Guide to Energy Options for Small-Scale Rural ICT Projects

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List of Acronyms

AC	Alternating current
ACPI	Advanced configuration and power interface
AP	Access point
APM	Advanced power management
BD	Biodiesel
BIOS	Basic input/output system
BOS	Balance of systems
CFL	Compact fluorescent light
COE	Cost of electricity
CPE	Customer premise equipment
CPU	Central processing unit
CRT	Cathode ray tube
DC	Direct current
ELC	Electronic load controller
EPA	Environmental Protection Agency
GHG	Green house gases
HDPE	High density polyethylene
HF	High frequency
ICT	Information and communication technology
IEEE	Institute of Electrial and Electronics Engineers
ISP	Internet service provider
IT	Information technology
ITU	International Telecommunication Union
LAN	Local area network
LCD	Liquid crystal display
LED	Light emitting diode
LMR	Land mobile radio
LOS	Line of sight
LTSP	Linux terminal server program
LVD	Low voltage disconnect
NGO	Non-governmental organization
NPC	Net present cost
NTC	Negative thermal coefficient
O&M	Operation and Maintenance
OS	Operating system
PC	Personal computer
PDA	Personal digital assistant
PSH	Peak sun hour
PV	Photovoltaic
PVC	Polyvinyl chloride
RAM	Random access memory
RE	Renewable energy
SME	Small and medium enterprises
TFT	Thin film transistor
UHF	Ultra high frequency
UNEP	United Nations Environment Programme
UPS	Uninterruptible power supply
USAID	United States Agency for International Development
VCR	Videocassette recorder
VHF	Very high frequency
VSAT	Very small aperture terminal
WISP	Wireless internet service provider

Scope of Guide

This guide addresses the challenge of meeting the small-scale energy needs of ICT installations in rural and remote areas where there is insufficient access to high-quality, reliable electricity to meet the needs of the ICT installation. Compared to the use of ICTs in developed countries, the economics of ICT ownership are very different when there is no readily available supply of high-quality electricity, as in the following cases:

(1) There is no access to the grid at the desired location and grid extension is unaffordable or unavailable;
(2) Access to electricity is intermittent or unreliable, as with community diesel generators operated only in the evenings and electricity grids with frequent and long-lasting outages;
(3) Electricity is available but is characterized by extremely poor quality.

S*mall-scale* energy needs are defined in this guidebook as the consumption of no more than 10 or 12 kilowatt-hours (kWh) of electricity per day. These needs can typically be met by power systems with rated capacities ranging from tens of Watts up to 2 to 3 kilowatts (kW) of peak power. In practical terms, power systems within this size range are capable of supporting applications such as battery charging for cellphones; a satellite dish, television and videocassette player for distance education; or a rural telecenter with eight to ten energy-efficient computers. Once the demand for electricity starts to exceed the range defined above, greater economies of scale in the purchase of energy system equipment begin to tip the balance of cost-benefit analyses toward different solutions and approaches than those described in this guide.

The guidebook intentionally excludes consideration of broader rural energy issues such as household electrification and independent power producers. The issues of rural electrification and service provision are broad and complex, and have been debated elsewhere. Although it would be ideal if the energy needs of rural communities were addressed in an integrated and comprehensive manner, the practical reality is that there may be good reasons to extend ICT-based programs into off-grid areas before the general community is electrified, for example as part of public health and education campaigns.

Who is This Guide For?

This guide is designed for:

(1) ***Program Managers*** and officials in government agencies, NGOs and other organizations with responsibility for rural ICT program implementation and support.
(2) ***Entrepreneurs*** engaged in the process of establishing telecenters or other ICT-based businesses in poorly electrified or off-grid areas of developing countries.
(3) ***Decision Makers*** who are responsible for critical screening and approval of rural ICT initiatives.
(4) ***RE Engineers*** who need information on the power requirements of ICTs in order to assist and advise customers on planning their systems.

Questions This Guide Answers

- What options are available for powering small-scale ICT installations in off-grid areas?
- Can my off-grid ICT project save money by selecting low-power computers and equipment?
- What are some guidelines on the power consumption of different kinds of ICTs?

1 Introduction

Information and Communication Technologies (ICTs) are contributing to the achievement of development goals in diverse and ever-expanding ways. They are used to increase the effectiveness and reach of development interventions, to enhance good governance and to lower the delivery costs of many public and private services. When used appropriately, ICTs facilitate the creation and strengthening of new economic and social networks with the potential to advance and even transform the development process. As illustrated in **Box 1**, ICTs are increasingly applied to interventions in such critical sectors as education, health, agriculture and disaster management.

A number of crosscutting issues arise in almost every application of ICTs to development processes. These include equity in the access and use of ICTs by competing social groups; the capacity to reorient ICTs to multiple uses; ensuring information flows across the barriers of illiteracy and limited access; production of meaningful content for distribution via ICTs; and the challenge of utilizing ICTs in areas where infrastructure such as electricity and technical support are notably lacking. A growing number of organizations seek to apply ICT best practices in unelectrified areas, but are faced with the questions of how to adapt those practices to the conditions in rural and remote areas and how to meet ICT energy needs given the limited availability of financing.

To help answer these questions, this guide describes a variety of energy systems that can power small-scale ICT projects in off-grid areas and identifies practical ways to reduce the costs of those systems. Informed selection of ICTs can net savings of thousands of dollars for off-grid projects by reducing the need for energy. As will be demonstrated in Section 3 of this guide, simply using energy efficient notebook computers instead of desktop systems can reduce the net investment in an off-grid telecenter by over US$30,000. One of the primary goals of the discussion is to raise awareness of the relationship between ICTs and energy, and the financial benefits of considering energy needs early in the process when planning ICT programs in unelectrified areas.

Box 1: Positive Benefits of ICTs for Development

Quality and Access to Education
ICTs can enhance the quality and effectiveness of education in schools by expanding teachers' and students' access to instructional materials and educational resources. The combination of ICTs with broadcast technologies and thoughtfully designed content, through programs such as interactive radio instruction (IRI), educational television and distance education, can be an efficient and cost-effective way to reach remote students and address shortages of teachers and physical materials.

Agricultural Development
As farmers' exposure to competition from outside their national markets has increased, so has their need to access and interpret timely market information and to find new ways to market existing products. When added to traditionally effective tools such as radio broadcasting and communication systems, the Internet and ICT systems can be powerful tools for providing access to critical market and technical information. Because the potential of ICTs is recognized throughout the agricultural sector, a significant demand has been created for improved ICT services in rural areas.

E-governance
Local, regional, and national governments are using ICTs to improve the delivery of government services, to make government processes more efficient and transparent, and to foster voting and political participation by the populace.

Health and Wellness
ICTs are being used to disseminate public health messages and techniques for prevention of diseases, such as HIV; to enable more effective epidemiological surveillance and response mechanisms; to facilitate remote medical consultation, diagnosis and treatment; and to facilitate collaboration and research among physicians, among other applications.

Disaster Mitigation and Response
ICTs help governments, international agencies and NGOs monitor and respond to natural disasters, thereby reducing developing countries' vulnerability to these events.

Environmental Monitoring and Resource Management
ICTs can be used to collect, process, and disseminate information between distributed locations. This can enable a better understanding of complex cross-border issues such as climate change and biodiversity, and help to monitor ecological conditions so that prevention and mitigation measures can be activated.

Preservation of Cultural and Indigenous Knowledge
ICTs appear to have potential as a tool for recording and preserving indigenous populations' culture and traditions, and for educating the rest of the world about the importance of protecting indigenous values and ways of life.

2 Small-Scale Power Systems

There are a number of ways to power small-scale ICT installations in locations that are not served by the electricity grid. Typically, the easiest and least expensive solution from the end user's perspective is to arrange for the extension of the electricity grid to the project site. The cost of grid extension increases with the distance from the grid at a rate of several thousand U.S. dollars per kilometer (**Table 1**). Therefore grid extension often starts to become economically prohibitive farther than three to five km from the grid.

When grid extension is not an option, a *standalone* or *distributed* power system can be installed to generate electricity at a location close to the site where the electricity is needed. (For those who require an introduction or refresher to the basic concepts and terminology of electricity and power generation, Annex 1 contains a brief review of these topics.) Examples of small-scale, standalone power systems include generator sets powered by diesel, solar PV systems, small wind systems, and micro-hydro systems. As illustrated in **Table 1**, the cost of providing power in off-grid locations is influenced by the technology, the size or capacity of the system, and the ongoing operating costs of fuel and maintenance.

Table 1 Costs of Energy Options for Off-Grid ICT Installations

	Grid extension	**Solar PV**	**Small Wind**	**Micro-Hydro**	**Diesel/Gas Generator**
Capital Costs	$4,000 to $10,000[1] per km	$12,000 to $20,000 per kW	$2,000 to $8,000 per kW	$1,000 to $4,000 per kW	$1,000 per kW
Operating Costs	$80 to $120[2] per 1,000 kWh	$5 per 1,000 kWh[3]	$10 per 1,000 kWh[4]	$20 per 1,000 kWh[5]	$250 per 1,000 kWh[6]

Sections 2.1 to 2.5 introduce to these and other commercialized, field-tested energy options that have been used to power small-scale installations around the world. The technologies described include some that are relatively familiar and widespread in rural areas, such as generator sets, as well as more site-specific options such as wind power and micro-hydro.

The information that follows is not intended to be a substitute for professional advice. To ensure a safe and effective power solution for a particular situation, an experienced professional should always participate in the design, installation and maintenance of electrical systems.

2.1 Solar Photovoltaics

Photovoltaic power offers a proven and reliable source of electrical power for remote, small-scale ICT facilities. PV systems turn sunlight directly into electricity for use by communications devices, computers and other kinds of equipment. Since there are typically no moving parts in PV systems, they require minimal maintenance. While often more expensive than other renewable technologies, the modularity of PV systems and the broad availability of the solar resource, sunlight, often make PV the most technically and economically feasible power generation option for small installations in remote areas.

The initial investment in a PV system typically accounts for most of its lifetime acquisition, operation and maintenance costs. Careful selection, planning and management of ICT loads are critical to controlling this upfront cost. The cost of a PV system rises in direct proportion to the total size of the loads. Experience

[1] NRECA, February 2000.
[2] Based on retail electricity rates of $0.08 to $0.12 per kWh.
[3] U.S. Office of Technology Assessment, 1992.
[4] U.S. Office of Technology Assessment, 1992.
[5] U.S. Office of Technology Assessment, 1992.
[6] Assuming price of diesel is $0.50/l. U.S. Office of Technology Assessment, 1992.

has shown that failure to specify the size of the ICT load when requesting quotations for PV systems can result in proposals that are grossly oversized and cost tens of thousands of dollars more than necessary. This is not ordinarily due to any attempt by suppliers to take advantage of the situation; it simply reflects the fact that when the equipment power consumption is not specified in a request for quotes, system engineers will tend to err on the side of caution.

Resource

The solar resource is available all over the world. Insolation, or the rate at which solar energy is received over a period of time, is measured by the number of peak sun hours (PSH) per day. The number of PSHs is very important when sizing the PV system because it tells how much energy can be “harvested” from the sun in a specific location.

Insolation tends to be higher around the equator, in tropical zones, in deserts and in semi-arid regions, but is also affected by factors such as cloudiness and altitude. The fewer cloudy days an area experiences during a year, the better the system will perform. Average insolation in Cairo, Egypt is approximately 5.68 PSH, while insolation far to the north in Goose Bay, Canada is only 2.78 PSH. Although the city of Quito, Ecuador is situated only 25 km from the equator, its location high in the Andes mountains and long rainy season result in average insolation of only 3.82 PSH. Average annual insolation levels around the world tend to range between 3 PSH and 6 PSH (see **Figure 1**).

Since PV energy is only produced when the sun is up, most systems require batteries to support loads during nighttime and periods of cloudy weather. The battery bank is sized to provide power over the course of a given number of days of *autonomy*, or the maximum length of time the facility can be powered from the batteries without recharging. Battery storage adds to the cost and complexity of the system, but increases the availability of power at sunless times of the day and year.

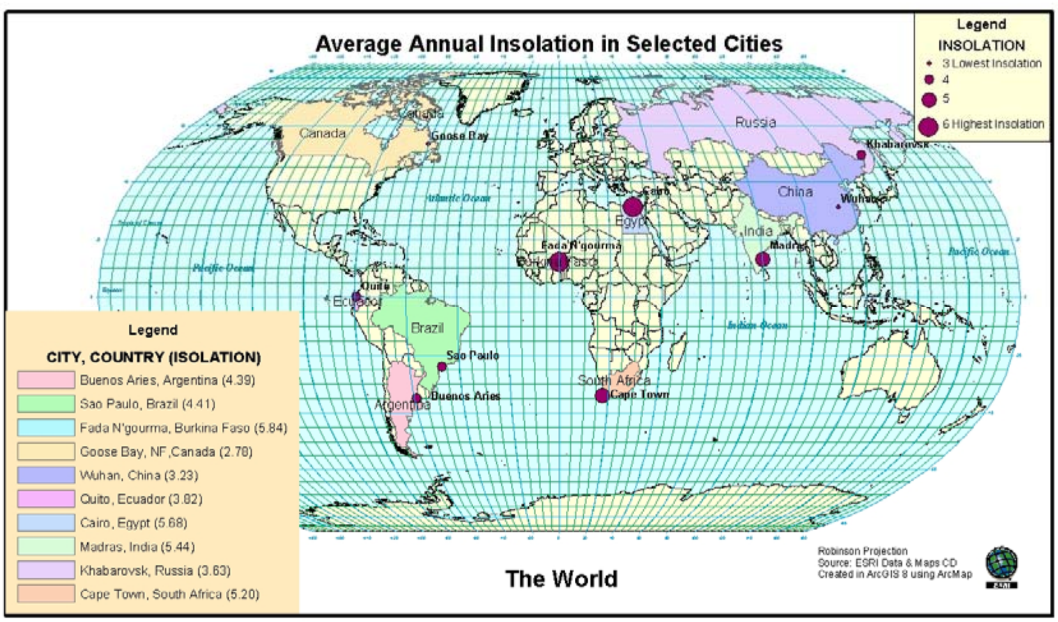


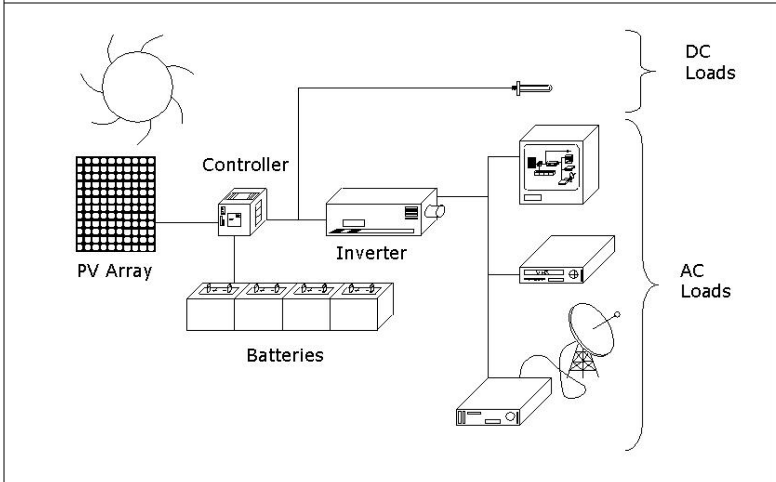
Figure 1 Average Annual Insolation in Selected Cities

Components

Typical components of a solar PV system include PV modules, controllers, inverters, battery banks, and BOS (**Figure 2**). A PV *module*, also called a solar panel, is a set of PV cells that are electrically interconnected, sealed together in a casing and weatherproofed. The type of PV cell technology used can affect the design of the system, but has little, if any, impact on the functioning of the system. Since there are no moving parts, modules are very reliable and durable.

Modules come in several different sizes. The most common size for a module is 50W nominal power, although modules are produced in sizes ranging from 10W to 300W nominal power. There are different types of modules that vary in longevity, from 15 to more than 25 years.

Figure 2 Components of a Photovoltaic System



Source: NMSU

Two or more modules connected together form an *array*. The energy output of an array is dependent on the rated power of each module, the number of modules in the array, and the number of hours of direct sunlight received. You will get twice the energy from two modules as from one. Very large arrays can have several hundred modules.

PV arrays, like batteries, output electrical energy in the form of direct current. In some PV system designs, such as the one illustrated in **Figure 2**, there is an inverter to convert the electrical energy to AC. In other designs there is a DC-DC converter to produce the appropriate DC voltage for the loads.

Location

Due to energy losses when transporting electricity over distances, especially at the low voltages typical of small PV projects, PV systems should be located within a reasonable distance of the point of energy use. Fortunately, PV modules can be placed anywhere the sun shines, including the roof of a building. Care must be taken to secure the modules in areas of high winds to prevent loss or damage. PV modules are very sensitive to shading. The shading of 5% to 10% of the surface area of a module can lead to a drop in power output of 30% to 50% or more.

Operation and Maintenance (O&M)

The minimal O&M requirements of a PV system make this technology well suited for isolated locations and rural applications where assistance may be infrequently available. Preventive maintenance, such as routine system cleaning and inspection, are always recommended. The most common maintenance required for typical PV systems is the periodic addition of distilled water to the batteries when flooded batteries are used. More expensive systems, using sealed batteries, can run for extended periods (months) without user intervention.

When PV systems are used and managed by community organizations or system owners, there is a critical ongoing need for training and/or assistance in system maintenance and troubleshooting. Sometimes the malfunctioning of a small fuse can be the reason for a system failure. In this case, a routine inspection by an experienced technician could reveal what caused the original problem that burned the fuse.

Environmental Impacts

A PV system produces negligible pollutants during normal operation. The main environmental impact associated with PV systems comes from the failure to properly dispose of batteries used in conjunction with the arrays.

Costs

The cost of a standalone PV system varies greatly depending on local market conditions and the quality of the equipment used. While the PV modules themselves may cost US$4.00 to US$7.00 per Watt, the total upfront investment cost of a PV system, including batteries, inverter, installation, etc., typically ranges between US$12.00 and US$20.00 per Watt installed. Costs per installed Watt depend on system size, the installation site and component quality. Smaller systems (less than 1 kW) tend to be at the higher end of the cost range. Additional factors that influence overall costs include government subsidies, the scale of the equipment procurement (with larger volume orders benefiting from lower per-unit costs), and the competitiveness of the local PV market.

The initial cost of a small-scale PV energy system typically rises by about US$640 (+/- $160)[7] for every additional 100 Watt hours (Wh) of energy that the system must supply on a daily basis. This is about the amount of energy needed to run a 17" CRT computer monitor for an hour a day. A 17" LCD monitor of the same size consumes only about 35 Wh of energy each hour, thus necessitating an additional capital investment of only $224 (+/- $56) in the photovoltaic system.

O&M costs for small-scale PV systems are generally low, at less than 1% of initial investment costs annually. If poor quality BOS components are used, these may fail and lead to higher costs to diagnose the problem and replace the faulty components.

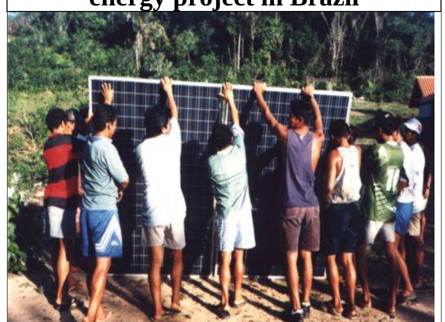
Viability

The PV option is most likely to be competitive when tens or hundreds of peak Watts are required in remote or hard-to-reach areas. Depending on the situation, PV may also be competitive when only a few kilowatts of energy are needed. In many rural areas, diesel or gas generators and PV systems are the only viable alternatives. Unlike generator sets, PV systems are quiet and do not generate pollution. With proper design, installation and maintenance practices, PV systems can be more reliable and longer lasting than generators.

The modularity of PV systems enables systems to be well matched to the demand. When there are multiple small sites requiring electrification, PV is best installed in the form of independent systems sized to match each individual load.

PV systems are more likely to fail in areas that lack the commercial and technical infrastructures needed to ensure long-term sustainability. This infrastructure includes PV markets that are active enough to sustain the field over time, including suppliers of warranted PV system components, installers and maintenance technicians. Another key requirement is end-user acceptance of the technology, both in terms of the solar PV energy system and the ICT services being implemented. If the end-user does not share part of the responsibility for the cost, installation, maintenance and supervision of the system, the project is unlikely to survive.

Community involvement in a solar energy project in Brazil



Source: Aurélio Souza – Winrock Brazil

2.2 Small Wind Turbines

Wind power is a potential source of energy for electrical power in rural and remote areas. Wind-driven turbines capture mechanical energy, which can be converted to electrical energy through a generator. Small wind systems are considered to be those turbines with a generating capacity of less than 100 kW.

Small wind turbines for off-grid use are commercially available in a wide range of sizes and ratings. For

[7] A shorthand method for estimating the peak Watt capacity required for a solar PV system is to take the load, measured in terms of the number of Watt hours per day, multiply it by two, and divide the result by the average rate at which solar energy is received at the given location, measured in terms of peak sun hours (PSH) per day. The load is multiplied by two in order to account for energy losses due to inefficiencies in the system hardware. The example in the text is based on the assumption of 5 PSH. Thus the additional PV capacity required to supply 100 Wh of daily energy is (100 Wh x 2) ÷ 5 PSH = 40 Wp. The final cost assumes a PV system price of $16 (+/- $4) per peak Watt for a complete turnkey system, including installation.

small applications of the type needed for standalone ICT applications, wind turbines of 100 W to a few kilowatts are appropriate. Although 90% of global wind power capacity is installed in Europe and the United States, usage in other countries and regions is growing. India is one of the top five wind energy markets in the world, and China has installed more than 150,000 small wind turbines[8].

Wind Turbines

From left: 400 W, 900 W, 10 kW, 50 kW

Source: Bergey Wind Power and Southwest Wind Power

Resource

The faster the wind speed, the more energy there is in it. The energy in wind has a cubed relationship to the wind speed, a squared relationship to the turbine radius, and a direct relationship to the duration of the wind. Roughly speaking:

$$\boxed{\text{Wind Energy} \propto (\text{wind speed})^3 \times (\text{radius of turbine})^2 \times \text{time}}$$

The cubed relationship between wind energy and wind speed means that small increases in wind speed yield significant increases in energy output. Air flowing at 5 meters per second can yield twice the energy of air flowing at 4 m/s, and nearly 5 times the energy as air flowing at 3 m/s.

It is not uncommon for wind speed to have very large daily and seasonal variations and to be influenced by local terrain and microclimates. If the wind is very strong only for a few hours a day or a few months a year, wind power alone may not provide enough continuous power to support an ICT facility that operates year-round.

Components

The typical components of a small wind system include:

- A rotor, which comprises the blades and the hub of the wind turbine. For small-scale ICT applications, rotors of less than four meters in diameter are usually sufficient.
- A generator, typically housed in the turbine, to convert mechanical energy to electrical energy.
- A tower 10 to 20 meters tall, which supports the turbine far above the ground to capture higher wind speeds. The tower should be high enough so that the bottom of the rotor is at least 10 m above any turbulence-producing object within 100 m.
- A solid foundation and/or guy wire to prevent the wind turbine from toppling in high winds.
- A safety disconnect switch located between the generating components and the system electronics.
- A controller and/or regulator.
- A battery bank.
- An inverter to power AC loads, if necessary.

[8] Mike Bergey, "Small Wind Systems Tutorial", Village Power Conference Workshop, 2000.

Because wind turbines typically produce larger fluctuations in voltage and current than PV systems, they may require controllers and other system components designed specifically for small wind systems.

Location

The process of deciding on the site for setting up a wind turbine is called siting. The suitability of a particular site is affected by the duration and regularity of wind flows over the course of the day and the year. Large wind farms use complex computer models for siting. However, smaller wind turbines can be set up by using some rules of thumb, such as:

- Elevated areas such as hilltops receive more wind.
- Gentle sloping in the prevailing direction of the wind tends to increase wind speed but a very steep slope leads to turbulence that can impact the lifespan of the turbine.
- Ideally, there should be no hindrance to the flow of wind about the turbine within a distance of about 100 times the diameter of the rotor.
- The bottom of the rotor should be at least 10 rotor lengths higher than any surrounding obstacles.
- Local vegetation may be indicative of the existence of a wind resource and the prevailing direction of the wind.

