POWERING EDUCATION

OPTIONS FOR IMPROVING ENERGY SERVICES AT EDUCATIONAL FACILITIES IN SENEGAL

OCTOBER 2009

This publication was produced for review by the United States Agency for International Development. It was prepared by Pamela Baldinger of USAID's EGAT Office of Infrastructure and Engineering – Energy Team, Walt Ratterman of SunEnergy Power International, and Cherif Seye of QuinTsens S.A.

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EXECUTIVE SUMMARY

In late June-early July 2009, the USAID Energy Team (EGAT/I&E/E) responded to a request by the USAID Senegal mission to assist its education program. USAID/Senegal is supporting the Government of Senegal (GOS) to construct new middle schools around the country, and some of the sites are in locations not currently connected to an electric grid. To date, 57 schools have been constructed under the PAEM program, and more schools are expected to be built in the future (under a different contractual framework). USAID/Senegal seeks a strategy on how to meet the energy needs of these schools, in order to ensure a quality education for students and inform future USAID programming in the education sector.

Energy Team staff, together with a local and international expert on renewable energy, conducted a two-week assessment trip to five different regions to collect data upon which the team could base recommendations. The team visited 4 schools from the USAID/PAEM program, and met with staff from the Ministry of Education; the PAEM program, other donors; and private-sector energy service companies in Senegal. The team was able to visit a school in Soum with a solar system installed through the PAEM program, and spent considerable time reviewing the plans for installation of another 8 solar systems. Detailed recommendations on these plans have been provided in a separate report to the USAID COTR and PAEM Chief of Party.

FINDINGS AND RECOMMENDATIONS:

Based upon the fieldwork and discussions noted above, the Energy Team has the following recommendations for USAID/Senegal to incorporate in future education programming:

- **Energy should be a criteria in the selection of equipment supplied to schools**: Although USAID's implementing partner and the GOS seem to have agreed upon a standard package of electrical equipment to be delivered under the PAEM program, little thought has been paid by either party to the electricity demand of this equipment, since most schools within the program are connected to the electric grid. However, Senegal's grid frequently suffers power cuts and voltage fluctuations. In the future, USAID must take the availability of electricity into account when designing equipment packages for schools. Given the cost of on-site electricity generation, off-grid schools should be provided only with equipment deemed critical, and the most energy-efficient models should be procured. Schools on-grid would also benefit from energy efficient equipment; expensive/important equipment should also be paired with components that protect against power surges/cut-offs and voltage fluctuations (i.e., UPS units for computers).
- **Experts should be enlisted to assist in the design of an energy strategy, as well as selection and installation of energy equipment**: Energy (especially alternative energy) is a highly specialized area, and expert advice should be solicited before strategies are crafted and acted upon, even if energy represents a relatively small piece of a project. Before the Energy Team's assessment, the mission had made no provisions to contract expert advice centrally, nor has it insisted/budgeted for its education contractors to enlist such advice. As a result, education specialists who lack the requisite knowledge and training are making energy-related decisions with negative consequences.

- **Seek local assistance to the extent possible**: Expert assistance may be solicited in-country or abroad, but it is always desirable to secure expertise and equipment locally, if possible. Ideally, an expert will come up with the overall strategy and energy system design, and then help USAID, the GOS, or their partners procure the necessary equipment and inspect the installation. Based on the USAID Energy Team's assessment, Senegal possesses firms capable of doing solar design, procurement, and installation. Canadian CIDA is funding a UNICEF initiative to provide small solar systems to off-grid primary schools in Senegal, and may be a good resource for USAID to consult with. Similarly, the EU is funding a solar pumping program; both programs conducted tenders to solicit proposals from professional firms who are managing the installation and maintenance of the solar systems. The USAID Energy Team is also available to assist with further strategy development (beyond the basic strategy laid out in this document).
- **Consider all energy options**: Given Senegal's rural electrification plans, USAID and the GOS need to develop a strategy that will consider all possible options—grid connection, diesel generator, solar pv, and battery/inverter—to supply electricity to any given site before selecting which is most appropriate and cost-effective. Each decision should be based upon specific, standardized criteria (i.e., cost, need, availability of equipment/fuel, capacity to maintain/service equipment, etc.) and should not reflect a knee-jerk predilection for one type of solution over another.
- **Any provision of energy equipment must be accompanied by strategies that address enduser training and service/maintenance**: Any plan developed by USAID and the GOS to supply power generation equipment to Senegalese schools must be accompanied by a strategy to provide routine, periodic training to endusers on how to operate and maintain the equipment they receive, as well as a strategy to provide/fund more specialized service and maintenance. This is particularly important for systems involving batteries. NO energy system is maintenance free. Generally speaking donor-funded programs tend to have a poor record when it comes to sustainability of energy systems, so this is an issue that needs to be addressed in both program planning and implementation. USAID/GOS should examine the feasibility of maintenance contracts for equipment provided under education programs.

The attached report provides more details on the above recommendations, focusing on options for schools for which grid connection is not technically or economically feasible. The report discusses 3 scenarios based on energy demand—high, medium, and low. The schools with low energy demand would need small energy systems to power basic computer labs. The medium-demand scenario applies to schools with a computer lab and electrical devices in the administration area. The high energy demand scenario encompasses facilities with more equipment and more hours of use.

Cost projections for various types and sizes of power-generation equipment are provided for each scenario, to help USAID/Senegal and the GOS plan for the next phase of the school construction program. A summary of these costs is provided in the two tables below.

The first table illustrates the upfront costs of purchasing and installing a system (Init Cost), as well as the levelized Cost of Energy (i.e., the cost in US dollars per unit of electricity produced by the system over an estimated 20 year lifespan. The COE includes initial capital costs as well as operations costs and periodic replacement of key components). These figures were derived from HOMER, a modeling software designed by the US National Renewable Energy Laboratory. Data collected from Senegal was fed into the program, to make the costs as realistic as possible. Nevertheless, the figures are illustrative and should be used for planning purposes only. The importance is in the magnitude of cost of any given system RELATIVE to any other.

