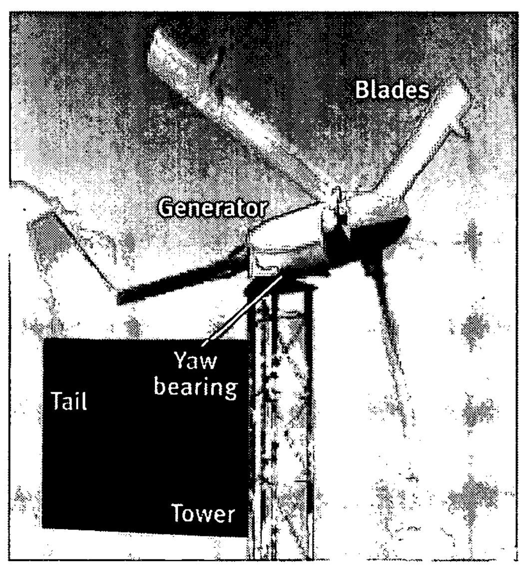


Figure 3.3. Typical wind-turbine components

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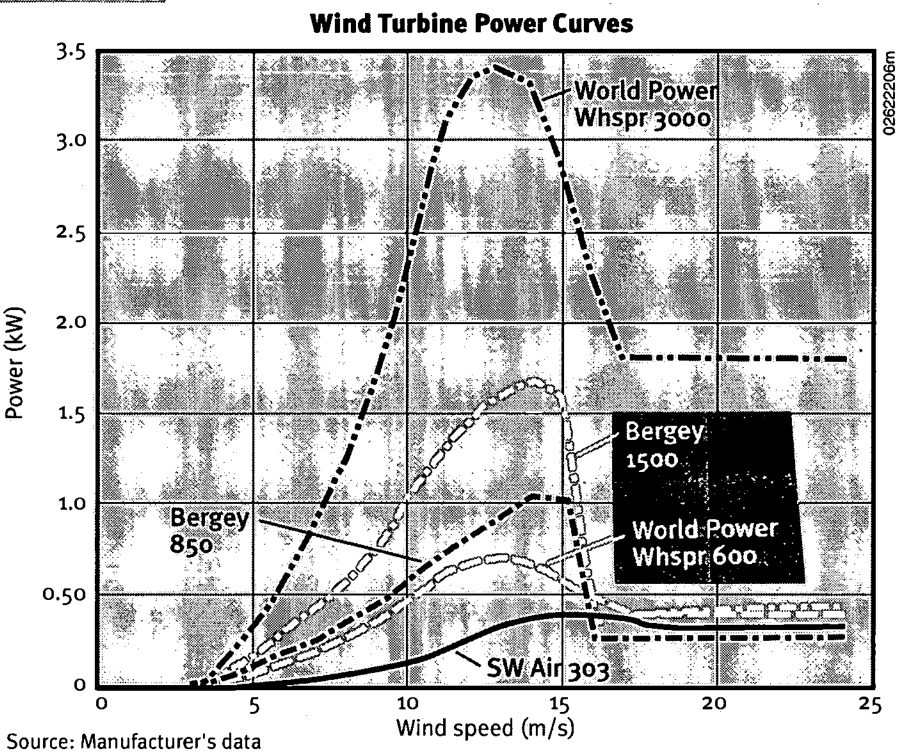


Figure 3.4. Selected wind-turbine power curves

density in moving air is proportional to the cube of the velocity. Thus, wind turbines produce much more power at higher wind speeds than at lower wind speeds, until the wind speed reaches the "cut-out" speed. Most small turbines produce peak power at about 12–15 m/s. The turbine will produce at peak power until the wind speed reaches the turbine's "cut-out" speed. Cut-out, usually occurring at 14 to 18 m/s, protects the turbine from overspinning in high winds. Most small turbines cut-out by passively tilting (furling) the nacelle and rotor out of the wind. After cut-out, wind-turbine power output usually does not decrease to zero, but remains at 30%–70% of rated power.

Wind turbines are rated by their power output at a specified wind speed, e.g., 10 kW at 12 m/s. The wind speed at which a turbine is rated, though usually chosen somewhat arbitrarily by the manufacturer, is typically near the wind speed at which the turbine produces the most power.

The non-linear nature of the wind-turbine power curve makes long-term energy performance prediction more difficult than for a PV system. Long-term performance prediction, requires the wind speed distribution rather than just the average wind speed. Long-term performance can then be found by integrating the wind-turbine power curve over the wind speed distribution. Wind-turbine performance may also depend upon the application for which it is used.

Wind-Turbine Costs

Wind-turbine prices vary more than PV module prices. Similar sized turbines can differ significantly in price. This is caused by wide pricing variations among different turbine manufacturers and by widely varying tower costs based on design and height. Installed costs generally vary from $2,000 to $6,000 per rated kW. Unlike the case for PV, wind turbines offer economies of scale, with larger wind turbines costing less per kW than smaller wind turbines.

Maintenance costs for wind turbines are variable. Most small wind turbines require some preventive maintenance, mostly in the form of periodic inspections. Most maintenance costs will probably be due to unscheduled repairs (e.g., lightning strikes and corrosion). Gipe[1] claims a consensus figure of 2% of the total system cost annually.

Micro-hydro

Introduction

Micro-hydro installations convert the kinetic energy of moving or falling water into electricity. These installations may require more extensive

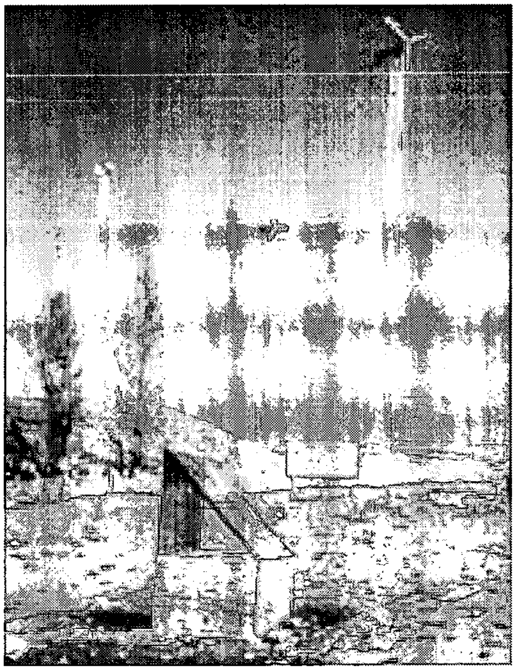


Figure 3.5. Small wind turbines, solar oven, and radio tower at the Las Cortaderas Primary School 250 km west of Neuquén, Argentina.

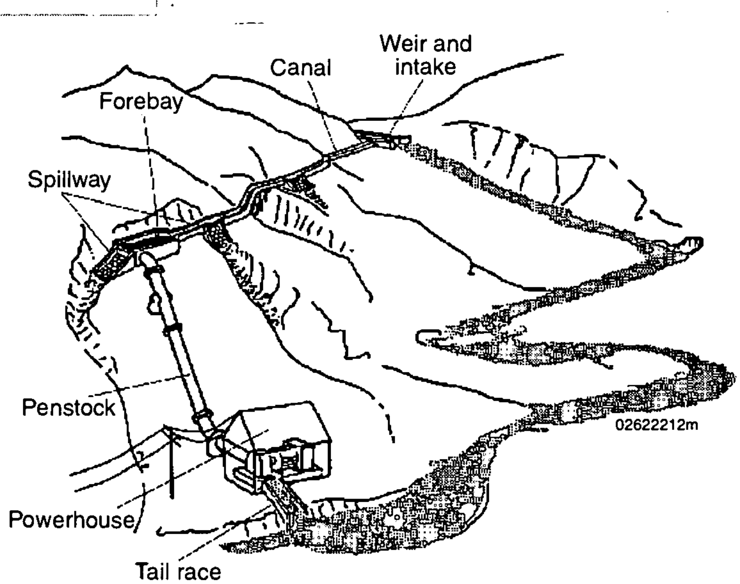


Figure 3.6. Components of a micro-hydro installation. Fraenkel, Peter (1991) Micro-hydro Power: A Guide for Development Workers. IT Publications in association with the Stockholm Environment Institute, London.

civil works than other technologies, but at appropriate sites, micro-hydro can be, on a life cycle basis, a very low cost option. The water resource of a micro-hydro installation may be subject to seasonal weather extremes such as drought or freezing, but unlike PV or wind turbines, a micro-hydro installation can produce power continuously on a day-to-day basis. Because of this continuous power production, even a small installation will produce large amounts of energy.

Components

The components of a micro-hydro installation are shown in Figure 3.6. The civil works, consisting of a water channel, diverts water from the stream or river to the penstock. The penstock conveys the water under pressure to the turbine. The piping used in the penstock must be large enough to avoid excessive friction losses. Different types of turbines are available, depending on the head and flow rate available at the site. Impulse turbines, such as the Pelton or Turgo turbine have one or more jets of water impinging on the turbine, which spins in the air. These types of turbines are most used in medium and high head sites. Reaction turbines, such as the Francis, Kaplan, and axial turbines are fully immersed in water. They are used more in low head sites. The turbine is connected to a generator that produces electricity. Both AC and DC generators are available. Governors and control equipment are used to ensure frequency control on AC systems and dump excess electricity produced by the wind turbine.

Performance and Cost

The power output of a micro-hydro system is a function of the product of the pressure (head) and flow rate of the water going through the turbine. Figure 3.7, shows the expected generator output under various site conditions. The selection of a site is usually a compromise between the available head & flow rate and the cost of the water channel & penstock. Because micro-hydro systems produce continuous power, even a small system will produce a large amount of energy. For example, a 125-watt system will produce

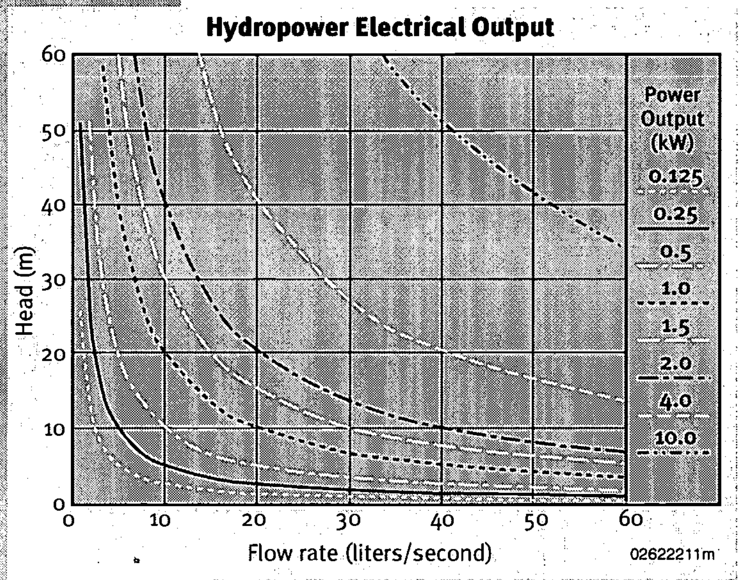


Figure 3.7. Estimated hydropower generator output as a function of head and flow rate.

3 kWh a day. The water resource of a micro-hydro installation may be subject to seasonal variations due to winter freezing, spring runoff, and drought. In cases where peak power demand is greater than what the installation can supply, a battery bank can be used to store energy during low demand periods for use in high demand periods.

Due to varying requirements for water channels and penstock, the cost of micro-hydro systems will vary widely from location to location. In general, the cost for most systems is $1,000 to $4,000 per kW. Maintenance costs are loosely estimated to be around 3% of the capital cost per year. Much of the maintenance consists of regular inspections of the water channel and penstock to keep them free of debris. Micro-hydro installations can be very long lived, with maintained systems lasting in excess of 50 years.

Unlike PV and wind systems, micro-hydro installations are not modular. The available water resource and size of the civil works and penstock place an ultimate limit on the power output of a given micro-hydro system. Increasing the capacity of the civil works is expensive. Thus, micro-hydro installations require that long-term load demand be carefully considered.

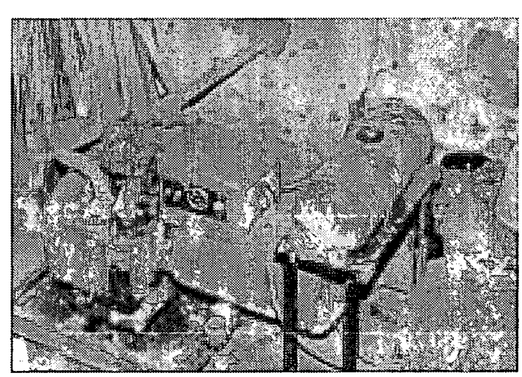
Diesel Generators

Introduction

Generators consist of an engine driving an electric generator. Generators run on a variety of fuels, including diesel, gasoline, propane, and biofuel. Generators have the advantage of providing power on demand, without the need for batteries. Compared to wind turbines and PV panels, generators have low capital costs but high operating costs.