Due to losses in efficiency from transporting energy over distances, wind systems should be located within a reasonable distance of the point of energy use, i.e. within about 100 m for a typical school-sized system.

Operation & Maintenance

Small turbines are specifically designed for high reliability and low maintenance. Today's state-of-the-art small wind turbines have adopted simple designs with three to four moving parts and automatic operation. Operating under normal conditions, they typically require infrequent maintenance. However, particularly harsh environments can require more robust designs and more expensive equipment, with a risk of increased maintenance costs as well.

Environmental Impacts

Wind power is a clean, renewable source of energy that produces negligible pollutants during normal operations. As with PV systems, battery disposal and recycling is the main environmental issue. Large wind turbines are known to generate noise that may negatively affect nearby species of animals, and there are also instances of flying birds colliding with turbines. However, noise and bird collisions are not typically associated with the smaller systems discussed here. Potential environmental impacts such as these can be evaluated on a case by case basis.

Costs

Small wind turbines are relatively inexpensive due to manufacturing economies of scale. Typical prices for the turbine only are in the range of $1.90 / Watt for a 500 W unit with a rotor 1.7 m in diameter, and $1.60 / Watt for a 10,000 W unit with a 7 m rotor.

Initial investment in small wind systems typically ranges from $2,000 to $8,000 per rated kW, including installation costs. Operation and maintenance costs tend to be in the range of $0.01 per kWh. Based on life cycle costs, wind is usually less expensive than PV for locations with an adequate wind resource. However, wind turbine efficiencies and cost per kilowatt vary from product to product.

Viability

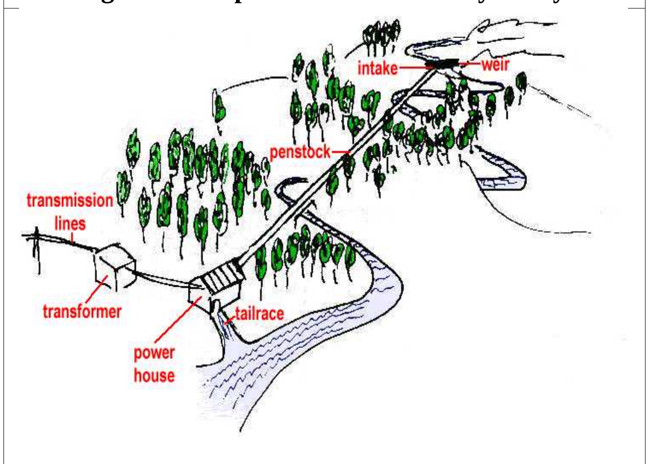
The cost effectiveness of a small wind system is dependent on the amount of wind available. Many parts of the world have excellent wind resources. Sites with average annual wind speeds of at least 3.5 m/s are more likely to be viable than those with lower average wind speeds. Annex 1 provides several starting points for obtaining wind resource data and maps for different countries.

Where there are sufficient energy resources to meet off-grid energy needs through either wind or PV systems, wind power tends to be the more cost-effective option. The more challenging aspects of a small wind project may include building the tower, maintaining a large area of clearance around the turbine throughout the lifetime of the system.

When evaluating wind projects, it is critical to assess the wind conditions at the proposed turbine site. Sites with an intermittent or irregular wind resource may benefit from the use of a *hybrid* energy system. A hybrid system integrates two or more energy generation technologies, such as wind power and solar PV, or wind power and a diesel generator. Hybrid energy systems are addressed in Section 2.5.

2.3 Micro-hydro

Figure 3 Components of a Micro-Hydro System



Source: http://www.microhydropower.net

Where the resource exists, micro-hydropower offers a proven and reliable source of electrical or mechanical power on demand, usually at a lower life cycle cost than diesel engine, wind, or PV systems. Using the energy of falling water, micro-hydropower systems supply mechanical energy that can be used directly or be converted to electrical energy through a generator, for use in lighting, refrigeration, information and communications technologies (ICT) or to run electric motors.

Micro-hydro systems typically produce more energy per rated kilowatt on a daily bases than wind energy or solar PV systems. This is possible since micro-hydro systems operate round the clock whereas solar and wind power systems generate power for only a few hours each day. For example, a 100 peak Watt solar PV system might produce 100 W * 4 hours = 400 Wh on a sunny day; a 100 W wind energy system might produce 100 W * 8 hours = 800 Wh per day; whereas a micro-hydro system of the same size can, in theory, produce 100 W * 24 hours = 2,400 Wh per day.

Hydropower plants of less than 100 kW capacity are generally categorized as 'micro-hydro'[9]. Plants in the 1–100 kW range generally supply power through a mini-grid to a rural community. Such plants mostly produce alternating current (AC) and as such the supply is not much different from the supply of electricity from the national grid. This section focuses on very small micro-hydro systems of less than 1 kW – sometimes referred to as 'pico-hydro' – which a user might consider installing specifically to power ICTs in isolated rural areas.

Resource

Power from falling water comes from its two primary components:

Flow: the rate of water flow, measured in liters per second (lps);
Head: the water's vertical drop, measured in meters.

The power potential of a site is proportional to the product of these two components. In metric units,

[9] There is no universally accepted definition of the size of micro-hydro vs. pico-hydro systems. The most common convention is to label systems under 100 kW as micro-hydro. Pico-hydro systems are often considered to be under 1 kW. Knowing the prevailing definition of micro- or pico-hydro can be important because in some countries, these designations have implications for local laws and regulations.

$$P = g * e * Q * H$$

where:

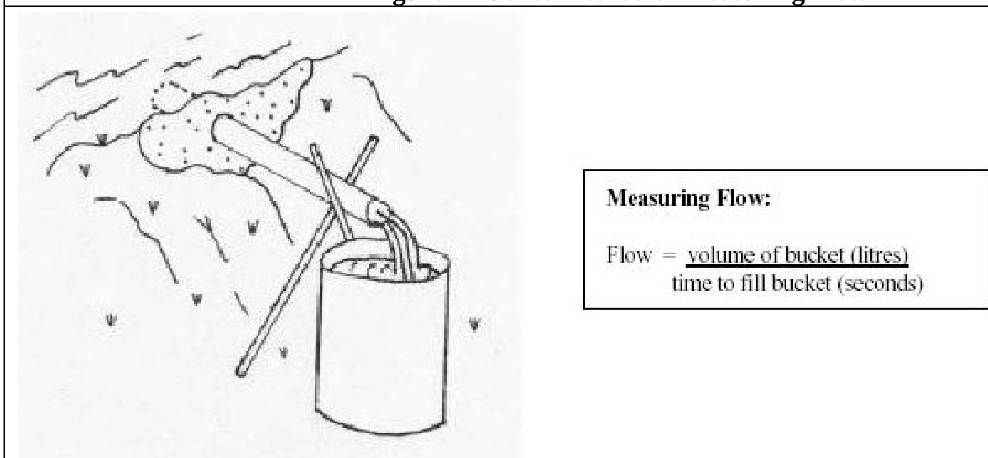
P = power (Watts)
g = 9.8 m/s^2 (acceleration due to gravity)
e = efficiency (%)
Q = flow (liters/second)
H = head (meters).

The efficiency term 'e' indicates that not all the potential of the site is available to the user due to losses in the equipment and structures. Average efficiency for small micro-hydro systems is around 50%.

For example, a flow of 10 liters per second falling through a head of 10 meters would yield power of 490 Watts, assuming a system efficiency of 50%. Because of the product relationship between head and flow, this same power could also be produced by a flow of 20 lps falling through a head of 5 m, or alternatively by a flow of 5 lps falling through 20 m of head.

The bucket method is a simple way of measuring flow in very small streams. The entire flow is diverted into a bucket and the time for the container to fill is recorded. The flow rate is obtained simply by dividing the volume of the container by the filling time (**Figure 4**).

Figure 4 Bucket Method of Measuring Flow



Source: PowerPal / Asian Phoenix Resources Ltd. Reprinted with permission.

Flows of up to 20 lps can be measured using a 200-liter oil barrel. The rate of flow that is measured during the driest season is used for the system design so that constant power is available throughout the year. Alternatively, a larger system can be installed and a small reservoir built to collect water during the dry season to generate full power for some critical hours of the day.

The head can be roughly measured using a simple eye-level and tape measure or more accurately with a theodolite. The details of different head measuring techniques can be found at: http://www.microhydropower.net/head.html.

Components

The basic components of a micro-hydro hydro system include:

- An intake where the water is diverted from a stream or a spring;
- a desilting tank which allows the sand and silt to settle out before the water is conveyed toward the turbine;

- a head race to transport the water to a forebay tank just above the power plant through a canal or a pipe;
- a forebay tank to collect the water and screen out debris before it is transported to the turbine;
- a penstock pipe to transport the water from the forebay tank to the power plant;
- a turbine to convert the power of the falling water into mechanical rotational power;
- a generator to convert the mechanical power to electricity;
- a controller to maintain a constant load on the generator;
- a tailrace to return the used water to the stream; and
- transmission and distribution lines to the users.

In some cases, the headrace and penstock pipes are the same and there is no forebay tank, as in **Figure 3** at the beginning of this section.

Since these systems are small, they can easily be transported or carried to rural areas even where there is no road access. The turbine, generator, control systems and other major components usually come in one unit, simplifying installation. A simple water flow diversion mechanism can be used to divert the water to the penstock pipe. Locally available plastic pipe (HDPE or PVC) can be used for penstock pipe for low cost and ease of installation.

The same precautions apply when operating ICTs off a mini-grid as with electricity supply from the national grid, such as the use of an uninterrupted power supply (UPS) or relay-based protection from fluctuating voltage. To be assured of high quality supply, users of ICTs may wish to confirm that the system is regulated by a load controller.

Available micro-hydro hydro technologies can be divided into two broad categories – those that produce direct current (DC) and are used to run DC loads or charge batteries, and those that produce alternating current (AC). Micro-hydro systems that produce DC power have many similarities to solar PV or wind energy systems. The energy they produce is used to charge batteries, which store the energy for use in applications such as lighting or powering ICT equipment. Often an inverter will be used to convert the DC output to AC.

Micro-hydro systems can also produce AC directly to be used with conventional appliances. Water supply from a stream or a spring is much less intermittent than other renewable energy sources like solar radiation or wind speed. This makes it possible for homes to be supplied with AC power as it is generated from a micro-hydro system without having to go through batteries. This reduces costs compared to solar PV or wind energy systems, which must use batteries for most electrification (non-water pumping) applications.

While micro-hydro systems that produce AC power are less expensive than those that produce DC power, they also pose some challenges for ICT applications. One major challenge is that the systems have difficulty supplying brief spikes in power demand from the loads. The starting current of certain appliances, such as CRT monitors, can be extremely high. Laser jet printers also draw high current spikes. A large current draw, even of momentary duration, can sometimes kill the excitation process, particularly of systems which use induction generators. When this happens, the voltage of the system will be reduced to zero even as the turbine is running at overspeed. Battery-based systems generally don't have this problem since the batteries are able to provide the momentary high power requirement.[10]

There are a number of solutions to these problems. One of them is to use laptop computers or desktop computers with LCD screens to avoid the problem of high current draw. In case these are not available, a *negative thermal coefficient* (NTC) resistor can be used in series with the appliance to limit the maximum current draw.

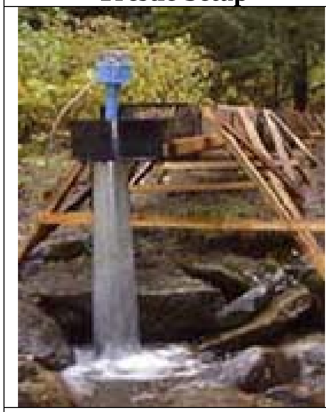
Location

Due to losses in transporting energy over distances, hydropower systems should be located within a reasonable distance of the point of energy use.

[10] Here too, however, the inverter must be able to supply the large momentary current required.

Operation & Maintenance

PowerPal Low Head Using Trestle Setup



Source: www.powerpal.com

The operation of a very small micro-hydro system, such as the blue PowerPal unit shown at left, is relatively simple compared to larger micro-hydro systems. There is no need for extensive training for the operator. The operation manual and/or manufacturer's guidance are often sufficient to enable operation of the system. Nevertheless, the involvement of a professional is strongly recommended in light of safety considerations, particularly for systems producing AC power.

Environmental Impacts

Micro-hydropower is a clean renewable source of energy that produces negligible pollution during normal operations. There can be an effect on the riparian area both at the settling pool and along the length of river from which the water has been diverted from the increase or decrease in soil moisture. For larger projects, clearing areas for construction and transmission lines may have environmental impacts. All of these factors can be mitigated with good planning and construction practices.

Costs

Micro-hydro systems generally cost between $1,000 and $4,000 per installed kW (see **Box 2**). The fact that many micro-hydro components can be fabricated in developing countries helps to keep costs low. Cash outlays for labor and materials for civil works may be reduced by contributions from the community.

Viability

Micro-hydro systems under 1 kW can provide power to rural communities located near a source of running water. Micro-hydro systems are usually less expensive than PV or small wind systems in terms of initial investment and lifetime cost of electricity. For larger projects, community involvement can both reduce the cost of civil works and improve the long-term viability of the project.

A variety of circumstances can reduce the feasibility of a micro-hydro project. Micro-hydro systems take longer to plan and install, and require substantially more civil construction works than solar PV systems. Reliable water sources and appropriate sites with a sizeable vertical drop may not be available at a location close to the community. Available water flow might also diminish during severe dry spells or from competing usage from other applications such as irrigation. Floods, landslides, or other natural calamities can also destroy the systems and can interrupt power generation unexpectedly and for long periods.

Box 2 Microhydro Costs

In a micro-hydro project in Kathamba, Kenya, implemented by the Micro Hydro Centre at Nottingham Trent University, the local community contributed nearly all of the labor as well as the land for the turbine house, building materials for the intake and turbine house, and distribution poles made from local trees[11]. The reported cash expenditure of the Kathamba project was US$3,788 for a 1.1 kW system ($3,444 per kW). A second micro-hydro project implemented by the same organization in Thima, Kenya had a total project cost of US$6,365 for a 2.2 kW system[12] ($2,893 per kW), while a third project in Nepal reported total costs of US$9,763 for a 4.4 kW system ($2,219 per kW). All of these projects relied on community contributions to reduce out-of-pocket costs.

2.4 Generator Sets

[11] P. Maher, "Community Pico Hydro in Sub-Saharan Africa/ Case Study One/ Kathamba, Kirinyaga District, Kenya." Micro Hydro Centre, The Nottingham Trent University, 17/01/02. URL: http://www.eee.ntu.ac.uk/research/microhydro/picosite.

[12] P.Maher, "Community Pico Hydro in Sub-Saharan Africa/ Case Study Two/Thima, Kirinyaga District, Kenya." Micro Hydro Centre, The Nottingham Trent University, 07/02/02. URL: http://www.eee.ntu.ac.uk/research/microhydro/picosite.

Small-scale electricity generator sets – commonly known as gensets – are among the most technologically and commercially mature options for distributed energy generation. Gensets are manufactured on a large scale worldwide, and they are used often to provide primary or backup power in off-grid and underelectrified areas. Generator sets have relatively low capital costs but high running costs due to the need to purchase fuel and provide regular maintenance. If routine maintenance tasks are not carried out regularly, the genset may break down before its time. This is a common fate of community-run gensets in rural areas.

Resource

For generator sets with a capacity of less than 3 kW, gasoline and diesel are popular fuels. Genset engines may also use other fuels, such as propane, kerosene, biogas, biofuels or fossil/biofuel mixtures. Biofuels, generally in liquid form, and biogas are fuels obtained from biomass such as crops, grains, seeds, tubers, animal fats, agro/forestry residue and wastes, wood and effluent. Examples of biofuels include alcohols such as (bio) ethanol and (bio) methanol; vegetable oils and fats; and biodiesel (BD).

All types of generating sets that use gasoline as a fuel, irrespective of the size of the generator, can utilize gasoline/ethanol (gasohol) blends containing up to 25% ethanol. However, many generating sets are warranted only for use of a 10% ethanol blend (E10). All types of generating sets that use diesel as a fuel can use biodiesel in any blend proportion with diesel. However, in many countries, suppliers' warranties and recognized standards permit the use of 20% biodiesel (B20) only. **Box 3** provides two examples of biofuels that, if available locally at an affordable cost, can be used to run small diesel generators for ICTs and other applications.

Box 3: Alternative Genset Fuels

Restaurant Oil Wastes

Ordinary vegetable oils can be used to power diesel engines in cars, trucks and generator sets. Restaurant waste oils can be used as fuel after filtering and treatment in a waste oil conversion system, or in a diesel engine that has been modified to treat the oil before injection. With some knowledge about which oils are most appropriate and how to operate and maintain the diesel engine to avoid corrosion and other problems, used cooking grease discarded by restaurants can become a cheap source of genset fuel. See Annex 4 for more information about liquid biofuels and links to related web sites.

Biogas

Biogas, although typically used for heating and cooking, can also be used to fuel a genset to produce electricity. Biodigesters convert animal or human waste and water into methane through anaerobic digestion, a biological process that occurs naturally in the absence of air. The process produces a gas that is typically 55% to 75% pure methane. This gas can be used for a variety of energy applications. Where there are simultaneous needs for improved sanitation, gas for heating and cooking, and electricity for ICTs, a biogas digester may be a feasible option. Although not often used to power ICTs in remote areas, some 3.4 million biogas digesters are in daily use in India, and smaller countries such as Nepal are installing around 26,000 digesters each year.

Components

The main components of a small-scale generator set are the internal combustion engine and the generator. Some models also come with a built-in inverter to output AC electricity.

Operation & Maintenance

Small portable gensets typically require maintenance every 200 to 400 running hours. Maintenance tasks include draining and changing the engine oil, changing the filter, and disposing of the used oil and filter. Maintenance may be performed in-house or by external service companies, such as the genset manufacturer or distributor.

If maintenance tasks such as changing the engine oil are not carried out on a regular basis, genset components can deteriorate, resulting in reduced efficiency and shortened equipment life. In Winrock's experience, generator set maintenance is at risk of being neglected in schools and other non-commercial facilities, where there is little personal incentive for teachers and other volunteers to ensure long-term care of the equipment. Entrepreneurs whose livelihoods depend on keeping the gensets running smoothly are more likely to make sure that proper maintenance is done.

Environmental Impacts

The main environmental drawbacks of genset use are air pollution, noise, and emission of greenhouse gases. It is also common to have leaks or spills of engine oil and fuel around the generator during the process of maintenance and refilling the tank. This can introduce pollutants to nearby waterbeds and rivers.

Noise can be an important environmental factor for local communities to take into account when considering the use of a generator set. The noise level for a 3 kW diesel generator can be 70 or 80 dB, about as loud as freeway traffic or an alarm clock. Generator noise has caused problems in rural schools when the generator is located near a classroom.

The type of fuel used can lessen air pollution to some degree. Compared to diesel, biodiesel reduces emissions of carbon monoxide and particulate matter as well as total unburned hydrocarbons. Since the sulfur content of biodiesel is very low, it does not contribute to the sulfur dioxide emissions that are often a major concern with the use of regular diesel. A joint study by the U.S. Department of Energy and Department of Agriculture estimated that biodiesel reduces life cycle carbon dioxide by 78%[13].

Costs

The initial cost of a small-scale generator system, including additional components and services such as batteries, BOS, installation and engineering, is in the range of $1,000 per kW installed, less for higher capacity systems. However, this does not include the cost of fuel and maintenance, which are likely to be multiples of the initial investment over time if the generator is used as the primary power source.

Fees related to labor and parts depend on local conditions. According to the California Energy Commission, the maintenance costs of gasoline gensets range from US$0.007/kWh to US$0.015/kWh, while maintenance costs of diesel gensets range from US$0.005/kWh to US$0.010/kWh[14]. One Indian manufacturer of small portable gensets provides maintenance service at a cost of 250 Rupees (US$5.45) for labor plus Rs150 to Rs250 (US$3.27 to US$5.45) for materials. At the latter rates, a generator with output of 1.5 kW, that required maintenance every 200 to 400 running hours, would have an O&M cost ranging from $0.015/kWh to $0.036/kWh.

The price of a diesel-fueled portable generator is normally higher than that of a gasoline-fueled generator. However, diesel generators tend to have lower fuel costs than gasoline generators over time. Fuel costs represent the largest ongoing cost of operating a genset, and fuel prices vary widely from country to country. In late 2003, diesel costs worldwide ranged from less than $0.35/liter (Philippines) to $0.90/liter (Rwanda). Biodiesel is normally more expensive than diesel. The production price difference between the two types of fuel is reduced in some markets as many governments provide various tax incentives for "green" fuels.

Purchasing a genset often appears to be the simplest and least expensive option for powering a small-scale ICT facility. This perception is at least partly due to the relatively low up-front capital costs of gensets compared to other options. However, when the lifetime costs of fuel and maintenance are included in the equation, a genset is not necessarily the least-cost option, particularly for very small loads. In extreme cases, the cost of purchasing and installing the generator set may account for less than 5% of the lifetime

[13] Sheehan, J.; Camobreco, V.; Duffield, J.; Graboski, M.; Shapouri, H (1998). Overview of Biodiesel and Petroleum Diesel Life Cycles. 60 pp.; NREL Report No. TP-580-24772.
[14] California Distributed Energy Resource Guide, web site of the California Energy Commission, April 2004. URL: http://www.energy.ca.gov/distgen/equipment/reciprocating_engines/cost.html.

costs of the system.

Viability

Gensets can be robust and reliable power systems if properly maintained. Gensets are most viable when the funding for up-front investment in the power solution is severely limited, while the high ongoing costs of purchasing fuel and maintaining the equipment over time can be tolerated. As the size of the total load increases, gensets typically become more economical.

The more a genset is used on a regular basis, the more often it will incur the inconvenience and cost of routine maintenance. A generator that runs 10-14 hours a day may need an oil and filter change every 2-3 weeks. These burdens are reduced considerably if the genset is used mainly for backup power on an occasional basis.

Small-scale gensets may have difficulty powering rural ICT facilities without causing damage. Genset power feeds are not always pure, and the frequency and voltage may not be as stable as required by the ICT equipment. In addition, there may be up to a two-minute window between the time a power outage occurs and the time the generator kicks in. This two-minute period may be enough to cause serious damage to computer and network systems. If a battery back-up system is present, the problem may be alleviated since the battery power kicks in between the main power feed going off and the generator feed coming on. The battery bank also serves to "clean up" or stabilize the power feed from the generator.

For generators whose capacity is small in relation to the total load, the nonlinear fashion in which some computers, UPS systems and other ICTs draw power can cause voltage fluctuation and disruptive currents that can damage sensitive computer components. The effects of nonlinear loads can also lead to excess heat in the generator. Over time, these side effects can shorten the lifespan of the ICT devices, the genset or both. There are a number of ways to compensate for the effects of nonlinear loads on a small genset, but they are technically complex and difficult to generalize. One fairly straightforward practice is to oversize the generator in relation to the loads it is serving. This typically requires that the generator have a rating at least 2 to 3 times the rating of the entire load. However, due to wide differences in output impedance for generators, it is not possible to specify an oversizing factor that guarantees a solution to the problem.

2.5 Battery Backup Systems

Two common situations in rural and remote areas leave ICT-based businesses and facilities with intermittent or poor quality power that is insufficient to meet their needs. One situation arises when communities without grid access operate their own fossil-fuel generators, which are often connected to end users through a localized mini-grid. Because fuel is expensive, these generators may be run for 4-6 hours a day only, typically at night when there is a need for electric lighting. While operational, the generators often produce more energy than the loads consume. The unused energy is simply wasted.

Another familiar situation in rural, remote and even some urban areas is one in which grid electricity is available, but there are frequent power outages. Grid outages are particularly common in communities that lie at the end of low voltage rural lines. This predicament is often accompanied by unpredictable power surges, voltage sags and other phenomena that can easily damage ICTs.