Table 1. Upfront Capital Costs and Levelized Cost of Energy of Various Systems

	Small 4,000 Whr/Day		Medium 14,000 Whr/Day		Large 29,000 Whr/Day	
System	Init Cost	COE $/kwhr	Init Cost	COE $/kwhr	Init Cost	COE $/kwhr
GRID CONNECTED SYSTEMS						
Grid / Inverter / Battery	6,200	1.00	23,600	0.92	44,800	0.78
OFF GRID SYSTEMS						
PV / Inverter / Battery	23,350	1.17	77,300	1.07	161,000	1.07
Gen / Inverter / Battery	17,000	2.92	44,800	2.76	65,400	2.20
Generator Alone*	6,000	10.60	12,400	12.76	12,400	6.16

This table shows that solar PV systems have the largest upfront costs (many times higher than a generator), but the lowest levelized energy cost of any of the off-grid options. Adding a battery/inverter to a generator will increase the upfront costs, but decrease the long-term operating costs of generator-based systems. The grid-connected option shows approximate costs for a battery-based back-up system that can supply electricity to schools when the grid is down.

The second table removes the initial investment costs, and focuses specifically on the cost of energy. The “full cost” columns incorporate the approximate capital AND long-term operation costs for each system over 20 years. The “no initial costs” columns represent the costs of operating each system (i.e., those costs that must be borne by the enduser), but not the upfront costs of purchase and installation.

Table 2. Levelized Cost of Energy With and Without Initial Equipment Costs

System	Cost of Energy (COE) USD/kWhr					
	Full Costs			No Initial Costs		
	Small	Med	Large	Small	Med	Large
Reliable Grid	.30	.30	.30	.30	.30	.30
Generator Only	10.60	12.76	6.16	10.34	12.61	6.09
Grid / Inverter / Battery	1.00	.92	.78	.74	.64	.57
Gen / Inverter / Battery	2.92	2.76	2.20	2.21	2.10	1.83
Solar PV / Inverter / Battery	1.17	1.07	1.07	.19	.13	.10

From this table it becomes clear that the electric grid will almost always provide the most economic cost of energy (these figures do not include connection costs), and grid connection should always be the first option explored to power off-grid schools.

Solar PV systems, despite their high upfront costs, have a comparatively low cost-of-energy over the long term, provided the batteries are maintained well. The grid/inverter/battery option is supplied to illustrate the cost of supplying back-up power to schools connected to the electric grid.

1. INTRODUCTION

In late June-early July 2009, the USAID Energy Team (EGAT/I&E/E) responded to a request by the USAID Senegal mission to assist its education program. USAID/Senegal is supporting the Government of Senegal (GOS) to construct new middle schools around the country, and some of the sites are in locations not currently connected to an electric grid. To date, 57 schools have been constructed under the PAEM program, and more schools are expected to be built in the future (under a different contractual framework). USAID/Senegal seeks a strategy on how to meet the energy needs of these schools, in order to ensure a quality education for students and inform future USAID programming in the education sector.

Energy Team staff, together with a local and international expert on renewable energy, conducted a two-week assessment trip in Senegal from June 22 to July, 3 2009. The team, together with local PAEM project staff, conducted site visits to several schools and met with education officials in Soum (Fatick), Tambacounda, Fongolimbi (Kedougou), and Dakar. The map below shows the team's route.

Map of the team's route.

The PAEM schools are built to a standard design: 3 buildings in a U shape (1 administrative block in between 2 classroom blocks), and a latrine block.

A classroom block at a grid-connected middle school in Kaolack.

The program is providing the following electrical equipment to schools on the grid:

- 7-8 desktop computers
- 1 laptop computer
- 1 printer
- 1 photocopier
- 1 video-projector
- 1 UPS
- 1 telephone/fax
- 6-7 power strips

It was not clear from discussions with PAEM staff if the same equipment package was being provided to schools off-grid (this is discussed further in later sections), but this is a critical issue for selection of power generation systems for the off-grid schools.

The primary goals of the field visits and interviews were:

1. Ascertain the energy needs of middle schools participating in the PAEM program (as representative of the needs of future schools);
2. Understand what measures were currently being taken to meet the energy needs of these schools;
3. Assess the various technological options available to meet the schools' needs; and
4. Gain a better understanding of the Senegalese market for on-site power generation equipment, to determine if local expertise is available to assist USAID/Senegal.

The team's findings are discussed in the rest of this report as follows:

- Section 2 focuses on energy demand, explaining the concept of "load" in order to highlight the importance of energy efficiency and provide a framework with which to size and cost alternative energy systems.

- Section 3 examines three real load scenarios (small, medium, and large) based on equipment being used in the schools visited during the fieldwork.
- Section 4 examines the costs of various technological options for each scenario.
- Section 5 addresses steps that the donor/user must take in order to assure the sustainability of renewable energy systems.
- Section 6 summarizes the team's conclusions and recommendations.
- Annex A contains more information on technological options.

2. THE IMPORTANCE OF LOADS AND ENERGY EFFICIENCY

In order to identify and price options for providing energy to educational facilities that are not connected to a reliable national electricity grid, one must first know the daily quantity of energy required by a given facility. The amount of energy required may be referred to as a site's energy "load." (Sometimes the equipment requiring energy may also be referred to as the load). The cost of providing energy to an off-grid site varies directly with the quantity of energy to be supplied. For this reason, the selection of electrical/electronic equipment supplied to schools by the Senegalese government or donor programs needs to be closely coordinated with the electricity supply (grid or off-grid) in order to minimize investment costs and ensure that the equipment provided is usable. This concept is not well-understood in the current PAEM program or by USAID education staff.

