Document 524
PRELIMINARY DESIGN REPORT

CHAPTER: North Carolina State University
COUNTRY: Sierra Leone
COMMUNITY: LemonAid Village School
Lower Allentown
PROJECT: Sierra Leone Renewable Energy

PREPARED BY
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Submittal Date

ENGINEERS WITHOUT BORDERS-USA
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Preliminary Design Report Part 1 – Administrative Information

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2.0 Travel History

Dates of Travel	Assessment or Implementation	Description of Trip
Dec. 27, 2010 – Jan. 9, 2011	Assessment	The water systems team traveled to assess the water situation at the school
December 28, 2011- Jan 7, 2012	Assessment	The renewable energy team travelled to assess the energy situation at the school

3.0 Project Discipline(s): Check the specific project discipline(s) addressed in this report. Check all that apply.

Water Supply
____ Source Development
____ Water Storage
____ Water Distribution
____ Water Treatment
____ Water Pump

Sanitation
____ Latrine
____ Gray Water System
____ Black Water System

Structures
____ Bridge
____ Building

Civil Works
____ Roads
____ Drainage
____ Dams

Energy
_X_ Fuel
_X_ Electricity
Agriculture
____ Irrigation Pump
____ Irrigation Line
____ Water Storage
____ Soil Improvement
____ Fish Farm
____ Crop Processing Equipment

Information Systems
_X_ Computer Service

4.0 Project Location

Longitude: W13° 9’ 24.6”
Latitude: N8° 25’ 9.7”

Preliminary Design Report Part 2 – Technical Information

1.0 INTRODUCTION

The purpose of this document is to provide the first 30% of our team's design of a solar PV system to be implemented at the Village Learning Environment in Lower Allentown, Sierra Leone. This report will discuss background of the program, preliminary design, project ownership, constructability of the system, operation and maintenance of the system, sustainability of the project, the community agreement, a cost estimate of the project, and an affirmation of our project by our professional mentor.

2.0 PROGRAM BACKGROUND

Dr. Nancy Peddle is founder and CEO of the non-profit organization LemonAid Fund which is committed to assisting sustainable development projects in Sierra Leone and throughout West Africa. Dr. Peddle initially contacted EWB-USA during the construction of the LemonAid Village schools. The LemonAid Village Learning Environment consists of a preschool, primary and secondary school, serving more than 600 students. At the time, Dr. Peddle foresaw two primary issues of concern for the future of the school, a supply of clean drinking water and a stable energy supply. This project focuses on a renewable energy solution for the LemonAid Village Learning Environment.

From December 27, 2010 through January 9, 2011 an EWB-USA assessment team from the North Carolina State University chapter travelled to the LemonAid Village Learning Environment in Lower Allentown, Sierra Leone. Traveling with water systems engineer, Crag Perry, the primary objective of this trip was to analyze the water situation at the school. The team assessed the water distribution system and spent time strengthening ties with the local community.

Our project's assessment trip from December 28, 2011 through January 6, 2012, explored the energy needs of the school. In the words of Francess Browne, head mistress of the LemonAid Village Learning Environment, "We are having energy failure and we are in desperate need of supplemental energy through source such as solar panels and energy storage facility. We are looking forward to working with you and to let this problem be put to an end."

Currently the school relies on the inconsistent power grid of Freetown which only runs a few hours a day, and uses a gasoline generator for most of their energy needs. In order to power their small computer lab they must turn off power to other appliances such as the refrigerator in the office and some of the lights in the classrooms. A renewable energy source is desired which will provide the school with a clean and consistent source of power for their daily activities. A large portion of the school's energy load can be reduced by using more efficient appliances such as laptops instead of old computers with CRT monitors.

After our assessment trip, our team carried out an alternatives analysis in order to determine the best solution for the school's energy needs. Some solutions we considered were a solar energy system, wind energy system, battery bank storage, and energy efficiency improvements. The factors we used to judge these solutions were construction materials, natural resource availability, safety, reliability, efficiency, complexity, security, cost of the system, feasibility, social acceptance, climate effects, land use, long-term operation and maintenance, and project sustainability.

Through careful consideration of every one of these factors in relation to each solution, it was determined that a combination of a solar energy system and energy efficiency improvements would work best for the school. Some of the best aspects of the solar energy system were the natural availability of sunlight in Sierra Leone, ability to place the system on existing school, acceptance in the community, availability of solar energy parts in country, and the relatively easy installation of such a system.

Energy efficiency is a key part of the solution because decreasing the school's energy load will decrease the size, and thus cost, of any system we will be implementing. The cost afforded by replacing the school's computers, for example, is nominal compared to the cost of buying parts to increase the size of the solar energy system.

Overall, a solar energy system is best for the school because it is the most cost effective in the long run, most supported by the community, and most feasible.

3.0 FACILITY DESIGN

3.1 Description of the Facilities

It is planned for the schoolhouse of Sierra Leone to be running with a stand-alone photovoltaic electricity generating system. The PV system will be designed to provide all of the electricity needed for the school, and will be designed to be tied into the existing (but unreliable) utility grid power, as well as an existing gas generator. This system will include an array of solar panels and accompanying mounting hardware for the solar panels, a battery bank for storing energy, a charge controller, an inverter, and all necessary breakers, wires, and control circuits to make the unit function. The size of the photovoltaic array will be about 4.8 Kilowatts STC. The system is planned to be placed on the North roof of the building. We plan to have the schoolhouse create a small cinderblock structure around where their generator is currently located to house our electrical equipment, generator, and battery bank.