Cost and Performance

Diesel generators are the most common type. They are available in sizes ranging from under 2.5 kW to over 1 megawatt (MW). Compared to gasoline generators, diesel generators are more expensive, longer lived, cheaper to maintain, and consume less fuel. Typical costs for small diesel generators (up to 10 kW) are $800 to $1,000 per kW. Larger diesels show economies of scale, costing roughly $7,000–$9,000 plus ~$150 per kW. Typical diesel lifetimes are on the order of 25,000 operating hours[2]. Larger diesels are usually overhauled rather than replaced. Overall maintenance costs can be estimated to be 100% to 150% of the capital cost over this 25,000-hour lifetime. An operator must provide day to day maintenance and the generator must be periodically overhauled by a qualified mechanic. Diesel generator fuel efficiency is generally 2.5–3.0 kWh/liter when run at a high loading. Efficiency drops



Tom Lawand, Solargetics/PIX08277

Figure 3.8. Typical generator at an isolated mountain school. Teachers and custodians generally have no training in the maintenance and operation of these units.

off sharply at low loads. This poor low-load efficiency is the bane of many generator-only systems. The generator must be sized to cover the peak load, but then often runs at low load much of the time.

Less common than diesels, gasoline generators cost less and are available in very small sizes (as low as a few hundred watts). Otherwise, gasoline generators are inferior in most respects to their diesel counterparts. For sizes larger than about 1 kW, prices range from $400 to $600 per kW. The minimum price is roughly $400 regardless of size. Lifetimes are short, typically only 1,000 to 2,000 operating hours. Fuel efficiency is poor, peaking at roughly 2.0 kWh/liter. Part-load fuel efficiency is worse than for diesel generators. Gasoline generators are best used when the loads are very small or the anticipated run hours total no more than roughly 400–600 hours per year.

Given the previous discussion, several points regarding the optimum use of generators emerge. For maximum fuel economy, the generator should be run at a high load (> 60%). Conversely, low-load operation should be avoided. Not only does this decrease the fuel efficiency, there is evidence that low-load operation results in greater maintenance costs.

Batteries

Introduction

Batteries are electrochemical devices that store energy in chemical form. They store excess energy for later use in order to improve system availability and efficiency. By far the most common type of battery is the lead-acid type. A distant second is the nickel-cadmium type. The remainder of this section discusses the lead-acid battery.

Battery Selection Considerations

Deep-Cycle versus Shallow-Cycle

Although batteries are sized according to how much energy they can store, in most cases a lead-acid battery cannot be discharged all the

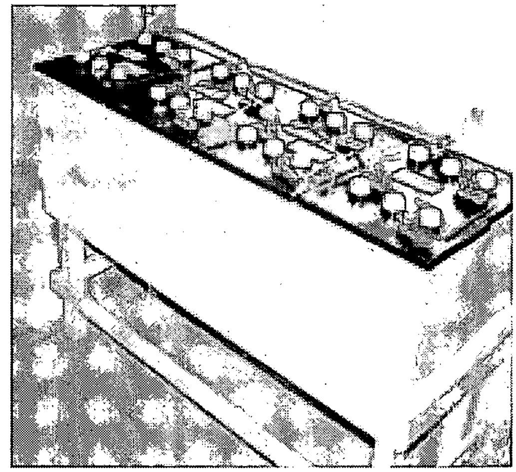


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Figure 3.9. Batteries allow an RE system to provide 24 hour power. Photovoltaic panels or a wind generator can recharge the batteries.

way to a zero state of charge without suffering damage in the process. For remote power applications, deep-cycle batteries are generally recommended. Depending upon the specific model, they may be discharged down to a 20%–50% state of charge. Shallow-cycle batteries, such as car batteries, are generally not recommended, though they are often used in small PV systems because of the lack of any alternatives. They can be prudently discharged only to an 80%–90% state of charge and will often be destroyed by only a handful of deeper discharges.

Flooded versus Valve Regulated

Flooded batteries have their plates immersed in a liquid electrolyte and need periodic rewatering. In contrast, in valve regulated batteries, the electrolyte is in the form of a paste or contained within a glass mat. Valve regulated batteries do not need rewatering. Flooded batteries generally have lower capital costs than valve regulated batteries and with proper maintenance, tend to last longer. On the other hand, where maintenance is difficult, valve regulated batteries may be the better choice.

Lifetime

Battery lifetime is measured both in terms of cumulative energy flow through the battery (full cycles) and by float life. A battery is dead when it reaches either limit. For example, discharging a battery twice to 50% is one full cycle. For many batteries, as long as the battery state of charge is kept within the manufacturer's recommended limits, the lifetime cumulative energy flow is roughly independent of how deeply the battery is cycled. Depending upon the brand and model, battery lifetimes vary widely, ranging from less than 100 full cycles to more than 1500 full cycles. Float life refers to how long a battery that is connected to a system will last, even if it is never or only lightly used. Typical float lives for good quality lead-acid batteries range between 3 and 10 years at 20°C (68°F). Note that high ambient temperatures will severely shorten a battery's float life. A rule of thumb is that every 10°C (18°F) increase in average ambient temperature will halve the battery float life.

Size

The storage capacity of a battery is commonly given in amp hours at a given rate of discharge. When multiplied by the battery's nominal voltage (usually 2, 6, or 12 V), this gives the storage capacity of the battery in watt-hours. (Dividing this number by 1000 gives the battery storage capacity in kWh) This storage capacity is not a fixed quantity, but rather varies somewhat depending on the rate at which the battery is discharged. A battery will provide more energy if it is discharged slowly than if it is discharged rapidly. In order to facilitate uniform comparison, most battery manufacturers give the storage for a given discharge time, usually 20 or 100 hours. Individual batteries used in RE and hybrid systems are available in capacities ranging from 50 amp hours at 12 V to thousands of amp hours at 2 V (0.5 kWh to several kWh).

Cost

The variations in cycle and float life, described earlier, make comparison of the cost-effectiveness of different batteries somewhat problematical. As a general starting point, costs are on the order of $70–$100 per kWh of storage for batteries with lifetimes of 250 to 500 cycles and float lives in the range of 5 to 8 years. There will be additional one-time costs for a shed, racks, and connection wiring.

Inverters

Introduction

Inverters convert DC to AC electricity. This capability is needed because PV modules and most small wind turbines produce DC electricity which can be used by DC appliances or stored in batteries for later use. Most common electrical applications and devices require AC electricity, which cannot be easily stored.

Inverter Selection Considerations

Output wave form: Inverter output wave forms fall into one of three classes, square wave, modified sine wave, and sine wave. Square-wave inverters are the least expensive, but their output, a square wave, is suitable only for resistive loads such as resistance heaters or incandescent lights. Modified sine-wave inverters produce a staircase square wave that more closely approximates a sine wave. This type of inverter is the most common. Most AC electronic devices and motors will run on modified sine wave AC. Some sensitive electronics may not work with modified sine wave AC and require sine-wave inverters. Sine-wave inverters produce utility grade power, but of course cost more than the other types of inverters.

Conversion efficiency: Inverter efficiency varies with the load on the inverter. Efficiencies are poor at low power levels and generally very good (>90%) at high power levels. Mid range efficiency varies widely between inverters and may be an important selection criterion. Other items to consider are the inverter's no-load power draw and the presence of a "sleep mode". Sleep mode reduces the inverter power draw to a few watts when there is no load on the inverter.

Switched versus parallel: A parallel inverter can supply power to a load simultaneously with a diesel generator. With a switched inverter, either the inverter or the generator, but not both at the same time, supplies power to the load.

Stand-alone capability: A line-commutated inverter uses the 50Hz/60Hz signal from the grid to regulate the frequency of its output. Such units are not for use in stand-alone systems unless it is planned to keep a diesel on continuously. A self-commutated inverter doesn't need the grid for frequency regulation. Related considerations are how tightly the inverter can regulate frequency and voltage and its ability to supply reactive power.

One-phase or three-phase: Whether to get a one phase or three phase inverter depends upon the loads to be served and the type of distribution system to be used. Three phase inverters are more costly than one-phase inverters because each phase requires a separate inverter stage. A consideration when selecting a three-phase inverter is its ability to serve unbalanced loads.

Sizing: Inverters are usually sized according to their maximum continuous power output. Most inverters, however, are capable of handling significantly more power than their rated size for short periods of time. This surge capability is useful for meeting the occasional oversized load such as starting a motor.

Costs: Inverter costs are roughly $600–$1,000 per kW for good quality modified sine- wave inverters. The technology for inverters larger than 5 kW is not as mature as for smaller inverters and costs may be somewhat higher.

Controllers/Meters/Balance of Systems

Introduction

Controllers and meters act as the brains and nervous system of a RE or hybrid system. Controllers route the energy through the system components to the load. Metering allows the user to assess system health and performance. In many cases, the various controlling and metering functions of a system will be spread out over several different components. The complexity of the controls depends upon the size and complexity of the system and the preferences of the user. Controllers have had problems with reliability and lightning strikes, making careful controller design and lightning protection important considerations.

Purposes and Functions

- Battery high/low voltage disconnect: A high-voltage disconnect protects the battery against overcharging. A low-voltage disconnect protects the battery against over discharging. These are critical functions that should be included in all systems with batteries.
- System protection: A controller can include fuses or breakers to protect against short circuits and current surges.
- Battery charging: A controller with a proper battery charge algorithm (with temperature compensation) will do much to increase battery lifetime.
- AC and DC bus current and voltage monitoring: Monitoring the current and voltage on the DC and AC buses lets the user check that the components and system are properly operating.
- Turn components on or off: The controller can be programmed to turn components on and off as needed without user intervention.
- Divert energy to a dump load: The purpose of a dump load is to shed excess energy. Dump loads may be needed if the system contains wind turbines, micro-hydro, or generators. A dump load is essentially one or more big resistors that dissipate electricity by converting it to heat. Available dump loads are either water- or air-cooled. Dump loads are sometimes used to control the frequency of the AC output of a system.
- Balance of system (BOS): The BOS includes the additional items such as wiring, conduit, and fuses that are needed to complete a system.
- DC source center use: Several manufacturers now offer DC source centers. These combine much of the system wiring, fusing, and controllers into one tidy, easier to install package. The use of source centers will increase system costs somewhat, but offer easier system installation, less complex wiring, and easier system monitoring and control. The use of a source center should be considered, especially for systems in remote sites that lack easy access to technical assistance.

CHAPTER 4: SYSTEM SELECTION AND ECONOMICS

Introduction

The first section of this chapter describes life-cycle cost analysis and explains how and why it should be used when analyzing the economics of various options. The second part of this chapter discusses the various factors influencing system design: load, available resource, component costs, and desired level of service. Included are charts that show how typical system costs vary as a function of load and resource.

Life-Cycle Cost Analysis

Why Use Life Cycle Cost Analysis?

A common error when performing simple economic analysis is basing the analysis upon initial cost and short time periods. Because the total cost of a project is the sum total of its initial cost and its future costs, life-cycle cost (LCC) analysis is more appropriate. Initial costs are incurred at the beginning of the project; these typically include expenditures for equipment purchase and installation. Future costs are incurred later in the life of the project, including operation and maintenance costs such as personnel, fuel, and replacement equipment.

System options will have different combinations of initial and future costs, making consistent comparison between the options more difficult. This issue is pertinent to school electrification because RE options tend to have high initial costs and low operating costs whereas generators have low initial costs but high operating costs. Choosing options based solely on initial cost may lead to higher overall costs over the life of the system.

LCC is the preferred method for evaluating the economics of different projects with differing initial and future costs. LCC involves calculating the total cost of an option by summing the discounted annual costs of that project over its lifetime. Any economics textbook will provide more details on how to do an LCC analysis. The results of LCC and most other economic analyses are sensitive to the inputs; thus, parametric analysis should be done over a plausible range of input values.

LCC implicitly assumes that the options being compared provide comparable levels of service. If the options provide differing levels of service, this difference should be accounted for in the option selection process.

Operating Costs

Some RE projects fail or incur higher than expected operating costs caused by improper installation and lack of operator training. Sufficient project funds should be allocated to ensure proper training of installers and operators.

The cost of servicing single systems in dispersed communities can also contribute to high operating costs. The cost of servicing RE systems can be greatly reduced if the systems can be serviced locally and the service costs are shared with other applications in or near the community.

Fuel Subsidies

In many countries, fuel costs are artificially low because of government subsidies. The probability and effects of the removal of fuel subsidies some time during the lifetime of the project should be considered.

Income Generation

RE systems often produce excess energy, which can be used to generate income in the community. This income can be accounted for in the LCC analysis.

Design Considerations and Economics

This section describes the factors that affect system configuration and costs. The main considerations driving system selection are load, resource, costs (component, fuel, and operating), and quality of service.

Load

The load is a major driver of RE system design. A designer needs to know the peak load, the average load, the seasonal and diurnal load distribution, and the quality of service needed.

Determining in advance the energy load of a school is a study in itself. Questionnaires and methodologies have been developed that permit the detailed assessment of the potential energy demand for the school. Unfortunately, given the general lack of resources in most instances, detailed assessments are not made. Planners and designers of projects are located at considerable distances from the schools and often provide standard designs.