Generally speaking, when grid power is available, most people/facilities do not think much about the quantity of energy they are purchasing. They expect the electricity to be available when they want it, and know that the electric utility company (i.e., Senelec) will charge for it based upon the quantity they've consumed. The meter on the enduser's home or building records the amount of electricity that is consumed and the utility sends a bill to the consumer for these units. If the user needs more energy, to power a new piece of electrical equipment, for example, he just consumes the electricity and then pays for it in his monthly bill.

Sites that cannot be connected to a reliable grid may have to generate their own electricity. In these cases, the user cannot assume that his supply of energy is unlimited—he must pay careful attention to ensure that he is able to generate enough energy to meet his needs. Since the equipment needed to generate electricity is expensive, it is very important to keep electric loads as low as possible, in order to minimize upfront investment and ongoing operation costs.

2.1 WHAT ARE WATTHOURS?

A watt is a measure of electrical power (power reflects the rate at which energy is used). Electrical devices are rated in watts, telling the user how much power the device will consume in 1 hour. Watthours, the product of watts and time (watts x hours = watthours), are a measure of energy. A kilowatthour (kWhr) is 1,000 watthours. Watthours or kilowatthours form the basis of all of the designs that deal with providing reliable energy to an off-grid facility.

For example, a light bulb that consumes 20 watts of power in 1 hour will require a supply of 100 watthours of energy if left on for 5 hours. (20 watts x 5 hours = 100 watthours).

Determining the total daily energy requirement of a facility involves an exercise in which one first identifies all of the devices requiring electricity, then multiplies the watts of each device by the hours it will be used to determine the amount of watthours required to use that device. Then all of the watthours for all of the devices are added together to come up with the daily energy requirement of the facility.

2.2 CALCULATING THE DAILY ENERGY REQUIREMENT IN WATTHOURS (WHRS):

An example of the watthours required in one day by a very small facility could look something like the following:

Load	Watts	Hours	Whrs/Day
Light	20	4	80
Computer	125	4	500
Fan	75	4	300
Total			**880**

The three devices listed in the above table, if required for 4 hours in a day, would require a reliable supply of energy in the quantity of 880 watthours each day. In a real facility, the load requirements can vary from something this conservative to a system that would easily require 10,000 to 40,000 watthours of energy per day.

The quantity of required watthours/day becomes the basis for all of the system design and costing that follows. Therefore, when considering the type of energy system to provide to an off-grid school, it is imperative to go through this process. Although the energy advisor (or sometimes equipment vendor) will conduct the actual calculations, the education staff must be closely involved, as they need to understand the capacity and limitations of the systems they ultimately will acquire.

Providing energy by non-traditional methods can get quite expensive, as the cost of supplying energy is nearly linear. So, the cost to provide a system that will supply 20,000 watthours of energy per day will be twice as expensive as a system that will provide 10,000 watthours of energy per day. Therefore, the exercise of determining the daily load is normally an iterative one, requiring that the energy advisor not only thoroughly reviews the loads to be sure none are missed, but also takes a hard look to be sure all possible economies have been incorporated. The process likely will require considerable interaction between the energy advisor, program planner/funders and education staffs, and it is not unusual to re-calculate the daily energy requirement several times as compromises are made between cost and necessity. To date, the PAEM program has not undertaken a sufficient load analysis.

2.3 IMPORTANCE OF EQUIPMENT SELECTION

The following table provides illustrative ranges of the power consumption of devices commonly found in educational facilities.

Load	Watts
Fluorescent Tube Light	10W to 40W
Compact Fluorescent Light	7W to 22W
Fan – Small Wall Mounted	40W
Fan – Ceiling Mounted	75W to 150W
Desktop Computer – Efficient	125W to 150W
Inveneo Desktop Computer	Varies – possibly 60W
Laptop Computer – Standard	40W to 80W
Laptop – One Laptop per Child	6W to 15W
LCD Projector – Standard	300W
Photocopier	1200W and up
Printer	200W to 400W
Cell Phone Charging	5W
Laboratory Microscope	40W

The power consumption figures listed above are all representative of typical pieces of equipment. When designing a system, it is best to know the actual power requirements of the equipment that will be utilized in the facility, since there can be significant variation from the low end to the high end in many of these categories. It is almost always cost-effective to purchase the most energy efficient products available, especially for use in off-grid sites. Although energy efficient products may cost more initially, their lower energy consumption will enable the purchase of a smaller energy system, and may also save on fuel and replacement costs.

A facility load assessment might start off with the following table:

Qty	Load	Watts	Hours	Whrs/Day
10	Light	40	6	2,400
15	Desk Top Computer	125	6	11,250
4	Fan	75	6	1,800
1	LCD Projector	300	4	1,200
1	Photocopier	1200	2	2,400
	Total			**19,050**

Since a renewable energy solution that can provide this amount of watthours/day would be quite costly, the team should consider ways to reduce the number of watthours needed each day, and conduct the exercise again. A second iteration that incorporates (a) changes to more efficient equipment, and (b) reductions in the number of hours the high energy-consuming equipment is used could result in the following assessment:

Qty	Load	Watts	Hours	Whrs/Day
10	Light	**20**	**4**	800
15	**Lap Top Computer**	60	6	5,400
4	Fan	75	4	1,200
1	LCD Projector	300	2	600
1	Photocopier	1200	**0.5**	600
	Total			**8,600**

The result of the energy review in this hypothetical example took the daily energy requirement from 19,050 to 8,600–or a reduction of more than half. The reduction was accomplished by changing the type of computer and light bulbs being used, and limiting the usage times for certain pieces of equipment (see bolded type in the table above), but the end result does not represent a significant change in the quality of service to be delivered. However, the cost of the system needed to supply energy for the equipment in the second example would be less than half that required for the first example.