3.2 Description of Design and Design Calculations

Many calculations went into sizing the various components of this system, such as array generation capacity, battery bank size, etc. This section will review all calculations and decisions made on our part for the design of the photovoltaic array.
The panels chosen for this preliminary design are based on hopes that we will receive a grant that includes the PV panels. Other equipment chosen for this preliminary design is based on what we anticipate will be locally available.

Load Sizing

On our assessment trip, we determined the demand of the schoolhouse to be 10.314 Kilowatt-Hours per day. The peak demand for the schoolhouse was 7.125 Kilowatts and the total aggregate surge rating on all electrical items in the schoolhouse summed to 4.884 Kilowatts. If the load excludes the use of the popcorn popper and cotton candy machine, both of which are still sitting in their boxes in a closet at the moment, the maximum load was calculated to be 5.175 Kilowatts.

Climate

Climate plays a large role in designing an appropriate photovoltaic energy generation system. Our research shows Freetown, Sierra Leone receives the least amount of average daily insolation during the rainy months of July and August, where we can expect 3.85 full insolation equivalent hours per day during this time. The average maximum temperature during this time is less than or equal to 26.31 degrees Celsius. We will be designing our array around generating enough electrical energy to power the schoolhouse during this time of the year. The absolute maximum and minimum temperatures recorded in Sierra Leone are 29.83C and 23.68C. These points will be used to determine maximum currents and voltages for component selection. Our climate data was collected from http://eosweb.larc.nasa.gov/sse/. We feel the website is reliable.

Array Size

We will be sizing our array around generating at least 10.314 Kilowatt-Hours every day during the rainy season when we receive the least amount of insolation. By doing some calculations, we came up with a value of 67 type FS-272 solar panels required to generate this level of energy on a daily basis for the schoolhouse, which equates to about 5 kilowatts of standard test condition panel wattage. The appendix includes a detailed section on the calculation of these figures.

Battery Bank Sizing

We designed our battery bank around providing three days of autonomy with an average daily load of 10.314 Kilowatt-Hours of energy consumed per day. It was determined that our battery bank must provide 231 Amp-Hours per day at 48 Volts under zero solar input to deliver this amount of energy to the load. After considering the design around three days of autonomy, we determined it necessary to purchase 48 2 Volt 498 Amp-Hour type G75-11 Pb-Acid batteries to meet these requirements arranged in a 2x24 orientation. It was also calculated that the minimum voltage the batteries will see under their discharge limit is 46.4 Volts. The appendix includes a detailed section on the calculation of these figures.

Charge Controller Sizing

After having calculated the need for at least 67 72.5 Watt panels, the charge controller was sized for input voltage and current input requirements. It was found that under the most intense climate conditions we expect to see in Freetown, Sierra Leone, the open circuit voltage would never exceed 82 Volts and the short circuit current would never exceed 83.6 Amps with all 67 solar panels stacked in a parallel fashion. When doing research on charge controllers, it was not possible to find a practical controller for our application that would allow stacking the panels with more in series because the open circuit voltage exceeded the ratings on all practical controllers researched. We selected the Outback FLEXmax60 charge controller for our application with the intent of stacking two in parallel. The appendix includes a detailed section on the calculation of these figures.

Inverter Sizing

The selection of the inverter must be large enough to provide maximum load conditions. The inverter must be able to provide maximum load conditions. We designed the selection of the inverter around providing 5.175 Kilowatts of power indefinitely while needing to supply surge power of 12 Kilowatts. This would allow indefinite operation of everything except the popcorn maker and the cotton candy maker and meet surge requirements. We selected to place two Outback FX2348ET 2300 Watt inverters in parallel. This pair of inverters would allow a maximum surge rating of 11.5 Kilowatts, a 30 minute overload rating of 6.2 Kilowatts, and power an indefinite sustained load of 4.6 Kilowatts. We believe it to be highly unlikely that the loading conditions at the school should exceed the ratings on this inverter even though it is technically a little undersized. No appendix calculations were shown for this section, as no complicated equations were needed to calculate these values.

Load Voltage Drops

We were unable to find specific schematics on the wiring of the schoolhouse. All we know is the schoolhouse has a feed line where all AC power will flow in and around the schoolhouse. We will be designing the wire leading from our inverters to the schoolhouse with the goal of keeping the voltage at the feed-in bus inside regulation, which is +-5% of rated bus voltage. It was found that with the Outback FX2348ET inverter selected and a 175 feed line of 6 AWG, the voltage on the bus feeding into the school would never exceed 2% over rated voltage or 4% under rated voltage, comfortably inside the requirements. A detailed section on these calculations is shown in the appendix.

Breaker Sizing

We plan on utilizing the Flex Power 2 from Outback Power. This product will contain all charge controllers, inverters, and breakers required for our system in one simple pre-wired custom-ordered package. We will need to specify the size of the breakers needed to ensure proper system operation for our array size and load size. The following table lists the calculated sizes of each breaker in the schematic shown in 3.3. The appendix includes information regarding the calculation of these values.