A number of considerations affect the amount and type of energy needed at a particular school. They include:

• The projected operating hours of the school (Both time of day and time of year). Early morning, late afternoon or evening classes will lead to a larger lighting load than schools with a strictly daytime schedule. In some areas, schools don't operate in the winter due to excessive snowfall. These schools will have a reduced heating load compared to a similarly situated school that operates in the winter. The effect on energy demand of local conditions, such as the modification of of school hours during planting and harvesting seasons should also be taken into consideration.

• Except in circumstances where solar cooking proves practical, a school offering a hot meal will have larger fossil fuel or biomass requirements.

• Energy requirements of teacher and family: In many remote schools in developing areas, the teachers generally come from urban, developed regions of the country. They are by no means accustomed to living without regular and reliable sources of energy. In order to ensure stability, it is vital that they can be comfortable so that they can fulfill the conditions of their teaching contracts.

• Whether the school is primarily used in the daytime for education, and the degree to which it is used as a community center during non-school hours, and whether there are student residents on a regular basis.

• The design and construction or the school and related buildings. Proper building design can reduce energy requirements tremendously. Daylighting reduces the need for lighting during the day. In cold climates, adding proper insulation, sealing the building and proper passive design will reduce the heating load.

All of the above factors have a direct impact on the energy demand in the school for a variety of services including electricity, thermal energy for space and water heating, cooking energy for the provision of meals, etc.

The system components, especially the wiring and power electronics, must be sized so that the system can deliver the peak load. The average load drives the size of the energy producing components and influences the components selected. PV systems are most competitive at meeting loads of less than 1-2 kWh per day, and may be competitive at meeting larger loads as well. Wind turbines and generators become more competitive with somewhat larger loads. Diurnal and seasonal load variations must be considered and may influence component selection. Summer and daytime loads favor PV. Winter loads may be more suited for generators; if winter is the windy season, wind turbines may be a good choice. If the wind and solar resource are seasonally complementary (i.e., the wind resource is good during the low-insolation season), then a wind-PV hybrid system may be more appropriate.

The last important load-related consideration is the quality of service desired. Quality of service refers to the system's capability to meet the load given the variability in the solar and wind resources. For a 100% RE system, the costs may be excessive if very high quality of service is needed. If system components, especially the battery bank, are sized for the worst possible case, the system will be oversized at all other times.

A school may have a mixture of critical and less critical loads. In this case, with proper load management, the system can be designed to be somewhat less robust than would be needed if all the loads were critical. During times of low resources, the less critical loads are turned off.

Even with the extra costs associated with high levels of service, 100% RE systems are often still the most cost-effective solution for meeting the small electrical load demands of rural schools. A lower quality of service requirement will improve the economics of RE in general and wind turbines in particular.

Resources

The available wind and solar resources greatly influence both the configuration and the cost of a hybrid system. A good wind resource will favor the use of wind turbines, whereas a good solar resource will favor the use of PV. Another consideration is the variability of the resource, both daily and seasonally. For a stand-alone RE system, the designer may be most interested in the monthly average resource and size the PV array or wind turbines (or both) based upon the lowest resource month. For a system with generator backup, basing the size of the RE components upon the average annual resource may be more appropriate.

Most locations experience seasonal variations in solar insolation and wind speed distribution. These variations make it difficult to get consistent production from PV arrays and wind turbines. Seasonal variations in insolation are usually driven by the changing length of the day as the seasons progress. This type of variation can be partially overcome by proper tilting of the PV panels. Insolation may also vary because of the existence of a rainy or cloudy season. The wind resource is also often seasonally variable. Even areas with relatively good winds often have a one or two month period of low average wind speeds. In this case, a wind/PV, wind/diesel or wind/PV/diesel hybrid may be appropriate.

Although long-term averages drive the sizing of the wind turbine and PV capacity, the short-term (on the order of days) fluctuations in wind and sun will influence the amount of storage required. The longer the expected length of lulls in the wind and sun, the larger the amount of storage needed. These lulls drive up the cost of 100% RE systems. Systems with generator back up do not need batteries sized to meet the largest anticipated lull in the resource.

Some of these points are illustrated in Figure 4.1. This figure shows, for a particular location and set of cost assumptions, how the configuration of the lowest cost system

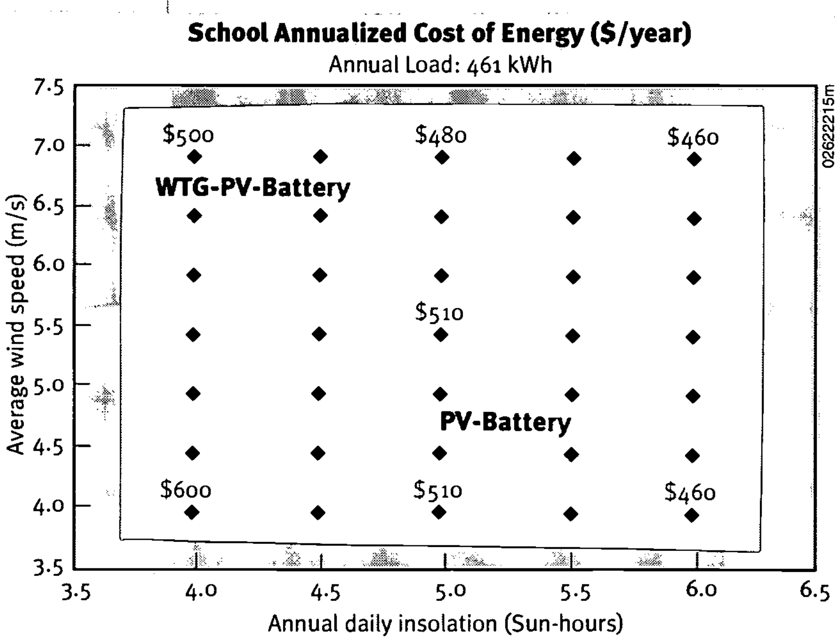
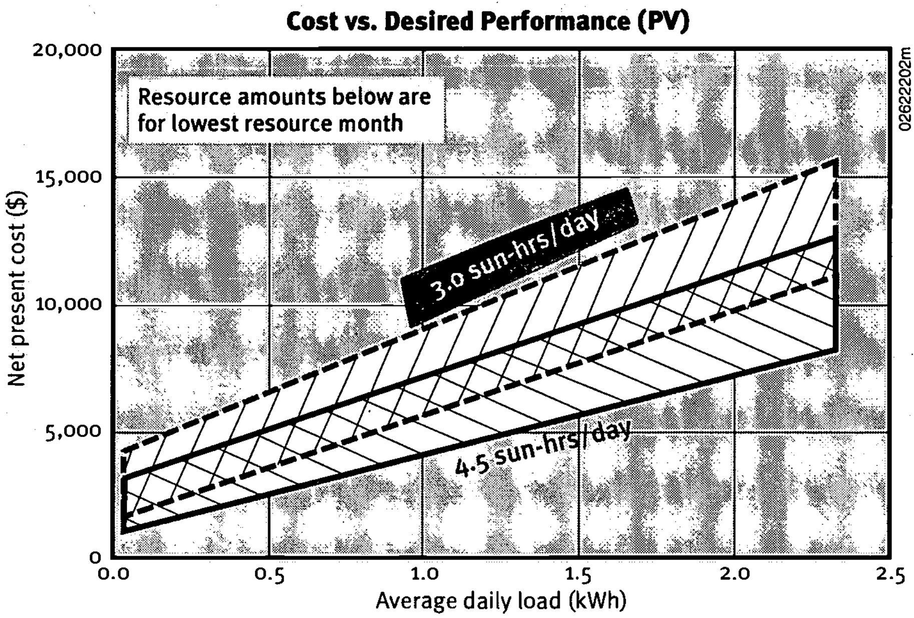


Figure 4.1. This graph shows the least cost configuration for a hypothetical school as a function of average wind speed and average daily solar insolation. The results are meant to show general trends only, and may not apply to a particular site. PV = photovoltaics, WTG = wind-turbine generator. Source: Author's analysis.



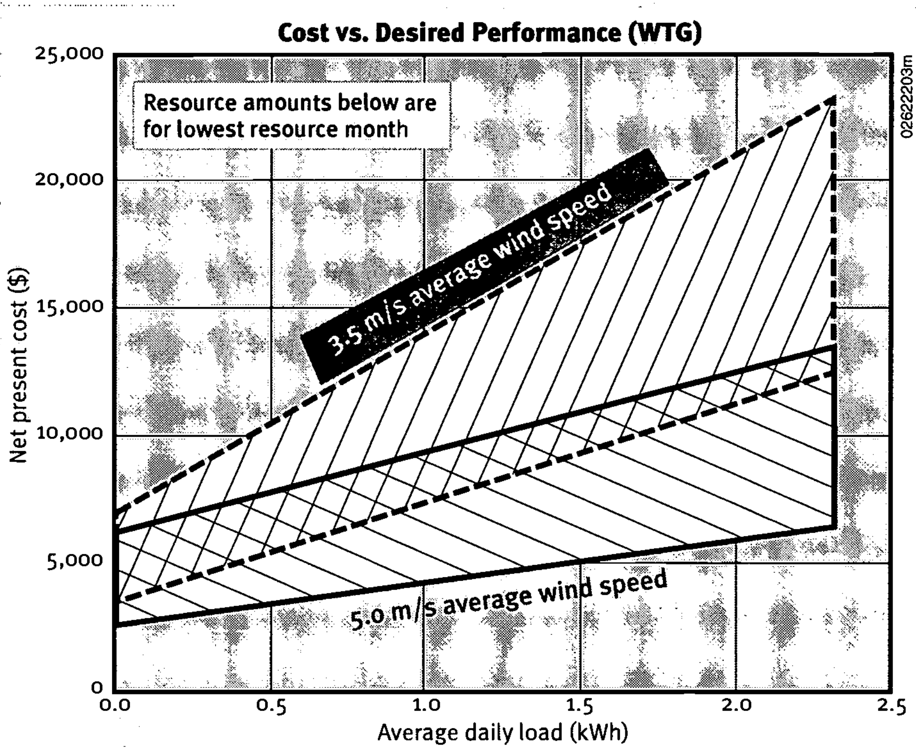


Figure 4.2. These graphs show the typical cost range of the listed technology (photovoltaic or wind turbines) for a system as a function of average daily load. The resource availability listed (for both wind and sun) is the month with the lowest resource availability. Source: Author's analysis.

varies depending upon the local solar and wind resource.

Figure 4.2 shows the typical range of costs for PV and wind-turbine generator (WTG) systems over a range of loads. Each graph shows two bands that reflect costs given two levels of resource availability. Because these are 100% RE systems, the resource level is not the annual average, but rather the average for the worst month. A couple of examples will clarify the use of the graphs. Figure 4.2 (top) shows that a PV system capable of handling an average daily load of 0.5 kWh, in a locale with the worst month insolation (3.0 sun hours/day), is expected to have a 25-year net present cost of between $2,500 and $5,000. Figure 4.2 (bottom) shows a WTG system that meets an average daily load of 1.0 kWh costs between $4,000 and $8,000 in a location with a worst month average wind speed of 5.0 m/s.

Generator Considerations

For larger loads (above ~1–2 kWh/day), the big decision is whether to use a generator. Ultimately, this decision will depend upon an analysis of the site in question. The big advantage of generators is their ability to provide power on demand. The disadvantages of generators include high operating costs, because of fuel and maintenance, as well as noise and pollution.

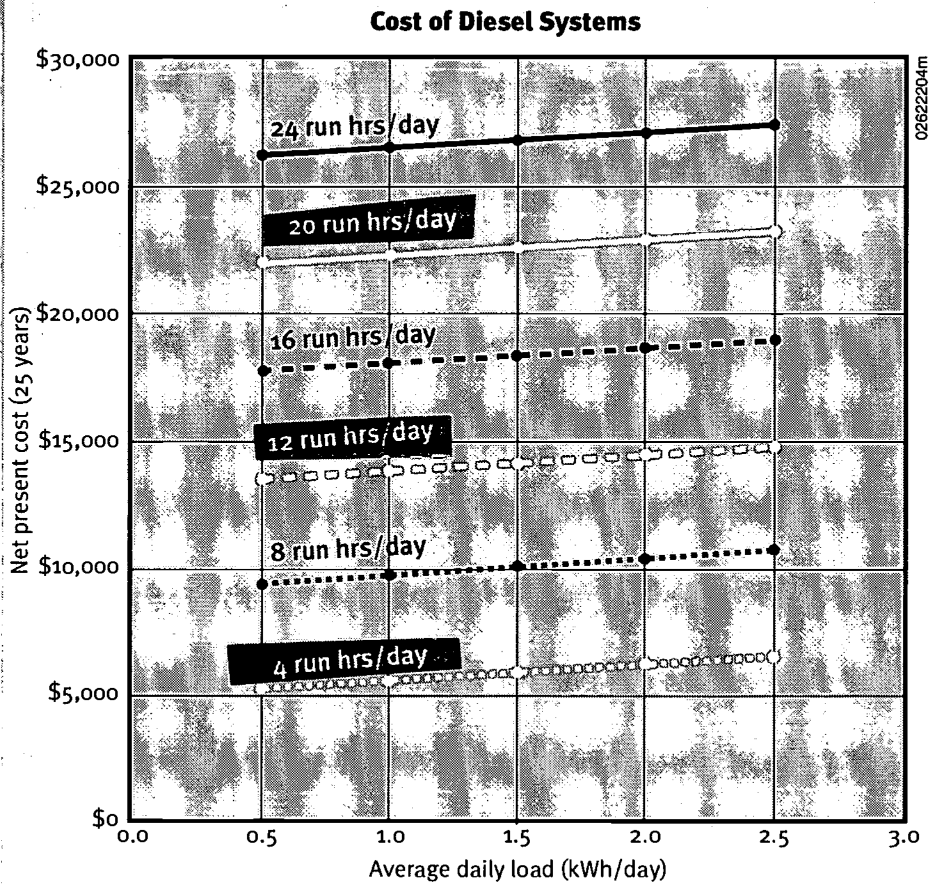


Figure 4.3. This graph shows the 25-year net present cost of operating a diesel generator. The two variables are average daily load (kWh/day) and daily run hours. Note how the costs vary only slightly with load, but escalate rapidly with increasing run hours.