In such situations, the establishment of an ICT facility that needs consistent, high-quality power may be enabled by installing a battery backup system that stores energy when the electricity supply is available. The battery backup system will convert the available variable-quality power to high quality AC power on a continuous basis and recharge the batteries while generated power is available. This solution was implemented in three USAID-funded community internet centers (CICs) run by local entrepreneurs in Rwanda in 2004.

Resource

Battery backup systems require charging by an external source of power such as a grid connection, PV system or generator.

Components

The components of a battery backup system typically include batteries, a charge controller, an inverter (to power AC loads), and BOS. **Figure 5** shows a simplified diagram of a battery backup system.

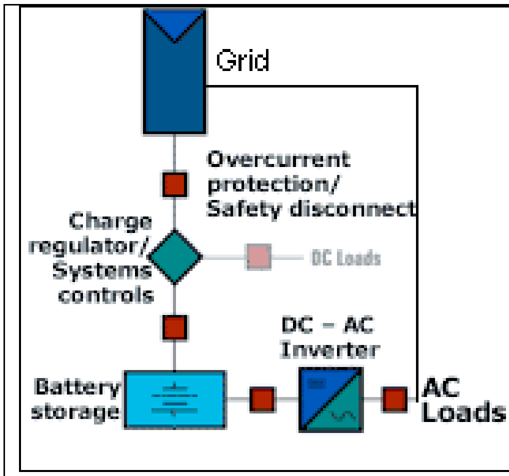


Figure 5 Diagram of a Typical Battery Backup System

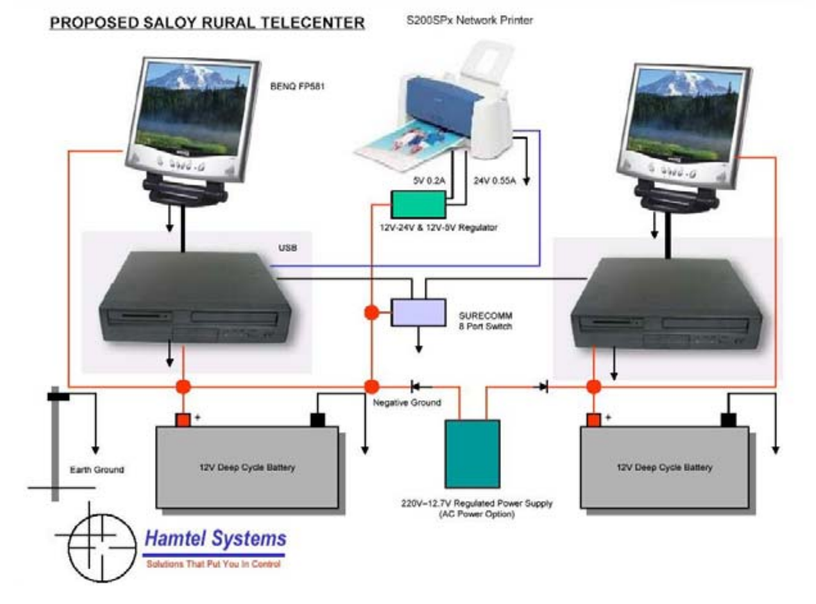
Winrock recommends the use of low maintenance, *deep-cycle* batteries for frequently used battery backup systems. Deep-cycle batteries are designed to withstand repeated and deep discharging of up to 80% of capacity, and will therefore provide more power over their lifetimes than standard batteries. In general, battery replacement frequency depends on how deeply the batteries have been depleted and how quickly the current is drawn from the batteries during the depletion. With less deep discharge cycles, deep-cycle batteries can last for five to seven years.

There are a number of ways to acquire small-scale battery backup systems for ICT applications. Electrical contractors can custom-design a battery backup system using locally available or imported components. There are also fully integrated and automated power packages, which are designed to support a given load for a desired period of time. Commercial standby power systems are available in many models ranging from a few Watt-hours to hundreds of Watt-hours of battery capacity. They usually incorporate maintenance free, deep-cycle batteries and a modular design for flexibility and expansion.

One way to reduce power system costs when using a battery bank is to run the ICT equipment directly on DC, thus eliminating the need for an inverter. In order to take advantage of this approach, the USAID-funded Alliance for Mindanao Off-grid Renewable Energy (AMORE) program, implemented by Winrock International, contracted a local computer firm called Hamtel Systems to design and assemble low-power, DC-only computing equipment for a small computing center donated to a rural farming cooperative. This computer network is described further in **Box 4**.

Box 4: DC-Only Computer Network in the Philippines

Network Diagram of Computer Center in Saloy, Mindanao



Source: Hamtel Systems

When running an ICT facility directly off batteries, it can make sense to select end-user equipment that runs directly on DC. A DC-only configuration does not require an inverter to convert output from the batteries into AC, and therefore less of the stored energy is lost on the way to the devices and the cost of the inverter is avoided. This approach was used in May 2004 by Hamtel Systems, an IT systems integration company based in Davao, Mindanao in the Philippines, for the USAID-funded Alliance for Mindanao Off-Grid Renewable Energy (AMORE) program implemented by Winrock International. Hamtel designed a small off-grid computer center with two low-power desktop computers, LCD monitors, an inkjet printer, and a network switch that were all designed or modified to run on DC (see diagram above). The desktop computers were designed by Hamtel based on the Mini-ITX platform using VIA low-power CPUs, hard drives designed for notebook computers, and DC power supplies. The telecenter, which ran off two 12 V batteries charged by a local micro-hydro site, thus requires only 350 – 400 Wh per day to operate.

An uninterruptible power supply (UPS) that can be coupled with additional batteries to extend runtime is potentially suitable as a backup power option for extended periods of time. These units must have a connector for attaching external batteries.

One additional consideration is whether to supplement grid power for charging the batteries with electricity from a genset, PV array or other renewable energy technology. Back-up power generation can be expensive, which is why many program managers consider it only when grid electricity is not available for enough time each day to maintain the battery bank in a charged state. If a back-up power generator is required, generators often have distinct advantages in urban areas whereas renewable energy systems become more competitive when the load is in remote rural areas, distant from regular power utility services.

Operation & Maintenance

Battery backup systems are reliable, quiet and easy to operate. If flooded batteries are used, distilled water must be added to the batteries periodically. Sealed batteries can run for extended periods (months) without user intervention.

Environmental Impacts

Improper battery disposal is the main environmental hazard associated with battery backup systems. As a rule of thumb, if the used batteries do not hold a value after their lifetime is over, it is likely that they will be improperly discarded and will pollute the environment. In regions such as the Amazon Forest, batteries that are not recycled often end up at the bottom of a river. Battery recycling tends to be more widespread when there are incentives offered by manufacturers or governments.

Costs

Prices for batteries, inverters, racks and other components vary by country. Good-quality inverters often cost $1,000 per kW or more.

UPS maintenance costs include the replacement of batteries and other components over the years of operation. Battery replacement can represent up to 60-70% of these costs.

Viability

Deep cycle batteries are not readily available in all countries and they can be prohibitively expensive, particularly when imported. It is possible to use automotive or “shallow cycle” batteries, which tend to be cheaper and more widely available in rural areas. In order to maintain a reasonable battery lifespan when automotive batteries are used, the maximum depth of discharge should be no more than 20%. One key to successfully using shallow-cycle batteries for backup power systems is to make sure there is a low voltage disconnect that is set at a voltage, called the *LVD setpoint*, that is low enough to disconnect the batteries before they are deeply discharged. Energy efficiency measures, user training and capacity building are fundamental to keeping battery backup systems as inexpensive as possible.

3 ICT Power Requirements

An understanding of the relative power requirements of different types of ICTs is needed in order to make appropriate and cost-effective selections of equipment for off-grid projects. This section is designed to give program managers, energy system designers and decision makers an idea of the power requirements of different categories of computing and communications equipment. The ICTs discussed fall into four main categories:

1) Computer systems, including desktop computers, notebook computers, thin clients, personal digital assistants (PDAs) and monitors;

2) Computer peripherals and network devices, including printers, copiers, scanners, fax and multifunction devices;

3) Broadcasting receivers and recording devices, including television sets, radios, videocassette recorders and DVD players; and

4) Customer premise equipment (CPE) for two-way wireless communications, including mobile cellular phones, fixed cellular phones, mobile satellite phones, fixed satellite phones, land mobile and HF radio handsets, spread spectrum wireless terminals (e.g. WiFi) and VSAT remote stations.

For the sake of completeness there are also brief mentions of other electrical appliances that are useful in off-grid facilities, such as lights, fans, uninterruptible power supplies, and automated shutoff devices.

In the discussions that follow we use the term “computer” to refer to the computer hardware components enclosed in a case with the motherboard, while “computer system” refers to the computer and the monitor together.

Readers are advised that the features, selection and power consumption of ICTs available in your particular country/region may differ substantially from the energy requirements described here. Particularly in the PC market, both technologies and power consumption parameters can change significantly with new hardware and software developments. Readers are encouraged to use the data that follows as points of comparison with similar products.

3.1 Computers

Because computers consist of a wide variety of power-consuming components, power consumption varies substantially from one computer to another. To determine the size of an energy system for off-grid computing facilities, the key parameter that needs to be established is the average power consumption of the computer while running the types of software applications that will be used.

Computer processing units (CPUs), also known as processors or computer chips, are responsible for a significant percentage of a computer's power consumption. As the power of processors has increased with each new generation of chips, maximum CPU power has risen as well. For example, the Intel P4 desktop processor, which is available at clock speeds ranging from 1.3 to 3.2 GHz, consumes significantly more power than the previous generation of desktop chips (see **Figure 6**). Within a given family of processors, CPU power consumption generally increases along with clock speed. Processors designed to be used in notebook computers typically consume much less power than those designed for desktop computers.

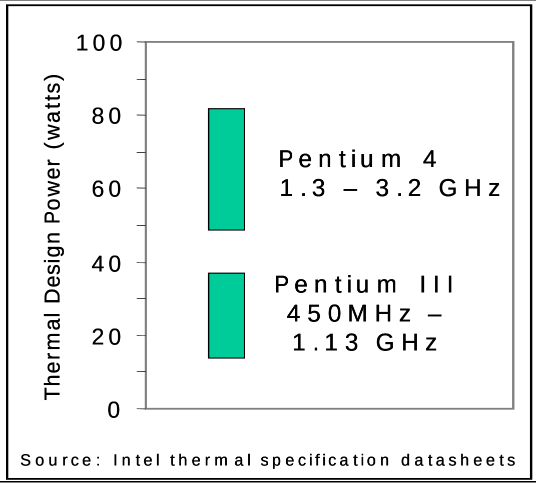


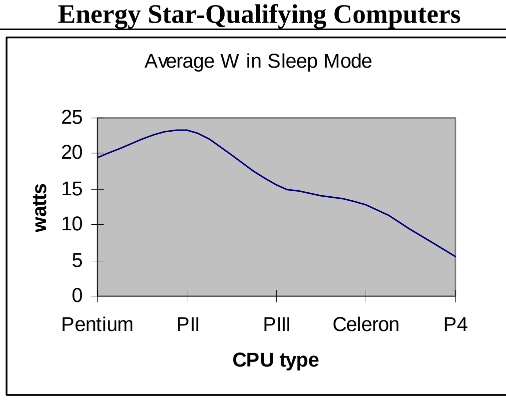
Figure 6 Desktop CPU Thermal Design Power

While there is little published information about the power consumption of computers by the world's major manufacturers, there is even less information regarding "white box" computers assembled by local companies in developing countries. Many factors, such as the quality of power supplies and system design, can affect total PC power consumption. Locally assembled computers cost significantly less than imported models, and have come to dominate many local markets in terms of market share. In Guatemala, for example, white boxes account for 70% of all computers sold[15]. Within a given country there may be dozens of local companies participating in the computer market. Local companies may well be willing to respond to requests for information on the power consumption of their computer models.

Energy system designers often use a desktop computer's power rating[16] to represent the electrical load when sizing renewable energy systems. Information on the rating power is almost always available as it is printed on the computer's power supply for safety reasons. However, a variety of studies have shown that computers typically consume less than the maximum power rating. In some cases computers have been found to consume as little as 5% to 50% of the rated power level (Roth, 2001:18). One brand name computer manufacturer indicated that its desktop units are configured to consume no more than 75% of the power rating during typical operation[17]. As a result of this discrepancy between rated and actual power consumption, it may be possible to reduce the size and cost of the required energy system by measuring the true power requirements of the intended computers.

Power Management

Figure 7 Sleep Mode Power Consumption of Energy Star-Qualifying Computers



Source: U.S. Energy Star, March 21, 2003.

Computers reduce power consumption by shutting down system components when they are not in use. Power management enables a computer to enter reduced power states such as standby and sleep mode. Perhaps the best known power management guidelines are those set by the U.S. Environmental Protection Agency (EPA) Energy Star program. Desktop computers that meet EPA Energy Star guidelines power down to no more than 15 percent of maximum power use while in sleep mode. Computer models registered with EPA Energy Star typically consume between 5 and 25 W in sleep mode (**Figure 7**). For the purpose of selecting off-grid ICT products, it is important to understand that Energy Star computer guidelines were designed only to reduce wasted energy while computers are idle, such as power consumed by office

[15] Suchite (2001); U.S. & Foreign Commercial Service; and U.S. Department of State.
[16] See Section 1.2 for an explanation of the term "power rating."
[17] Author's personal communication with Ernie Mandese, Personal Computer Division (PCD) of IBM, May 28, 2003.

computers left on overnight. Computer products that are compliant with Energy Star guidelines are not necessarily energy efficient or low power during normal operation.

There are a couple of power management standards for IBM-compatible PCs. Advanced Power Management (APM), first introduced in 1992, defines five power states: Ready, Standby, Suspended, Hibernation and Off. The successor to APM, Advanced Configuration and Power Interface (ACPI), has been available since 1997. Intel offers an emerging PC power management technology based on ACPI called 'Instantly Available PC' [18].

A computer's hardware, BIOS and operating system must all support power management in order for it to function properly. Older computer models do not necessarily have all of these components, or the capabilities may exist but they are not enabled. If a PC is running Windows 98 but the BIOS does not support APM or ACPI, then power management will not function properly. All new computers running the latest Microsoft Windows or Apple Macintosh OS support power saving modes such as standby. Computers with older hardware and operating systems may support limited or no power management features. **Table 2** provides a quick summary of the extent to which common desktop operating systems support power management.

Table 2 Operating Systems and Power Management

Operating System	Power Management
Microsoft Windows	Windows 95 OSR2 supports APM. Windows 98/98SE and all subsequent Windows editions support APM and/or ACPI. The Windows NT operating system and the original version of Windows 95 do not support power management.
Macintosh OS	Mac OS 9 and Mac OS X operating systems have power management capabilities.
Linux	The Linux OS is available in a large number of distributions, within which power management has not yet been universally implemented. Some distributions may have power management capabilities while others may not.

Power consumption using Linux can be expected to emerge as a topic for additional research over the next few years. A small but growing number of users in developing countries are choosing Linux in order to reduce licensing costs, particularly when using donated computers. In November 2003, the DabaweGNU Linux user group of Davao City, Mindanao and the Philippine Department of Education donated a server running Linux Terminal Server Program (LTSP) and a network of ten clients to the Kapitan Tomas elementary school, with the intention of continuing to provide donated computers to schools in urban and rural areas. As organizations such as DabaweGNU extend their programs in off-grid areas, power consumption will become more of a concern.

3.1.1 Desktop computers

Standard desktop computer systems consist of two main parts: the central processing unit (CPU) and other hardware components enclosed in a case with the motherboard, and a monitor or display device. Since these two parts of a desktop system are typically separate standalone devices, we consider their power consumption requirements separately. This section discusses the power requirements of the computer without a monitor. The power consumption of the monitors is addressed in Section 3.2.

Table 3 Benchmarks for Power Consumption of New and Used Desktop Computers*, 2004
20 – 40 W (low)
40 – 60 W (average)
60 – 80 W (average/high)
80 – 150 W (high)
Source: Winrock International

*Not including monitor.

In 2001, a study by the Lawrence Berkeley Laboratory (LBL) estimated that the average desktop computer – excluding monitor – consumed 50 to 55 W during normal activity, 25 W in low power mode, and 1.5 W when off (Kawamoto et al, 2001). Based on the LBL study and the review of power specifications of dozens of computer models, Winrock offers a range of updated benchmarks in **Table 3** regarding desktop power consumption, against which program managers may compare the models available to them in local new and used computer markets. These benchmarks are based on power consumption while the computer is in use or idling at full power mode, not in standby or other low power

[18] For more information on Instantly Available PC see Intel's web site: http://developer.intel.com/technology/iapc/.

modes.

Data on the power consumption reported by PC manufacturers Dell and HP for selected desktop models are presented in **Annex 3**.

Inside view of a low-power desktop. Passive cooling enables fanless operation, which helps reduce power consumption.

Source: HUSH Technologies, Ltd.

3.1.2 Low-Power Desktop Computers

This guide considers low-power desktop computers to be those models with low-power CPUs and average power consumption between 20 W and 40 W, excluding the monitor. All-in-one desktops, in which the motherboard and an LCD monitor are integrated into a single casing, provide additional energy benefits because the LCD monitor uses the same power supply as the computer and therefore consumes less energy.

Low-power desktops often include custom-built and off-the-shelf models based on the Mini-ITX or VIA EPIA series mainboards. Because the availability of low-power desktop models and the manufacturers who produce them change with market conditions, one way to identify low-power desktop options is to search the web sites of low-power chip manufacturers such as Transmeta Corporation, VIA Technologies, and Intel for links to desktop systems based on their low-power products, such as those listed in **Table 4**.

Table 4 Examples of Low-Power Desktop Computers

				Power Consumption (W)	
Model	**CPU**	**Speed (MHz)**	**RAM (MB)**	**Active Mode**	**Sleep Mode**
Wincomm WPC-650	VIA Ezra	933	256	33-36[19] (average)	18
NEC PowerMate eco	Transmeta Crusoe	900	n.d.	31[20] (including monitor)	13.3

3.1.3 Notebook Computers

Notebook computers consume much less power than desktop systems. First, notebook computers use energy-saving LCD monitors. Second, the CPU, components and software in a notebook computer are designed to conserve power so as to maximize battery operation times. Third, notebooks use external power supplies that are much more efficient than the power supplies used in most desktop systems[21].

When describing the power consumption of notebook computers, the power consumption of the monitor is automatically included because the display is integrated into the unit. A few years ago, notebook computers typically ranged from 15 - 20 W power consumption with average consumption for the class of 15 W (Kawamoto, 2001). As of 2004, the average power consumption of new notebook computers is beginning to spread over a wider range, from about 10 W to 50 W. Whereas notebooks used to be designed primarily for business users whose primary requirements were portability and long battery life, they are now also serving as desktop replacement units and DVD/multimedia systems. These market changes have contributed to the higher power consumption reported for some models.

Particular notebook models and power-saving technologies change rapidly in the fast-moving computer

[19] Tested at Winrock International, June 2003.
[20] Source: Manufacturer specifications and U.S. Energy Star product data for the NEC PowerMate Eco personal computer. This model includes a built-in 15” LCD monitor whose power consumption is included in the figures listed above. In August 2003, NEC discontinued new shipments of the 900 MHz model in regional markets.
[21] PC Energy Efficiency Trends and Technologies. Intel Corporation, 2002. http://www.intel.com/ebusiness/pdf/prod/related_mobile/ar024103.pdf

market. At the time of publication, typical notebook computers ran for 2-3 hours on a fully charged battery. Notebooks based on Intel's Pentium M processor – which includes those labeled as Centrino technology – advertise 4 to 5 hours on their main batteries[22]. Using two batteries, some notebooks advertise battery life of up to 10 hours[23]. Intel's Centrino technology, introduced in March 2003, is actually a combination of three Intel components used together: the Pentium M processor, the Intel 855 companion chipset, and a WiFi wireless Ethernet chipset. External lithium ion battery packs, small solar chargers, DC-DC adapters and other accessories can be purchased to extend the mobile runtime of notebooks (for example, see www.lindelectronics.com).

Recent generations of mobile processors reduce power consumption by clocking down the processor frequency and stepping down the supplied voltage when battery life needs to be extended. Battery-extending notebook technologies such as Intel's SpeedStep, AMD PowerNow! and Transmeta LongRun automatically clock down the CPU in certain situations, such as when the notebook loses AC power and switches to the battery, while the system is idle or when the applications running on the notebook don't require maximum processor performance[24]. For example, a 1.4GHz Intel Pentium M processor can clock down to as low as 600 MHz. When this happens the drain on the battery is reduced.

Notebook power-saving technologies are frequently subject to user modification through the computer's power management settings. The user can choose settings that guarantee maximum processor performance, maximum battery life, or settings in between. The exact settings depend on the type of processor, manufacturer, the driver software and the operating system installed on the notebook.

3.1.4 Thin Clients

Server-based computing is a model in which client terminals share the hardware and software resources of a central computer or server. Server-based computing solutions can support all of the standard applications that run on personal computers, such as Internet access, email and word processing.

The server can be configured with additional processing power and memory in order to run software applications requested by, and displayed on, the clients. Because most of the processing is done on the server, the client terminals don't have to include all of the components of a standalone computer. These stripped down computer products are known as "thin clients."

Server-based computing can reduce total power consumption compared to a fully distributed computing model[25] by reducing the number of power-consuming components in the client terminals and by increasing the utilization rate of network resources through sharing. Some thin clients consume as little as 7 Watts in operation (excluding monitor).

There are only a few examples in which the thin client concept has been considered and/or implemented in off-grid areas order to reduce ICT power requirements. Because thin client systems are not as common as standard PC networks, these solutions may require specialized configuration, training and technical support skills. In those cases where IT training and support are available to off-grid communities, thin client networks may offer a viable option for reducing power consumption as well as meeting other program needs related to cost of equipment, ease of maintenance and management of IT resources.

3.1.5 Personal Digital Assistants (PDAs)

Palm- or pocket-sized personal digital assistants (PDAs) are portable, battery-run computing devices with simplified operating systems and applications. Most offer the ability to enter text through graphics recognition programs and to 'synchronize' or transfer information on the PDA to a standard computer. External keyboards can be purchased as PDA attachments to facilitate text entry. PDAs are best used as complements to desktop/notebook systems. PDAs support applications such as scheduling/date books,

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[22] Bill Howard, "The New Notebooks." PC Magazine, April 15, 2003.
[23] For example, the IBM ThinkPad X Series indicates running times of up to 10.1 hours when using two Lithium-Ion battery packs.
[24] PC Energy Efficiency Trends and Technologies. Intel Corporation, 2002. p.4.
[25] For example, see Greenberg, Steve and Christa Anderson, "Desktop Energy Consumption: A Comparison of Thin Clients and PCs." Wyse Technology Inc., 2001.

calculators, simplified word processing and spreadsheets, games, electronic texts/e-books, e-mail, field questionnaires and mobile reference guides.

PDAs typically run on standard "AAA" or rechargeable lithium-ion batteries. With limited daily usage, batteries commonly last two to three weeks. The PDA's operating system and factory-installed applications are stored in read only memory (ROM), which means that these programs are stored whether or not the unit has a source of power. Data input by the user is typically stored in the unit's Random Access Memory (RAM). Even when the PDA is turned off, RAM memory draws a small amount of current from the batteries in order to keep its memory cells charged and the data intact. The result is that PDAs run the risk of data loss even when the unit is not being used. If the power source is removed or the batteries completely lose their charge, then the user has about one minute to restore power before the data stored in RAM is lost. When using PDAs in off-grid areas it is a good idea to have regular data backup procedures in place. This is particularly important in situations where batteries cannot be reliably replaced or recharged, or when the PDA may remain unused for a few weeks.

3.2 Computer Monitors & Displays

3.2.1 CRT Monitors

CRT Monitors in Use at a TARAhaat Telecenter, Niwari, India

Photo Source: Winrock International

Cathode ray tube (CRT) monitors are the standard displays used in desktop computer systems.

In the average desktop computer system, 60% of the energy consumption is due to the cathode ray tube (CRT) monitor. The normal power requirements of 15" to 21" CRT monitors typically fall between 65 W and 120 W. However, like television sets, the energy consumption of CRT computer monitors can vary widely among different models, even units of the same screen size. An average 17" CRT monitor consumes 85 W during typical usage (Kawamoto, 2001). Black and white monitors consume less power than color monitors.