Breaker	Number Needed	Voltage (Volts)	Current (Amps)	Type
PV Combiner	14	82.06302	7.798446	DC
PV Disconnect	2	82.06302	52.24959	DC
PV Ground Fault	2	82.06302	52.24959	DC
CC to Battery/Inverter	2	52	65.42969	DC
AC Input	2	241.5	75	AC
Battery to Inverter	2	52	173.9324	DC
Inverter to Load	2	234.6	33.29871	AC
Electrical Room	1	234.6	5	AC
Bypass Breaker	1	241.5	66.59742	AC

3.3 Drawings

Our system drawings include an overall concept of the system, the expected physical layout of our electrical room, the physical layout of our panels on the roof, and the wiring schematic for the internals of the Flexpower 2 unit we wish to purchase from Outback Power. Figure 1 contains the wiring diagram for the Flexpower 2 unit. This unit contains the bulk of the power electronics required for the project, including charge controllers, inverters, and breakers. Figure 2 contains a drawing of a possible layout for our panels, leaving room for access for cleaning the panels. The dimensions of this particular layout are 16' x 62'. Figure 3 contains a conceptual sketch of how our entire system will look as a whole. We are unsure how they currently hook the generator up to the grid tie, so for now it is shown as a simple connection. It should be noted that the generator is not part of our project. Figure 4 contains some possible layouts of the room for our electrical equipment we will need constructed. All of these layouts meet NEC code requirements.