Analysis assumptions:
Generator Size: 2.5 kW
Generator Cost: $1,750
Generator Lifetime: 25,000 operating hours
Levelized Maintenance Cost: $0.07/operating hour
Fuel Cost: $0.50 liter
No Load Fuel Consumption: 0.125 liters/hour
Marginal Fuel Consumption: 0.25 liters/kWh
Discount Rate: 5%

Providing fuel and maintenance to remote sites is often problematical. Figure 4.3 shows the 25-year net present cost (NPC) of a 2.5 kWh diesel generator as a function of average daily load and average daily run time. The Figure plainly shows that it is the number of operating hours that drives the cost of using a generator. If the number of operating hours is low, generators can be competitive sources of energy. As the operating hours increase, costs escalate. If the loads consist of things such as lights and water pumps that are only on a few hours per day, then an all-diesel system may be cost competitive.

If the generator must be run more than a few hours per day, another solution is needed. One possible solution is to use a generator-battery system. When the generator runs, it charges a battery bank that will then be used most of the time. The savings from reduced generator run time vastly outweigh the conversion losses caused by cycling energy through the battery.

Another solution is to combine the generator with PV panels and/or wind turbines, and batteries. The RE components minimize the generator run time, keeping the generator operating costs to a minimum. The generator precludes the need to oversize the RE components and thus reduces the capital costs.

CHAPTER 5: INSTITUTIONAL CONSIDERATIONS

Chapter Introduction

Although this Chapter focuses mostly on various institutional, organizational, and social issues that should be addressed prior to initiating a large-scale project, much of the information in this Chapter is also applicable to smaller scale projects as well. The advantages and disadvantages of various institutional arrangements are discussed. The need to provide adequate resources for post-installation service and support is stressed throughout this Chapter.

Issues

Reliability, convenience of use, and cost-effective supply are major considerations for energy delivery systems for virtually all applications. For many remote community schools, there is often a lack of basic services, including running water for washing and toilets as well as energy for lighting, heating, and cooking. All these applications require energy.

Despite increased government and donor spending on RE systems for rural schools, these projects remain underfunded. In many countries operation and maintenance of existing services to schools often occupy most of the budget allocation, leaving little for upgrading rural schools with RE systems.

Policy and Planning

Policy and planning concerns with respect to energy supply to rural schools should include:

• **Availability and quality of information:** Typically, little information about energy supply options, particularly RE systems, is available in developing areas. Without good cost and reliability data, planners cannot make good decisions about which technologies to use.

• **Resource assessment:** Renewable energy resource data is usually unavailable. The data that does exist often has not undergone any quality control or analysis. The solar and wind resource should be assessed to determine whether they are adequate to operate RE systems at the time of the year when the school is in use. Similar considerations apply to projects using biomass.

• **Availability of rural energy specialists:** Public agencies often lack energy specialists capable of determining which technologies are most appropriate for a particular application.

• **Financial considerations:** If the system is not expected to be self financing, then options for supplementary financing include subsidies, fiscal incentives, and low interest loans.

• **Technical options:** This requires an assessment of resource availability, energy demand profile, life-cycle costs, and environmental considerations. Electricity generation can make use of wind, solar PV, micro-hydro, or biomass fired generators. The merits of mini-grids versus direct application in a school may need consideration. Thermal energy needs can be supplied by solar/wood-charcoal/biogas cook stoves, biomass/passive solar space heating, and solar water heating.

• **Combined applications:** A facility can be designed to serve multiple uses. For example, a school may also be used as a health clinic and a community center. Other applications that may be served in addition to a school, include water pumping and battery charging. Planning for such combined applications can make the system much more valuable to the community for only a small additional cost. Combining applications may allow the agency/organization paying for the school RET to cost share with other agencies.

Barriers

• Initial lack of institutional capacity (in implementation, operation, and maintenance infrastructure).

• Lack of information about the various rural energy supply options.

• Perceived risk of introducing new technological systems based on RET's by administrators familiar with conventional energy systems.

• Import restrictions and other trade barriers; duties can distort costs and lead to inappropriate technology choices.

• Privatization of state-owned enterprises can sometimes lead to a decline in rural energy supply.

• Perceptions that RETs are too costly due to the comparing options using initial cost rather than life cycle costing.

• Fuel and grid extension subsidies discourage the use of RETs by reducing the cost of conventional energy technologies.

• Remote rural schools may have difficult access, thus hindering system installation and follow up maintenance.

• In many countries, policies concerning the use of renewable energies for rural applications are non-existent.

• Unclear institutional roles and responsibilities.

In many countries, schools are frequently under national government control. In other countries, they come under regional, state or provincial purview. Additionally, religious and ethnic schools are operated by a variety of non-governmental organizations (NGOs). This diversity can mean that there is no universal policy framework upon which to build a strategy for RE use in schools. Programs will have to be developed at the national, provincial, regional or local level on a country by country basis. Therefore, considerable effort may be needed in many countries to bring together the key parties at various levels to develop national-level commitments that will facilitate removal of barriers such as import duties on RE equipment and subsidies for fossil fuels. Commitment on the national level can lead to the creation of an adequate technical infrastructure for the operation and maintenance of RET systems.

Delivery Approaches

Several channels exist for implementing RETs in rural schools. Three commonly used implementation models include:

• Government agencies handling all activities

• Implementation using a combination of government agencies and private companies

• Implementation by NGO's (frequently involving both Government and private sectors).

Regardless of the model used, the approach should assist the country in establishing an indigenous supply and maintenance capability for RET systems. The ultimate aim is the sustainable and appropriate application of RE systems in schools and other public and private buildings.

Management and Implementation by Government Agencies:

In this institutional approach, the government, e.g., Ministry of Education, does the planning, system design, installation, maintenance, and repair of the RE systems. Often, it will rely on another government agency (e.g., the government owned utility or the Ministry of Energy) to design, install, and implement and maintain energy systems.

There are certain advantages to using this approach, one of which is that generally, the schools come under the purview of a Government Ministry. In any case, Governments must order the components for the different systems from the private sector, where they are either manufactured or where the importation of their components is handled.

In addition:

• National education programs have an established infrastructure for planning, management, technical, and logistical support to rural schools. This existing infrastructure may be used to implement RE systems.

• Programs on a national scale may be large enough to have sufficient critical mass to develop and support a service infrastructure.

The disadvantage of the institutional approach to managing RE systems is that a limited number of trained personnel in government services familiar with RETs, both in numbers and technical experience, are available to accommodate the needs of all regions of the country. The same will commonly apply to Ministry of Education technicians, who may be familiar with conventional energy systems, but will need training in the installation, maintenance, and repair of energy and RE systems. Proper training of technicians will create a solid infrastructure, particularly in the early stages of planning, to adequately deal with RET systems.

Combined Government/Private Sector Approach:

Another operational scenario uses management of the implementation programs by government agencies with the actual implementation using private contractors. In this approach, government officials plan the program to include RE solutions, and issue requests for bids to provide equipment and services. Private contractors provide equipment including installation services. In addition, the contractor may provide maintenance and repair services under a service agreement. Alternatively, the Ministry of Education may accept the service responsibilities once the installation is complete. In Argentina, this is the model that has been used successfully to date in the provinces of Neuquén and Salta as part of a larger electrification concession. (See Case Studies One and Two in chapter Six). South Africa also used this model in its school electrification program. The utility, ESKOM, designed the systems and private contractors did the installations. The program was done this way to assist the development of South Africa's RET industry.

There are some advantages to this type of program:

• Private contractors in the business of selling and installing RE systems are usually equipped with the knowledge, skills, and tools to provide the required services on a contractual basis.

• Ministries of Education may be better equipped to establish and manage the program for supply and implementation of RET than to actually perform the installation.

• Competitive procurements often result in lower costs.

With this type of institutional configuration, it is important for government agencies to provide clear specifications for the procurement of equipment and standards of acceptance for the quality of installations in the field. In addition, they will need to detail the needed user training and post installation maintenance support that the successful bidder will be expected to provide. This will result in higher quality installations that will have lower failure rates and thus lower maintenance and repair costs. With the proposals that fail to meet the standards screened out, government purchasing agents can select the best offer from among the remaining proposals, without having to be concerned with significant differences in the relative quality of the submitted proposals.

Training of RET system operators is essential to ensure that systems will function with a minimum of down time. Any operator training and post-installation maintenance support required of the contractor should be clearly specified.

Government agencies can also certify that private contractors are competent to install systems professionally in the field and establish lists of qualified bidders for the installation of RE systems.

However, in many developing areas, competent private sector contractors may not exist or may be reluctant to undertake work in remote areas because of excessive transportation and labor costs that result in low or negative margins.

Management and Implementation by Non-Governmental Organizations

Many NGOs run educational facilities in rural communities. In this approach, the NGO procures, owns, operates, maintains, and repairs the RE system.

Primary education throughout the world is under the aegis of Government Ministries, who provide school-operating permits and set educational standards. Hence, the NGO is directly in touch with public officials and can be brought into the loop when they are planning and implementing national or regional RE programs. There are other advantages:

• NGOs are often run by committed and motivated individuals who operate efficiently and effectively on limited budgets. Decision-making and project implementation is generally less bureaucratic than a government process.

• NGOs generally have strong community relationships. Consequently, they may be better able to generate community support and participation as well as collaborate with other service sectors such as health, agriculture, and enterprise.

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Figure 5.1. Technician training course.

In dealing with NGO's, one must bear in mind the following:

• NGOs generally operate programs for a limited number of establishments that they operate and maintain themselves. The scale of their program may not lend itself to significant support of a commercial service infrastructure.

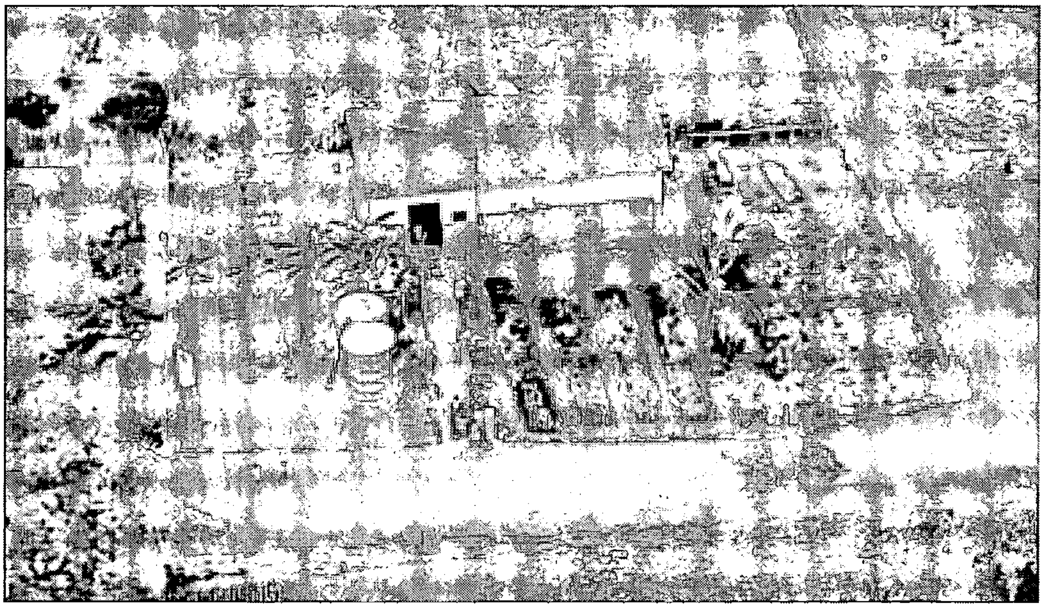
• NGOs may not have the specialized technical knowledge or skills to implement RE technologies without technical assistance.