CRT monitors that qualify for Energy Star designation are required to power down to 15 W or less after 15 to 30 minutes of inactivity and down to 8 W after 70 minutes of activity[26]. Some monitors continue to consume 5-8 W of power after they have been shut down. In this case it is a good idea to make sure that the monitors have been turned off by hard switch or unplugged completely at night to avoid wasting electricity. On some monitors, there is a small LED light on or near the on/off switch that lights up to indicate activity. If the LED is lit or flashing, the monitor is still drawing some amount of power.

CRT monitors require a burst of energy upon startup equivalent to 2-5 times normal operating power consumption. For very small energy systems, it is advisable to test the inverter of your energy system to make sure it can power up the CRT monitor reliably and consistently, particularly for the larger monitors.

3.2.2 LCD Monitors

Liquid crystal display (LCD) monitors are built into notebook computers and are available as standalone, flat monitors for connection to desktop computers. The most common type of LCD is the thin film transistor (TFT) display, also known as an active matrix display.

LCD monitors typically consume one third to one half the power of a comparably-sized CRT monitor. The

[26] Energy Star power management Frequently Asked Questions, July 2003.

15” standalone LCD monitors reviewed for this guide typically had a maximum power rating of about 30 W and reported normal active power consumption of 20-25 W. As of July 2003, prices for 15” LCD monitors started at about $300. Although pricing in developing countries may be significantly higher due to import duties and other markups, it is worthwhile to keep checking local availability and prices because global manufacturing capacity for LCD displays has increased over the past several years and further significant declines in price are expected.

When selecting an LCD monitor for community applications, it is advisable to keep in mind the horizontal and vertical viewing angles. Wider viewing angles allow better viewing of the screen contents from different positions around the monitor, which makes it easier for multiple viewers to share a terminal. The viewing angles of standalone LCD monitors reviewed for this guidebook ranged from 120°/90° (horizontal/vertical) to 170°/170°.

3.3 Printer/Copier/Scanner/Fax Machines

Multi-function (all-in-one) devices are machines that support two or more of the functions described above, such as fax machines that also make photocopies, or combined printer/copier/fax machines.

The power consumption of devices in this category varies greatly by capacity and speed of printing/copying, type of technology and quality of output. As a general rule, ink jet printers typically consume significantly less energy than laser jet printers. Kawamoto et al (2001) reported stock-wide average power consumption of 17 W for ink jet printers compared to 30 W for residential laser printers and 77 W for commercial laser printers. As with all consumer ICT devices, one must check the power consumption specifications for each particular model.

While ink jet printers are generally recommended for their low energy consumption compared to laser jets, the costs of purchasing paper and ink may subtract from energy-related cost savings. The ink costs per page for popular ink jet printers often range from $0.02 to $0.07 for black and white documents and $0.07 to $0.13 for color printouts[27]. Typical ink costs for mid-range laser printers are closer to $0.015 to $0.02 for black and white documents. Color laser jet printouts can still reach $0.08 to $0.12 per page[28]. Paper costs are extra, as is the cost of printing items that use a greater amount of ink, such as photographs. Similarly, dot matrix printers may offer significant savings in the operating costs of printing while requiring slightly greater levels of power than inkjet printers.

A common feature of printing and multifunction devices is the relatively large gap between average and peak power consumption. For example, Winrock monitored the power consumption of an HP LaserJet IIISi printer at Winrock offices over a 4-hour period during normal working hours. During standby periods – the mode in which the printer is ready to print without noticeable delay – power consumption was only about 46 W. However, the peak power during the printing cycle reached 900 W. Small induction motors geared to supply a constant source of electricity may have difficulty supplying the peak power levels for high-performance laser printers and multifunction devices.

3.4 Television and Radio

3.4.1 Television Sets

Television sets have no internal moving parts and are therefore very reliable. Although conventional television sets are built on the same CRT technology as standard computer monitors, television sets contain in-built tuners to receive and decode the television signals whereas computer monitors do not. Most standard television sets operate with AC power, although there are also television sets that operate directly on DC.

Some types of televisions are more energy efficient than others. Of the main TV display technologies, LCD

[27] “Summary of Features: Personal Ink Jets,” PC Magazine, 5 November 2002.
[28] Sources: “Summary of Features: Color Laser Printers,” PC Magazine, 25 March 2003. “HP Color LaserJet and LaserJet Series Printers – Cost Per Page,” web page viewed August 2003, URL: www.hp.com.

televisions usually consume the least energy for a given screen size, followed by CRT tube displays, flat-screen CRTs, plasma televisions, and LCD rear projection displays. Television sets with CRT picture tubes are by far the most common and least expensive units. **Table 5** provides Winrock's recommendations for the level of power consumption by CRT color television sets that is appropriate for off-grid use.

Table 5 Recommended Power Consumption of CRT Color Television Sets for Off-Grid Projects

Screen Size	**Standard**	**Low Power Range (W)**
13-15in. (34-36cm)	NTSC	50 – 60
13-15in. (34-36cm)	PAL/SECAM	30 – 40
25-27in. (61-64cm)	NTSC	75 – 90
25-27in. (61-64cm)	PAL/SECAM	60 - 75

Source: Winrock International

Turning on a TV set demands two or three times more power than is used during normal operation. If the inverter does not have enough starting capacity, it may be difficult to start up the television. It is always advisable to test the inverter to make sure it can power up the TV set reliably and consistently.

Many television sets continue to consume electricity when they appear to be turned off, particularly those that have a remote control. Even television sets that meet U.S. Energy Star requirements may continue to consume up to 3 W in standby mode. To avoid the costs of powering such 'phantom loads,' procedures can be put in place to ensure that the sets are physically unplugged, or otherwise disconnected from the power supply, when not in use. This takes on increased importance in PV or small wind power systems because of the relatively limited amount of power produced. One option is to use an inverter with a switch that cuts the power to the whole load. Also, some television sets have a "hard off" switch on the main body of the unit that disconnects the device from the external power supply, even though the TV power cord remains plugged in to the outlet.

3.4.2 VHS/VCR/DVD Players

Typical VCRs use 20–25 W in operation, up to 45 W maximum and 7-8 W in standby mode. Combination VCR/DVD players have similar power consumption rates. DVD players tend to be slightly lower, in the range of 10-15 W with power on and 1-5 W in standby. VCRs that meet U.S. Energy Star guidelines consume no more than 4 W while in standby mode. However, all VCRs have internal clocks that consume energy all the time while they are connected. If the clock does not perform any critical functions, the VCR can be disconnected when not in use.

The best way to care for a VCR is to keep the tapes free of dust and humidity. This prevents the heads of the VCR from getting dirty in a short period of time. A head-cleaning cassette can also be used periodically.

3.4.3 Broadcast Radio

Power is needed for both radio receivers and small community radio broadcasting stations based in remote, off-grid communities. In 1999, WorldSpace introduced satellite radio broadcasting in Africa, providing a source of information to many rural and remote areas for the first time. On the ground, hundreds of community radio stations have been established over the past 15 years to serve isolated rural communities. The radio stations play an important role in the economic and social life of the communities by bringing news of local happenings, education and entertainment to listeners in their own language.

Many portable radios, WorldSpace satellite radio receivers and tape recorders are designed to operate with both DC and AC, using "D", "C" or "AA" size dry batteries. The cost of replacing the dry batteries is very high, even when compared to the cost of solar energy. It is feasible to power any radio or tape recorder with a PV system. This is done by connecting cables to the appropriate terminals in the compartment that normally houses the batteries. This is not a very elegant solution, but it is a more efficient and less costly way of operating a radio or tape recorder with a PV system. The voltage required by these devices can range from 3 to 12 V, depending on the model. There are low cost converters that produce a variable voltage from 12 V for this purpose.

Power consumption for a portable, double speaker radio/tape recorder rarely exceeds 20 W at full volume and with the cassette player in operation. A consumption of 8 to 12 W is more typical. If only the radio is used at a moderate volume, consumption can be as low as 3 or 4 W. A CD-player/boom box might consume 25 W.

Community radio stations may require several kilowatt-hours of power in order to broadcast 24 hours per day and maintain radio station operations in remote areas. Although the energy demand of a commercial radio station can be much higher than the 2-3 kW peak loads addressed in this guidebook, some small community radio stations with limited areas of coverage may operate within this range (for example, see **Box 5** below).

Box 5: PV-Powered Community Radio Stations in Mali

Radio Kamadjan of Nafaji, Mali

Source: Winrock International

In the West African country of Mali, 26% of the country's 46 community radio stations use solar PV systems to power their broadcasts. One example is Radio Kamadjan, shown in the picture at left. Radio Kamadjan serves the village of Nafaji in the Mande region, southwest of the capital, Bamako. The station broadcasts for at least five hours per day, typically from 6pm to 11pm. The FM transmitter has a range of almost 30 km, and runs on two batteries charged by the solar panels. The equipment was donated to the community by its twin city in France.

Community radio stations fill a vital need by bringing news and information from the outside world to hundreds of remote, isolated communities across Africa. The radio stations are run by local people who know their communities and speak the local language. Maintaining an affordable, reliable source of electrical power is an ongoing challenge for many of these stations – one of several challenges the stations must face in order to sustain their activities.

3.5 Wireless Voice and Data Equipment

3.5.1 Cellular and Satellite Phones

Mobile cellular phones and mobile satellite phones provide voice telephony services in rural and remote areas. In some cases they also support short message service (SMS) and low-speed data transfer. Mobile phone services are increasingly becoming available and affordable options for communications in remote areas. Coverage from cell sites along intercity roads and highways often spills over to include rural towns and villages. Satellites' large coverage areas make them one of the few feasible options for providing connectivity services in very remote, sparsely populated areas where terrestrial communications infrastructure is unaffordable. Fixed applications of cellular and mobile satellite services can be implemented when mobility is not a requirement.

Handheld cellular and satellite phones typically consume less than 5 W on average, requiring less than 120 Wh of energy per day, which is typically provided by internal batteries and/or external battery packs. Fixed cellular and fixed satellite phones may run on AC or DC. There is already a thriving trade in battery recharging services for cellular handsets in many off-grid areas. However, providing a separate renewable energy system to power a single wireless telephone may be an expensive route given the low energy requirements, as explained in **Box 6**.

Box 6: Powering Small Loads: Energy for Public Telephones

PV-powered Payphone in Guzman, Dominican Republic

Photo source: Soluz, Inc.

Power systems incorporating RE technologies can be very appropriate for powering small loads, such as telephones for public use. Soluz, Inc., a developer of rural energy delivery companies, has implemented several commercial approaches to powering cellular telephones with renewable energy, balancing technical and financial needs. As part of its work to support microenterprise and expand productive applications of PV, Soluz installed a pilot PV-powered cellular payphone in a rural store in 2001. The store, already renting a PV system for lighting, radio, and television from Soluz's local subsidiary, received a separate, dedicated system for the telephone, with a 50 W PV module, battery, and controller.

The system operated smoothly for the three years it was piloted, but was not financially self-sustaining. Though at times well used, the payphone did not generate enough revenue to cover the cost of the dedicated power system. The system was oversized, able to produce much more energy than the phone needed, and as such was more expensive than necessary.

Low-power loads such as the cellular payphone can benefit from an alternate approach to energy supply. As additions to larger power systems like the store's, such loads can use existing batteries and controllers, requiring at most a small upgrade in power-system capacity. The incremental cost of adding a 10 W PV module, for example, is minor compared to the cost of a standalone 10 W PV system.

In small loads, as with larger ICT systems, efficiency can be important. The payphone piloted by Soluz consumed 50-100 Watt-hours per day, but could be designed to consume half that by turning it on for outgoing calls only. Many Soluz customers power standard portable cell phones for their own use with negligible energy from their household or business PV systems. Such phones can also be operated as businesses in underserved areas. For example, a village payphone program in Uganda, based on the Grameen Village Phone program in Bangladesh[29], sells a micro-financed payphone business equipment package consisting of a mobile phone, antenna, solar panel and battery, cables, airtime cards, signage, and manuals for a total cost of US$256[30].

[29] See www.grameenphone.com/village.htm.
[30] Source:"Replicating The Grameen Model: The Case for Rural Cell Phone Micro-Businesses in Uganda", a presentation by David Keogh and Tim Wood of Grameen Technology Center, March 2004.

3.5.2 Land Mobile and HF Radio

The land mobile radio (LMR) category includes a wide variety of wireless communication systems in the high frequency (HF: 3-30 MHz), very high frequency (VHF: 30 – 300 MHz) and ultra high frequency (UHF: 300 – 3,000 MHz) bands. LMR systems are typically used for two-way voice communications and low-bandwidth data transfer. Examples include walkie-talkies, citizen band (CB) radio, amateur radio and specialized mobile radio (SMR, also called trunked radio). High frequency (HF) radio systems support long-distance communications over tens to hundreds of kilometers, and have been employed as a communications option in rural and remote areas for decades.

Portable radio in Mexico

Source: Winrock International

Applications of LMR and HF radio systems in remote and off-grid areas include public and private two-way voice communication services; private voice and data services on a campus or industrial complex; low-bandwidth email, internet and bulletin board system (BBS) access; and public safety and security networks. Many systems are used to provide communication services to discrete user groups, while others, such as SMR, can support interconnection to public switched telephone networks.

Typical bandwidth for LMR is 15 – 30 KHz per analog voice channel (NTIA, 1995). These systems are increasingly capable of supporting packetized data transfer as well as voice services. Common data transfer rates over packet radio are 1200 and 9600 bps, although technological developments are pushing these rates higher. For reference purposes, this is similar to the rate that fax machines can provide, and would not be appropriate for anything beyond email.

Important LMR and HF radio system components include portable (handheld) user terminals, mobile radio or base stations, repeaters, modems, antennas and switching or controller equipment. The systems typically operate on DC power. Transceivers (transmit and receive devices) often consume the bulk of the power in an installation, and power consumption is highest while transmitting (see **Table 6**). When evaluating product specifications for a wireless transceiver it is important to note that the power consumption of the device is not the same as the transmit (Tx) or output power. The transmit power refers to the strength of the radiowave signal as it propagates in space away from the transmitting antenna. Power consumption is the rate of electrical current that the system draws in order to generate the radiowave.

Power consumption for LMR and HF radio systems varies widely by product and type of system. In general, the higher the transmit power (which is related to the range of the signal) the higher the energy consumption will be.

Table 6 Typical Power Consumption of HF/VHF/UHF Radio Systems

Device	Power consumption (W)
Radio transceiver transmitting @Tx power 3 - 20 W	25 - 65
Radio transceiver transmitting @Tx power 50 - 100 W	160 - 320
Radio transceiver (standby mode)	<3 - 30
Terminal node controller (TNC)	<2
Handheld unit (battery operated) Transmitting (1 – 7 W) Receiving Standby	 7 – 27 2 – 4 <1

Source: Icom, Kantronics and Symek product data sheets.

3.5.3 WiFi / Spread Spectrum

Wireless local area network (LAN) systems are based on a variety of technologies, but the most widely produced systems belong to the 802.11 family of standards established by the Institute of Electrical and Electronics Engineers (IEEE). Wireless LAN systems that comply with IEEE 802.11b, also known as WiFi, are low-power systems that use the unlicensed bands in the 2.4GHz spectrum to support data transfer at rates of 11 Mbps, 5.5 Mbps, 2 Mbps and 1 Mbps[31]. Other standards within the 802.11 family include 802.11a, which uses the 5 GHz band and supports data rates up to 54 Mbps; and 802.11g, approved in June 2003, which operates in the same bands as 802.11b but supports data rates up to 54 Mbps. The maximum data transfer rate decreases as the distance between the nodes increases.

Wireless LAN systems can be configured for two largely distinct applications: (1) replacing the wired connections between computers on a local area network (LAN), or (2) bridging or routing between LANs in different buildings through point-to-point or point-to-multipoint links. For an example of the first application in a remote area of the Dominican Republic, see **Box 7**.

802.11b systems are required by regulators to have low output power so as to limit the range and reduce potentially harmful interference with other systems that have priority in the designated frequency bands. The result is that the input power for 802.11b systems is also low – less than two Watts for most PC cards, and typically 4-7 W for access points.

Box 7: Solar-Powered Rural WiFi Links

Source: Enersol

In 2002, Enersol's EduSol program in the Dominican Republic (DR) worked with District Office 16 of the Ministry of Education to provide Internet access to three remote schools in the Sánchez Ramírez province. The project centered on the rural community of Comedero, where the local high school operated a VSAT connection to the Internet. With 15 computers sharing a 4 Mbps downlink, the available satellite bandwidth was substantially underutilized.

The solution that Enersol selected employed 802.11b wireless networking technology at 2.4 GHz (WiFi) to connect the remote schools to the VSAT connection at Comedero high school. There were few other data connectivity options to consider. The cost of a VSAT installation for each school was prohibitive. Analog cellular offered a maximum connection speed of 4.8 bps, suitable for email but not fascimile or browsing the Internet. By comparison, the WiFi setup that was selected permitted students in the remote schools to connect to the internet at 90 kbps, close to twice the speed of a typical urban dial-up connection.

The wireless network consisted of a Cisco Aeronet 350 Access Point (AP) installed at the high school, a second AP installed as a repeater, and three wireless Cisco Workgroup Bridges installed at each of the remote schools. High-gain, 25 dB parabolic antennas, one of which is shown in the picture at right, were installed at the remote schools and a 14 dB antenna was used at the high school. Although all three schools were located within a four-kilometer radius of the high school, the repeater was needed to reach one school which did not have a line of sight to Comedero.

Each remote school received two laptop computers and a 4-port ethernet hub, which were wired to the Workgroup Bridge. Except for the AP at the high school, which had grid electricity, the power requirements of the wireless nodes were met by solar PV systems. Each node required only 5-6 W of power to operate. Power was delivered from the PV systems to the Workgroup Bridges over the Ethernet cables.

The repeater was installed with its own 24-hour remote power system despite concerns that both would be at risk of theft. The repeater sits on a water tank set on a hill 0.5 km from the high school (see photo below). It has a 24 V Access Point (AP), set in repeater mode, which is powered by a PV module of 40 W.

[31] The data transfer rate reflects the total number of bits transmitted by the system each second, including system overhead such as packet addressing information and wireless protocols. The rate of throughput, or the amount of end-user data moved across the network, is typically about half the data transfer rate or less.

Source: Enersol

A controller of 10 A and a lightning arrestor are installed in a lockbox to protect against damage to the installation. Each school is 1.6 to 3.2 km from the tank. Using the AP in repeater mode does reduce data throughput to 5 Mbps, but is not a constraint in this configuration since the bandwidth of the VSAT satellite connection is lower.

While the strategy provided significant savings on the upfront and ongoing costs, there were also risks to this approach. The need to invest in an independent VSAT was avoided by clustering the project sites next to a facility with existing Internet service. This saved roughly US$4,000 in the upfront investment. The schools were also able to save on ongoing costs for bandwidth, estimated at US$150-300 per month, because the government had a 10-year contract with a national telecommunications provider. However, this arrangement also has institutional risks. The high school's service has been interrupted due to contractual issues between the service provider and the Ministry of Education. Similarly, the electrical service from the grid that powers the VSAT in Comedero proved to be extremely unreliable, and it took several months for the Ministry's contractors to configure the backup power systems (diesel genset and inverter) so that they would work with the VSAT.

The overall investment was roughly US$10,000. Equipment (57%) and international labor (28%) accounted for most of the total, with 14% for local labor and fuel. The cost of the installation at the high school was roughly US$2,000, of which the major components were the Access Point (51%) and international labor and travel (22%). The repeater was the most costly node at roughly US$2,700, 70% of which is accounted for by the AP350, international labor and travel, and PV equipment. The cost of the client schools varied due to the need for towers in two locations to achieve line-of-sight with the repeater. Where a 20-foot tower was needed the cost was US$1,900 versus US$1,570 without.

The cost for a rural network with the same physical characteristics could be reduced to US$6,500-7,500 by relying more heavily on Dominican contractors, who have moved up the learning curve, and by saving on equipment costs. Rural wireless LANs are still emerging in the DR. Before the project virtually no technicians outside of the capital had the knowledge to design and build networks. Now the use of the expatriate expert could be restricted to design and quality control, with most fieldwork done by a local radio communications entrepreneur. Similarly, equipment costs would fall by roughly US$1,100 due to heavy cost cutting by Cisco and other equipment manufacturers on the WiFi units since 2002. However, it should also be noted that the radios and antennas were hand-carried into the DR. Under conventional arrangements it is possible that a 36% tax[32] might be assessed, which would have increased costs by US$1,250-1,500.

[32] It is unclear whether the radios and antennas as networking equipment qualify for the tax exonerations.

3.5.4 VSAT

A very small aperture terminal (VSAT) is a small satellite earth station with an antenna used for transmitting and/or receiving signals from a satellite. VSAT antennas generally range from 0.45 m to 1.8 m in diameter, and support a variety of applications in rural and remote areas, including:

- Satellite television broadcasts for distance education programming or entertainment (usually one-way service);
- Thin route rural telephony (typically 1-3 telephone lines);
- One-way Internet access with terrestrial return channel; and
- Two-way Internet access (narrowband or broadband).

Distance education VSAT with PV energy at secondary school in Durango, Mexico

A typical VSAT unit can draw around 60 W. Low-power VSAT models for rural telephony are available which consume about 30 W on average - less than 40 W in operation, 15 W while idle, and as little as 5 W in standby with power management software. Many conventional satellite receivers only accept AC, but there are models designed specifically for use in rural areas that accept DC input.

Manufacturers suggest that certain VSAT models should not be disconnected so as to eliminate the need to reprogram or recalibrate them. While not all VSAT models have this requirement, those that do may consume a significant amount of energy even when the service is not being used. While unfortunate, there is little way to avoid this problem since VSAT stations for different satellite systems and services are generally not interoperable.

3.6 Other Electrical Devices

3.6.1 Lights

Compact fluorescent lights (CFLs) are recommended for off-grid projects for both indoor and outdoor lighting, given their superior efficiency and longevity over incandescent lights. CFLs are increasingly available in developing regions, particularly where solar home systems have been installed in large quantities. Typical lamps available include 9 W, 11 W and 15 W, with lumen (illumination) equivalencies of 25 W, 40 W, 60 W incandescent bulbs, respectively. A useful feature of CFLs, when compared to standard fluourescents, is that the former can be screwed into the sockets of traditional incandescent light bulbs. Light emitting diodes (LEDs) are also a rapidly improving lighting option for off-grid use, offering improved durability and high energy efficiency.

Winrock recommends 15 W CFLs for indoor lighting, and 9 W lamps for outdoor safety lighting, based on field experience that suggests these provide appropriate levels of illumination for their respective uses. While CFLs are several times as expensive as incandescents, their lifetimes (typical rating is 10,000 hours) outweigh the cost differential, and offer significant energy cost savings. It is important, however, to ensure that ICT facility operators are conscious of the reasons for using efficient lighting, and are prepared to replace the fluorescent lamps appropriately.

3.6.2 Fans

Fans are commonly found in rural facilities to promote cooling for both people and electronic systems. Small desk fans typically consume 20-40 W. Larger floor-standing fans and ceiling fans may consume 60-

100 W. There are small clamp-on units that can serve one user at a time that consume approximately 15 W.

3.6.3 Automated Shutoff Devices

There are a number of hardware devices that can reduce electricity consumption by automatically shutting off computer monitors, laser printers, lights and other electrical devices. Devices can be shut off using a simple timer, or monitored in a more intelligent manner to detect when they have remained unused for a predetermined amount of time. These devices offer the advantage of reducing energy consumption without regular human intervention. If ensuring compliance with ICT shutdown policies is a serious problem for a particular off-grid facility, program managers may find these devices to be worth the cost. Due to differences in mains power voltage, frequency and plug configurations, the selection and availability of such energy saving devices will vary by country. Check with your local power supply or electronics retailer for information on locally available products.