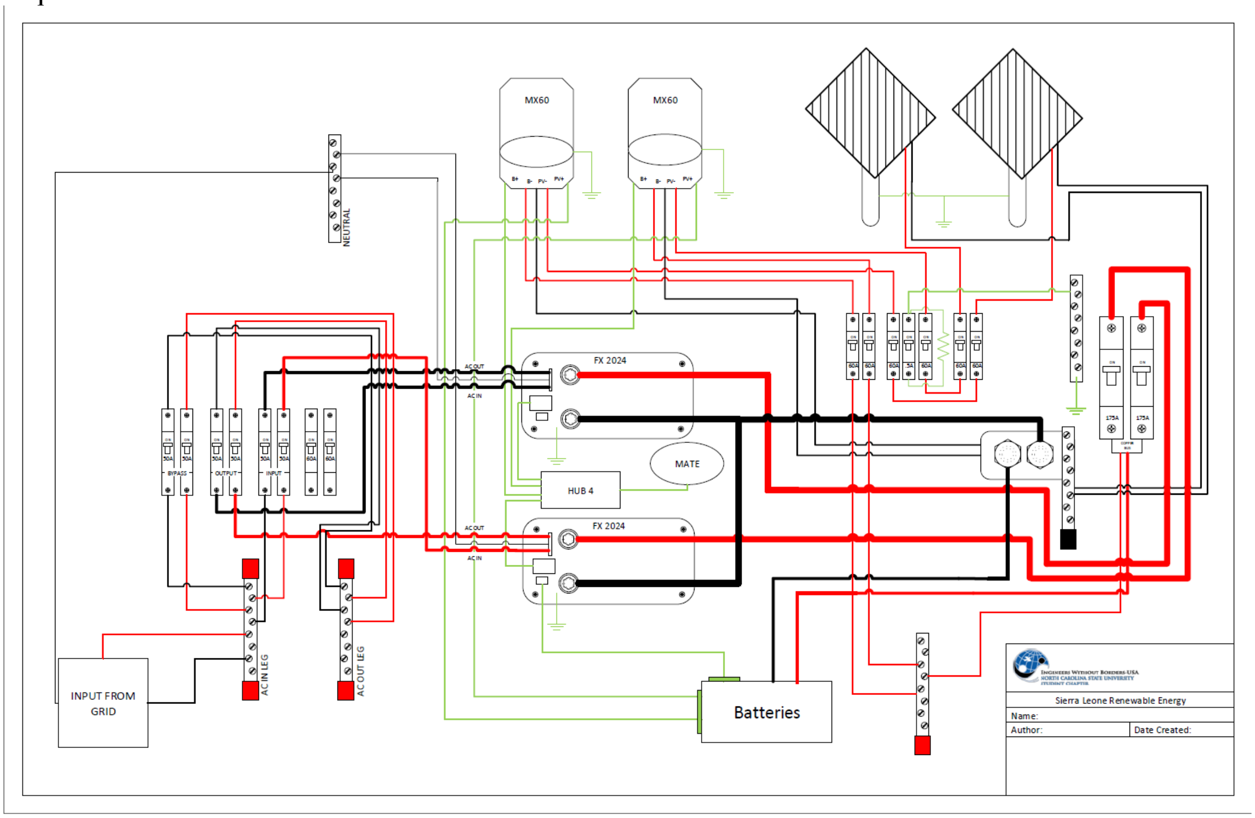

Fig. 1: Wiring diagram for Flexpower 2

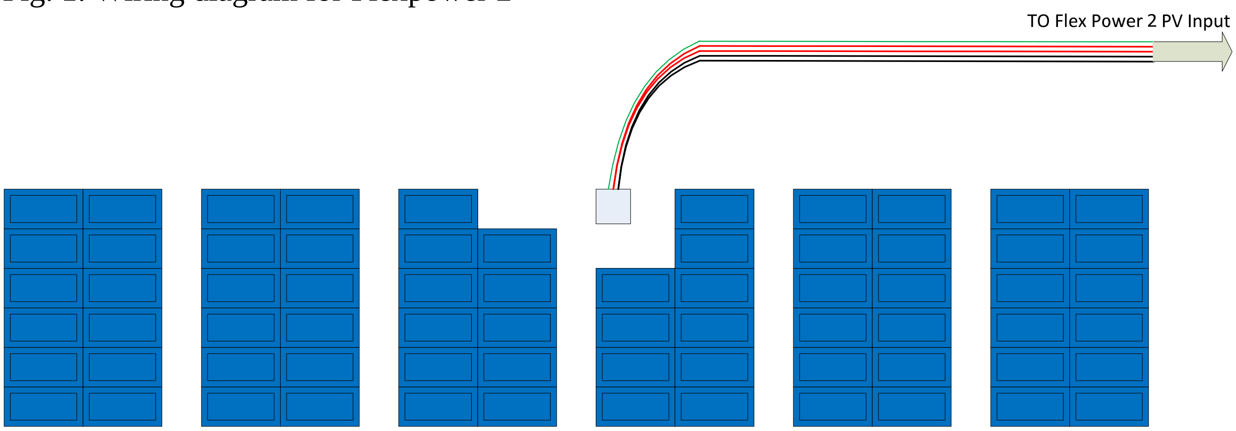

Fig. 2: PV Roof Layout

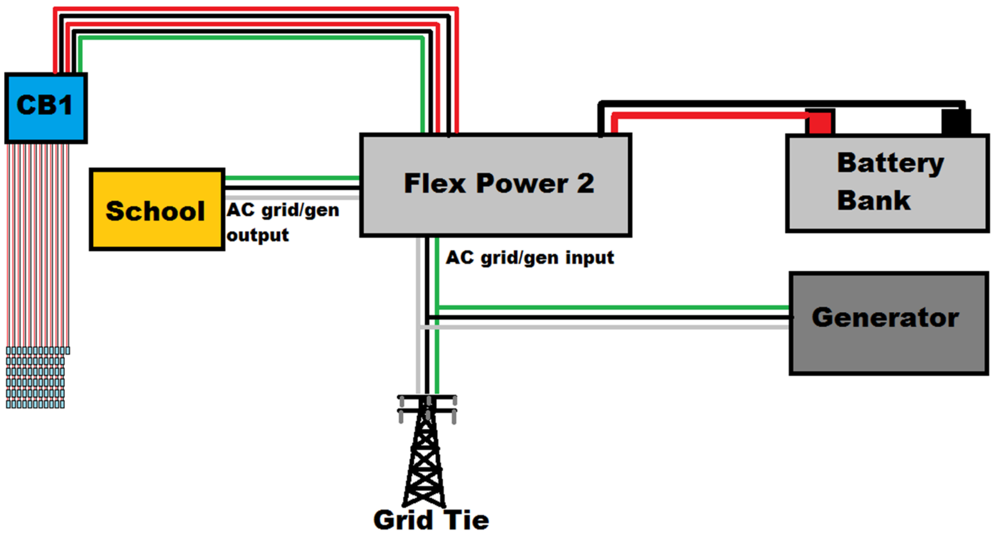

Fig. 3: Overall Project Picture

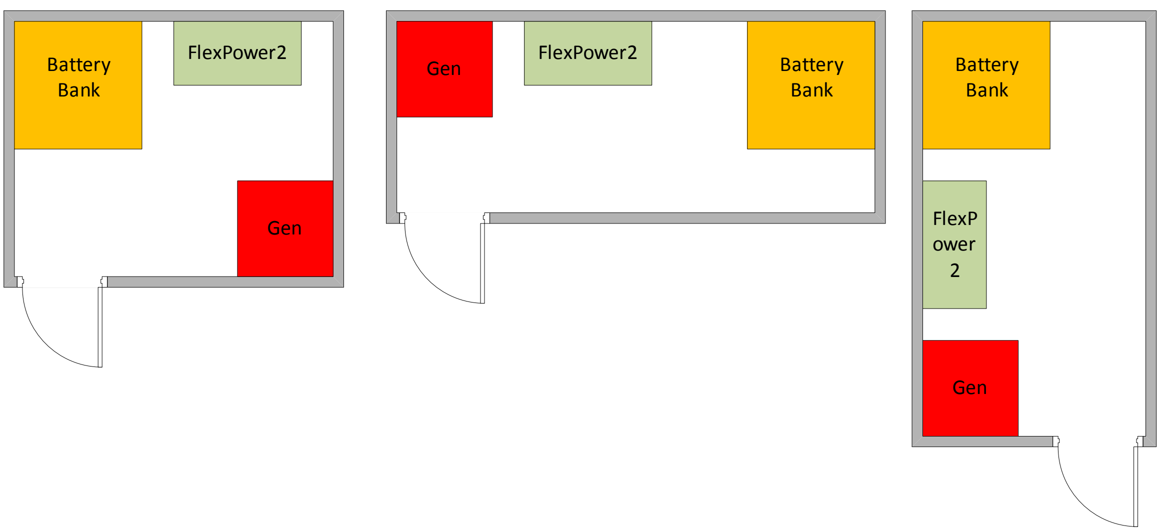

Fig. 4: Possible Electrical Room Layouts

Calculation of Array Size

The following figures and values will be used in this calculation:

$P_{consumed}$=10.314 Kilowatt Hours per day

P_{array}=13.957 Kilowatt Hours per day, calculated here

$E_{battery}$=0.81 battery efficiency, found online through research and assumption of slow discharge

$E_{charge\ controller}$=0.981, charge controller efficiency found in datasheet

$E_{inverter}$=0.93, inverter efficiency found in datasheet

$P_{panel-derated}$=66.6 Watts, panel power output during rainy season temperatures, calculated here
$P_{panel-listed}$=72.5 Watts, listed power output of panel under STC
T_p=0.0025, thermal power loss constant found on solar panel's datasheet
T_{high}=26.31C, average high during the rainy season in Freetown, Sierra Leone
$E_{mismatch}$=0.97, panel mismatch loss. Typical values for this are 0.97 to 0.995. This was not listed on the panel datasheet so we were conservative with our value.
E_{dirt}=0.85, panel dirt loss. Typical values for this are 0.95-1.00 but our assessment trip showed Sierra Leone to have a very high dirt level. This is a pessimistic value.
NOCT=45C, Normal Operating Cell Temperature, found on solar panel's datasheet
H_{sun}=3.85, rainy season average daily insolation hours.