In summary, the important points to remember are:

- Energy is expensive – especially when working with off-grid solutions.
- Energy is measured in watthours.
- Energy efficient equipment, though sometimes more expensive to purchase than conventional equipment, is almost always a good investment for off-grid sites.
- An energy expert can do a lot upfront to reduce the number of watthours required by a facility, and therefore the cost of the energy system required by an off-grid site.
- The USAID/GOS education team should work with an energy expert to come up with a mutually agreeable determination of daily energy requirements for Senegalese schools, in order to ensure that the future education program plans equipment purchases accordingly and that relevant staff understands exactly what the recommended energy generation equipment will be able to power.

3. LOAD SCENARIOS AND COST COMPARISONS

Based on our analysis of the PAEM project, we've specifically selected three load scenarios which can provide a basis for the mission's future deliberations on energy system/electrical equipment packages. These three system sizing assumptions are then used to project costs of the various on-site generation systems identified as most feasible, and discussed fully in Appendix A. The representative energy usage scenarios--low, medium, and high--are based on actual conditions witnessed in the field. Of course, there are numerous possible variations on these scenarios, depending upon what equipment package USAID and the GOS ultimately select. For purposes of the illustration of costs, we will use these three.

3.1 LOW ENERGY USE SCENARIO/SMALL SYSTEM

In this system, the goal is for the school to be able to use 8 laptop computers, 8 hours/ day. The underlying assumption is that the laptops are used during the day, and charged at night. This scenario could apply widely to some of the more remote, off-grid schools.

Low Energy Use Scenario (Laptop charging only)

Area	Qty	Load	Watts Each	Hours of Usage		Total Watt Hours	Total Conn Watts
				Day	Night		
Computer Lab	8	Laptop Computers	60		8	3,840	480
Grand Totals						**3,840**	**480**

Therefore, we will use a daily estimated load of 4,000 watthours, which will require a relatively small energy system.

3.2 MEDIUM ENERGY USE SCENARIO/MEDIUM SYSTEM

The medium energy use scenario adds a small administrative area to the "small" scenario. The assumption is that the computer lab still operates during the day, while batteries are charged at night. The administration area also operates during the day.

Medium Energy Use Scenario (Computer lab and small admin area)

Area	Qty	Load	Watts Each	Hours of Usage Day	Hours of Usage Night	Total Watt Hours	Total Conn Watts
Computer Lab	8	Laptop Computers	60	8		3,840	480
Admin Area	4	Desktop Computers	200	8		6,400	800
	1	Printer	200	2		400	200
	1	Copier	1200	2		2,400	1,200
	1	LCD Projector	300	2		600	300
Grand Totals						**13,640**	**2,980**

We will use a daily estimated load of 14,000 watthours for this scenario, which will require a medium-sized energy system.

3.3 HIGH ENERGY USE SCENARIO/LARGE SYSTEM

For the highest energy use scenario, we will assume that the computer lab has desktop computers, and that some lighting is added so that the administration area or study hall can be used at night. Some of the equipment operates longer hours.

High Energy Use Scenario (Computer lab, admin area, night use and longer daytime hours)

Area	Qty	Load	Watts Each	Hours of Usage Day	Hours of Usage Night	Total Watt Hours	Total Conn Watts
Computer Lab	10	Desktop Computers	200	8		16,000	2,000
Admin Area	4	Desktop Computers	200	8		6,400	800
	1	Printer	200	2		400	200
	1	Copier	1200	4		4,800	1,200
	1	LCD Projector	300	2		600	300
Lighting	8	Compact Fl. Bulbs	22	4		704	176
Grand Totals						**28,904**	**4,676**

We will use a daily estimated load of 29,000 watthours for this high-use scenario, which will require the largest system. (Note that the watthour requirement of this system could be reduced significantly by swapping desktop to laptop computers, or by using desktop computers that are far more efficient, such as the Inveneo computers that are now being purchased and delivered in some instances in Senegal.)

4. TECHNOLOGY OPTIONS AND COSTS FOR EACH SCENARIO

Based upon our site visits and assessment of locally available technologies, the most likely options to provide energy to off-grid schools in Senegal are:

- Connection to the national grid;
- Grid Connection with an Inverter / Battery back-up system;
- Generator, alone or with an Inverter / Battery System; and
- Solar photovoltaic (PV) system with Inverter / Battery

If the national or local grid is located within a reasonable distance of the school and reliably provides power for at least 6-8 hours per day, paying for grid connection will generally be the most economic choice. The cost will be based upon the distance that must be wired (the utility normally will provide a quote in cost/km for the connection); and any equipment necessary to make the connection (i.e., transformer, meter, etc). These costs must be judged against those of the other options noted above. The on-going costs of a grid-connected system are the monthly utility bills. As the cost of grid connection will vary, we did not include this option in our costing table. However, in cases where grid power supply is available but not continuously (i.e., it may only be available at night or during certain other time periods), a battery/inverter may be used to ensure electric power is available when needed. In this scheme, the grid charges the battery, which can then be used to provide power when the grid supply stops. This option is included in our costing estimates.

In cases where the grid is not available or extension too costly, our cost projection data covers three technology options:

- PV / Inverter / Battery
- Generator / Inverter / Battery
- Generator Alone

4.1 COST ASSUMPTIONS

The figures in the following tables were derived from HOMER, a modeling software designed by the US National Renewable Energy Laboratory. The software runs calculations based on assumptions of costs, resources, and economics. Although actual current data from Senegal was fed into the model, any adjustment to the assumptions used (i.e., to interest rates, future fuel costs, etc) could have a significant impact on the long-term cost of energy for any given system. For this reason, the figures in these tables should be viewed as illustrative only, as costs of equipment and fuel change frequently. The significance is in the magnitude of cost of any given system RELATIVE to any other.

The assumptions/data used in the model include:

- **Equipment costs**: cover all major energy system components, wiring/cabling between the components, and installation. We have used cost data obtained from Senegalese vendors in Dakar to feed the model. For PV, the systems are based on conditions in southern Senegal, but there will be system variations in different locations throughout the country depending upon local climatic conditions and solar insolation. Equipment

costs do NOT include allowances for USAID costs, subcontract costs or other management-related costs that are not within the control of the equipment suppliers.