The following companies provide products that monitor and manage electricity loads. These web sites are listed for informational purposes only as to the types of products in existence, and in no way constitutes an endorsement, expressed or implied, by the authors of this handbook.

http://www.electricitymetering.com/
http://www.optimumenergy.com/
http://www.bayviewtech.com/

3.7 How to Obtain Information on Power Consumption

There are a few different ways to discover the power consumption of ICT products being considered for off-grid use. Manufacturers' specifications are the first place to look. New equipment should come with information about the equipment's power rating, the highest wattage that the device can safely tolerate. This information provides an upper bound to potential power consumption. Specifications, user's guides and other documentation may provide more useful data on peak, average or normal power consumption in various states of operation. In the case of second-hand ICT equipment that lacks documentation, you may be able to contact the manufacturer or check the manufacturer's web site for archived information on older products.

If there is an electricity meter installed on the premises, you may be able to determine the power consumption from the change in kWh recorded by the meter. This approach was used successfully by Winrock as part of the USAID-sponsored dot-ORG program in Rwanda to determine the power consumption of a grid-connected telecenter that needed a backup power system. In this case, the telecenter's electricity was on a separate circuit and was metered independently, so that the power draw of individual devices could be determined by shutting off all devices but one, in turn. The power readings captured using this method were reasonably consistent with professional readings taken at a later date.

Measurement Tools

Another option is to measure the power draw of the equipment using a Watt meter or an ammeter. If you want to do it yourself and feel that your needs are significant enough to warrant purchasing a portable meter, this type of equipment typically costs from US$100 for a small Watt meter to several hundred dollars for more accurate and sophisticated devices.

The Watt meter should display the instantaneous power (Watts) consumed by the load as well as the total energy consumed over a period of time (kilowatt hours). When selecting a Watt meter, make sure that the device displays a sufficient number of decimal places to get a useful reading for your ICT device. If you will be measuring one device at a time, it is more convenient to have instantaneous readings delivered in Watts rather than kilowatts. For cumulative readings, kilowatt hours and hours should be reported with at least one decimal place (increments of 100 Watts hours and tenths of an hour, respectively).

If you don't have a metering device and don't wish to purchase one, a local electrician, technician, renewable energy installer or a local telecommunications company that already owns the necessary equipment may be able to take the measurements.

Taking Measurements

For devices with varying power consumption, it is best to calculate the average power consumption rate under actual usage conditions. For computers, the average power consumption under actual usage conditions will be greatly affected by the percentage of time that the computer is active, idle and in sleep mode.

If it is not possible to measure the average power consumption during actual usage, one alternative is to measure the power consumption of the ICT device in each operating state or mode and multiply by the expected number of hours of usage in each mode. For example, television sets will typically have an active mode and a standby mode, in which the set appears to be “off” but can be turned on by remote control. Power consumption may differ significantly in each mode. **Table 7** lists operating modes that may be important to measure for certain ICT devices.

Table 7 ICT Operating States to Measure

Device	Operating states to measure
Television	▪ Initial start-up power. ▪ Active (displaying picture and sound). ▪ Standby/Off (TV screen is off/blank but can be turned on by remote control).
Personal computer	▪ Active power consumption. A quick way to produce active power consumption is to drag an open window on the screen in circles for a few seconds. ▪ Idle power consumption. The computer is booted and active, but not running any programs or receiving user input through the keyboard or mouse. ▪ Standby/sleep mode(s) ▪ Off
CRT Monitor	▪ Initial start-up power (typically 2-3 times higher than average power) ▪ Active (displaying output from booted computer). The monitor should be tested while operating at the desired resolution level (e.g. 800 x 600, 1024 x 768). As with CRT television sets, the power consumption can vary slightly with adjustments to brightness/contrast and sound volume. ▪ Sleep / deep sleep modes.

4 Computer Selection Considerations

Of all the categories of ICTs described in Section 3, computers often present the most complex selection considerations in terms of energy demand, application requirements, training needs, shapes, sizes, shipping costs, and a host of variables that can have a significant impact on the long-term success of a program. The selection process is not simply a question of finding the lowest price, but involves balancing a range of features and life cycle costs, including:

- Total cost of ICT equipment plus required power system;
- Current and anticipated application requirements;
- Maintenance and repair options;
- Mobility, theft and security considerations;
- User acceptance;
- Waste disposal and environmental hazards; and
- Availability of donated equipment, with associated savings and costs.

Section 4 identifies and examines some of the main issues that project managers face when choosing computers for off-grid projects. Section 4 begins with an analysis of the cost implications of computer power consumption on initial investment in PV-powered telecenters. Sections 4.2 through 4.7 briefly discuss the other considerations listed above. These issues have arisen out of the field experiences of many different organizations as computers have made their way into pooly electrified rural and remote areas. Since each community has its own mix of needs and resources, the goal of the sections that follow is to identify options and strategies to meet project needs rather than to make blanket recommendations.

4.1 PV-Powered Telecenters

The following section presents a graphic illustration of the sensitivity of solar PV system costs to ICT power consumption. The principles shown here can be applied to other types of energy solutions as well, but the potential savings are greatest in the case of PV.

To isolate the effects of computer power consumption on initial telecenter investment, Winrock calculated the total costs of ICT equipment and appropriately sized PV energy systems for small, medium and large off-grid telecenters. The cost analysis was based on desktop design of telecenters with standardized ICT equipment configurations. Telecenters of a given size were equipped with identical ICT complements, with the exception of the type of computer. Four different computer options were evaluated, with power consumption ranging from a low of 15.8 W to a high of 208W, including monitors. Each computer option has the functionality required to support the same standard services, such as word processing, IT skills training, web browsing, e-mail, telephony and printing. PV energy system costs were calculated based on daily energy demand, and added to the total ICT costs to obtain total telecenter investment costs.

The results illustrated the stark financial consequences of failing to manage energy demand in off-grid situations. Telecenters with the highest power consumption cost more than twice as much to establish, on average, as the most energy-efficient telecenters. In real terms, this amounted to a cost differential of up to US$31,421 between telecenters with equivalent service offerings.

Computer Selection

Each of the four computer options used in the analysis is a composite based on the specifications, pricing and physical forms of actual computer models. The prices used in the analysis should be taken as examples only, since there is a considerable range of prices for computers in all four categories. The main principles in assigning the prices were that notebook computers cost significantly more than desktop computers, LCD monitors cost more than CRT monitors, and state-of-the-art components cost more than older technologies.

The first computer option is a notebook computer with average power consumption of 15.8 W in operation and 0.8 W in sleep mode (**Figure 8**). This option has the lowest energy requirements of the four. The second computer option is a low-power desktop computer with an LCD monitor. Companies such as Intel, Via Technologies and Transmeta offer specially designed processors that can form the basis for a low-power desktop system. These processors typically range up to about 1.4 GHz in clock speed. Low-power desktops are suitable for the same basic applications as standard desktop computers of comparable power and configuration. The low-power desktop computer and LCD monitor in this example consume 55 W, on average, during operation.

The third computer option is a business desktop PC computer with an LCD monitor, consuming a total of 89 W during active usage and 9.5 W in sleep mode. This option is referred to as a "business PC" because it is designed to support typical office applications at a reasonable price, rather than including all of the bells and whistles of a state-of-the-art system. This type of computer would typically have a Celeron or P4 processor between 2.2 and 3.2 GHz, integrated graphics, and 128 MB to 256 MB of RAM.

The final computer option is an entertainment PC with advanced graphics performance designed to support the highest quality video and 3-D games. This type of computer has a fast processor between 2.5 and 3.2GHz and an advanced graphics card such as the ATI Radeon 9700. In this example, the entertainment PC consumes 108 W on average. It is connected to a 15" CRT monitor that consumes 100 W. Most CRT monitors consume between 70 W and 120 W and are responsible for about 50% to 70% of the power consumption of a desktop computer system. Standalone LCD monitors, such as those used with the low-power desktop and business PC options above, typically consume between 20 W and 50 W.

Figure 8 Computer Options Used in Telecenter Cost Analysis[33]

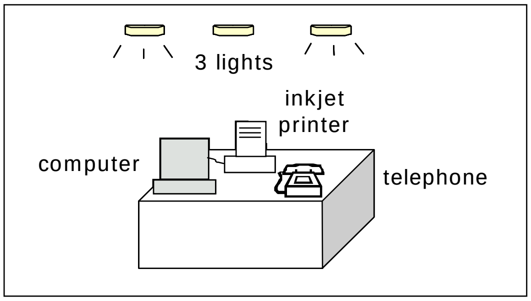
Notebook	Low-Power Desktop	Business PC + LCD Monitor	Entertainment PC + CRT Monitor
			
Power Consumption Active: 15.8W Sleep: 0.8W Price: $1800	Power Consumption Active: 55W Sleep: 5W Price: $950	Power Consumption Active: 89W Sleep: 9.5W Price: $1078	Power Consumption Active: 208W Sleep: 15W Price: $1050

Equipment Configuration and Daily Energy Requirements

Based on the four computer options listed above, average daily energy demand was calculated for small, medium and large off-grid telecenters. The smallest telecenter, illustrated in **Figure 9**, consisted of one computer, one inkjet printer, one telephone, and three 15 W compact fluorescent lights. The initial cost of ICT equipment and lighting for the small telecenter was $1,975 for the notebook option, $1,125 for the low-power desktop option, $1,253 for the business PC, and $1,225 for the entertainment PC. As shown in **Figure 9**, the average daily energy demand for the small telecenter ranged from 0.144 Wh to 1.38 kWh.

[33] Pictures shown are for illustrative purposes and do not represent the "actual" models used.

Figure 9 Configuration and Energy Demand of Small Rural Telecenter

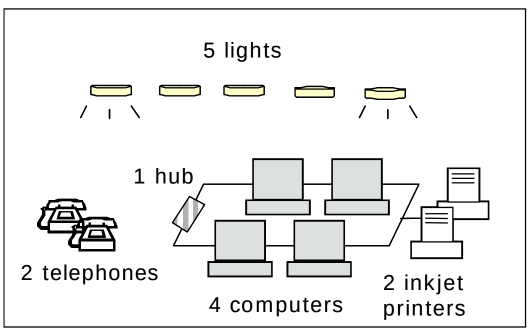


If the computer option is ...	Telecenter energy demand* is around ...
Notebook	0.14 kWh/day
Low-power desktop	0.40 kWh/day
Business PC + LCD monitor	0.62 kWh/day
Entertainment PC + CRT monitor	1.38 kWh/day

*Usage Assumptions: Telecenter open 11 hrs/day, 6 days/wk. PC – 65% active, 35% sleep mode. Printer – active 1.4 hrs/day. Telephone – 1.5 hrs/day off-hook. Lights on – 4 hrs/day.

The medium-sized telecenter included four computers, two inkjet printers, one Ethernet hub, two telephones and five 15 W compact fluorescent lights (**Figure 10**). The initial cost of ICT equipment and lighting for the medium-sized telecenter was $7,585 for the notebook option, $4,185 for the low-power desktop option, $4,696 for the business PC, and $4,585 for the entertainment PC. The energy demand of the medium-sized telecenter ranged from 638 Wh to 5.6 kWh.

Figure 10 Configuration and Energy Demand of Medium Rural Telecenter

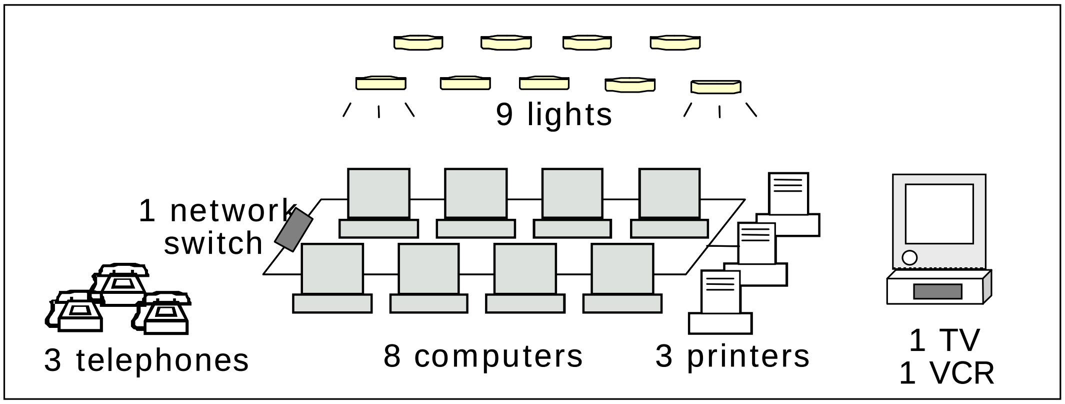


If the computer option is ...	Telecenter energy demand* is around ...
Notebook	0.64 kWh/day
Low-power desktop	1.7 kWh/day
Business PC + LCD monitor	2.5 kWh/day
Entertainment PC + CRT monitor	5.6 kWh/day

*Usage Assumptions: Telecenter open 11 hrs/day, 6 days/wk. PCs – 65% active, 35% sleep mode. Printers – active 1.4 hrs/day. Telephones – 1.5 hrs/day off-hook. Lights on – 4 hrs/day.

Finally, the large telecenter consisted of eight computers, one inkjet printer, one dot matrix computer, one multi-function printer/ scanner/ copier/ fax, one network switch, one TV, one VCR, three telephones, and nine 15 W compact fluorescent lights (**Figure 11**). The initial cost of ICT equipment and lighting for the large telecenter was $15,916 for the notebook option, $9,116 for the low-power desktop option, $10,138 for the business PC, and $9,916 for the entertainment PC option. The energy demand of the large telecenter ranged from 1.4 kWh to 11.3 kWh per day.

Figure 11 Configuration and Energy Demand of Large Rural Telecenter



If the computer option is	Telecenter energy demand* is around
Notebook	1.4 kWh/day
Low-power desktop	3.4 kWh/day
Business PC + LCD monitor	5.2 kWh/day
Entertainment PC + CRT monitor	11.3 kWh/day

***Usage Assumptions: Telecenter open 11 hrs/day, 6 days/wk. PCs – 65% active, 35% sleep mode. Printers - active 1.4 to 2.1 hrs/day. Telephones – 1.5 hrs/day off-hook. TV / VCR on – 1.5 hrs/day. Lights on – 4 hrs/day.**

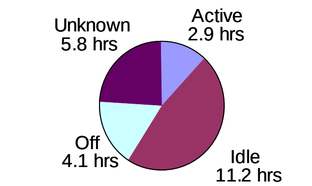
In calculating daily energy demand, Winrock assumed a 65% utilization rate for the computers during operating hours[34]. The usage rates selected for estimating energy demand can have a large impact on system size, and need to be assessed on a case by case basis. As illustrated in **Box 8**, actual computer usage varies widely in development contexts.

[34] Based on the profile of a basic telecenter "Cabina Publica Prototype" in Proenza et al (2001). The usage rate for computers in the telecenters described in the above source ranged from 60-70%. The target usage rate for rural telecenters in this study is 65%; in other words, the computers are assumed to be in use 65% of the time that the telecenter is open.

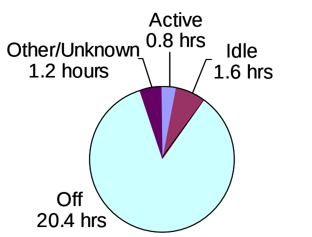
Box 8: Estimating Energy Demand: How Many Hours of Use Do Computers Really Get?

Average Daily Hours of PC Usage Reported by Survey Participants

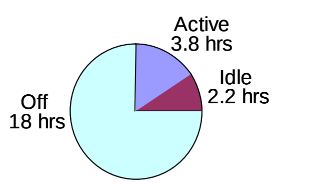
PC3 Telecenter e-World
Omourtog, Bulgaria
September 20 – November 13, 2003



Telesecundarias (High School)
Chihuahua, Mexico
October 1, 2003 – March 23, 2004



World Links Computer Centre,
Zenzega 3 High School
Chitungwiza, Zimbabwe
November 15 – 29, 2003



When estimating the energy demand of an off-grid telecenter, the question of how many hours per day to allocate for PC usage is not a trivial one. If assumptions about expected usage are too high, the energy system will be oversized and will cost more than necessary, reducing the available funding left for other projects. If the usage assumptions are too low, then the energy system may fail to provide enough power.

To begin the process of establishing benchmarks for PC usage norms in different types of environments, we asked a small number of grid-connected telecenters and schools around the world to let us monitor their PC usage for at least two weeks. Usage was monitored using Watt Savvy Corporate Edition software provided by Blue Owl Technologies of California, USA[35]. Data on the percentage of time each computer spent in active mode, standby mode, turned off, and other states of power consumption was reported automatically over the internet or sent manually by email.

There were three participants from which useful information was gathered during the trial period. One was PC3 e-World, a for-profit telecenter in the remote Bulgarian town of Omourtog. PC3 e-World was established in September 2001 with training and assistance from dot-ORG, a USAID-funded project implemented by the Academy for Educational Development (AED). This telecenter has operating hours from 9am to 11pm daily, and is connected to the electricity grid. The second participant was a Telesecundaria high school in Chihuahua, Mexico. Telesecundaria schools in Mexico provide secondary education with support from curriculum-based television programming. The Telesecundaria in Chihuahua operates a computer center for classroom and extra-curricular use during the school week from Monday through Friday, and is connected to the electricity grid. The final participant was a World Links Computer Centre located at Zenzega 3 High School in Chitungwiza, Zimbabwe. The Centre is operated as a community telecenter in which users pay a fee to access the computers. The Centre staff indicated that the facility is open for 10 hours per day, and is connected to the electricity grid.

The results of this small sample showed that the commercial PC3 e-World telecenter had the highest usage pattern with the computers in active or idle mode for an average of 14.1 hours per day. PC3's usage data revealed that several of the computers were kept running 24 hours per day and did not enter standby mode, even when idle for several consecutive hours. The World Links Computer Centre in Chitungwiza, Zimbabwe reported that its PCs were powered on for an average of 6.0 hours per day and shut off for the remaining 18 hours per day during a two-week period in November 2003. Finally, computers at the Telesecundaria in Chihuahua, Mexico were powered on for an average of 3.6 hours per day and shut off for an average of 20.4 hours per day[36]. The monitoring period, extending from October 2003 to March 2004, included weekends and several periods of vacation when the school was closed and the computers were not in use, thus reducing the average daily activity rates. The data showed that the school shut down the computers on most nights and weekends in addition to longer vacations.

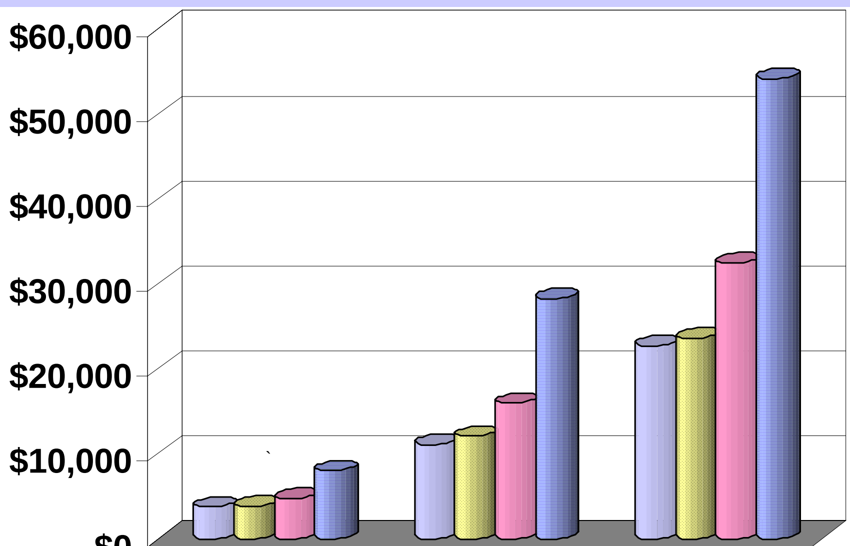
The range of PC usage rates from 3.6 to 14.1 hours per day points to the tremendous impact that end-user behavior can have on the amount of energy required to power an off-grid telecenter. The institution of simple procedures such as shutting off computers and monitors each night and using standby modes to reduce computer and monitor power consumption while idle can significantly reduce the amount of energy required on a daily basis.

[35] www.wattsavvy.com. This web site provides a great deal of information on computer power consumption.

Total Initial Investment in ICT and Energy Systems

The results of the analysis described above revealed total upfront ICT and energy costs for telecenters ranging from $3,724 to $54,136 (see **Figure 12**). Telecenters with notebook PCs represented the least expensive option in each size category, followed closely by telecenters with low-power desktops. As the scale of the telecenters increased, so did the cost disparity: a large telecenter with the notebook computer option cost $22,715, compared to $54,136 with entertainment PCs and CRT monitors. Overall, there was a net increase of approximately $4,000/computer in initial energy and ICT costs for telecenters using the entertainment PC systems compared to notebook computer systems. This disparity takes into account the fact that each notebook computer was priced $750 higher than each entertainment PC system.

Figure 12 Initial Investment in ICT and PV Energy Systems



	Small (1 PC)	Medium (4 PCs)	Large (8 PCs)
Notebook	$3,724	$11,050	$22,715
Low-power desktop	$3,784	$12,077	$23,598
Business PC + LCD monitor	$4,718	$15,928	$32,453
Entertainment PC + CRT monitor	$8,025	$28,265	$54,136

Most of the simulated PV system costs fell between $12/Wp and $19/Wp, inclusive of all system components such as the inverter and BOS, taxes (import and value-added), vendor markups and installation costs. These prices correlate fairly well with reports Winrock has received from individuals and installations in the field, as well as its own projects. Recent prices bid for complete PV systems include $11/Watt to $17/Watt (Ghana[37]); $16.69/Watt to $20.25/Watt (Honduras[38]); $14.02/Watt to $15.71/Watt (Rwanda[39]). Pricing at the lower end of the range is more likely for large-scale procurements and/or in

[36] The monitoring software reported a usage state of "unknown" for an average of 1.2 hours per day at the Telesecundaria. According to the software manufacturers, the "unknown" reading typically indicates that the end-user shut down the monitoring program. Therefore we included unknown periods in the total hours of active and idle usage.
[37] Source: Email communications between Wisdom Ahiataku-Togobo of the Ministry of Energy in Ghana and Dr. Abeeku Brew-Hammond, September 2003.
[38] Sources: Robert Foster, NMSU; Guillermo Mazariegos, COHCIT, 8/12/2003.
[39] Source: dot-ORG Rwanda, 2003.

countries where there are government subsidies, low import duties, significant domestic manufacturing of PV systems or components, or highly competitive PV distribution markets.

The PV system capacity required to meet telecenter energy demand ranged from 40 Wp for the lowest power telecenter – a single notebook computer, inkjet printer, telephone and three lights – to 3,500 Wp for an 8-computer telecenter with entertainment PC systems (shown in **Table 8** and **Table 10**, respectively). Telecenters configured with the low-power desktop option were similar but slightly higher in cost than the notebook-configured options. It is instructive to note that the small telecenter configured with a high-power desktop required the same capacity energy system as the large telecenter configured with eight notebook computers, three printers, a TV, a VCR and nine compact fluorescent lights.

Table 8 Investment Costs in ICT and PV Energy Systems: Small Telecenter[40] (1 computer)

Computer Option	Energy Demand (Daily Wh)	PV System Size (Wp)	PV System Cost	ICT Equipment Cost	Total ICT + Energy Cost
Notebook (16 W)	144	40	$1,749	$1,975	$3,724
Low-Power Desktop (55 W)	399	140	$2,659	$1,125	$3,784
Business PC + LCD Monitor (89 W)	622	200	$3,465	$1,253	$4,718
Entertainment PC + CRT Monitor (208 W)	1,380	420	$6,800	$1,225	$8,025

Table 9 Investment Costs in ICT and PV Energy Systems: Medium Telecenter (4 computers)

Computer Option	Energy Demand (Daily Wh)	PV System Size (Wp)	PV System Cost	ICT Equipment Cost	Total ICT + Energy Cost
Notebook (16 W)	638	200	$3,465	$7,585	$11,050
Low-Power Desktop (55 W)	1,654	540	$7,892	$4,185	$12,077
Business PC + LCD Monitor (89 W)	2,547	850	$11,233	$4,696	$15,928
Entertainment PC + CRT Monitor (208 W)	5,580	1,700	$23,680	$4,585	$28,265

Table 10 Investment Costs in ICT and PV Energy Systems: Large Telecenter (8 computers)

Computer Option	Energy Demand (Daily Wh)	PV System size (Wp)	PV System Cost	ICT Equipment Cost	Total ICT + Energy Investment
Notebook (16 W)	1,372	420	$6,800	$15,916	$22,715
Low-Power Desktop (55 W)	3,405	1,150	$14,483	$9,116	$23,598
Business PC + LCD Monitor (89 W)	5,190	1,550	$22,315	$10,138	$32,453
Entertainment PC + CRT Monitor (208 W)	11,257	3,500	$44,220	$9,916	$54,136

These principles have been developed as a result of experiences in the field, and have already been used in projects at the forefront of off-grid rural computing. For an example of how decision-makers have used ICT equipment selection to reduce the total costs of PV-powered telecenters, see **Box 9** below.