Knowing the schoolhouse demands 10.314 Kilowatt-Hours each day, we can calculate the panel output power required with the following formula.

$$P_{array} = \frac{P_{consumed}}{E_{battery} * E_{charge\ controller} * E_{inverter}}$$

Doing some online research led us to using a value of 0.9 for battery efficiency if charged and discharged relatively slowly. Since our battery bank will sustain 3 days of autonomy, this will be a very slow discharge, and relatively efficient. The value, however, must be squared since we are currently assuming that all power must be stored in the battery and taken back out, and that no power flows directly from charge controller to inverter. This, of course, is not true but we were unable to get daily load use information from the Sierra Leone schoolhouse so we must be as conservative as possible for things we do not know.

Having calculated the power output requirement for our array, the next step is to calculate how many solar panels we will need to generate this amount of power. It is possible to calculate the amount of power we can expect from these panels under our conditions with the following formula.

$$P_{panel-derated} = P_{panel-listed} * (1 - T_p * \left(T_{high} + \frac{NOCT - 20}{0.8} - 25\right))$$

Knowing the actual expected power output of each panel as well as the amount of daily power demanded from our array, we can calculate the number of panels required with the following formula.

$$Panels\ Needed = \frac{P_{array}}{P_{panel-derated} * E_{mismatch} * E_{dirt} * H_{sun}}$$

This result yielded value of 67 for Panels Needed. If in the future we are able to relax a few more restraints and pessimistic assumptions such as the assumption that all energy must flow into and out of the batteries and that our dirt loss really is better than 0.85, the number of panels required will only shrink further.

Calculation of Battery Bank Size

The following values and figures were used in the following battery calculations:
$P_{consumed}$=10.314 Kilowatt-Hours, average daily consumption of energy by the schoolhouse
$I_{battery}$=231 Amp-Hours, average daily amperage demanded of battery bank
$E_{inverter}$=0.93, inverter efficiency, found on selected inverter datasheet
V_{system}=48 Volts, determined based on what charge controllers and inverters we could find that met the rest of our needs. Generally a higher voltage is better for less copper conduction loss in the system.

Days=3, number of days the system can run on batteries with zero input from the sun.
$D_{battery}$=0.8, discharge limit of batteries, found on battery datasheet
$I_{capacity}$=498, battery amp-hour listed capacity, found on datasheet
$B_{parallel}$=2, number of batteries in parallel needed to meet current demand
B_{series}=24, number of batteries in series needed to stack up to V_{system}
$V_{battery}$=2, battery rated voltage
$V_{min-system}$=46.4V, system minimum voltage under discharge limit of batteries

The average amp hours demanded of our battery bank can be calculated using the following formula, which yielded a resulting 231 amp hours per day being demanded on average.

$$I_{battery} = \frac{P_{consumed}}{E_{inverter} * V_{system}}$$

Using this value, it is now possible to compute the number of batteries needed in parallel to deliver this amount of current for the required number of days of autonomy. The following formula will calculate how many batteries are needed in parallel to meet this current demand.

$$B_{parallel} = \frac{I_{battery}}{Days * D_{battery} * I_{capacity}}$$

The result of this formula yields a value of 1.74 batteries in parallel. The provider we wish to purchase from does not have a smaller amp hour battery available so this value must be rounded up to 2 batteries in parallel. We will also need $\frac{V_{system}}{V_{battery}}$=24 batteries in series to supply the system voltage. The product of $B_{parallel}$ and B_{series} yields a total value of 48 batteries required to supply three days of autonomy to our load.

The minimum battery voltage can also be calculated for use later. Doing some online research, it was found that at an 80% discharge a 12 Volt cell will measure 11.6 Volts. We can calculate our minimum battery voltage with the following formula, which yields a result of 46.4 Volts.

$$V_{min-system} = \frac{11.6}{12} * V_{system}$$

Calculation of Charge Controller Size

The following values and figures will be used in the following calculations:
Panels Needed=67, number of panels required to deliver enough energy to our load on a daily basis
$Panels_{series}$=1, number of panels linked in series in our array
$Panels_{parallel}$=67, number of panels linked in parallel in our array
I_{sc}=1.23 Amps, short circuit current rating on our panels, from panel datasheet
V_{oc}=88.7 Volts, open circuit voltage rating on our panels, from panel datasheet
T_I=0.0004, current thermal constant, from panel datasheet
T_{max}=29.83C, maximum temperature seen in Freetown, Sierra Leone, from climate research
T_V=-0.0025, voltage thermal constant, from panel datasheet
T_{min}=23.68, minimum temperature seen in Freetown, Sierra Leone, from climate research
NOCT=45C, Normal Operating Cell Temperature, from panel datasheet
$Iarray_{sc}$=83.6 Amps, array short circuit current, charge controller must be able to handle this
$Varray_{oc}$=82.1 Volts, array open circuit voltage, charge controller must be able to handle this

The following equations can be used to calculate the array open circuit voltage and short circuit current.

$$Iarray_{sc} = I_{sc} * Panels_{parallel} * (\left(T_{max} + \frac{NOCT - 20}{0.8} - 25\right) * T_l + 1)$$

$$Varray_{oc} = V_{oc} * Panels_{series} * (\left(T_{min} + \frac{NOCT - 20}{0.8} - 25\right) * T_V + 1)$$

This resulted in the values $I_{arraysc}$=83.6 Amps and $Varray_{oc}$=82.1 Volts. It may seem a bit weird that the open circuit voltage of our array will never exceed 82.1 Volts, yet the panels are rated for 88.7 Volts, but that can be attributed to how constant the temperatures here are. The open circuit voltage is rated when the panel is at STC, which it is not cool enough to reach in Freetown, Sierra Leone. Needless to say, this small difference, however, did not affect our selection of charge controller.