- **Resource costs**: include fuel costs, i.e., the price of diesel and electricity from the grid. During our visit, diesel prices were approximately $1.50/liter at the pump. Costs to deliver fuel to the site vary widely, but in our experience it is not unusual for these costs to double the pump price. Therefore, we have used a diesel cost of $3.00/liter. This includes the cost to purchase the fuel, load it into barrels, load the barrels into a pickup truck, transport and off-load the barrels at the site, re-load the empty barrels and return to town. For grid-supplied electricity, we used an average billing cost of $0.30/kWhr (Senelec charges different prices to different consumers; this is neither the highest nor lowest).
- **Lifetime of equipment and system**: the cost comparison is run for 20 years, the lifespan of the PV panels. The life of the batteries is determined by HOMER and the manufacturer's data; typically 5-7 years. The system includes the replacement cost of the batteries when they are expected to wear out in the simulation. The inverter life is presumed to be 10 years. Generator life is estimated at 15,000 operating hours.
- **Interest rates**: we have based the cost of energy calculations on an investment interest rate of 2%.

4.2 SYSTEM COSTS

The following table shows the estimated upfront cost of each system size in each scenario, as well as the levelized Cost of Energy (COE). The COE is the cost in US dollars per unit of electricity that is produced by the system. It is a weighted average over the 20 year presumed life of the system. This figure can be compared against the assumed $0.30/kWhr cost of electricity from the national grid.

Upfront Capital Costs and Levelized Cost of Energy of Various Systems

	Small 4,000 Whr/Day		Medium 14,000 Whr/Day		Large 29,000 Whr/Day	
System	Init Cost	COE $/kwhr	Init Cost	COE $/kwhr	Init Cost	COE $/kwhr
GRID CONNECTED SYSTEMS						
Grid / Inverter / Battery	6,200	1.00	23,600	0.92	44,800	0.78
OFF GRID SYSTEMS						
PV / Inverter / Battery	23,350	1.17	77,300	1.07	161,000	1.07
Gen / Inverter / Battery	17,000	2.92	44,800	2.76	65,400	2.20
Generator Alone*	6,000	10.60	12,400	12.76	12,400	6.16

Notes: (*): This does not include the cost of grid connection. (**) Only certain sizes of generators were modeled here. For the small system a 5 KW generator was used. For the medium and large systems, a 13KW generator was used. With perfect design, smaller generators could be used in all cases, but typically larger generators are provided to accommodate for increased future load or for other reasons.

The figures for the generator COE therefore are likely realistic estimates of the actual cost of energy that would be experienced by these sites.

Some general observations can be made from this table:

1. In general, if grid electricity is available at the site for a minimum of six hours, it usually makes sense to rely upon it. If fewer hours are available, the site may require additional energy generation or storage equipment (i.e., the battery-based back-up system shown above), which will bring costs up to the level of some off-grid solutions.

2. Solar PV systems have the largest upfront costs (many times higher than a generator), but the lowest levelized energy cost of any of the off-grid options.

3. Generators have the lowest upfront costs of the off-grid options, but their COE is much higher than for the other systems. A large savings in COE can be achieved by adding an inverter / battery system, which enables the user to operate the generator fewer hours (therefore, less fuel and maintenance is required).

4.3 SIMPLE PAYBACK IN YEARS

The big difference between the systems is quite obviously the large initial cost of doing anything other than using a generator. All other options cost more on the first day of operation, but result in significant savings in the long-term cost of energy.

Of course, this means that if the site being considered is only going to be around for 1 year or less (or will be connected to the grid soon), then perhaps the generator IS the best option. To take a deeper look at the different options, we can look at the simple payback for some of the system examples. While this is not an exhaustive economic analysis, it does give some perspective to the choices that are left to the system designer.

Looking only at the Off-Grid solutions for the high energy use scenario of 29,000 watthours (or 29 kWhr) per day:

To switch from the Generator Only option to the Generator / Inverter / Battery system, we would have to spend an additional $53,000 in initial cost. However, we would save almost $4.00 / kwhr in energy costs. At 29 kWhr/day, annual consumption totals 10,585 kWhr/year. The cost savings in one year would be $41,917. ($3.96 / kWhr x 10,585 kWhr). The simple payback for switching to an inverter / battery / generator system in this example would be $53,000 in additional cost / $41,917 in energy savings per year, or 1.26 years.

To switch from the Generator / Inverter / Battery system to a system that provides most of the energy from PV, similar calculations would result in an approximate payback of 8 years.

To compare the PV system to using Generator only, the calculations would yield a payback of about 2.5 years.

Therefore, determining the optimal system for a given site should include some assessment regarding how long the site will be in operation. Other factors will influence payback calculations as well, particularly the estimates for future fuel costs, the cost of generators to be purchased in the future, and estimates for the life of batteries (see section 6 for more on batteries)

4.4 THE PERSPECTIVE OF THE RECIPIENT

In order to view the cost of various systems from the perspective of the recipient (who will not bear the cost of system purchase in a donor-funded project), we have calculated the cost table again, eliminating the initial costs for equipment and installation. This leaves the ongoing costs of fuel, maintenance, equipment replacement, etc. Often the responsibility of paying for ongoing costs (particularly for fueling a diesel generator) is not adequately accounted for in donor-funded projects, resulting in quick failure of the system. (This is discussed further in Section 5).

Upfront Capital Costs and Levelized Cost of Energy of Various Systems

	Small 4,000 Whr/Day		Medium 14,000 Whr/Day		Large 29,000 Whr/Day	
System	Init Cost	COE $/kwhr	Init Cost	COE $/kwhr	Init Cost	COE $/kwhr
GRID CONNECTED SYSTEMS						
Grid / Inverter / Battery		0.74		0.64		0.57
OFF GRID SYSTEMS						
PV / Inverter / Battery		0.19		0.13		0.10
Gen / Inverter / Battery		2.21		2.10		1.83
Generator Alone*		10.34		12.61		6.09

In the solutions where the generator is the prime energy provider, there is little change in the long term COE regardless of who pays for the initial costs. This is because most of the costs are in the fuel and maintenance, which are the responsibility of the recipient.