[40] See **Figures 9, 10** and **11** above for equipment complement and usage assumptions regarding small, medium and large telecenter configurations.

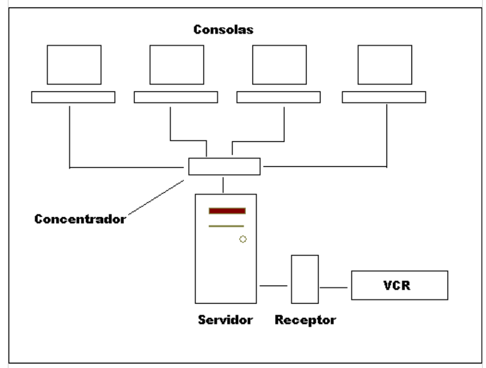
Box 9: Piloting Off-Grid Telecenters in Honduras

In 2003, the Honduran Council for Science and Technology (COHCIT) began implementing the pilot phase of a plan to establish 100 rural community centers around the country. The community centers were to provide a variety of ICT services, and would be equipped with computers, printers, photocopiers, television/VHS equipment, and presentation projectors. Between 10 and 15 of the centers would not have access to the electricity grid. Having tried installing full-power desktop systems in a PV-powered telecenter in a previous project called Aldeas Solares, COHCIT realized that the new off-grid centers would need to be powered by renewable energy systems and would thus require a modified approach to equipment selection.

With support from the World Bank, SWTDI-New Mexico State University (NMSU), Sandia National Laboratory and the International Telecommunication Union (ITU), COHCIT considered options for reducing total investment costs in the off-grid telecenters by selecting energy efficient ICT equipment. Compared to centers with grid electricity, the off-grid centers would be reduced in size: four to seven personal computers, a TV, a VCR, and an ink jet printer instead of a laser jet printer.

To reduce the power requirements even further, the project considered the installation of thin client terminals connected to a single on-site server in off-grid centers (see diagram at right). With a VCR connected to the server, the thin client LCD displays could be used for watching recorded programs, thus eliminating the need for a conventional television set.

Proposed Thin Client Network for Community Center



Source: COHCIT

COHCIT issued a request for PV system quotations in which the thin client network was proposed for a community center in Las Tejas, while a network of standard desktop systems was proposed for a second off-grid center in Montana Grande. The standard desktop configuration led to a quotation of $23,500 for a 1,200 Wp system, whereas the thin client configuration resulted in a quotation of $12,250 for a 700 Wp system,[41] a cost reduction of nearly 48%.

Wireless Connectivity

Telecenters that lack access to the electricity grid are frequently located beyond the reach of landline telephone networks as well. Wireless connectivity options that can be installed in off-grid telecenters, these options add to the telecenters energy requirements.Three different wireless connectivity options were considered, offering voice telephony, data transfer or both: Very Small Aperture Terminal (VSAT) satellite remote stations, narrowband packet radio, and WiFi.

In contrast to computer systems, whose costs are highly front-loaded, many communications services incur ongoing service charges that may exceed the initial cost of the equipment many times over. In its own projects, Winrock has not found it practical to select wireless connectivity options based on the power consumption of the equipment, although it is a consideration in determining whether a given option is

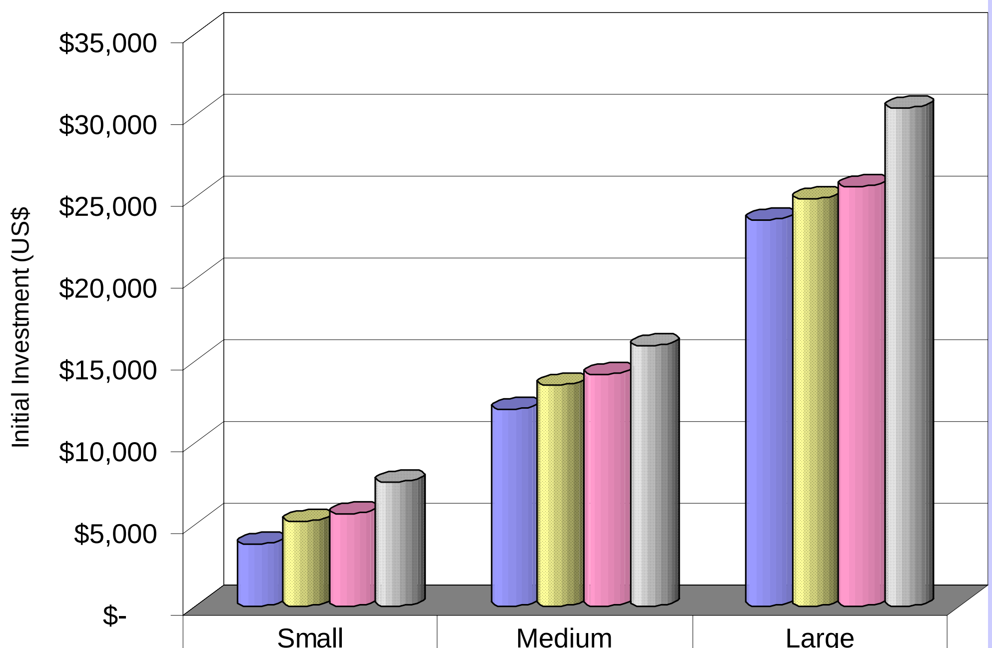
[41] Despite the energy cost savings associated with the thin client network, it was not implemented on the grounds that the risk to business operations was too great if all of the center's computer services relied on a single server.

financially feasible for the community involved.

To provide some reference points for the potential impact of wireless connectivity on PV system costs, Winrock considered WiFi, packet radio and VSAT connectivity options and added the marginal costs of the equipment and energy system capacity to the totals listed above in Table 7. The usage assumptions for the wireless connectivity equipment were the same for all three options: the equipment was active three hours per day for small telecenters, five hours per day for medium telecenters, and seven hours per day for large telecenters[42]. Due to wide variability in the cost of professional installation services based on the availability of local expertise and the difficulty of reaching remote locations, we did not include installation costs for the connectivity equipment.

The results, summarized below in **Figure 13**, indicated that WiFi connectivity increased initial equipment and energy costs by about $1460, packet radio by about $2000, and VSAT connectivity by $3800-$6900, depending on the number of telephone lines supported by the VSAT model. Service charges, such as monthly usage fees and ISP charges, were not included in the analysis. Additional details on the assumptions about each connectivity option are provided below.

Figure 13 Initial Investment in ICT, PV Energy and Wireless Connectivity Systems



	Small	Medium	Large
No connectivity	$3,784	$12,077	$23,598
WiFi connectivity	$5,244	$13,536	$24,876
Packet radio connectivity	$5,689	$14,164	$25,595
VSAT connectivity	$7,590	$15,961	$30,463

[42] For the remote telecenters in the packet radio and spread spectrum scenarios, we assumed the breakdown of transmit/receive activity to be 35%/65%. This assumption was necessary because power consumption is much higher in transmitting mode.

VSAT Connectivity

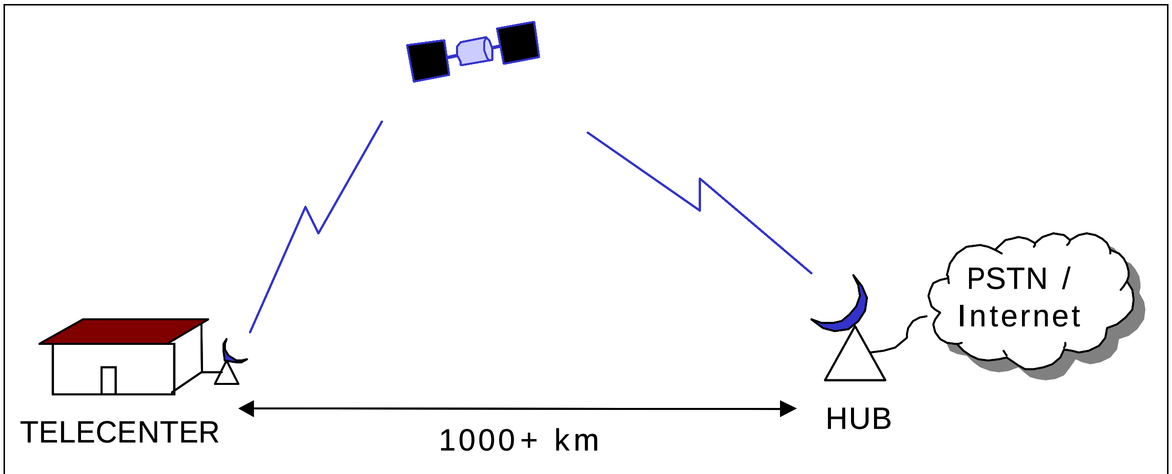


Figure 14 Telecenter with VSAT Connectivity

The VSAT connectivity option (**Figure 14**) is a low-power system that is capable of supporting telephony and data services. VSAT systems have become a familiar component of remote telecenters due to their ability to offer connectivity in virtually any location. There are a variety of benefits and drawbacks to the use of VSATs; however, these are outside the scope of this particular discussion. What is important in the energy context is to raise awareness that there are low-power VSATs that are designed for off-grid usage, and they consume as little as 25 W-30 W on average.

Based on the usage assumptions described above, VSAT connectivity added between 256.3 and 335.1 daily Watt hours to the telecenters' energy load (**Table 11**). One of the reasons these figures are so high is that the VSATs were assumed to remain operating in standby mode during the nighttime and on Sunday when the telecenter was closed. This assumption was made because some VSAT manufacturers discourage users from shutting off the power to the VSAT on a frequent basis. Not all satellite receivers need to follow this practice, however, so it is worthwhile to check with the supplier.

Table 11 Additional Telecenter Energy Demand with VSAT Remote Station

Telecenter size	Additional daily Watt-hours	VSAT equipment costs
Small	256.3	$3,000
Medium	295.7	$3,000
Large	335.1	$5,500

VSAT equipment costs were chosen to represent fairly advantageous market pricing for thin route rural telephony/internet VSAT terminal and receiver equipment. In many countries, factors such as vendor markup, import duties and regulations will increase costs for the basic equipment. The large telecenter was assigned an upgraded VSAT package in order to support four telephone lines (three telephones plus a separate fax line) plus Internet access, whereas the smaller telecenters sufficed with three telephone lines.

When combined with the low-power desktop computer option, the VSAT scenario increased total ICT plus energy costs for the telecenters by $3,806 for the small telecenter, $3,884 for the medium telecenter, and $6,865 for the large telecenter.

Narrowband Packet Radio

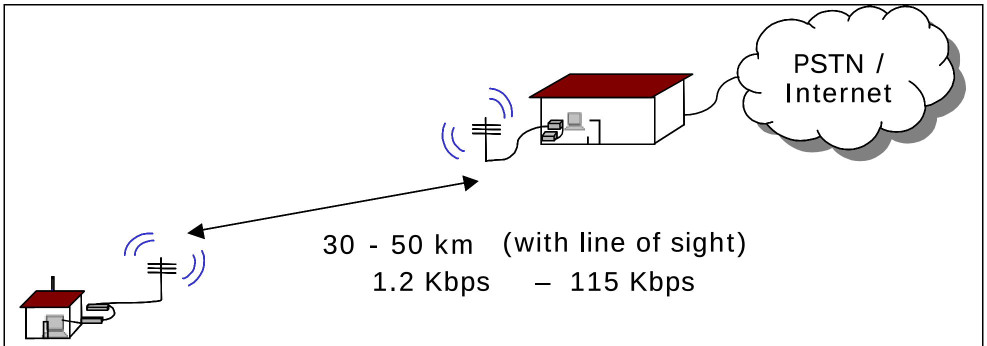


Figure 15 Telecenter With Narrowband Packet Radio

The narrowband packet radio option (**Figure 15**) uses a terminal node controller and an amateur radio transceiver for low-speed wireless data transfer. Packet radio hardware and software can be added to HF, VHF and UHF radio systems that have a long history of use in rural areas for open-air voice communications. The use of packet radio to provide internet access for rural telecenters has been pilot tested in Honduras in a project supported by the ITU and Hondutel. Packet radio is being used to connect multipurpose community telecenters in the towns of Santa Lucía and Valle de Angeles to smaller telecenters in a number of villages surrounding the main towns[43]. The power supply for nodes and repeaters is one of the main costs for this type of connectivity solution[44].

For this connectivity scenario, Winrock chose equipment in the 2 m amateur radio band (144-145 MHz), with a transmitter output power level of 20 W. The system supports data rates ranging from 9600 baud (using 12.5 kHz of spectrum) to 153 k baud (using 200 MHz). Winrock also assumed that the packet radio system would be powered only during telecenter operating hours and that the equipment would be shut off and disconnected, consuming no electricity, at other times.

Table 12 Additional Telecenter Energy Demand with Packet Radio Connectivity

Telecenter Size	Operating mode	Estimated usage (hours)	Power consumption (W)	Average daily Watt hours	Packet radio equipment cost
Small	transmitting	1.1	63.4	57.1	**$1,541**
	receiving	2.0	4.3	7.2	
	standby	8.0	2.2	14.8	
	subtotal			**79.0**	
Medium	transmitting	1.8	63.4	95.1	**$1,541**
	receiving	3.3	4.3	12.0	
	standby	6.0	2.2	11.1	
	subtotal			**118.2**	
Large	transmitting	2.5	63.4	133.2	**$1,541**
	receiving	4.6	4.3	16.8	
	standby	4.0	2.2	7.4	
	subtotal			**157.4**	

[43] “Multipurpose Community Telecentres: Connecting people from Timbuktu to Kabul.” *ITU News*, No.5/2002.
[44] PV power supply was estimated at 45% of the cost of a packet radio repeater for the Honduras ITU project. Final Report of ITU-D Focus Group 7: New Technologies for Rural Applications, International Telecommunication Union (ITU), 2001, Section 4.1.

Based on the usage assumptions indicated in Table 12, packet radio connectivity increased daily telecenter energy requirements by 79.0 Wh for the smallest telecenter, 118.2 Wh for the medium telecenter, and 157.4 Wh for the large telecenter. Of the three wireless scenarios, narrowband packet radio installations are most likely to diverge significantly from the estimates of energy demand presented here. This is due to the wide range of equipment configurations, component quality and transmitter output power levels that can be used to achieve packet radio connections.

With the addition of packet radio connectivity, total telecenter investment increased by about $2,000 on average.

WiFi Connectivity

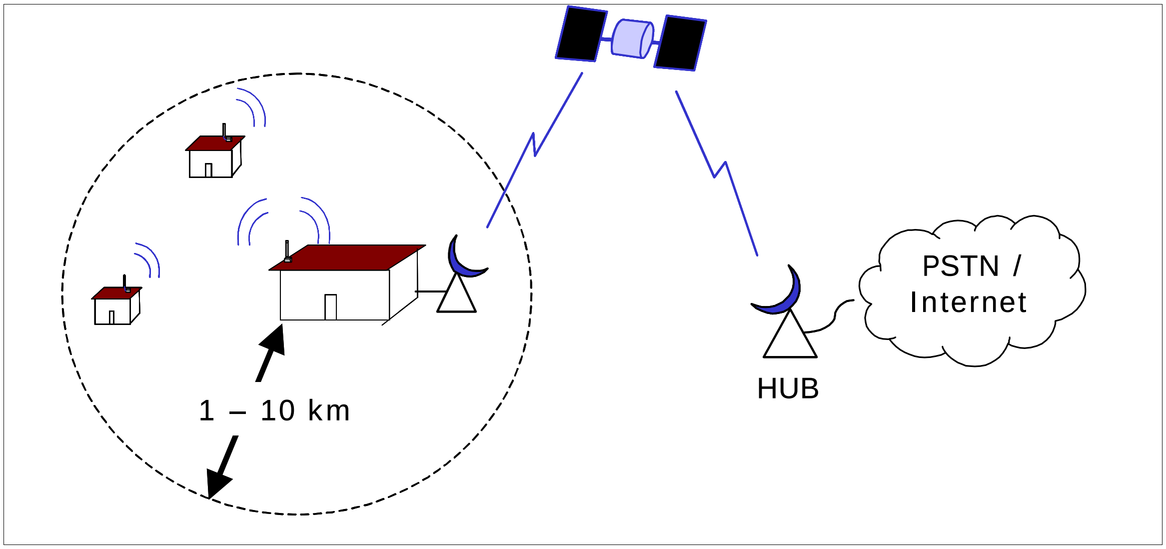


Figure 16 Telecenters With VSAT and WiFi Links

The third wireless connectivity scenario (**Figure 16**) consisted of a network of off-grid telecenters with one centrally located telecenter acting as a wireless ISP (WISP) to two remote telecenters. The WISP receives its Internet connection through a VSAT installed on site, and distributes Internet access to the remote telecenters through a WiFi fixed wireless spread spectrum network. Depending on the distance and the quality of the wireless connection, the WISP would transmit data to the remotes at rates ranging from 1 Mbps to 11 Mbps, although the speed of Internet access would ultimately be limited by the VSAT bandwidth, which might realistically be 64 kbps.

The wireless network in this scenario has a point-to-multipoint configuration with line of sight (LOS) between the WISP and the remote telecenters. Depending on local terrain and sources of interference, it is realistic to expect a range of one to ten kilometers between telecenters using this type of technology and configuration. In some cases it is possible to achieve longer distances using high gain antennas, either by putting the antennas on higher masts or installing repeater nodes.

The additional energy demand entailed by spread spectrum connectivity at the remote telecenters is fairly low, ranging from 30.0 to 42.6 Watt hours (see **Table 13**). These calculations are based on the assumption that the connectivity equipment remains powered in standby mode when the telecenters are closed. Spread spectrum systems in the WiFi family have relatively low power requirements because their output power (and, hence, range) is limited by regulation. For short-range links of a few kilometers, spread spectrum technology is a good solution for speedy, reliable, low-power data communications.

Table 13 Additional Telecenter Energy Demand with WiFi Connectivity

Telecenter Size	Operating mode	Estimated usage (hours)	Power consumption (W)	Average daily Watt hours	WiFi equipment cost

Small	transmitting	1.1	10.0	9.0	**$1,278**
	receiving	2.0	1.8	3.0	
	standby	21.0	1.0	18.0	
	subtotal			**30.0**	
Medium	transmitting	1.8	10.0	15.0	**$1,278**
	receiving	3.3	1.8	5.0	
	standby	6.0	1.0	16.3	
	subtotal			**36.3**	
Large	transmitting	2.5	10.0	21.0	**$1,278**
	receiving	4.6	1.8	7.0	
	standby	4.0	1.0	14.6	
	subtotal			**42.6**	

With the addition of WiFi connectivity, total telecenter investment increased by about $1,400 on average.

As would be expected, the central telecenter with both VSAT and WiFi equipment had higher energy demand than the remote telecenters with WiFi systems only. As indicated in **Table 14**, VSAT and WiFi equipment added a combined total of $4,000 to $7,000 in ICT equipment costs and increased total energy demand by 300 Wh to 400 Wh compared to the telecenters without any connectivity. In some cases, these costs may be offset with potential revenue from WISP services and/or cost-sharing arrangements with the remote telecenters.

Table 14 Additional telecenter energy demand with VSAT and WiFi connectivity

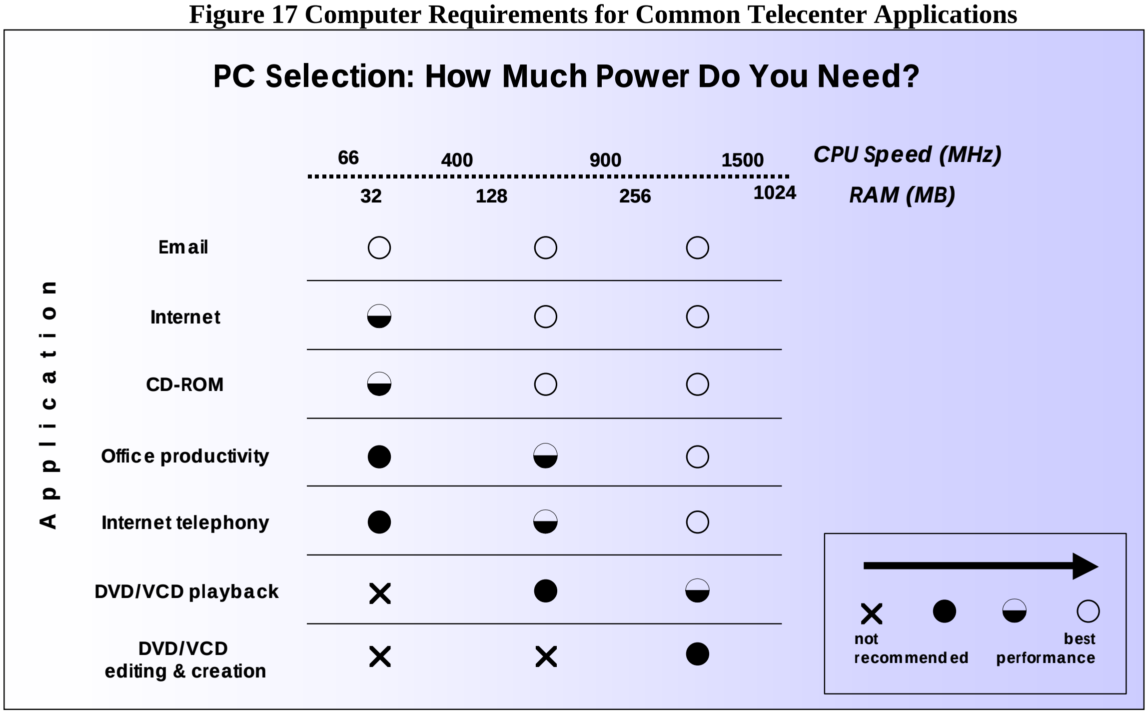
Telecenter size	Average daily Watt-hours (VSAT)	Average daily Watt-hours (WiFi)	Average daily Watt-hours (total)	VSAT + WiFi equipment cost
Medium	295.7	40.3	336.0	$4,351
Large	335.1	53.4	388.6	$6,851

When combined with VSAT and WiFi connectivity, total investment in medium and large telecenters with low-power desktops reached $17,494 and $31,490, respectively.

4.2 Application Requirements

The hardware and software requirements of a computer depend on the applications for which it will be used, as well as the buyer's philosophy and budget. Some argue that rural telecenters should purchase state-of-the-art computers that will support the latest software applications for as long as possible. Others prefer good value computers that support current and anticipated application requirements, but don't charge extra for sophisticated features and capabilities that are unlikely to contribute to the goals of the project. While minimum application requirements vary for each specific software program and operating system, **Figure 17** provides an indication of the computing resources needed for certain common applications.

Figure 17 Computer Requirements for Common Telecenter Applications



4.3 Maintenance and Repair

When ICT systems are installed in rural areas, special measures must be taken to care for the components, including training for those who will operate the technology and access restrictions for unauthorized people. In many rural areas, elements such as dust, humidity and insects are generally difficult to control. Under these conditions, even devices as reliable as TV sets can suffer breakdowns after a few months of use. One survey has shown that the failure to keep computers clean and physically well maintained is responsible for 72% of CPU failures and 85% of breakdowns in printers[45]. Such problems are compounded in rural and remote areas, and the effects of breakdowns are often increased because of limited access to spare parts and repair services, especially in the case of notebook computers.