Calculations on Load Voltage Drops

The following values and figures were used in the calculations below

Ω_{kft}=0.3951 Ohms/1000 feet, wire resistivity for 6 AWG wire

L_{wire}=175 feet, length of wire that will feed into the school from our system

Ω_{wire}=.138 Ohms, total combined resistance of both feed in live wire and return wire for our system

I_{max}=31.61 Amps, maximum sustained load current

P_{max}=7125 Watts, maximum sustained load power

V_{rated}=230 Volts, rated voltage of feed in bus

V_{reg}=0.02=2%, voltage regulation of inverter, found on inverter datasheet

V_{high}=234.6 Volts, highest possible feed bus voltage under lowest load conditions

V_{low}=221.03 Volts, lowest possible feed bus voltage under highest load conditions

The resistance that we will encounter when attempting to feed power from our system to the schoolhouse can be calculated using the following formula.

$$\Omega_{wire} = 2 * \Omega_{kft} * L_{wire}/1000$$

Using this value, the voltage regulation on the inverter, as well as the maximum load, it is possible to compute the highest and lowest voltages seen on the feed bus for the schoolhouse. These are calculated below.

$$I_{max} = \frac{P_{max}}{V_{rated} * (1 - V_{reg})}$$

$$V_{high} = \left(1 + V_{reg}\right) * V_{rated}$$

$$V_{low} = \left(1 - V_{reg}\right) * V_{rated} - \Omega_{wire} * I_{max}$$

It was found that by using wire of 6 AWG or better, the voltages on the feed bus can be kept within 5 percent of the rated value. V_{low}=221.03 Volts=96% of rated voltage. V_{high}=234.6 Volts=102% of rated voltage.

Calculation of Breaker Sizes

The following values and figures were used in the following calculations.

OC=1.25, overcurrent safety factor

I_{sc}=1.23, short circuit current of our solar panel, found on the panel datasheet

T_I=0.0004, current thermal constant, found on the solar panel datasheet

T_{max}=29.83C, maximum temperature recorded in Freetown, Sierra Leone

NOCT=45C, Normal Operating Cell Temperature, found on solar panel datasheet

V_{oc}=88.7, panel open circuit voltage, found on the solar panel's datasheet

T_V=-.0025, voltage thermal constant, found on the solar panel datasheet
T_{min}=23.68C, minimum temperature recorded in Freetown, Sierra Leone
P_{cc}=4858 Watts, maximum power that can be delivered at any given time from our charge controller, calculated as product of number of panels required and panel STC power rating
$V_{min-system}$=46.4 Volts, minimum battery voltage under a full discharge
CC=2, number of charge controllers we will be using
$Panels_{series}$=1, number of panels in series in our system
$Panels_{parallel}$=67, number of panels in parallel in our system
$V_{max-system}$=52, fully charged battery voltage
$Panels_{wired-together}$=5, number of panels that will be connected to each combiner breaker
I_{ac-in}=60 Amps, total inverter AC input current rating for battery charging
Panels Needed=67, number of solar panels required to meet our power consumption demand
V_{rated}=230 V AC, voltage rating of the AC side of our system and load
V_{reg}=0.02, voltage regulation of our inverter, found on the inverter datasheet
$P_{max-surge}$=12.008 Kilowatts, maximum load and surge power our load will ever consume
IN=2, number of inverters in our system
$E_{inverter}$=0.93, inverter efficiency, found on the inverters datasheet

The following equations were used to calculate the ampacity and blocking voltage of each breaker in our system. Note we also include a circuit room breaker that blocks the AC voltage and allows only 5 amps to conduct. This breaker's ampacity value was chosen somewhat arbitrarily.

$$PV\ Combiner\ Ampacity = OC * I_{sc} * \left(\left(T_{max} + \frac{NOCT - 20}{0.8} - 25\right) * T_I + 1\right) * Panels_{wired-together}$$

$$PV\ Combiner\ Voltage = V_{oc} * Panels_{parallel} * (\left(T_{min} + \frac{NOCT - 20}{0.8} - 25\right) * T_V + 1)$$

$$PV\ Disconnect\ Ampacity = PV\ Combiner\ Ampacity * \frac{Panels\ Needed}{CC * Panels_{wired-together}}$$

$$PV\ Disconnect\ Voltage = PV\ Combiner\ Voltage$$

$$PV\ Ground\ Fault\ Interruptor\ Ampacity = PV\ Disconnect\ Ampacity$$

$$PV\ Ground\ Fault\ Interruptor\ Voltage = PV\ Disconnect\ Voltage$$

$$CC\ to\ Battery\ Ampacity = \frac{OC * P_{cc}}{CC * V_{min-system}}$$

$$CC\ to\ Battery\ Voltage = V_{max-system}$$

$$AC\ in\ Ampacity = OC * I_{ac-in}$$

$$AC\ in\ Voltage = V_{rated} * 1.05$$

$$Battery\ to\ Inverter\ Ampacity = \frac{OC * P_{max-surge}}{V_{min-system} * E_{inverter} * IN}$$