But, when a PV system is provided by a donor and upfront costs are excluded from the PV system option, there is a drastic change in the resulting COE. From the recipient's point of view, the donor is essentially pre-purchasing energy for many years to come. The resulting COE is a function of the maintenance costs and the periodic replacement of batteries and inverters. If the batteries are managed well, these ongoing costs should be far less expensive than the costs of fuel, maintenance and generator replacement for a generator-only system. Nevertheless, even PV systems require routine maintenance, and poor battery management can dramatically increase the costs (and reduce the functionality) of a PV system.

Regardless of which option is selected, it is imperative that arrangements be made to allocate appropriate funds (from fuel savings, government budgets, donor funds or other sources) to pay for the required ongoing supervision, maintenance, monitoring and training involved with any of these systems. Otherwise, the initial investment may well be in vain.

5. SUSTAINABILITY ISSUES

In order to assure that an alternative energy system is able to perform as designed, USAID must ensure that adequate attention and commitment is paid to long-term sustainability issues. These include:

- Proper Maintenance
- Proper Operation
- Proper Monitoring

5.1 MAINTENANCE

Almost all of the energy system solutions noted previously in this report include batteries and, often, a generator. Both of these equipment items require ongoing maintenance.

The maintenance requirements for generators are fairly well known, since generators have been part of remote energy systems for so long. Nevertheless, maintenance on generators is usually severely lacking. In order for the generators to last, the manufacturer's recommendations on regular maintenance procedures must be adhered to. Quite often, this is not done because there was no financial commitment either by the donor, host government, or recipient to budget for these ongoing costs.

The same applies to batteries. In general, batteries are less understood than generators. Some batteries require less maintenance than others, but no system utilizing batteries is "maintenance free"--regardless of marketing assurances that claim otherwise. Battery systems are expensive, and the proper operation and maintenance procedures can determine whether the batteries last 6 months or 6 years. (This has been a hard lesson learned for PAEM).

We have found that it is best, at least in the first year (s) of an installation, to subcontract out the monthly maintenance requirements of the generator and batteries. This stipulation can be included in tender documents, and may involve additional cost. The maintenance work should be combined with ongoing staff training, so that after a reasonable amount of time, on-site staff can take over the maintenance functions.

5.2 TRAINING AND MONITORING REQUIREMENTS

On-site power generation systems are designed to operate under certain assumed conditions. As explained in Section II, these assumptions include:

- Loads to be connected to the system; and
- Time that the loads are to be on in a given day.

Once systems are completed, a common reason for failure is that the system was not operated as designed. If the energy system is designed to power 6 computers for 4 hours each per day, but the computers are left on 8 hours/day, and other loads are plugged in as well, the system is clearly going to fail. Yet often facility staff are unaware of the constraints of their energy systems. They are not trained adequately (if provided training at all) on how the system operates, and how their own behavior will impact the system's performance.

Since many of the new schools being built in Senegal are in relatively remote areas, it will be important to train on-site staff how to regularly monitor key energy consumption and generation

variables. At a minimum this will include filling out daily logs. In some cases the data can be submitted electronically to a website maintained by the equipment vendor, to enable remote monitoring. The proper monitoring system will vary depending upon project location, system complexity, and staff, but some form of monitoring is always required.

6. CONCLUSION AND RECOMMENDATIONS

There is a large, recognized need to expand the quality of education services throughout Senegal. In most cases, the increased education services will include a need for electrical energy. There are many school sites throughout Senegal that either are not connected to the national grid, or are supplied with a grid connection that will not support daytime energy needs. Therefore, creative, alternative methods need to be developed to be able to provide energy under these off-grid, or sub-standard grid conditions.

Providing alternative energy to these sites will require a commitment from all of the parties involved to learn about the possible solutions, and to dedicate the time, energy and resources into designing and installing the appropriate systems. Energy system investments can be costly; therefore, thorough planning is a must before funds are committed. USAID, together with the Government of Senegal and other partners, must first determine which energy needs are critical so that there is a commonly understood and accepted load profile to guide energy system design and costing.

Bulk procurement will usually result in a lower per unit cost and/or better service package for any technology. USAID should consider separating energy investments from larger education projects in order to ensure that adequate expertise is utilized and the best possible prices are obtained. At a minimum, contract language should necessitate that implementing partners procuring energy equipment utilize the services of a qualified, experienced system designer and solicit competitive bids for equipment, installation, and maintenance. USAID and the Government of Senegal must also assure that the appropriate training and ongoing maintenance of alternative energy systems are ensured. Otherwise, the systems will not perform as expected and the expensive equipment will sit idle.

ANNEXES

A. TECHNOLOGY OPTIONS

There are many technical options available to provide power to schools in Senegal. The most technologically and economically feasible are covered here. (We did not investigate the feasibility of wind or micro-hydro, since they are so site-specific and unlikely to be applicable to many locations).