Although the anecdotal evidence is inconclusive, notebooks are perceived to be more susceptible than desktops to physical damage in the rural environment. The components in notebook computers are generally more difficult and costly to repair than for desktop systems. This is partly a result of the technology involved and partly due to the much greater number of desktop systems in the marketplace.

[45] 2002 Dust-Off® Survey of PC Hygiene, August 2002. Survey applied to PCs in the U.S.A. http://www.computerhygiene.com.

Special technology and expertise is required to repair a notebook's LCD display. In some cases, replacing the display is the only practical option. This is the single largest cost component of a notebook computer.

In rural areas, the cost of replacement parts is compounded by the relative scarcity of notebook repair facilities. When local desktop repair facilities are unable to service notebooks it can take longer to deliver, service and return a notebook computer, translating into greater loss of service revenue for the telecenter operator if a unit malfunctions. However, if the nearest computer repair facility is located some distance from the telecenter, the cost of transporting notebooks for repair may be less than that for transporting desktop systems, because of the former's smaller size and compact shape.

One way to reduce wear and tear on notebooks is to attach inexpensive external keyboards and mice. Ruggedized notebooks are available that can withstand harsh environmental conditions such as temperature extremes, physical shocks and humidity. Panasonic and Itronix are two of the largest suppliers. While ruggedized models may cost 2-3 times more than standard systems when purchased new, it is possible to obtain used or donated equipment at more reasonable costs. Used ruggedized notebooks can periodically be found up for auction on e-Bay (www.ebay.com) selling for a few hundred dollars.

To maximize equipment lifespans, computers and other electronics should not be placed in direct sunlight, near water or corrosive battery fumes. When the devices are not in use, they should be covered to prevent dust build-up inside. Built-up dust retains humidity and can start a corrosion process in a device's components. Electronic devices need air to flow through them in order to dissipate heat (unless they have specialized design features such as heat sinks and cooling fins). It is important not to block the vents when the devices or appliances are working. In very humid sites, the risk of condensation at night is significant.

Few people should have unrestrained access to the computers and other equipment. When children or untrained people operate the equipment, a trained person should be present. Measures must be taken to discourage vandalism. This includes constant surveillance and locking the systems up when not in use, particularly at night and during weekends.

4.4 Mobility, Theft and Security

The mobility of notebooks can be both a benefit and a challenge. While some programs take advantage of notebook portability to integrate computers into school and community activities, others perceive notebooks as prohibitively risky in terms of opportunity for theft. Both issues can have serious implications for the success of a project and for the willingness of local project personnel to take responsibility for equipment safety.

In the Digital Enhancement Education Project (DEEP) in rural schools of South Africa's Eastern Cape, funded by the Education Department of the UK's Department for International Development (DFID), the portability of notebook computers allowed for greater flexibility in achieving educational goals as well as in their storage and maintenance (Leach et al, 2002). The notebooks were integrated into classroom activities during which groups of students took turns at the keyboard. Teachers carried the notebooks to a nearby hospital to have their batteries recharged, and used them outside the classroom on evenings and weekends. After school hours, the notebooks were moved for safekeeping to teachers' houses or the principal's home, rather than remaining locked unattended in the schools, where they might have been targets for theft.

4.5 User Acceptance

Field experiences have revealed that decision makers, program managers, telecenter operators, teachers and even individuals who have never used a computer before can have strong preferences regarding the selection of computing equipment. Despite savings in the initial investment costs due to the energy efficiency of notebook computers, they can be perceived as expensive, difficult to use and generally inferior to desktop systems. In the case of the off-grid computer lab established at Myeka High School in South Africa, for example, school members cited various objections to the use of notebooks, including difficulty of repair, concern about theft, lack of robustness and durability, and teachers' perceptions that notebooks simply were not "proper computers" (Cawthera, 2001: p.31). As a result of these concerns, desktop computers were installed, despite the fact that using notebook computers would have lowered the cost of the PV energy system used to power it. Since the PV system was donated to the high school, the cost issue was not paramount. For a contrasting perspective, read **Box 10** on Enersol's experience with laptop computers.

Box 10: Reducing PV Energy Costs Through Donated Laptops

Enersol's EduSol program provides solar-powered laptops for educational purposes to rural schools in Latin America and the Caribbean. As a small NGO, Enersol's funding comes primarily through smaller donations from private foundations. The NGO works hard to achieve the maximum benefit from the available financial resources.

Source: Enersol

Enersol selected laptops as a standard component of their solar-powered computer kits after field experimentation with both laptops and desktops. The laptops' lower power consumption and relative ease of shipping and transport were determining factors in the decision[46].

The hot, humid and often dusty conditions of many rural schools pose challenges to keep the systems operational. Surprisingly, the computer hardware itself has not been problematic. To ease wear and tear on the notebooks and improve ergonomics, EduSol supplies inexpensive keyboards and external mice. The peripherals pose greater problems. In particular, the external CD drives are susceptible to breakdown because they have a greater proportion of moving parts.

The program has successfully shown how much can be accomplished with very basic computing hardware. In 2004, EduSol schools continue to make good use of donated laptops with 100 MHz CPUs, 24-40 MB of memory, and 0.8GB of storage to teach general keyboarding, file management and Microsoft Office skills. External CD-ROM readers also allow the use of learning games and reference materials. The newest machines include Pentium II processors, 64 MB of memory, and 3-5 GB of storage.

Corporate equipment donations have been easier to work with than individual donations, since the former often provide multiple units of the same make and model. This has allowed the users in different schools to move up the learning curve more quickly by learning from each other's experiences. Discarded computers have also provided an inventory of spare parts for repairs or increases in capacity.

By relying on laptops, Edusol can provide ample service for a modest investment in energy equipment. A center that opens for seven hours a day, including three hours of lighting at night, and limited printing, consumes approximately 350 Watt-hours daily. This is what an urban family might use watching a few hours of television, but under these circumstances it can provide 28 students per day with 30 minutes on a machine. Increased learning is also possible by having each student alternate between keyboarding and direct observation.

In contrast to some other projects, EduSol has encountered almost no resistance to the use of laptops in the communities it serves. Perhaps this is because, from the project's inception, Enersol explains the benefits to the community of using energy efficient laptops that can keep PV costs down. This educational process is not limited to interactions with the community leaders, but extends to the school children and the entire community. Enersol reinforces the message by explaining that the community can either have one desktop that three to four students can use, or three to four laptops that eight to 12 students can use. By bringing the message directly to the end users, community members at all levels understand the reasons for choosing the lower power option.

[46] "Solar-Powered Computers Increases [sic] Educational Opportunities for Rural Youth in Latin America." *Monday Developments*, 8 October 2001. http://www.enersol.org/documents/solarpoweredcomputers.pdf.

In situations where there are strong objections to the use of notebooks, the computer selection process should not be seen as a black-and-white choice between desktops and notebooks. Intermediate solutions can be applied, such as the use of LCD monitors, low-power desktops, and thin client networks. These approaches provide some of the perceived benefits of desktop systems while reducing energy system costs compared to conventional solutions.

4.6 Waste Disposal and Environmental Hazards

All computing equipment should be disposed of properly after reaching the end of its life cycle. Computers and computer components can release a variety of harmful toxins into the environment when incinerated or dumped in landfills. According to a February 2002 report by the Basel Action Network and Silicon Valley Toxics Coalition, toxic materials found in computers and monitors include lead, lead oxide, cadmium, mercury, polychlorinated biphenyls (PCBs), brominated flame retardants and polyvinyl chloride[47]. According to the study, plastics account for 13.8 pounds of the average computer, and can release toxins when burned.

4.7 Donated Computers – Costs & Savings

Donated computers are attractive to many resource-constrained programs because they seem to reduce the initial outlay required to obtain computer access. However, donated computers are rarely "free" to the receiving communities. In addition to transport, refurbishing, software licensing and maintenance costs, recipients of donated computers in off-grid areas typically bear the cost of providing the energy system. Since it is frequently power-hungry desktop systems and CRT monitors that are available from corporate donors, the diesel generator or PV energy system bought by the recipients can mean that a "free" donated desktop system actually costs more money than it would take to buy a new notebook computer and the less expensive power system required to power it. In these cases, donated desktop computers may not be worth the expense. However, donated notebook computers can be an excellent option, as in the case of Enersol described in **Box 10** above.

[47] Jim Puckett, Leslie Byster, et al. "Exporting Harm: The High-Tech Trashing of Asia." Prepared by The Basel Action Network (BAN) and Silicon Valley Toxics Coalition (SVTC), 25 February 2002. URL: http://www.ban.org/E-waste/technotrashfinalcomp.pdf.

5 Conclusions

A variety of field tested, commercialized standalone power systems are available to provide electricity for smal-scale ICT applications in off-grid and poorly electrified areas. Widely available options include rechargeable batteries, solar PV, and generator sets. Where natural resources are available, small wind turbines and micro-hydro systems can also be cost-effective options. The turnkey equipment and installation costs of these energy systems in developing countries typically ranges between $1,000 and $20,000 per kW. Power systems based on renewable energy resources such as sunlight, wind and running water typically incur most of their costs up front with the initial purchase and installation of the system, whereas power options based on fossil fuels tend to have lower investment costs and much higher running costs over time.

When developing ICT-based projects in off-grid or poorly electrified areas, the cost of providing electricity can consume as much as 80% of initial project funds if energy demand is not managed properly from the outset. The selection of low-power ICT equipment, such as notebook computers, low-power desktop computers, LCDs screens, and ink jet printers (**Figure 18**), can result in significant net savings in initial ICT and energy investment costs. Energy management is particularly important when purchasing solar PV and small wind systems.

Figure 18 Energy-Saving ICT Options for Off-Grid Projects

Even when grid power is available, low ICT power consumption may be beneficial if the grid is unreliable and subject to frequent power outages. When the grid has frequent outages, a back-up battery system may be needed to ensure continuous availability of electricity. As with distributed energy generation systems, the cost of a back-up battery system typically increases with the capacity of the battery bank. In general, the less energy the ICTs are consuming, the less expensive it will be to supply any shortfalls that may arise during the lifetime of the project.

Annex 1: Power System Basics

Introduction to Electrical Loads

Every device that runs on electricity represents a *load* on the system supplying the electrical power, be that system a national electricity grid, a wind power system or even a simple battery.

Power is the rate at which an electrical device does work. The basic unit of power consumption is the Watt (W). One kilowatt (kW) is equal to 1,000 Watts.

Energy is the amount of work done over a given period of time. Energy is expressed in terms of Watt hours (Wh) or kilowatt hours (kWh). For example:

Rate of power consumption = 100 W
Period of time = 2.5 hours
Energy consumed = 100 W x 2hrs = 250 Wh

Direct Current (DC) is electrical current which flows in only one direction. Batteries produce direct current. A light fixture is an example of a typical DC load.

Alternating Current (AC) is electrical current of which the flow reverses direction from period to period. The frequency of AC is measured in cycles per second, or Hertz (Hz). Typical AC loads include household appliances, television sets, desktop computers, etc.

Over the course of one hour, a television set with a power consumption rate of 100 W will consume 100 Wh of energy. A television set with a power consumption rate of 50 W, operated for 2 hours, will also consume 100 Wh.

When designing an energy system for ICTs in off-grid or underelectrified areas, the first step is to add up the energy requirements of all of the planned AC and DC loads in order to determine the total amount of energy that the system needs to supply. The size, cost and composition of the energy system are directly related to the size and characteristics of the loads. Thus, for off-grid ICT facilities, it is important to determine the power consumption for each device in the installation, including lights, fans, and any other electrical appliances.

Manufacturers' specifications often provide information on the *power rating* of electrical devices. The power rating represents the maximum electrical power that can be tolerated by the device. The rating is an upper limit for the rate of power consumption. However, normal or average power consumption of an ICT device is usually lower, sometimes much lower, than the power rating and is a more precise indicator for the purpose of sizing standalone energy systems.

If information on power consumption is not provided directly in the technical specifications, it may still be possible to gain information about the power consumption of the device from the data provided.

For DC systems, manufacturers' specifications may describe power consumption in terms of the current drawn in amperes (A) or milliamps (mA). In this case, power consumption may be calculated as the product of the DC voltage, in volts (V), and the current, in amps (A).

DC loads:
Power (W) = Voltage (V) x Current (A)

The specifications for a radio transceiver (transmitter/receiver) in **Figure A-1** indicate a current drain of 7A while the device is in transmitting mode (Tx) with a signal output power of 25 W. The power supply voltage is given as 13.2V. Therefore we can calculate the power consumption of the transceiver while transmitting at 25 W as follows: 13.2 V x 7 A = 92.4 W. Note that the power of the signal transmitted by the receiver, 25 W, is not the same as the electrical power consumed by the transceiver in order to produce the signal. The lower portion of **Figure A-1** illustrates the calculation of power consumption for all of the operating modes listed in the specifications.

Figure A-1 Calculating Power Consumption from Manufacturer Specifications

GENERAL

• Frequency coverage :	
IC-F110	136–174MHz
IC-F210	400–430MHz
	440–490MHz
• Number of channels	: Max. 128, 8 banks
• Channel Spacing	: 12.5/25kHz, 12.5/20kHz
• PLL channel step	: 2.5, 3.125kHz (VHF)
	5, 6.25kHz (UHF)
• Frequency stability	: ±1.5kHz
• Operating temp. range	: –25˚C to +55˚C
• Power supply voltage	: 13.2V DC
• Current drain	: Tx at 25W 7A
	Rx Max. audio 1200mA
	Stand-by 300mA
• Antenna impedance	: 50Ω (SO-239)
• Dimensions	: 150(W)×40(H)×117.5(D) mm
• Weight	: 800g

Source: Icom IC-F110 Specifications

Operating Mode	Voltage		Current Drain		Power Consumption
Transmitting (Tx)	13.2V	X	7.0A	=	92.4 W
Receiving (Rx)	13.2V	X	1.2A	=	15.8 W
Standby	13.2V	X	0.3A	=	4.0 W

To determine the average power consumption of the transceiver in **Figure A-1**, one would need to know the percentage of time the device was transmitting, receiving and standing by. For practical purposes, it is sometimes easier to simply measure the cumulative power consumption of an ICT device over a period of time and then calculate the average consumption over the period. In addition, the transceiver specified in **Figure A-1** may be capable of transmitting at output power levels other than the one listed, 25 W.

Determining the power consumption of AC devices is more complicated. Some AC loads consume electricity at a fairly constant rate, such as a light bulb, while others are complex or reactive. Complex loads are also known as *nonlinear* loads, because the current drawn does not have a linear relationship to the voltage. Switched mode power supplies, uninterruptible power supplies (UPS) and adjustable-speed drives are all examples of nonlinear loads. The nonlinear relationship means that you can't simply multiply the current (A) by the voltage (V) to determine the real power consumption of the device; you also need to know a correcting *power factor* specific to that device. The power consumption of complex AC loads is calculated as follows:

Complex AC loads:
Power (W) = Voltage (V) x Current (A) x Power Factor

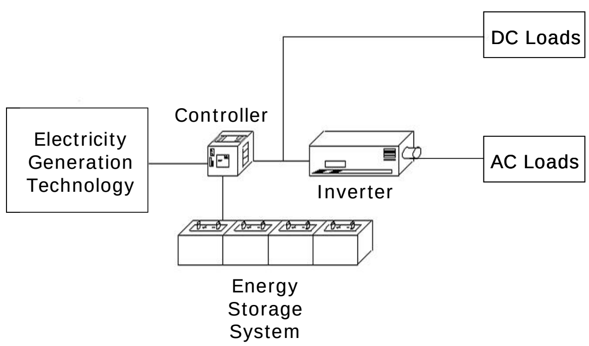
UPS systems often provide power output information in terms of a volt-amp (VA) or kilovolt-amp (kVA) rating. The real power output of the device in Watts, after the power factor has been applied, may also be provided.

Overview of Distributed Power Solutions

Electric power plants produce electricity on the order of megawatts (MW) and distribute it through a vast transmission network to towns, cities and whole regions. In contrast, a *standalone* or *distributed* power system generates a relatively small amount of electricity at a location close to the site where the electricity is needed. The electricity required to power individual ICT facilities is extremely small; a typical well-designed rural telecenter consumes much less than 10 kWh per day. Distributed power systems can supply this level of power in areas where the electricity grid is absent or inadequate.

There are a substantial variety of technologies, components and designs to choose from when selecting a standalone power system. Understanding a number of basic functional components that are likely to be encountered in any off-grid power system can reduce the potential confusion this may cause. These components, described briefly in **Box A-1**, include an energy generation component, an energy storage system, converters, regulators/controllers, and balance of system (BOS) components.

Box A-1: Overview of Standalone Power Solutions



Electricity generation technology **–** Electricity generation technologies transform energy from a resource, such as sunlight, wind or fossil fuel, into usable electricity. Distributed generation technologies include solar photovoltaic (PV), micro-hydro, diesel generators and wind power systems. During the transformation process, each technology incurs losses relative to the maximum energy available in the resource. The efficiency of a particular technology or device refers to the percentage of energy retained from the resource.

Energy storage system **–** Energy storage systems contain batteries to store and discharge electrical energy as needed. In addition to storing energy, energy storage systems such as uninterruptible power supplies (UPS) and household battery back-up systems can protect ICT equipment against damage from poor quality electricity by stabilizing the voltage and by absorbing transient currents. However, each time a battery is charged or discharged, some energy is lost from the system.

Controllers, Converters and Regulators **–** Charge regulators and controllers manage the flow of electricity between system components in order to protect equipment, such as batteries, from damage. *Recharge regulators* protect batteries against overcharge, while *discharge controllers* protect against overdischarge. Converters accept an electrical current in one form and output the current in another form. An *inverter* converts DC into AC, whereas a *rectifier* converts AC into DC. There are also *DC-DC converters*, which step up or step down the voltage of a DC current. As with all power system components, the use of converters results in energy losses due to inefficiencies; typical inverter efficiency is 85%.

Balance of System (BOS) **-** Energy that flows through a power system necessarily runs through a variety of devices and wires between the system components. The *balance of system* is a set of hardware devices that completes and connects the power system components described above. BOS components may include fuses and disconnect switches to protect the systems, wire connectors to link different hardware components, and dials and meters to monitor the performance and status of the systems. The selection of good BOS components is as important as the selection of any other part of the system. Low quality BOS is responsible for many avoidable maintenance problems in remote areas and can lead to premature failure and disuse of the whole system.

In addition to the brief descriptions of distributed energy systems described in Section 2, there are many published guides that detail the processes of selecting, procuring, installing and maintaining distributed and renewable energy solutions to provide general electrification for off-grid locations. For more information, see the resources listed in **Annex 2**.

Annex 2: Additional Resources on Renewable Energy Systems

A2-1 Biofuels

Biofuels are being used extensively in Latin America, North America, Europe, Asia and, to some extent, in Australia and Africa. In recent years many countries have shown a growing interest in this sector.

Biofuels are becoming more popular because they offer the following advantages:

- Reduce green house gases (GHGs) and mitigate their adverse effects.
- Reduce vehicular pollution resulting in lower medical care costs and increased longevity.
- Reduce dependence on imported fossil fuels and improve energy security of countries that do not have sufficient indigenous production of crude oil.
- Are readily biodegradable.
- Are from renewable sources of energy.
- Ethanol increases the octane number of gasoline and has low sulfur content.
- Biodiesel has a high cetane number; increases lubricity and reduces engine wear; a high flash point; and low sulfur content.
- Provide boost to economy, particularly rural, and generate employment.
- Use proven and low capital cost technology that can be readily implemented.
- Decentralized form of energy while petroleum is centralized.

Types of Biofuels

Ethanol

Ethyl alcohol, or ethanol, is a well-established fuel and an oxygenate that can be used for various IC (spell out) engine applications, including transport and electricity generation. The two leading countries using ethanol for transport and related sectors are Brazil and the USA. In 2002, the consumption of ethanol in Brazil was around 12 billion liters while that in USA was about 8 billion liters. The consumption of ethanol in India is expected to exceed 400 million liters in 2004. Ethanol is generally used in a blend of gasoline and ethanol known as gasohol. However, subsequent to engine modification, it can also be used in neat form (85% to 100% blends).

Biodiesel

Biodiesel consists of esters made from vegetable oils and fats. The use of biodiesel is growing rapidly in many countries.

Biodiesel can be manufactured from the following substrates:

- Fats – animal fats of any kind.
- Vegetable oil – from any plant source.
- Used vegetable oils or recycled cooking oil.

Biodiesel can be blended with diesel in any proportion from as low as 2% (B02) up to 100% (B100). The most commercially popular blends are those with up to 20% biodiesel (B20), as they are normally covered by warranties provided by many engine manufacturers.

Use of biofuels in small-scale generator sets

No engine modifications are necessary for the use of gasohol (up to E25) or diesel blended with up to 20%

biodiesel (B20). A minor adjustment or tuning of the engine may be required in the air fuel ratios. The energy content (calorific value) of biodiesel is slightly lower than diesel but this does not have a significant effect on fuel consumption.

Ethanol-blended fuels may accelerate corrosion marginally but this is not considered a significant factor when the ethanol proportion is less than 25%. However, if the fuel tanks contain water and are not properly cleaned, a phase separation occurs in which ethanol and gasoline separate out, causing engine problems. In such a situation, the fuel tank needs to be emptied and cleaned and fresh gasohol has to be added.

The use of 100% biodiesel (B100) may accelerate corrosion marginally, and may necessitate special care in very cold climates. Seals, gaskets & hoses should not be of ordinary rubber but of elastomers of desired quality. On the other hand, there is no report of 20% biodiesel (B20) causing any problems to the rubber in fuel system components or because of cold climate. The positive effect of biodiesel is that it reduces engine wear because of its superior lubricity properties. Biofuels are readily biodegradable and thus do not harm the environment. Biodiesel has a high flash point of 260° F as against 125° F for regular diesel. Thus it is much safer to use.

Costs

The cost of production of biofuels may be higher than that of conventional fossil fuels, keeping in mind that world oil prices have been subject, historically, to fairly wide market fluctuations. In a December 2002 presentation, Luiz Carlos Corrêa Carvalho of Brazil's UNICA reported average production cost of ethanol in center-south Brazil at US$25 per barrel ($40 per barrel including taxes) compared to a cost for gasoline of $35 per barrel at the refinery ($61 per barrel including taxes)[48]. In the USA, the price of ethanol is competitive with gasoline if the price differential per gallon is up to $ 0.50, as there is a federal excise rebate of $ 0.52 per gallon of ethanol when it is blended with gasoline.

Biodiesel is normally more expensive than diesel. If the average price of biodiesel in the USA is $2.00 per gallon as compared to $1.00 per gallon for regular diesel, then B20 fuel would cost about 20 cents more than diesel (although, the price difference between the two types of fuel is reduced as many governments in the world provide various tax incentives for "green" fuels. The prices of biodiesel (B100) in Germany and Austria are competitive to that of diesel and B05 is used extensively in France. This is possible because of long-term tax breaks given to "green" fuels. Such tax breaks and other incentives are necessary because the biodiesel industry is in its infancy. The European Union has set a target of 2% use of biofuels by 2005 and 5.75% by 2010. The state of Minnesota in the U.S.A. has set a target of 2% use of biodiesel (B02) by 2005.

Fuel grade characteristics must also be considered when comparing the price of biodiesel with regular diesel. The sulfur content of biodiesel is equivalent to that of ultra-low-sulfur diesel (ULSD), which is significantly more expensive than regular diesel. Biodiesel has better lubricity – which improves engine life – than ULSD and also has a higher flash point and cetane number. Matching these characteristics adds to the cost of manufacturing diesel of equivalent grade.

All reported disadvantages of biodiesel can be overcome without difficulty. The demerits of biodiesel are reported to be degradation over a period of time (shelf life) because of its biodegradability, and a marginal increase in nitrogen oxide emissions (+2%). The first issue has not caused any major problems anywhere in the world while the second can be addressed by the use of a catalytic converter.

Biofuels offer an ideal opportunity for providing renewable energy for rural ICT systems where the capital costs in generating systems are to be kept low. The use of biofuels in small generating systems is technically feasible and commercially viable. Depending on availability and warranty by the manufacturer, biofuels such as biodiesel and ethanol can be used in appropriate proportions such as B20 and E10.