$$Battery\ to\ Inverter\ Voltage = V_{max-system}$$

$$Inverter\ to\ Load\ Ampacity = \frac{OC * P_{max-surge}}{V_{rated} * \left(1 - V_{reg}\right) * IN}$$

$$Inverter\ to\ Load\ Voltage = V_{rated} * (1 + V_{reg})$$

$$Bypass\ Breaker\ Ampacity = 2 * Inverter\ to\ Load\ Ampacity$$

$$Bypass\ Breaker\ Voltage = 1.05 * V_{rated}$$

4.0 PROJECT OWNERSHIP

The owner of the solar energy system will be the Village Learning Environment. The school's headmistress, Francess Brown, will oversee the general well-being of the system in an administrative role, whereas Sahr "Patrick" Kpakima will be the primary operator and caretaker of the system. Sahr is the technician and computer teacher at the school, and trained as an electrical engineer at a technical school in the area. We are also talking with Sahr about training a second caretaker, should Sahr leave the school or be unable to take care of the system in any way. The NGO we are partnered with, the LemonAid Fund, owns the land that the Village Learning Environment is located on. But because the land is being operated in a public function (as a school), we feel this is ok.

5.0 CONSTRUCTABILITY

The proposed installation of our project is expected to take approximately two weeks. Provisions will be made, in advance of the project team arrival in Sierra Leone, for all necessary equipment and tools to be on site, and/or to be readily available in country. The proposed installation schedule will be as follows:

- Day 1: Arrive on site (at the school) and meet with the local representatives of the project team to review the construction plans and schedule, confirm that all equipment and tools are on site, and review the safety procedures for the project. Make plans to procure any additional materials needed for the project.
- Day 2: Set up the ladders, scaffolding, safety tie-off points, etc.
- Day 3 and 4:Lay out the location of the PV panels on the roof, and install any necessary structural support members (to have been determined in advance). Locate the batteries, inverters and other Balance of System Components in the mechanical area.
- Day 5 and 6: Attach roof mounting hardware, conduit and junction boxes. Run conduit between Balance of System components in mechanical room, and to the electrical interconnection location.
- Day 7 and 8: Installation of PV panels on roof. Pull wiring through conduit and land wires on terminals.
- Day 9 and 10. Make final connection of all components, and inspect complete system.
- Day 11: Commission system. Adjust settings of controller, inverter, monitors, etc based on specified system parameters.
- Day 12: System review and training with local project managers and school officials.

The chapter will play the role of general contractor in the construction, overseeing system progress and managing labor in order to complete construction. Our members will be training and including the community throughout the construction of the PV system. The project will require a range of skills and capabilities including general labor (carrying equipment and materials from the ground to the roof, picking up supplies, etc), carpentry and tool use (assembling scaffolding, building structural support members, attaching mechanical parts, etc.), as well as skilled electrical work. While the EWB project team will be selected based on the skills needed, the project will also require locally skilled workers who can be involved in all aspects of the project.

The materials required for construction include solar panels, mounting racks, charge controllers, inverters, a battery bank, circuit breakers, conduit, wiring and hardware and lumber. Additional equipment that will be necessary will include ladders, harnesses, helmets, and other safety equipment to work on the project.

6.0 OPERATION AND MAINTENANCE

The constructed facilities will consist of solar panels mounted on a roof, and an equipment room containing a battery bank, the charge controller, the inverter, and monitoring. The financial maintenance requirement of the system will be to repair or replace any parts that wear out, whether that is early in the life of the system, at the supplies' guaranteed warranty, or after the warranty has expired. We have proposed a saving schedule at the school where the LemonAid Fund, who provides funding for the school, will set aside 900 dollars a year for the next 10 years. This way when the batteries (or any other part) for the system stop working the school will already have the money to replace them. Administratively, Francess Brown, the headmistress of the school, will check that the system is working properly by merely seeing if they have electricity and will coordinate its maintenance. Knowledge of wiring, basic electrical concepts, and basic experience with solar technology will be required for the technical upkeep of the system and to troubleshoot if/when the system does not work. Sahr has all of these skills, since he trained as an electrical engineer at the Government Technical Institute in electrical engineering. The caretaker of the system will also have to clean the panels, as dust will decrease the output of the PV panels significantly. Our chapter is developing an operating manual to be left with the school so Sahr, and whoever else is responsible to operate the system, can have a reference to the wiring and setup of the system. As we said in the project ownership section, we are currently searching for another member of the community or school that has the necessary skills to be the secondary caretaker of the system.

7.0 SUSTAINABLITY

We believe our project will be sustainable for many years to come. Although many of the parts in a PV solar energy system have limited warranties of about 10-15 years, the saving plan we have proposed to the school and the LemonAid Fund is designed so that when some aspect of the system needs to be replaced, the school already has the money for it. We have specifically selected the components of the system so the school can get the replacement parts at local solar stores in Freetown such as RCD Solar. A quick trip to RCD Solar when a part breaks will be all that's needed to get the system up and running again. Construction materials such as nuts and bolts will also be purchased in country so they are easily replaceable. While our team is there during the implementation trip, Sahr and other members of the community will be alongside us building the system so they will understand how it works. Also we will hold a workshop with all of the teachers and some other key members of the community to teach them generally how the system works and stress how important the system is to the school. Members of our team are currently developing a curriculum for every age of student at the school (K-12) to teach them about the system at the school, solar energy, and electricity in general. We believe the education of the children about the system will create a generation of informed advocates of the system, fully aware of aspects of the system such as the need to keep dust off the panels. We are still working with the community to determine an appropriate length for the curriculum (ranging from a week to a year long), but in any case, the children will be taught age appropriate lessons on the source of the school's power.