A.1 GRID CONNECTION

Connecting a school to the grid involves, at maximum, the following installations:

Minimum requirements

- Low voltage connection Transformer – School: $ 8,000/km
- Control board and metering device: $ 75/connexion
- Internal wiring of the school: $ 200/connexion

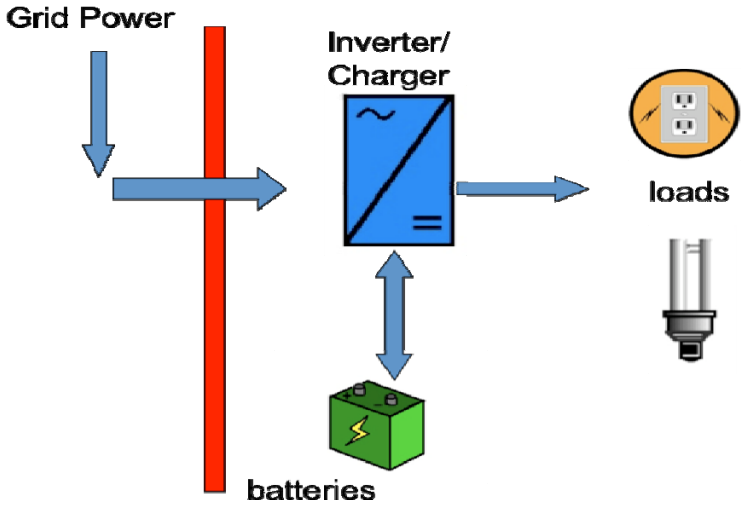
Possible additional requirements

- Medium Voltage cabling from grid to site: $ 11,000/km
- Medium/Low Voltage Transformer: $ 8,000/unit

Generally speaking the national utility company (Senelec) is in charge of everything but the internal wiring of buildings. To obtain an estimate of connection costs, the customer must request an assessment from the utility. After connection fees are paid, the only ongoing costs are for electricity consumption, which is billed monthly. Prepayment meters have been introduced for clients who prefer not having to pay monthly bills.

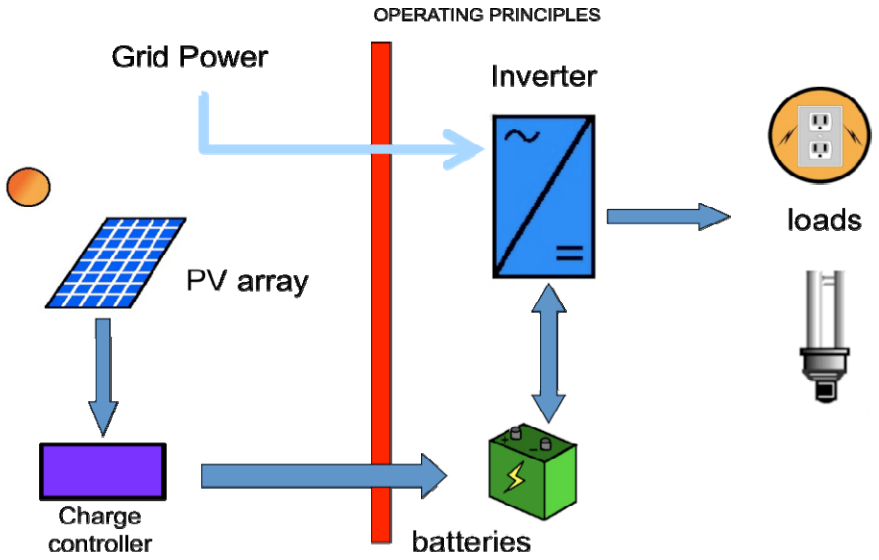
A.2 GRID WITH INVERTER / BATTERY

In cases where grid power supply is available but not continuously (i.e., it may only be available at night or during certain other time periods), a battery/inverter may be used to ensure electric power is available when needed. In this scheme, the grid charges the battery simultaneously as it powers the loads. The battery can then be used to provide power when the grid supply stops. The following graphic illustrates the components of such a system. This option was run in HOMER and the costs are explained in the text.



A.3 GRID WITH PV AND INVERTER / BATTERY OPTION

This option applies to sites where the grid power supply is available, but with long discontinuities of the service. The idea is to generate power where the grid supply is cut for a long period. Therefore, the system is designed to limit the cost of storage and find the best compromise between “storage” and “alternative power generation”.



The PV system and the grid system are both used to charge the batteries. When the grid supply is no longer present, the PV and the battery operate as a stand-alone power supply system. This system is unlikely to be economically feasible for USAID Senegal’s education program given budgetary constraints, and so is not included in the report. However, we did run the calculations in HOMER and can provide the figures if needed.

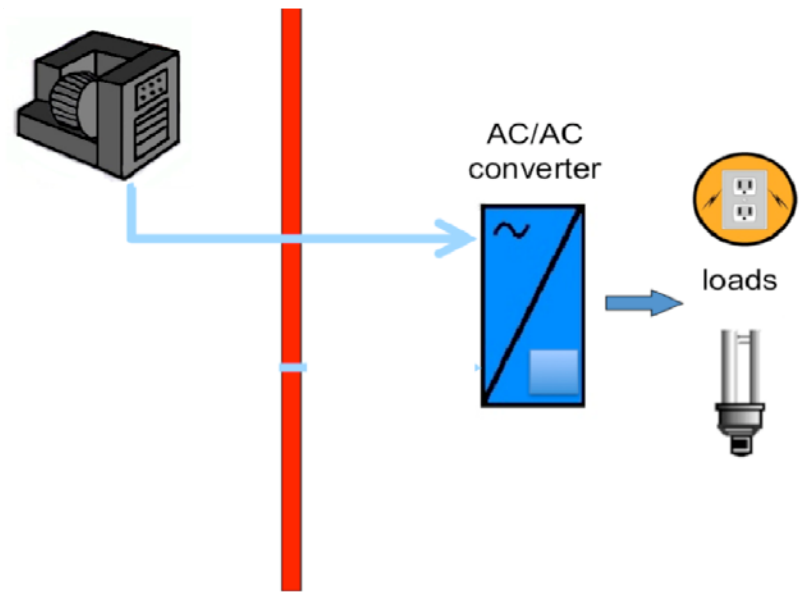
A.4 GRID WITH GENERATOR

This option applies to sites where grid power is available but suffers discontinuities of service. The generator operates as a back-up to the grid power supply, and stops as soon as the grid power supply recovers. We did not run this option in HOMER, as the battery/inverter option seemed a more plausible alternative.