However, there is a need to arrange for biofuels or produce them locally. There is a possibility of installing small decentralized biodiesel plants in remote areas that would provide rural employment in cultivation of oil seeds, extraction of oil and, if required, in production of biodiesel. The investment per unit of capacity

[48] Luiz Carlos Corrêa Carvalho, "Sugarcane as a Perfect Biomass for Energy Production," 3rd Lamnet Workshop in Brazil, December 2002. URL: http://www.bioenergy-lamnet.org/publications/source/bra/PPT-TM-5-Carvalho-LAMNET-WS-Brasilia.pdf.

for small-scale unit is likely to be 3 to 4 times that of large-scale. However, such a unit would operate on low overheads and the cost of transportation would be lower. Thus viability of each such unit needs to be examined individually, taking into account local conditions and costs of other forms of renewable energy. Biodiesel produced from such units could be used for various rural applications including generation of electricity for meeting requirements ICT and other needs, farming, operating tube-wells for irrigation and drinking water, and heating. The realization of the vision of making rural communities energy self-sufficient would make biodiesel a truly decentralized, low capital investment source of energy for the remote areas of underdeveloped countries.

Additional sources of information:

1. http://www.biodiesel.org - Web site of the National Biodiesel Board (USA).
2. http://www.ott.doe.gov/biofuels - Web site of the U.S. Department of Energy National Biofuels Program.

B. PV Systems

Solar Insolation Data

1. NASA Surface meteorology and Solar Energy (SSE) data set – The National Aeronautics and Space Administration (NASA) of the United States provides global data on solar insolation based on satellite measurements. Once free registration is completed, the data may be retrieved through an on-line interface by entering a latitude and longitude, or by clicking on the desired location on a global map. This dataset is coordinated for use with two PV design tools, RETScreen International and SolarSizer (see descriptions under PV Design Tools).

SSE Home Page: http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?na
SolarSizer Data Access (Login / Registration page): http://eosweb.larc.nasa.gov/cgi-bin/sse/sizer.cgi?email=na
RETScreen International data access (Login / Registration page): http://eosweb.larc.nasa.gov/cgi-bin/sse/retscreen.cgi?email=na

2. World Radiation Data Centre http://wrdc-mgo.nrel.gov - The WRDC data set contains solar radiation data from over 1,000 ground measurement sites in 127 countries around the world during the period from 1964-1993. The data can be searched on the WRDC web site, although the interface is somewhat difficult to use. The data can be retrieved through a more user-friendly interface at the NASA SSE web site (described above) by clicking on the "Ground Site" link from the SSE home page.

PV Design Tools

1. Hybrid Optimization Model for Electric Renewables (HOMER)

2. RETScreen International www.retscreen.net - The RETScreen International Renewable Energy Project Analysis Software is a unique decision support tool developed with the contribution of numerous experts from government, industry, and academia. The RETScreen International Photovoltaic Project Model (Version 2000) can be used world-wide to easily evaluate the energy production, life-cycle costs and greenhouse gas emissions reduction for three basic PV applications: on-grid; off-grid; and water pumping. For on-grid applications the model can be used to evaluate both central-grid and isolated-grid PV systems. For off-grid applications the model can be used to evaluate both stand-alone (PV-battery) and hybrid (PV-battery-genset) systems. For water pumping applications the model can be used to evaluate PV-pump systems. The web site, managed by Canada's CANMET Energy Technology Center - Varennes, is published in French and English. The software is provided free of charge by the Government of Canada and may be downloaded from the web site in English (1.34 MB) or French (1.4 MB) versions.

3. SolarSizer www.solenergy.org/html/about/SolarSizer.html - SolarSizer TM is a professional tool for designing and sizing photovoltaic systems. It uses a graphic interface to simplify the process of choosing components and making cost and energy calculations. A demonstration version of SolarSizer 1.6 is available as a free download (4.7 MB). This version of the software includes all the functionality of the full

SolarSizer except for the saving and printing abilities. Solar Sizer 1.6 incorporates the NASA Global Satellite Solar DataSet.

4. World-wide Information System for Renewable Energy (WIRE). http://wire0.ises.org. An initiative of the International Solar Energy Society (ISES). A multifaceted web-based resource with strong focus on solar energy. Includes modules on buildings, components, conferences, white papers, research papers, and a number of information exhange and discussion forums.

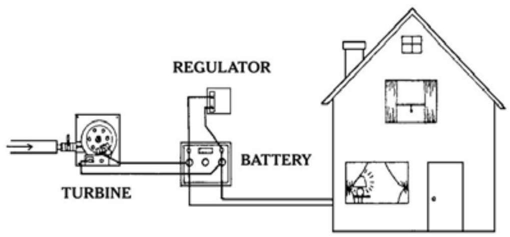
Online Training Courses

1. Solar Energy International (SEI) online courses www.solarenergy.org
2. Solar On-Line www.solenergy.org
C. Micro-hydro systems

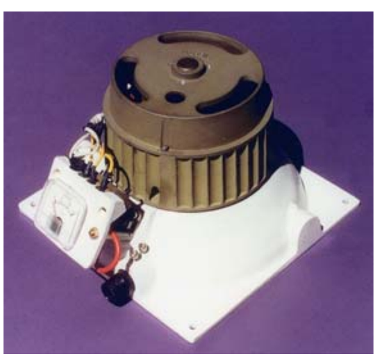
C. Micro-hydro

Readily available micro-hydro technologies which are used to charge batteries include Harris Hydro systems for higher head sites and Firefly systems for lower head sites.

1. Harris Hydro



Source:
http://www.harrishydro.com/configuration.htm



Source:
http://www.harrishydro.com/product.htm

The Harris hydro system is a battery-charging pelton turbine system suitable for a wide range of site conditions, from 6 meters of head to over 60 meters. Batteries are charged by the generator at low power round the clock and are able to produce large currents for short intervals to power a number of appliances simultaneously. A charge control regulator will make sure the batteries are not overcharged. The batteries can be used to power 12-volt appliances directly, as in the configuration shown at left, or they can be connected to a DC-AC inverter to operate conventional AC appliances.

System setup is based on the collection of water at an upstream location. The water is diverted to a small shelter where the turbine is installed. The turbine sits at the low end of a 2 to 6 inch diameter pipe. According to the manufacturer, the cost of Harris hydro turbines varies from US$1,000 to US$2,000, and the cost of battery storage capacity is about $150 per 100 W output. A DC system with output of 100 W is estimated at approximately US$1,500 (no inverter), while an AC system of 1,000 W output is estimated at US$7,800, including a $3,400 inverter. Additional details about the cost, power output, configuration and product features are available at: www.harrishydro.com.

2. Firefly Micro-hydro System

The firefly system is a very small micro-hydro system that is primarily intended to provide lighting in isolated communities without grid connection. For storing electricity, 12 Volt 'solar' batteries can be used. Twelve-volt lamps and other appliances can be powered directly from the battery. With an inverter, ordinary 110/220 V appliances such as ICTs can be used as well.

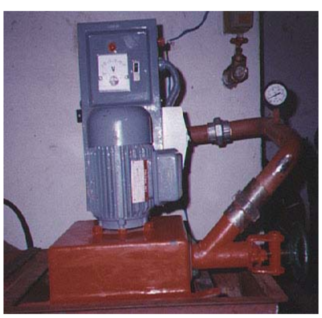
The firefly charger is a secondhand car alternator with a `crossflow' runner mounted directly on the shaft. The Firefly charger is quite flexible with respect to head. The minimum flow and head it requires are 10 lps and 5 meters. At higher head, flow and output power can be reduced by inserting a blocking timber in the nozzle. Over the whole head range, the charger can operate at its optimum speed because field current of the alternator can be regulated. The firefly charge indicator shows how far the battery has been discharged by means of 10 LEDs.

Firefly building manual is available at:
http://www.microhydropower.net/mhp_group/portegijs/firefly_bm/ffbm_index.html

Index page for Firefly and other related sites
http://www.microhydropower.net/mhp_group/portegijs/firefly_exp/ffexp_index.html

The technologies most commonly used for AC micro-hydro systems are Peltric sets for high head applications and Power Pal systems for low head applications.

3. Peltric Sets



Peltric set technology is a term coined in Nepal to describe a small Pelton runner attached directly to an induction generator. Water is directed at the runner from one or more nozzles. This rotates the runner together with the induction generator attached to it, generating alternating current. The induction generator derives from the ubiquitous induction motor connected to capacitor banks to provide it excitation. An Induction Generator Controller (IGC) keeps the load on the generator constant by diverting unused power to ballast heaters. Peltric sets are used for relatively high head sites, above 30 m. The flow required to produce 1 kW of power at this head would be around 7 lps. The induction generator is very robust and virtually trouble free since it has no carbon brushes to wear out and there are no coils on the rotor.

1 kW peltric set in workshop test rig (http://www.nepalmicrohydropower.com/peltricset.html)

Source: http://www.icimod.org.np/sus_options/bestprac3.htm#peltric

Peltric sets are available in different capacities but the most commonly used systems are below 3 kW. In Nepal, the cost of a 600 W peltric set including IGC, polythene pipe and other electrical accessories is around US$1,000. The total cost of installation is a little higher because of distribution and other installation costs.

The details of Peltric sets can be obtained from the following websites:

http://panasia.org.sg/nepalnet/crt/peltric.html

http://www.ioe.edu.np/retrud/papers/paper57.html

http://www.nepalmicrohydropower.com/peltricset.html

http://www.icimod.org.np/sus_options/bestprac3.htm#peltric

www.panos.org.np/publications/water_wisdom/ww_chap13.htm

3. PowerPal

PowerPal is manufactured in Vietnam under the supervision of a Canadian company, Asian Phoenix Resources Ltd. Low head PowerPal systems are available from 200 W to 1,000 W. According to the manufacturer, "A simple AC single-phase, brushless permanent magnet alternator is attached to a propeller turbine. All or part of the stream flow is diverted into an intake canal where it forms a vortex, causing the propeller to rotate as it exits through a draft tube to flow free again . All that is required is a vertical drop (head) and a sufficient rate of water flow, which are commonly obtained by installing PowerPal on a small waterfall, dam or diversion trench. Electricity passes along a wire and into a house, where an electronic load controller (supplied) stabilizes the voltage to 110 V or 220 V to protect electrical appliances during use. The ELC can also be used to set other voltages such as 120V, 230 V or 240V. Being lightweight and portable, installation is very simple and is explained in the Instruction Manual. Once installed there are no running costs and maintenance costs are extremely low."[49]

Source: http://www.powerpal.com/lowhead.html

The 200 W PowerPal unit cost US$ 145 ex-factory price at Hanoi, Vietnam and the requisite intake canal and draft tube costs another US$ 55 but could be made locally to reduce the freight cost. High head PowerPal systems are now also available in the range of 200 W to 500 W. Other than the change of turbine, the High Head system is identical to the Low Head system.

Low Head PowerPal in use in Vietnam (http://www.powerpal.com/1inuse.html)

1. Inversin, A.R. 1986. *Micro-hydropower Sourcebook.* NRECA International Foundation, Arlington, VA. Pp 285.
2. Harvey, A. Brown, A., Hettiarachi, P. and Inversin A. 1993. *Micro-Hydro design manual, a guide to small-scale water power schemes*. Intermediate Technology Publications, London.
3. Smith, N. 1994. *Motors as Generators for Micro-Hydro Power*. Intermediate Technology Publications. London. Pp. 82.
4. Khennas S. and Barnett A. 2000. *Best Practices for Sustainable Development of micro-hydro power in developing countries*, World Bank/ESMAP. Can be downloaded at: http://www.microhydropower.net/download/books.php.

D. Small Wind Systems

1. Small Wind Tutorial Workshop from Village Power 2000 Conference http://www.rsvp.nrel.gov/vpconference/vp2000/wind_workshop/wind_workshop.html.

[49] PowerPal web site, August 2003. URL: http://www.powerpal.com/lowhead.html.

2. Wind resource data:

Wind power resource data can be found on many websites.

Country	Organization	URL / source
International	National Oceanic and Atmospheric Association (NOAA)	http://www.ncdc.noaa.gov/cgi-bin/res40.pl?page=gsod.html. See instructions below.
Armenia, China, Dominican Republic, Indonesia, Mexico, Mongolia, Philippines	U.S. National Renewable Energy Laboratory (NREL)	Web page with links to wind resource data for countries listed at left. http://www.rsvp.nrel.gov/wind_resources.html
Cambodia, Laos, Thailand, Vietnam	World Bank	Wind Energy Resource Atlas of South Asia http://www.worldbank.org/astae/werasa
India	Ministry of Non-Conventional Energy Sources	http://mnes.nic.in
Various	Solar and Wind Energy Resource Assessment (SWERA)	A Global Environment Facility cofinanced, UNEP-lead project, SWERA is developing information tools for energy planners and project developers, including regional and national maps of solar and wind energy resources. http://swera.unep.net/

How to Access International Wind Resource Data From NOAA

1. Go to http://www.ncdc.noaa.gov/cgi-bin/res40.pl?page=gsod.html
2. Click on "Get/View Data"
3. Scroll down to the "CLIMVIS" (Climate Visualization) link and click.
4. Click on "Global Summary of the Day (12 Weather Elements)" Time Series link
5. Click "I Agree" to the NOAA Res 40 terms
6. Select "one parameter for specified time frame" and select region from map.
7. Select country
8. Select data collection station
9. Select "mean wind speed" parameter
10. Select a range of one year
11. Click "Submit Graph Values"
12. After graph has downloaded, click "download data file"
13. Cut and paste data into spreadsheet to compile into monthly averages (paste as unicode text in MS Excel)

Source: Bergey Wind Power (www.bergey.com).

3 www.consumerenergycenter.org/buydowncertified_smallwind.html - List of Certified Small Wind Turbines

4 www.consumerenergycenter.org/buydown/retailers.html - List of Registered Small Wind Turbine Dealers

5 www.nrel.gov/wind - National Wind Technology Center

6 Small Wind System Manufacturers

- Bergey Windpower - www.bergey.com
- Southwest Windpower - www.windenergy.com
- Wind Turbine Industries - www.windturbine.net

7 American Wind Energy Association

- www.awea.org
- www.awea.org/smallwind - Small Wind Systems Section

E. System Selection Tools

1. The Hybrid Optimization Model for Electric Renewables (HOMER). www.nrel.gov/homer - HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, standalone, and distributed generation applications. HOMER's optimization and sensitivity analysis algorithms allow you to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability. HOMER models both conventional and renewable energy technologies:

Power sources:
- solar photovoltaic (PV)
- wind turbine
- run-of-river hydro power
- generator: diesel, gasoline, biogas, alternative and custom fuels, cofired
- electric utility grid
- microturbine
- fuel cell

HOMER is available for download at no charge upon free registration. A six-month license, which can be renewed an unlimited number of times, is automatically granted at no charge.

Annex 3: ICT Power Consumption Reference Tables

The following tables present power consumption data for a variety of ICT products. The products listed in this Annex were not selected for any reason other than that the information happened to be gathered during the process of researching this guidebook. Those tables identified with specific manufacturers do not represent a complete listing of the products by that manufacturer. The appearance of a given product in these tables is neither a recommendation to use the product nor an indication of the product's energy efficiency or lack thereof.

Most of the power consumption data listed in Annex 3 was collected from the technical specifications published by the manufacturers and has not been independently verified by Winrock. Readers should note that some of the products listed may no longer be available, and that the technical specifications may have been revised by the manufacturers since the time this guidebook was published. The power consumption rates for each product apply only to the specific operating states and equipment configurations listed. In cases where the operating states and equipment configurations are not indicated, this information was not provided by the manufacturer.

Table A1 Dell Notebooks

				Power Consumption (W)				
Model	CPU	Speed (GHz)	RAM (MB)	Max	Min	Sleep	Off	Power Supply
Inspiron 5150	P4m	3.1	256	109.54	42.49	4.62	3.60	0.3
Inspiron 1100	P4m	2.4	512	93.24	36.95	3.52	2.39	0.4
Inspiron 5100	P4m	2.5	256	91.23	36.54	3.55	2.34	0.4
Inspiron 8500	P4m	1.9	128	54.41	32.20	1.47	0.67	0.5
Inspiron 8200	P4	1.5	n.d.	77.11	29.23	2.43	1.15	0.5
Inspiron 4150	P4	n.d.	n.d.	54.70	28.05	2.73	1.17	0.4
Inspiron 2650	P4	1.6	n.d.	52.89	26.00	3.32	2.11	0.4
Inspiron 500m	P4m	1.5	128	42.87	25.14	2.17	0.50	0.0
Inspiron 300m	Pm	1.2	256	32.96	23.07	1.15	1.46	0.4
Inspiron 8600	P4m	1.7	256	58.65	21.48	2.65	2.50	0.3
Latitude D500	P4m	1.3	128	60.64	46.32	1.96	0.52	0
Latitude D800	M	1.4	512	54.35	35.75	1.49	1.34	0.5
Latitude D600	M	1.5	128	57.37	34.63	2.48	0.9	0.1
Latitude C840	P4	1.5	n.d.	77.1	29.23	2.43	1.15	0.5
Latitude C640	P4-M	n.d.	n.d.	54.7	28.05	2.73	1.17	0.5
Latitude D400	P4m	1.7	128	45.85	24.17	1.63	0.34	0.5
Latitude C610	Intel	n.d.	n.d.	43.67	22.98	2.78	2.13	0.4
Latitude C510	Celeron	n.d.	n.d.	37.72	21.02	3.26	2.19	0.4
Latitude X300	Pm	1.2	256	30.78	20.15	0.95	1.48	0.4
Latitude X200	PIII	n.d.	n.d.	23.66	15.19	2.91	2.8	0.9

Source: Dell product specifications.

Table A2 HP Notebooks

	Power Consumption (W)				
Model	Operation	Standby	Sleep	Off	Date of Report
HP Compaq nx7000 (running on battery power)	15.8 (avg) 38 (peak)	<0.8	<0.1	n.d.	12/2003
HP Compaq nx7000 (running on AC power or auto/airplane DC adapter)	23 (on/idle)		2.5		3/2004[50]

[50] Rates for the HP Compaq nx7000 notebook while running on AC power were provided by HP in an email communication on March

	Power Consumption (W)				
Compaq Evo N610c	32	10	4	1	1/2003
Compaq Evo N620	32	10	4	1	3/2003
Compaq Evo N600	32	27	9	1	1/2003
Compaq Evo N1015v	30-50	20-40	18-30	0-5	1/2003
Compaq Evo N1020v	30-50	20-30	18-30	0-5	2/2003
Compaq Presario 1500	30-50	20-40	18-30	0-5	11/2002
Compaq Presario 900	30-50	20-40	18-30	0-5	11/2002
Compaq EVO N400	30	26	6	1	n.d.
Compaq NX9010 / Presario 2500	29.7	n.d.	1	1	9/2003
Compaq Evo N800c	27.8	2.2	2.2	0.1	11/2002
Compaq Evo N800v	27.8	2.2	2.2	0.1	1/2003
Compaq Presario 2800	27.8	2.2	2.2	0.1	10/2002
Compaq NX9000 / NX9005 / Presario 2100	27	n.d.	1.2	1.2	9/2003
Compaq Evo N800w	26	n.d.	2	<1.0	10/2003
HP Compaq TC1000 Tablet PC	23.1	15.7	1.3	0.974	8/2003
HP Compaq NC4000	16.2	16.2	0.37	0.41	11/2003
Compaq Evo N410c	30	15	6	1	1/2003
HP Compaq nc8000 / nw8000 Mobile PC	18	n/a	7.6	0.77	12/2003
HP Compaq NC6000	10.5	8	0.4	0.05	11/2003
Older/discontinued products as of January 2004:					
Compaq Armada V300, E500, E700, M700, M300	60 (max)	7.5	2.0	1.4	n.d.
Presario 1700	36 (b&w)	7	3	0	n.d.
Presario 1400	32 (b&w)	14	6	0	n.d.
EVO N160	31 (b&w)	23	8	1	n.d.
OmniBook 6000	25.5	1.3	1.2	1.2	8/2000
OmniBook 900	22.9	10.6	3.2	1.1	11/1999
OmniBook XE-2	22.9	10.6	3.2	1.1	11/1999
HP OmniBook 6100	22	3.8	3.8	1.6	8/2001
OmniBook 4150	14.4	7.4	1.3	1.3	11/1999
HP OmniBook & Pavilion XT-6050	n.d.	3.8	3.8	1.6	7/2001
HP OmniBook 510	n.d.	4.7	4.7	1.3	3/2002
OmniBook 500	n.d.	4.7	4.7	1.3	1/2001
OmniBook XE-3	n.d.	3.4	3.4	1	9/2000

Source: HP product specifications

Table A3 IBM Notebooks

			Power Consumption			
Celeron70045186.53Model	CPU	Speed (MHz)	Max	Normal	Sleep	Off
IBM i Series 1200 (1161-43S)	Celeron	700	45	18	6.5	3
IBM A series 2628 QSS	PIII	800	48	15	8.5	1
IBM X series 2662 64S	PIII	700	32	11	9	1
IBM TransNote 2675	PIII	600	62	9	3	1

Source: IBM Environmental Declarations

Table A4 IBM CRT Monitors

Model	Year Introduced	Viewable Size (in.)	Power Consumption (W)			
			Maximum	Normal	Standby	Suspend
6546 G52	1997	13.6	100	90	55	15
6517 E74M	2001	15.9	120	95	15	8
6551 P96	2000	17.9	140	120	15	15
6552 P260	1999	19.8	160	145	15	15

3, 2004. HP also noted “If a separate DC supply is used, it should be 15 V as this will operate the Mobile PC at full capacity, but not charge the battery - this is the same as running the Mobile PC using an airline adapter.”

Source: Manufacturer's specifications and environmental product declarations.

Table A5 LCD Monitors

				Power Consumption (W)			
Manufacturer	Model	Size (in.)	Viewing Angle (Horiz/Vert)	Max	Typical	Min	Sleep / Suspend
NEC/ Mitsubishi	MultiSync LCD1560V+	15	120/90	--	20	--	2
Dell	E151FPp	15		23	--	10	<2
Compaq	TFT1520	15	120/100	<30	--	--	<2
Hp	L1502	15	130/100	<30	--	--	<2
Dell	1504FP	15	160/160	30	25	--	<5
Hp	L1702	17	160/140	<40	--	--	<2
Compaq	TFT1701	17	150/125	<40	--	--	3
Compaq	TFT1720	17	150/140	<40	--	--	<3
Dell	1703FPs	17		75	--	55	<3
IBM	6658 T84H	18.1	n.d.	42	40	--	<3
Dell	1800FP	18.1		55	--	3	<3
Compaq	TFT1825	18.1	160/160	<60	--	--	<5
HP	L1925	19	170/170	<40	--	--	<2
Dell	1901FP	19		<75	55	--	<3
Dell	2000FP	20.1		62.4	--	50.8	<4.6
COMPAQ	TFT2025	20.1	170/170	<70	--	--	<5

Source: Manufacturers' specifications.

Table A6 Printers

			Power Consumption (W)		
Model	Description	Pages per minute	Max	Average	Standby
hp LaserJet 1000	Laser jet, black & white	10	n.d.	213	7
hp LaserJet IIISi	Laser jet, black & white	17	1100	n.d.	240
hp LaserJet 1300	Laser jet, black & white	20	320	n.d.	7
Lexmark T520 laser jet	Laser jet, black & white	20	435	n.d.	12
hp deskjet 3420	Ink jet, color	10	n.d.	23	8
Lexmark Z43 Inkjet	Ink jet, color	15	17.6	n.d.	7.9
hp officejet 6110	Ink jet printer, copier, scanner, fax	19	60	n.d.	n.d.
hp business inkjet 2230	Ink jet, color	15	68	n.d.	8
hp business inkjet 3000	Ink jet with "laser quality" printing, color	21	700	n.d.	<30
Lexmark Forms Printer 2490	Dot matrix, black & white	409 cps*	n.d.	38	7

*characters per second
Source: Manufacturers' specifications.

Table A7 VSATs

Manufacturer	Model	Typical power consumption (average)
Gilat Satellite	Dial@way	25
STM Wireless	SES Solante	30

Source: Manufacturers' specifications.

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