• Small NGOs often have limited cash flow that constrains their ability to maintain the installed systems.

It is important to incorporate a realistic understanding of the operating characteristics of NGO's into future Government planning vis à vis the introduction of RE techniques. For example, in the Bangladesh Biogas Case Study, Case Study #5, the school is an NGO whereas the plans and specifications for the biogas plant and the technical expertise are vested in government or para-government agencies. In order to maintain these plants in top working condition, it would be essential to incorporate regular maintenance and site visits of public sector technicians to ensure that the local staff are trained properly and that they are executing the operation and maintenance activities correctly.

Service Infrastructure

An infrastructure includes a committed and reliable institutional chain of command, adequate communication and transportation services, and the technology support structure (technical expertise, maintenance services, spare parts, etc.). Such an institutional infrastructure is essential so that operations concerning the project can be carried out with the least difficulty and expense, and within a reasonable time frame. This structure might include, for instance, the schoolteacher or principal, the regional or provincial school board, and the planning level above that. In addition, it may also include the local teacher, representatives of the local utility, and its chain of command.



Roger Taylor, NREL/PIX00017

Figure 5.2. Individual photovoltaic (PV) power systems at this village school in Ceara, Brazil are providing electricity for television, refrigeration, street lighting, and water pumping. International PV projects such as this one (partially sponsored by DOE and Brazilian utilities), are often financed through utilities, banks, or other governmental organizations.

Reporting on system operation and malfunctions, and the timely delivery of parts and services require satisfactory communication and transportation services. Proper communications equipment (e.g., short-wave radio) can be very useful in ensuring timely delivery of messages, services, and supplies.

Although the RETs under consideration are commercial, in remote areas of the developing world, there is frequently a lack of well-developed and reliable services to install, maintain, and repair systems in the field. This service in frastructure is not always easy to set up, but is critical to the success of a project. If the RET installation is the first or one of the first in an area, implementers need to consider carefully:

- **Reporting system malfunctions:** who reports them, how are they reported, and to whom do they report?
- **Maintaining the system:** who maintains it and how?
- **Maintaining a local stock of critical supplies, spare parts, and test equipment:** who orders the parts or supplies, who supplies replacement parts, and how are these parts delivered (especially to remote areas)?
- **Arranging regular training of field technicians, operators, and users:** who arranges the training, and where will the training take place?
- **Arranging training of new staff:** how can new staff at a particular school be re-trained?
- **Replacing failed and worn out components:** is there a budget for replacement parts and components, and what is unacceptable downtime?

User Interface/Training of Users

Training at all levels, from policy makers to system users, is a critical requirement for sustainability and replication. Training is required for all aspects of the project, including analysis, design, implementation, operation, maintenance, and evaluation. At the planning and decision-making level, training efforts should focus on information transfer and comparative analysis methodologies. In addition to initial training, there must be periodic refresher training. Due to turnover in the ranks of users and technicians, provision must be made to train individuals who become responsible for operating and maintaining RE systems in the months and years after the initial installations. It may be desirable to offer an accreditation program to the technicians.

In order to assure continuity in the operation of the RE systems, regular servicing by competent specialists is important. In addition, training the end users (i.e., the local teacher(s) and the school custodians) in operation and maintenance procedures will pay dividends since RE specialists may only be able to make periodic visits because of the remoteness of the school location.

In order to ensure adequate training in RETs at all levels, from system design to installation and maintenance, people with sufficient experience and understanding of local conditions should provide this training. These persons might not always be available and this could constitute a major barrier to the proper introduction of RE systems into a region. One method for establishing regional capability is to set up regional centers of excellence affiliated with local universities. An example of this is the Center for the Study of Wind Resources (CERES) at the Universidad de Magallanes in Punta Arenas, Chile. These Centers can provide design, training, and technical assistance to projects in the surrounding area.

Financing Questions:

In some instances, financing limitations constitute a major barrier to the introduction of RE systems. Adequate financing by itself, however, will not ensure that systems are properly managed and operated. Financing will be needed for the RE system program design, the purchase of equipment as well as the operation and maintenance of the systems, training, and if it doesn't already exist, the establishment and support of a supply and maintenance infrastructure. There exist unfortunate examples where national authorities and international agencies have provided funding for hardware and short term visiting specialists, only to have the systems eventually fail for lack of funds for complete training, operation, and maintenance, infrastructural support and communications. The lessons of the past need careful examination to ensure greater success with new RE programs.

CHAPTER 6: CASE STUDIES

Chapter Introduction

This chapter provides six case studies. The case studies highlight different aspects of RET implementation in schools. Combined, the case studies provide valuable lessons that can be used to improve future projects.

CASE STUDY #1A — School Electrification Program in Neuquén, Argentina

Introduction

This case study is divided into two parts. This first part describes the overall program. The second part describes a specific school in more detail.

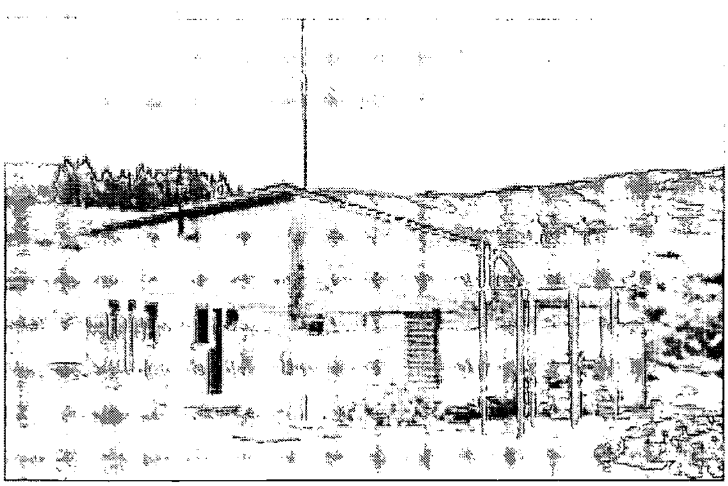
Background

The province of Neuquén is located along the Andean mountain chain in the northern section of Patagonia, stretching from latitude 36°S to 41°S. The province covers approximately 94,000 km^2 and has a population of 250,000 (1991). Warm, dry summers and cold, dry winters characterize the area. Night time temperatures often drop below freezing even in the summer. The annual average solar radiation is around 4.0 sun-hours per day, with seasonal extremes of 1.2 sun-hours/day in the winter, and 7.0 sun-hours/day in the summer. The Western half of the province is largely rural and mountainous with difficult access by road.

The local authorities have recognized that it is important to provide education in these remote communities. Hence, there are more than 150 schools located in remote and rural areas of the province. Because of the difficult access and heavy winter snows, many of the more remote schools operate on a spring/fall schedule and shut down during the winter. Teachers typically live on-site in adjoining or nearby housing.

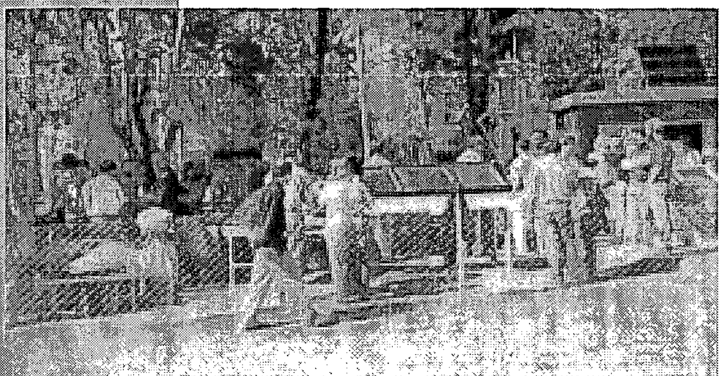
Of the 112 schools for which information is available, 34 are grid connected, 43 have gas or diesel-powered electrical generators, 27 use photovoltaic systems as their only source of power, and eight have no electricity. Nearly all of the schools have gas-powered stoves with which to cook, and wood stoves to bake bread. Wood or bottled gas is burned for water and space heating. In some of the schools, gas or diesel generators, when functioning properly, provide power for lighting and for pumping, distributing, and sometimes, heating the water. Most of the remote schools have battery-powered radio communication systems. At some schools, two small PV panels, mounted on an antenna tower, charge 12-V DC batteries for the radios. All of these systems require maintenance, which the schoolteachers undertake.

The principal alternative to PV are motor generator sets. The relative inaccessibility of the sites hampers proper maintenance and consequently these units are frequently out of service. The low population density of the region makes grid extension unlikely for most of the schools. For these schools, photovoltaic systems offer a good alternative. The PV systems must be properly designed, installed, and maintained—attention must be paid to training local operators.



Tom Lawand, Solargetics/PIX08278

Figure 6.1. Typical PV panel installation, Nahuel Mapi, Argentina.



Tom Lawand, Solargetics/PIX08282

Figure 6.2. RE Training and demonstration center, Neuquén Argentina.

The Renewable Energy Program

The Renewable Energy Program envisages the installation of photovoltaic systems (and to a lesser degree, wind-electric generators) in rural schools. During the period 1987 to 1989, the Dirección Provincial de Telecomunicaciones installed PV panels at schools for radio transmitters. The first PV system for lighting and educational aides in a school was installed in 1987. Since 1994, 26 additional PV systems and one wind-turbine system have been installed. There are no plans to extend this Program. The installation of additional PV systems generally responds to a request coming from the schools.

These photovoltaic systems are designed to provide electricity for the basic needs at the schools; lighting classrooms and operating small electrical appliances, such as short-wave and AM/FM radios, VCRs, and televisions. In general, the systems do not provide enough energy to operate large appliances such as microwave ovens, washing machines, refrigerators, and power tools.

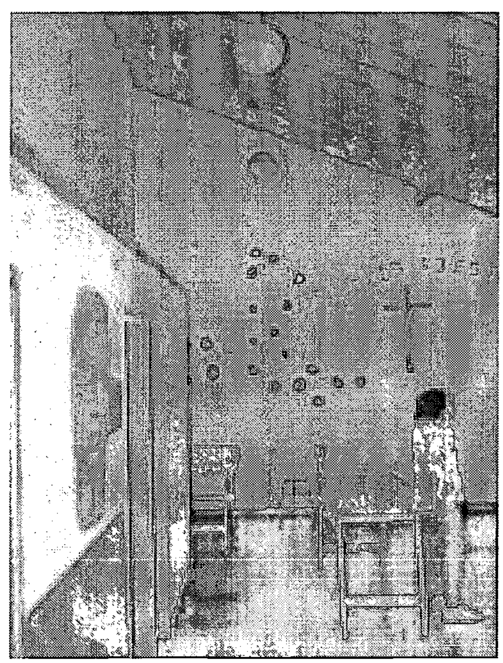
The main organizations involved in the program are the Consejo Provincial de Educación del Neuquén (responsible for education in the province of Neuquén) and the local utility (Ente Provincial de Energía del Neuquén—EPEN). EPEN purchases and installs the equipment and provides maintenance. The provincial government pays the capital, installation, and maintenance costs.

User Training

EPEN provides system maintenance training to the teachers. Each school receives a manual of operation and maintenance for the PV system. The teacher is responsible to verify that the batteries are properly functioning, the regulators are working, and the PV panels are clean. The teacher reports system malfunctions directly to EPEN offices.

EPEN has an agreement with the Provincial Secretary of Education to provide technical support to the Educational Program on Renewable Energy and Rational Use of Energy. EPEN staff gives courses for teachers and helps in the preparation of educational material.

This Program makes use of the Demonstration Center for Solar Energy Technologies established in Neuquén City, a co-operative program with the Brace Research Institute of McGill University, Canada. At this location, trainees are exposed to a variety of RE applications (including solar water heating, solar cooking, PV water pumping and lighting, improved wood stoves, and solar drying).



Tom Lawand, Solargetics/PIX08283

Figure 6.3. PV powered lights at a high school in Butalon Norte, Neuquén Province, Argentina.

Institutional Aspects:

In Argentina today there are several companies selling PV equipment, including manufacturers and importers. These companies have dealers in many cities that offer services and spare parts. However in the rural areas, services are very limited and replacement parts must often be ordered from the company headquarters.

Despite the limited presence of RE companies in the rural areas, the installation of a PV system in a school is often followed by the installation of additional PV systems in the surrounding community. These systems have proven to be the best choice for providing energy to remote rural dispersed houses. The rural people have adopted this technology without problems.

Program Assessment

In general, the photovoltaic and battery systems work satisfactorily. Most problems occur with system maintenance and the training of the local residents. To remedy these problems, a maintenance manual was written that provides step-by-step instruction in system maintenance procedures. Educational aids have been developed and demonstration workshops held to improve understanding of the systems. The high turnover of teaching staff makes it is essential that the school caretakers be involved in the use and maintenance of the systems. Steps have been taken by the utility to ensure that their local offices verify system maintenance. A thorough preliminary analysis of the energy and logistics problems at the schools is essential to achieve optimum technical and operational performance. Equipment should have minimum maintenance requirements and be easy to operate. It is important for the program to go beyond just the photovoltaic system components to include training manuals, training courses, systems management, and equipment.