GENERATOR-RELATED OPTIONS

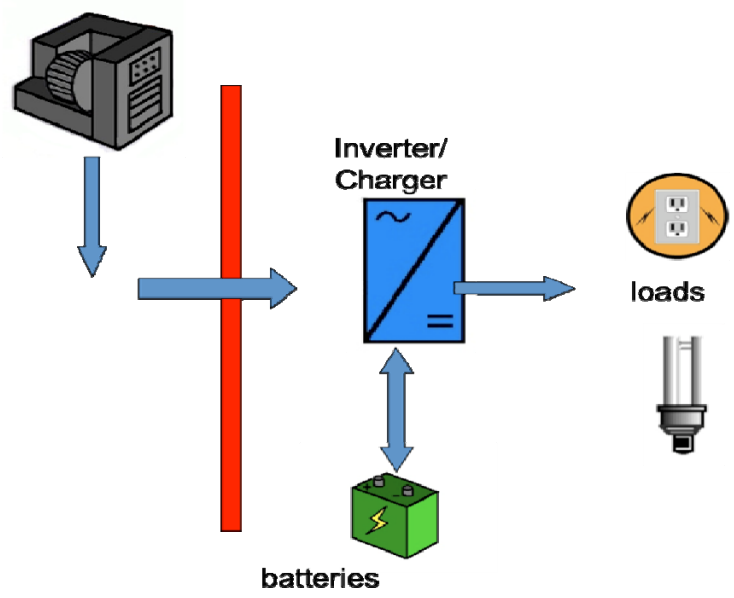
A.5 GENERATOR

This option applies to sites where grid power supply is not feasible and where the loads do not require continuous supply. This option was run in HOMER and the costs are explained in the text.



A.6 GENERATOR WITH INVERTER / BATTERY

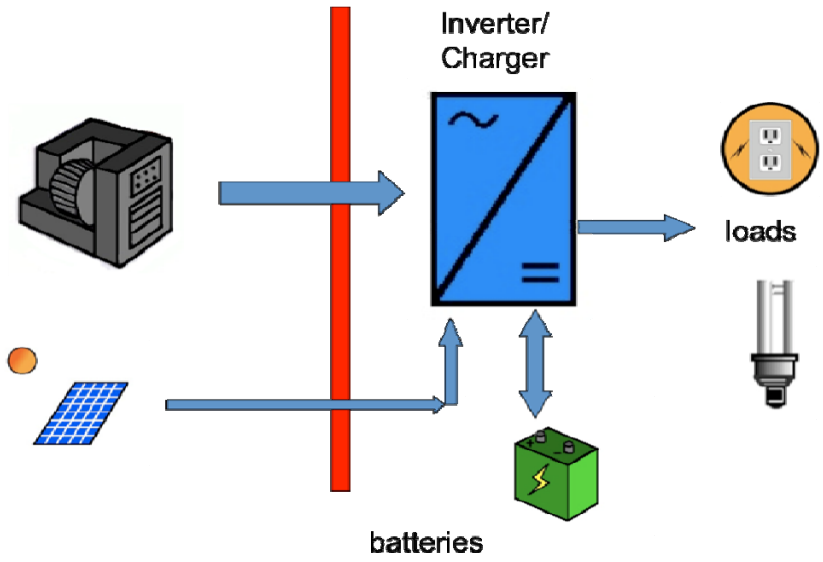
An inverter and batteries may be added to the generator, just as in the previous grid example. This option may be used at sites where grid connection is not feasible and the loads require long periods of supply. The generator charges the battery while simultaneously powering the loads. When the generator is off, the battery can be used to power the loads. In this situation the generator can be run at a greater efficiency, and for less time. The generator will therefore require less fuel and less maintenance over its lifetime than in the previous example. This option was run in HOMER and the costs are explained in the text.

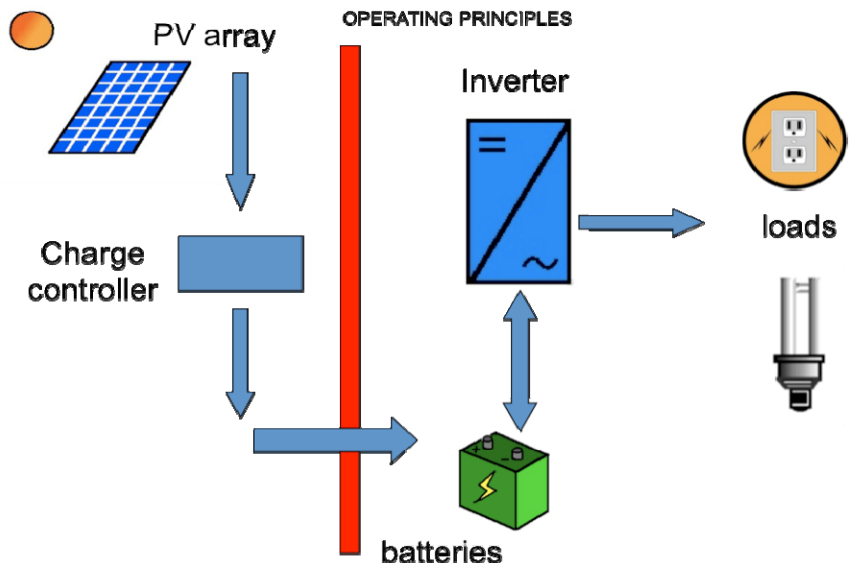


A.7 GENERATOR WITH PV AND INVERTER / BATTERY

This option adds a PV system to the system shown in option 6. The PV system ensures that the battery is always charged. The genset may be used to charge the battery whenever needed and may power the load simultaneously. When the generator is off, the PV system and/or battery

can power the loads. Due to the cost of this system and the relatively simple power needs of Senegalese schools, we did not run this option in HOMER.



A.8 PV WITH INVERTER / BATTERY

This option suits sites where grid power is not feasible and which are isolated (difficult to supply fuel, expensive access for maintenance). This option was run in HOMER and the costs are explained in the text.