8.0 COMMUNITY AGREEMENT/CONTRACT

See Appendix 1

9.0 COST ESTIMATE

Our team's preliminary cost estimate is 45,000 dollars. The subgroups of budget items are listed below:
Travel: $12,360
Travel Logistics: $1,475
Food and Lodging: $1,600
EWB-USA Quality Assurance: $3,675
Project Materials: $25,790
Misc.: $100
Total: $45,000

10.0 PROFESSIONAL MENTOR/TECHNICAL LEAD ASSESSMENT

10.1 Professional Mentor/Technical Lead Name (who provided the assessment) Edward Witkin

10.2 Professional Mentor/Technical Lead Assessment

This design document was prepared through the collaborative effort of several student committees, as well as myself. Dylan Cawthorne, the SLRE Project Lead, has overseen the process and has coordinated the committees, which have been assigned various specific tasks associated with this project.

The committees include: Education and outreach (8 students working on education initiatives at the school), Fundraising (5 students working on fundraising for the project), System Engineering and design (5 students working on the technical design of the project), and Laptop Donation (5 students working on partnering with a non-profit to get computers donated to the school).

Each committee has been working on their assigned tasks and meeting weekly to prepare and review the information that is included in this document.

My primary focus has been to work with the system design committee, to come up with a preliminary system design based on some assumptions of the equipment that will be available. While the PV system design included in this document is quite detailed, we have made

provisions to be able revise the plans easily once more specific information about the equipment is available.
I will be reviewing the plans with colleagues of mine in the solar electric industry as we move towards a complete system design.

10.3 Professional Mentor/Technical Lead Affirmation

I have been working closely with Dylan Cawthorne throughout this process, as well as meeting weekly with the system design team, and I feel confident accepting the responsibility for the course this project is taking.

Appendix 1: Community Agreement

Agreement between the Village Learning Environment (VLE),
the LemonAid Fund, and NCSU chapter of EWB-USA

This agreement is between the Village Learning Environment, the LemonAid Fund, and the North Carolina State University Chapter of Engineers Without Borders-USA for the purpose of setting guidelines for the solar PV system to be implemented at the VLE.

EWB NCSU agrees to do the following:

- EWB NCSU will design an appropriate PV (Photovoltaic) system for the school's current and projected needs.
- EWB NCSU will provide details to Village Learning Environment of the requirements for a building/structure that will support the PV panels and all of the balance of system components for this project.
- EWB NCSU will raise the initial funds for the PV system implementation.
- EWB NCSU will inform the Village Learning Environment and Lemon Aid Fund community of travel plans at least 3 months in advance of any trip to Sierra Leone.
- EWB NCSU will provide technical training to selected members of the Village Learning Environment community on how to operate and maintain the PV system.
- EWB NCSU will give technical support and troubleshooting to the project after implementation via email
- EWB NCSU will help the school partner with NGO's in order to provide energy efficient laptops, to replace the existing computers at the school.
- EWB NCSU will inform the school of the estimated ongoing maintenance costs of the PV system
- EWB NCSU will provide an operating manual and PV system information to the school.
- EWB NCSU will maintain contact with the VLE twice every month and preferably once a week in the two months before implementation

The Village Learning Environment agrees to do the following:

- Village Learning Environment will implement a plan to save money for maintenance and the replacement of parts totaling at least 3950000 Leones (900 dollars) each year for 10 years.
- Village Learning Environment will ensure that the PV System is only used for its intended purpose, and prevent any misuse of the system.
- Village Learning Environment will provide for the security of the system to ensure no parts are stolen or vandalized.

- Village Learning Environment will provide funding for and construct the building/structure to support the PV panels and house the balance of system components. This structure will be completed prior to the EWB NCSU implementation/ installation trip to Sierra Leone.
- Village Learning Environment will provide labor and support during the implementation, including the procurement of any local building permits, licenses and/or required local professionals for this type of project.
- Village Learning Environment will maintain, and repair, if necessary, the solar PV system implemented by EWB-USA NCSU
- Village Learning Environment will maintain contact with EWB NCSU twice every month and preferably once a week in the two months before implementation

The LemonAid Fund agrees to do the following:

- The LemonAid Fund will provide transportation in Sierra Leone for the travel members of EWB NCSU during the implementation/installation trip.
- The LemonAid Fund confirms they will have enough funding to maintain the system for at least the next five years.

On behalf of, and acting with the authority of the Village Learning Environment, the LemonAid Fund and NC State University chapter of EWB-USA, the under-signed agree to abide by the above conditions.

Dylan Cawthorne Signature______________________________ Date_________

EWB-USA NCSU SLRE Project Lead

Nancy Peddle Signature______________________________ Date_________

Lemon Aid Fund, CEO

Sahr Kpakima Signature______________________________ Date_________

VLE School Technician

Frances Brown Signature______________________________ Date_________

Headmistress, VLE

Dr. Andrew Grieshop Signature_______________________________Date_________

Faculty Advisor, EWB-USA NCSU