CASE STUDY #1B — School Electrification in Nequén, Argentina

An example of the PV equipment and installations for school #293, Villa Puente Picún Leufú, highlighted below, is typical of the technical setup at the other PV electrified schools in Nequén.

Location of the School

School #293—Villa Puente Picun Leufu—Departamento Catan Lil (39°10'S-70° W), province of Neuquén, Argentina.

The school is located in a mountainous region approximately 250 km west of the city of Neuquén.

Description of School

The school is a stone and brick building, 270 m^2, all on one floor. It has a pitched roof with the long axis in an east-west direction.

The school operates from the period September to May (summer cycle). The normal daily occupancy time is 08:00 to 14:00 hours.

Students and Staff

The school has 25 students, one teacher, and one porter. The students leave at the end of classes every day. There are occasional community meetings held in the school on an irregular basis. One of the staff members resides at the school.

Electrical Energy End Use in the School:

Electrical energy applications consist of 40 lights of 20 watts each for a total installed capacity of 800 watts.

There is also the following electronic equipment:

TV:	80 watts
VCR:	27 watts
Radio and tape recorder:	25 watts

Telecommunications equipment: there is a radio telephone that uses 120 watts while transmitting and 6 watts while on standby power

It should also be noted that no electricity is used for water pumping or water treatment undertaken at the school. Nor is electricity used for water heating, space heating, and cooking at this particular school.

Photovoltaic System Description

The array consists of nine ground-mounted, 48-W_p PV panels.

Battery storage consists of 4–12 volt, 220 Ah batteries. They are located in an insulated battery container under the panels. There is one 12-volt regulator, maximum current from the panels is 48 A, with load disconnection. A 250-watt inverter converts the 12-volt D.C. power into 220-volt AC.

Installation Information

Argentinean suppliers provided all the equipment:

- Solartec S.A. (Argentina) — modules, regulators, structure
- Williard Solar (Argentina) — battery
- HT Inverter (Argentina) — inverter

The equipment was installed in August 1997 and is currently operating with no difficulty.

Financial Considerations

- Cost of the PV system (including installation and taxes): U.S. $ 8,205.
- Cost of the internal installation (including light fixtures, wiring, labor and taxes): U.S. $5,185.

Total Cost: U.S. $ 13,390.

The system was paid for by the Government of the province of Neuquén. Financial arrangements were handled by EPEN. The local government of Neuquén handles operation and maintenance expenses. To date, the cost of maintenance has been very low because the system is relatively new and no parts require replacement. Based on EPEN's experience with other PV systems in schools, the batteries should have a life of approximately 4 years. Other costs have been estimated as follows:

- Replacement of PV modules: 1% annual
- Replacement of regulators and inverters: 5 % annual

The annual cost for maintenance is approximately U.S. $500.

Operation and Maintenance (O & M) of the Energy System

The teacher and porter monitor the PV system. Repairs and maintenance are handled by EPEN. The school authorities are pleased with the O & M situation. They have not noticed a change in the performance of the RE system since its installation.

Lessons Learned

The principal problems with the RES encountered under this Program are:

- Lack of 12- or 24-V lights for this application (The lights available in the marketplace are emergency lights.)
- Problems with the inverters.

It should be noted that there have been no problems with the use of PV systems in spite of the frequent change of teachers.

The principal lesson learned under this Program has been to confirm the advantages of RE systems compared to other stand-alone electrical generating systems.

Acknowledgements

Information for these Case Studies comes from Graciela Pedro of EPEN.

CASE STUDY #2 — The Concessions Program in Salta, Argentina

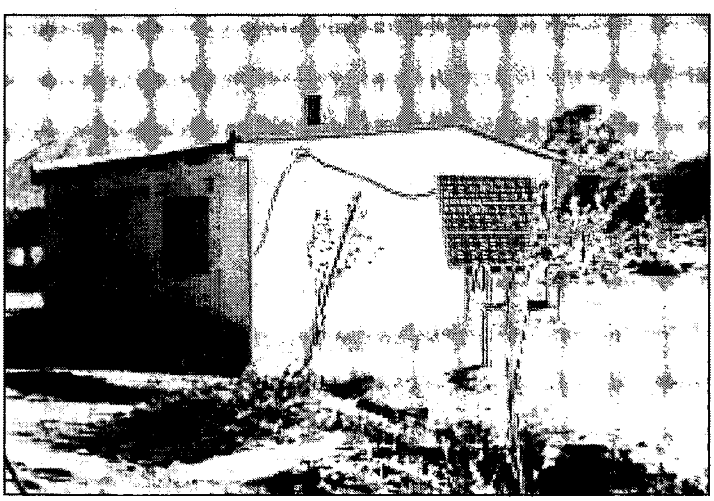
Background on the Provincial Program

The introduction of solar photovoltaic systems into rural schools in Salta has been ongoing since 1991, when a number of schools and clinics were equipped with PV systems. In mid 1998, however, a larger, more extensive program was initiated and a significant number of rural schools have subsequently been equipped with photovoltaic systems.

Argentina's remaining unelectrified population, estimated to number 2.5 million, lives widely dispersed in rural areas. Because of this dispersion, provision of electricity to this population through grid extension is estimated to cost U.S.$8,000 per household. As a result, the Argentineans launched an innovative concession project, Programa de Abastecimiento Eléctrico de la Poblacion Rural Dispersa (PAEPRA) to facilitate the introduction of RE systems into these isolated regions.

In the province of Salta, in northern Argentina, a concessionaire, Empresa Servicios Eléctricos Dispersos (ESED) installs the photovoltaic systems, and the program is regulated by a Government agency, the Ente Regulador de los Servicios Publicos (ERSP).

There are some 700 rural schools in the province of Salta that are not connected to the grid, nor are they expected to be connected in the near future. Of these, by February 1999, roughly 130 have received PV systems, and a significant number in addition are slated to receive similar systems during the next year.



Tom Lawand, Solargetics/PIX08284

Figure 6.4. A PV system provides electricity to this rural school in Salta province, Argentina.

Two companies, Solartec S.A. and BP Solar, provide the bulk of the photovoltaic systems for the rural schools. The systems come in three sizes and are designed to provide 11, 15 and 22 kWh per month, respectively. For the 11-kWh per month systems, the companies provide two 75-W_p panels, along with a supporting structure, a charge regulator, batteries, and ancillary equipment. For the 15- and 22-kWh per month sizes, the systems contain three and four 75-W_p PV panels, respectively. All systems are provided with a manual covering installation, maintenance, and use of the systems.

ESED's Obligation's with Respect to School Electrification

Empresa Servicio Electricos Disperses (ESED) is the company that installs the PV systems in the rural schools in Salta. They also install the internal and external wiring. Under its contractual obligations, ESED installs the systems and maintains them for the guarantee period. They may later be subcontracted to provide a service contract for system maintenance.

ESED is responsible for ensuring that the systems are well mounted and that the users at the school are trained in the operation and maintenance of the units. As non-electrified residences surround the schools, one aim of the program is to acquaint the local inhabitants with the benefits of RE systems.

The Role of ERSP

The Ente Regulador de Los Servicios Publicos (ERSP) acts as an intermediary among those wishing to be supplied with PV electricity, the companies supplying the services and equipment, and the funding agency, which is the province of Salta. The ERSP visits the areas in question and assesses their electrical needs. The government then subsidizes the installation and operation of the appropriate PV system. In the rural non grid-connected areas, applications include schools, clinics or individual households. One of the high priorities is to make the public aware of this subsidized electrical service, which the government offers through their contract with ESED.

As part of its intermediary function, ERSP monitors and regulates the services provided by the installation companies. By contractual obligation, the installation companies are required to service the PV systems. However, several factors can stand in the way of prompt service.

1) All of the installation companies are based in Salta, the capital city of the province, and are located hours away by road from the remote areas. This can cause long reaction times when responding to service calls from the remote areas.

2) Many PV system users in remote areas don't have access to local telephones for use in case of a problem. Finding telephone services, or using the postal system, can be a lengthy process, leaving the user without electrical power for several weeks or months.

3) The ERSP needs to examine claims by some PV system users prior to servicing. The installation company is responsible for technical problems with the PV systems, as well as any difficulties arising from these technical problems. If, however, the user has mishandled or neglected the proper operating guidelines of the system, then the individual is liable for the damages. In this event, the user must be prepared to pay for any repairs necessary.

For example, there have been some problems with appliances short-circuiting when operated from a PV system. In these events, the ERSP must examine the situation to determine liability. If, for example, a fault in the PV system caused an overload leading to the short circuit, then the installation company must replace the appliance. If, however, the PV system for example was damaged by water leaking from an unrepaired roof, the user is at fault and the installation company is not liable for any damages.

Financing

In most cases, the government subsidizes the installation cost. Generally, schools, clinics, and individual householders request the installation of PV systems directly from the ERSP. For example, a school in the Department of Anta, Santa Rita, site #118, purchased a 22-kWh system. The cost of the system was 450 Pesos (1 Peso = U.S.$1) of which the user was required to pay 100 Pesos—i.e., 78% subsidy. Initially, the school was the only entity in the community requesting a system. There are 14 residences in the immediate area of the school. The PV system was installed in August 1998.

Program Evaluation

Inspection by ERSP representatives identified the following problems.

- Improper installation of PV panels in some instances
- Varying inclinations of the solar panels (There should be greater standardization within the province.)
- Shading of the collectors at different times of the year from large trees
- Poorly mounted panels are subject to theft.

One of the greatest concerns of the Ente Regulador is that the local populations are not being sufficiently informed and made aware of the government subsidy program. Consequently, greater efforts are being made to publicize the program. To best promote the technology, visits should be organized to those locations that are already equipped with PV systems. In this way, the local population can see functioning systems and their benefits first hand.

Acknowledgment

Information for this Case Study was provided by :

Pierre Rieszer
Ente Regulador de los Servicios Publicos (ERSP)
Alvarado 677
4400 Salta, Argentina

CASE STUDY #3 — Wind-Turbine Installation for a School in Chile:

Introduction

Wind turbines supply electricity to a lodge used by boarding students at a school in Chile.

The School and Lodging

The school, G-35 "Diego Portales" is located in the village of Villa Tehuelche located about 100 km from Punta Arenas. School is in session March through December. The lodge currently houses 35 students (ages 6–14), and 3 adults (2 inspectors and 1 teacher) during the school year. During the summer, the lodge is closed except for some occasional weekend activities.

Electrical Loads

The electrical load consists of 50 Philips Lamps rated between 11 and 18 watts each. On average, 10 lamps are on an average of seven hours per day. In addition, there is a VCR and a 20-inch TV set.

System

Installation took place from November 1994 through March 1995 under the direction of the Center for the Study of Wind Resources (CERE) at the Universidad de Magellanes (UMAG) in Punta Arenas, Chile. Capital and installation costs totaled $14,000 and were paid for using regional funds.

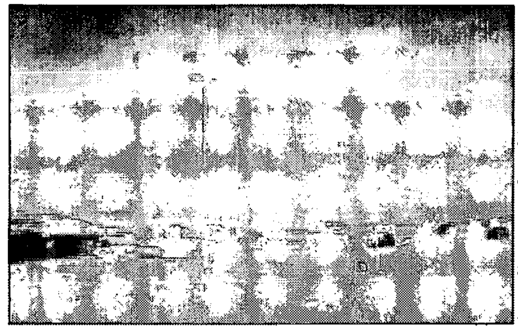

Artero Kuntsmann, CERES/UMAG/PIX08260

Figure 6.5. Two 1.0 kW wind turbines provide electricity to the dormatory of this remote school at Villa Tehuelche.

The system consists of two Whisper 1000 wind turbines, battery bank, controller, and inverter. The battery bank consists of eight Delco 105 Ahr, 12-volt batteries. The controller was designed and constructed by engineers from (UMAG). The inverter, rated at 1.5 kW, is from Trace.

Operation and Maintenance

Four staff members have been trained to operate the system. Backup maintenance is provided by CERE/UMAG. Yearly maintenance costs have proven to be variable but average $500 per year. ($300 for materials and manpower and $200 for travel costs.) The batteries were replaced in 1997 at a cost of $900.

Acknowledgment

Information was provided by:

Arturo Kuntsmann
Center for the Study of Wind Resources (CERE)
Universidad de Magellanes (UMAG)
Casilla 113-D
Punta Arenas, Chile


Richard Hansen, Soluz/PIX08286

Figure 6.6. Richard Hansen with students and staff of the school at Santa Cruz Minas.

CASE STUDY #4 — School Lighting in Honduras

Introduction: In the aftermath of Hurricane Mitch (October 1998) Soluz Honduras has installed a PV lighting system at the elementary school in Santa Cruz. The lighting system is used to provide night literacy classes to the local population.

The School: Santa Cruz Minas is located in the department of Santa Barbara in Northwest Honduras. The three-classroom facility is cinderblock construction with a corrugated cement fiber roof. There are five teachers, one of whom serves as the school director. The school serves over 200 students (grades 1—6) in two shifts, one from 08:00 hours until 11:00 hours and the other from 14:00 hours until 17:00 hours.

The System: Soluz Honduras installed the PV system and wiring in February 1999. The system consists of a 50-W_p, pole-mounted PV panel, a controller with high and low voltage disconnects and a 12-volt, 90 Ah battery. The battery, warranted for 18 months, is an imported model purchased through a local dealer. The applications consist of six (two per classroom) 9-watt PL compact fluorescent bulbs and one DC outlet.

Institutional/Financial Arrangements: Soluz Honduras is executing this project within the framework of its existing fee for service business. In this model, the customer pays Soluz Honduras a fixed monthly fee; Soluz Honduras retains ownership of the system and is responsible for system maintenance. Prior to the school installation, Soluz had performed about 20 home installations in the area on a full-cost recovery basis. The school project is similarly organized with Soluz owning the system, but in this case, waiving the monthly fee.

The PV modules were donated to Soluz to aid in the post-Mitch rebuilding effort. Soluz is donating the lights, wiring, and use of the controller. The school purchased the battery with financing provided by Soluz. The school director plans to use the proceeds from the adult literacy classes to repay the loan and pay for replacement batteries. Since Soluz retains ownership of the system (except for the battery), it can remove and relocate the system if the grid is extended to the village or the school proves incapable of replacing/maintaining the battery.


Richard Hansen,Soluz/PIX08287

Figure 6.7. PV installation at Santa Cruz Minas.

The battery requires the most frequent operator attention. School ownership of the battery provides an incentive to the school to properly maintain it in order to minimize replacement costs. This reduces the maintenance burden on Soluz and represents a tangible contribution by the school and community towards the creation and maintenance of the system.

Soluz performs maintenance on the remainder of the system, including replacement of lights. Because Soluz already has a maintenance infrastructure in the area, it expects the incremental cost of servicing the school system to be very low.

Soluz has enough PV panels to replicate this project at another dozen schools using the same donation arrangement. Soluz expects to perform other school installations over the next year.

Acknowledgment

The information was provided by:

Richard Hansen, President, Soluz, Inc.
John Rogers, Vice-President for Engineering, Soluz, Inc.
55 Middlesex Street, Unit 221
N. Chelmsford, MA, USA 01863-1561

CASE STUDY #5 — Biogas Plant in a Rural School in Bangladesh

Details of School Location

Faridpur Muslim Mission,
Shah Farid Madrasah Building,
Court Compound, Faridpur,
Bangladesh.

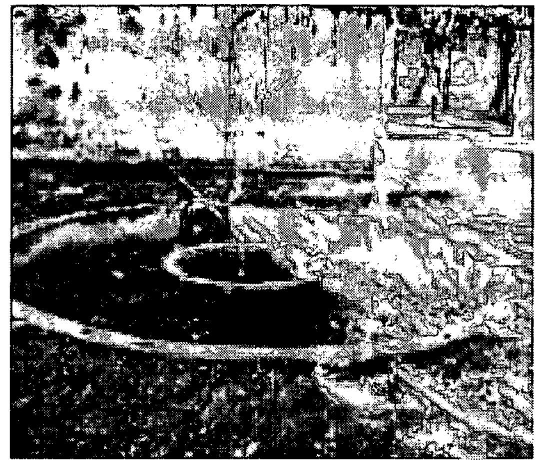
The energy system at the school consists of two biogas plants of the fixed dome type (only one is currently in operation). Biogas is used for cooking only, and the sludge from the plant is used as a fertilizer.

The School

The school consists of three tin-roofed shed buildings with south-facing open verandas. They are 118 m^2, 164 m^2, and 170 m^2 in area. The buildings house a maximum of 400 orphans. In addition, there is a technical training center.

Sylvia Mortoza/PIX08288

Figure 6.8. Entrance to the Faridpur Muslim Mission, Bangladesh.



Sylvia Mortoza/PIX08289

Figure 6.9. Biogas plant digester.

Students/Staff

Currently, the number of students/orphans is 350 and there are 50 staff members (teachers and custodians, etc.) The normal school year runs from January to December, with breaks during the summer and at the end of the year, plus religious holidays. The school week runs five days a week, six hours per day.

This is a boarding school. Students reside at the school all year long. In addition, 50 staff members reside at the school. The technical training center is open to both the orphans and to outside students.

Energy End Use in the School

A hand pump is used to pump tube well water.

The largest energy use is for cooking. There are four burners, with one using biogas and the other three using wood fuel, cow dung, jute stalks etc.

Educational Aids: There are four computers and a printer.

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The Biogas Plant

The biogas plant consists of: an inlet chamber, where sludge is collected from the toilets; a fermentation chamber; and a hydraulic chamber for the residue. It is based on a design of a household biogas plant using human excrement provided by the Local Government Engineering Department (LGED).

The plant is of the fixed-dome type originally developed in China. The feedstock is primarily human excrement. The biogas plant produces six hours of gas per day, which is enough for one burner only, and does not meet the entire cooking needs of the school. The second plant, which is incomplete, was designed to operate on a feedstock of cow dung, water hyacinth, and agricultural wastes.

Local masons, under the direct supervision of LGED, constructed the plant. The plant was constructed from brick and cement that are produced locally in Bangladesh. The construction took two to three months to complete in 1993. The plant has been in continuous operation since that time and is in good condition.

The total cost for the operational plant is Taka 17,000 (U.S. $351), the non-operational plant cost is Taka 30,000 (U.S. $619). LGED paid for the system and handled the financial arrangements for the capital investment. The school pays for operation and maintenance. In practice, O&M costs have proved to be negligible.

The cost of replacing the operational plant today would be Taka 25,000 (U.S. $515) and the non-operational plant would be Taka 40,000 (U.S.$825).

Operation and Maintenance of the Renewable Energy System

The school superintendent and secretary operate the plant. Local staff does maintenance and repairs. No major repairs have been undertaken in the first five years of the operation, except for a minor repair to the collection pit in 1998. No specific training programs for custodians or teachers have been instituted in the operation and maintenance of the RES. Though school administrators believe that proper training would be desirable, they consider operation and maintenance to be quite adequate. No performance change has been noted over the years. System malfunctions are reported to the school secretary who in turn notifies the Thana (precinct) engineer of the LGED.

Education and Sociocultural Considerations

Since the installation of these biogas plants, no new RE systems have been installed at the school. There has been no effort to use the plant for educational purposes at the school. There have been successful installations of additional biogas systems in the local community. The principal barrier to the uptake of this technology in the community is the cost and lack of financing.

The potential exists for the school to build additional biogas plants for lighting as well as for additional cooking fuel. This would depend on the availability of feedstock to run the plant. There are no seasonal or climatic limitations to using of the biogas plant on a daily basis. The Bangladesh Center for Scientific and Industrial Research (BCSIR) Dhaka is the national and regional support structure for this technology.

School officials have noted that it takes 50% less time to cook food on the biogas burner than on a comparable wood-fuelled burner. As the raw material is human excretion, there are no


Sylvia Mortoza/PIX08279

Figure 6.10. Oven fueled by biogas.

costs involved for its collection. They find the biogas is cleaner and more efficient than other fuels and it is definitely socially acceptable.

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CASE STUDY #6 — A Renewable Energy Training Center in Lesotho

Background

The Bethel Business and Community Development Centre, (BBCDC) is a private agency whose main goal is to develop the human, economic and technical potential of the area through practical education.

Details of Training

Total number of staff: 6.

Total number of students: 30 full time (2-year courses), 100 per annum (1-week courses).

Solar technology is taught as a core subject in the two-year rural development curriculum.

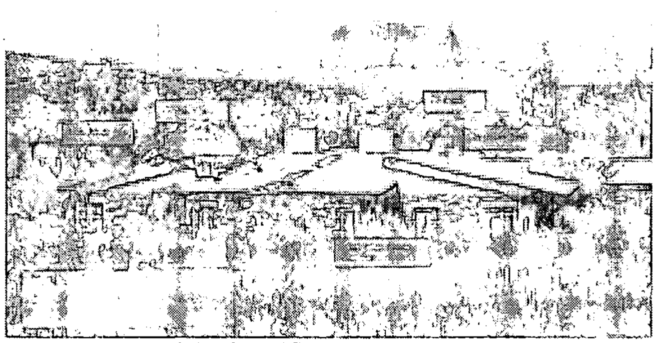
Bethel Center/PIX08280

Figure 6.11. Main conference center showing RE applications.

BBCDC can accommodate 10 to 16 guests for short courses, conferences, meetings, or retreats. It can also arrange for visits of several months by researchers and academics professionally engaged in RE research or other aspects of rural development.

Energy System Types/Services:

Photovoltaics, solar ovens, solar water heaters, underfloor solar mass heating systems, water tank mass heating system, solar greenhouse, radiative nocturnal cooler, passive solar design, daylighting, hydraulic ram pumps, and biomass for fuel wood coppice.

Renewable Energy System Description

Photovoltaics: Four staff houses, a guest flat, a conference center, and a library-office building are each fitted with 12-volt, stand-alone photovoltaic systems. Installed PV capacity is as follows:

- One-staff house: 220 watts, used for lights, 60-liter fridge/freezer, fan for solar underfloor heating, small spin washer, desktop computer, printer, satellite telephone, and small power tools. The house is also wired for 220 volts and has a 600-watt inverter.
- Two-staff house: 20 watts each, used for lights and radio.
- One-staff house: 55 watts, used for lights and radio.
- One guest flat: 10 watts, used for lights.
- Conference Center: 150 watts, used for lights and fans for underfloor heating, and 220 volts, used for the inverter for such equipment as videos and an overhead projector.
- Library-office building: 220 watts, used for lights, television, satellite receiver, a 120-liter fridge/freezer, and charging of cordless type power tools.

Solar ovens: Household solar ovens are being produced at BBCDC on a commercial basis. Two large prototypes with glass area of 0.5 m^2 and 1.0 m^2, respectively, are used in the school kitchen.

Figure 6.12. Staff house—note clerestory window.

Solar water heaters: Two thermosyphon water heaters are fitted on staff houses, each with 100-liter tanks and 1.2 m^2 of collector area. The Conference Center is fitted with an integral design thermosyphon heater with 2 x 150-liter tanks, and a 6.4-m^2 collector. One old batch-type water heater is soon to be replaced by an upgraded thermosyphon model.

Underfloor mass heating systems: One staff house is built with rock storage beneath the floor slab that is ducted to a collector on a wall facing the equator. A 12-volt fan is used to circulate air. The Conference Center is built with rock storage beneath the floor slabs of the guestrooms. Hot air from clear glazed solar attics on the central roof are ducted to the storage. Two 12-volt fans circulate air.

Water tank mass heating system: An extension to one of the staff houses has recently been completed and includes an 8000-liter roof water collection tank. The tank is within the house envelope and is designed to thermosyphon in winter to a ground mounted collector (4 m^2). The system is for space heating. It has not yet been through a winter and is under testing.

Brace design greenhouse: Nocturnal temperatures of -10°C are common in Lesotho in winter. A 3 x 5 meter (Brace Research Institute design) greenhouse is built on the campus and used for seedling production. Thermal mass consists of 3 x 100-liter barrels of water. It remains frost-free during the winter months.

Radiative nocturnal cooler: The climate in the highlands of Lesotho is suitable for radiative nocturnal cooling. A passive cooler is built on the Campus with eight cubic meters of interior volume. It is cooled by means of a roof pond and retractable roof. A 32-m^3 cooler has recently been built by BBCDC off-campus for a farmer's cooperative.

Passive solar design: The buildings are all well oriented and most of the residential buildings are fitted with wall and ceiling insulation.

Daylighting: The Conference Center is built with daylighting in the main classroom and in the bathrooms. Clear fiberglass panels are fitted on the outside, and a frosted glass panel is fitted on the inside ceiling. Light is tunneled using ordinary aluminized building paper. The interior glass panel is hinged to allow cleaning. A recent house extension includes daylighting in the bathroom and a clerestory window. Recent buildings have been fitted with double glazed window units built by BBCDC.

Hydraulic ram pumps: An old Blakes hydram is used to provide water for BBCDC and the Bethel Mission. BBCDC has also built ram pumps using 50mm and 80mm pipefittings and a few welded components.

Biomass for fuel wood coppice: the BBCDC campus has been extensively landscaped with earthworks for storm water capture. The result is greatly improved biomass production and poplar bluffs are becoming rampant. Photosynthesis is after all, the ultimate energy creator on the earth, and in arid climates water is the limiting factor.

Installation Information

PV panels and components have all been purchased. All other solar energy systems are in-house products, assembled from raw materials and basic components.

The following equipment has been used:

4 x 60-watt 12-volt panels: Solarex

4 x 55-watt 12-volt panels: Siemens

2 x 20-watt 12-volt panels (amorphous): Siemens

1 x 10-watt 12-volt panels: Arco

All other solar energy systems: BBCDC

Installations by: BBCDC staff and students.

Year Installed: incrementally, between Jan. 1, 1993 to present.

Present condition of equipment: excellent; continuous process of upgrading and expansion is carried out.

System Costs (US$)

10 watt Arco: U.S. $500.00 (1987)

20 watt Siemens: U.S. $75.00 (1993)

60 watt Solarex: U.S. $400.00 (1996)

55 watt Siemens: U.S. $300.00 (1997)

*The cost of all the other equipment is difficult to determine because it was all done in-house. Tanks for the solar water heaters, for example, were collected from scrap yards.

Who paid for the equipment? Some was purchased privately by staff members. Some was purchased by BBCDC out of its general revenue fund earned through commercial operations. Some was part of a grant allocation from the Irish Consulate in Lesotho. For financing, BBCDC has secured a U.S. $25,000 loan from E&Co., based in the United States, for solar energy commercialization. In the first phase of operations, this is allowing BBCDC to commercialize solar oven manufacturing and to market and install stand-alone PV systems.

Labor costs: BBCDC staff and students did all installation and fabrication.

Repairs and maintenance: All done by BBCDC staff and students.

Maintenance costs: Covered by BBCDC commercial revenues.

Training in System Operation and Maintenance

No one at BBCDC has been trained specifically for any of the above. In fact, none of the staff have a formal technical qualification in any field. The staff are self-taught. One of the staff members has recently been to a three-week course sponsored by the International Institute for Energy Conservation.

Are there national/regional markets?

These are in their infancy. The support structure is emerging, although little is being done to promote solar technology on a broad scale. The benefits to education are enormous, to say the least. The main lesson is that all of the systems at BBCDC are affordable on a "Do It Yourself" basis where local enthusiasm and industry can design, build, install, and maintain systems. It is extremely expensive on a "turn key" basis. Solar energy is an excellent way of using local resources, teaching general shop skills and applied sciences, and of greatly augmenting facilities.

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CHAPTER 7: LESSONS LEARNED

Chapter Introduction

Many lessons have been learned from past experiences. Lessons learned are a valuable resource for future success. These experiences apply at all levels: institutional, operational, system design, technology, and development.

Institutional

• A policy framework to integrate RE resources into school buildings, both for improving efficiency and for educational purposes, must be supported with political will and commitment.

• Perceptions are often inaccurate or over simplified. Common misperceptions are that RE power systems are unaffordable, a future technology, or that they require no maintenance.

• Donor funded programs often fail for lack of operating funds and inadequate local service infrastructure.

• Existing local service infrastructures may be adapted to provide routine maintenance and timely repair.

• Evaluation of system costs based only upon initial cost discourages the choice for RE sources.

• Cost analysis often lacks consideration for non-comparable qualities of service.

• There are great potential benefits from cooperation with other human service sectors such as public health, agriculture, safe water supply, economic development, and communications. These links are in need of development.

• Energy supply in the local community can generate income to support operating expenses.

• Energy supply in the local community has need for and the ability to economically support a commercial service infrastructure.

Operational

• Lack of maintenance is common and leads to system failure.

• Lack of installation standards of acceptance leads to system failure.

• Users are often unaware of the proper operation, care, or limitations of RE systems. Metering is often not understood or is confusing to the user.

• Training must be thorough and ongoing.

• Logistics are often underfunded and too bureaucratic.

• There is often a lack of spare parts, particularly with special parts.

• Systems should be supplied as simple and complete as possible.

• Pilot projects must be replicable and use proven technologies.

• Pilot projects must be of a manageable scale for those implementing them.

• Pilot projects must be monitored and evaluated prior to implementation of full-scale projects.

System Design

• Lack of procurement standards leads to confusion on the part of suppliers and often results in the least cost, least robust option.

• Although higher efficiency results in lower costs, simplicity in system maintenance should also be taken into account.

• Energy systems should be integrated with end use applications.

• The energy system/application must be the least expensive, highest benefit option to meet the needs of the school system.

• Systems should be designed and provided as completely and detailed as possible.

• Adequate technical and user manuals must accompany RE systems and equipment.

• One size does not fit all. Systems must be properly designed for particular site conditions.

• Sophisticated electronics may be vulnerable to damage by lightning.

Technology and Development Needs

• There is a need for more reliable resource data.

• The implementation process may require several (4–6) years for full start-up. Implementation is then on going.

• Choices must be driven by programmatic needs rather than technology.

• Program planners need reliable and understandable information regarding energy choices.

• The fact that schools are often located in remote, poorly accessible areas, dictates that the technical designs for RE systems should be simple, robust, and easy to maintain; this should constitute an overriding system selection criteria.

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GLOSSARY

Alternating Current (ac)—Electric current in which the direction of flow oscillates at frequent, regular intervals.

Altitude—The angle between the horizon (a horizontal plane) and the sun, measured in degrees.

Amorphous Silicon—A thin film PV silicon cell having no crystalline structure.

Ampere (A)—Unit of electric current measuring the flow of electrons per unit time.

Ampere-Hour (Ah)—The quantity of electrical energy equal to the flow of current of one ampere for one hour.

Angle of Incidence—Angle that references the sun's radiation striking a surface. A "normal" angle of incidence refers to the sun striking a surface at a 90° (or perpendicular) angle.

Annualized Cost—The equivalent annual cost of a project if the expenses are treated as being equal each year. The discounted total of the annualized costs over the project lifetime is equal to the net present cost (NPC) of the project.

Array—A mechanically integrated configuration of modules together with support structure, designed to form a DC power-producing unit.

Azimuth—Angle between true south and the point directly below the location of the sun. Measured in degrees.

Battery—Two or more "cells" electrically connected for storing electrical energy.

Battery Capacity—Generally, the total number of ampere-hours that can be withdrawn from a fully charged cell or battery. The energy storage capacity is the ampere-hour capacity multiplied by the battery voltage.

Battery Cell—A galvanic cell for storage of electrical energy. This cell after being discharged may be restored to a fully charged condition by an electric current.

Battery Cycle Life—The number of cycles, to a specified depth of discharge, that a cell or battery can undergo before failing to meet its specified capacity or efficiency performance criteria.

Battery Self Discharge—Self-discharge is the loss of otherwise usable chemical energy by spontaneous currents within the cell or battery regardless of its connections to an external circuit.

Battery State of Charge—Percentage of full charge or 100% minus the depth of discharge (see depth of discharge).

Charge Controller—A device that controls the charging rate and/or state of charge for batteries.

Charge Rate—The current applied to a cell or battery to restore its available capacity.

Concentrator—An optical component of a photovoltaic array used to direct and increase the amount of incident sunlight on a solar cell.

Conversion Efficiency (PV)—The ratio of the electricity energy produced by a photovoltaic cell (under full sun conditions) to the energy from incident sunlight on the cell.

Cost of Energy—The cost per unit of energy that, if held constant through the analysis period, would provide the same net present revenue value as the net present cost of the system.

Crystalline Silicon—A type of PV cell made from a single crystal or polycrystalline slice of silicon.

Current—The flow of electric charge in a conductor between two points having a difference in potential (voltage).

Cut-In Speed—The minimum wind speed at which a particular wind turbine will produce energy.

Cut -Out Speed—The speed at which a particular wind turbine will reduce its power output in order to protect itself from excessive wind speeds. Most small wind turbines do this by tilting out of the wind.

Days of Autonomy—The number of consecutive days a stand-alone system will meet a defined load without energy input.

Deep Cycle Battery—Type of battery that can be discharged to a large fraction of capacity many times without damaging the battery.

Depth of Discharge (DOD)—The amount of ampere-hours removed from a fully charged cell or battery, expressed as a percentage of rated capacity.

Design Month—The month having the lowest RE energy production to load ratio.

Direct Current (dc)—Electric current flowing in one direction.

Discharge Rate—The current removed over a specific period of time from a cell or battery.

Disconnect—Switch gear used to connect or disconnect components in a stand-alone system

Duty Cycle—The ratio of active time to total time. Used to describe the operating regime of appliances or loads in stand-alone systems.

Efficiency—The ratio of output power to input power. Expressed in percent.

Electric Circuit—A complete path followed by electrons from a power source to a load and back to source.

Electric Current—Magnitude of the flow of electrons.

Electrolyte—A conducting medium in which the flow of electric takes place by migration of ions. The electrolyte for a lead-acid storage cell is an aqueous solution of sulfuric acid.

Equalization—The process of mixing the electrolyte in batteries by periodically overcharging the batteries for a short period.

Grid—The network of transmission lines, distribution lines, and transformers used in central power systems.

Insolation—The solar radiation incident on an area. Usually expressed in Watts per square meter (W/m^2).

Inverter—A solid state device that changes a dc input to an ac output.

IV Curve—The graphical representation of the current versus the voltage of a photovoltaic cell, module, or array as the load is increased from zero voltage to maximum voltage. Typically normalized to 1000 watts per square meter of solar insulation at 25°C.

KiloWatt (kW)—One thousand Watts.

KiloWatt Hour (kWh)—One thousand Watt hours.

Life-Cycle Cost—An estimate of the cost of owning and operating a system for the period of its useful life; usually expressed in terms of the present value of all costs incurred over the lifetime of the system.

Load—The amount of electrical power being consumed at any given moment. Also, any device or appliance that is using power.

Maximum Power Point—The operating point on a PV array current vs voltage curve where maximum power is delivered.

Module (Panel)—A predetermined electrical configuration of solar cells laminated into a protected assembly.

NEC—An abbreviation for the National Electric Code which contains safety guidelines for all types of electrical installations. Article 690 pertains to solar photovoltaic systems.

Net Present Cost (NPC)—The value in the base year (usually the present year) of all expenses associated with a project.

Nominal Voltage—A reference voltage used to describe batteries, modules, or systems (i.e., a 12-Volt or 24-Volt battery, module or system).

Ohm—A unit of electrical resistance measurement.

Open Circuit Voltage—The maximum possible voltage across a photovoltaic array.

Orientation—Placement according to the directions, N, S, E, W; azimuth is the measure in degrees from true south.

Panel—See module.

Parallel Connection—The method of interconnecting electricity-producing devices or power consuming devices, so that the voltage is constant but the current is additive.

Peak Load— The maximum load or electrical power consumption occurring in a period of time.

Peak Watt (W_p)—The amount of power a photovoltaic device will produce during peak irradiance.

Photovoltaic (PV) Cell—A photo-electric cell that generates electrical energy when irradiance falls on it.

Photovoltaic (PV) System—An installed aggregate of solar array, power conditioning and other subsystems providing power to a given application.

Power Conditioning—The electrical equipment used to convert power from a photovoltaic array into a form suitable to meet the power supply requirements of more traditional loads. Loosely, a collective term for inverter, transformer, voltage regulator, meters, switches, and controls.

Power Curve—A graphical representation of a wind turbine's power output as a function of wind speed.

Renewable Energy (RE)— Energy produced by non fossil fuel or nuclear means. Includes energy produced by PV, wind turbines, hydro-electric, biomass, and solar thermal sources.

Series Connection—A method of interconnecting electricity producing devices or power using devices so that the current remains constant and the voltage is additive.

Short Circuit Current—Current measured when a PV cell (module) is not connected to a load or other resistance and is shorted.

Single-Crystal Silicon—A material formed from a single silicon crystal.

Solar Cell—see Photovoltaic cell.

Solar Thermal Electric—Method of producing electricity from solar energy by concentrating sunlight on a working fluid which changes phase to drive a turbine generator.

Stand-Alone System—A system that operates independently of the utility lines.

Standards of Acceptance—A set of characteristics; attributes, features and performance criteria which establishes the minimum acceptable quality and value of products and services. In the context of health care, these standards are adopted by the purchaser or authority responsible for procuring health care systems.

State-of-Charge—The available capacity in a cell or battery expressed as a percentage of rated capacity. For example, if 25-ampere-hours have been removed from a fully charged 100-ampere-hours cell, the new state of charge is 75%.

Sun Hours—A unit of measure of solar insolation: 1 sun-hour = 1000 watt-hours/m^2.

Surge Capacity—The ability of an inverter or generator to deliver high currents for short periods of time such as when starting motors.

Temperature Compensation—An allowance made in charge controller set points for changing battery temperatures.

Tilt Angle—Angle of inclination of collector as measured in degrees from the horizontal.

Volt, Voltage (V)—A unit of measurement of the force given to electrons in an electric circuit; electric potential.

Watt, Wattage (W)—Measure of electric power. Watts = Volts x Amps.

Watt-Hour (Wh)—A quantity of electrical energy when one Watt is used for one hour.

Wind Turbine—A device that converts the energy of moving air into electricity.

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Renewables for Sustainable Village Power

This is the second in a series of rural applications guidebooks that the National Renewable Energy Laboratory (NREL) Village Power Program is commissioning to couple commercial renewable systems with rural applications. The guidebooks are complemented by NREL Village Power Program development activities, international pilot projects, and the visiting professionals program. For more information on the NREL Village Power Program, please visit the Renewables for Sustainable Village Power Web site:

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