Power Audit Report

DeveloPPP Project: WP2 Power Audits

Power Audit at Mother and Child Hospital

Lagos, Nigeria

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1. EXECUTIVE SUMMARY

Mother and Child Hospital is one of the two SMEs selected as part of the DeveloPPP project for the implementation of a pilot power audit. During this visit, a OneShore engineer performed the power audit following the OneShore auditing process and installed the in-house developed measurement tool OneAnalyser for permanent power auditing.

During the site visit it was found that there are 600 m^2 of roof space available which could be assessed for PV installation. A OneAnalyser measurement device captured the electricity consumption from the grid and the main diesel generator at a minute resolution. The hospital requires power 24 hours a day for critical medical equipment and operation. The average power demand is around 40 kW and during main office hours between 08:00 and 16:00, when the consumption is often higher, the demand can reach peaks of 61 kW. The hospital suffers from a very poor 20% grid availability, which forces them to rely on the diesel generator and additional portable gasoline generators which are deployed to save some fuel costs.

To assess the potential of energy cost reductions and fuel savings, the following 4 scenarios were assessed:

1. Replacement of current lamps for higher efficiency lighting
2. Resizing of the large diesel generator and replacement of gasoline generators
3. Installation of a diesel PV hybrid system
4. Installation of a diesel PV hybrid system with energy storage (including a hybrid controller)

Below is a summary of the energy savings opportunities investigated in this report and their financial key indicators:

Case	Total Savings (USD)	Total Investment (USD)	Allows continuous power for hospital
Lighting replacement	$ 623 over 1.7 years	$ 360	No
Replacement of large generator	$ 88,200 (fuel) over 7 years $ 31,720 (on replacements)	$ 24,180	No (only possible with increased fuel cost)
PV with diesel generators	$ 46,467 over 20 years	$ 60,000	Yes
PV with battery and diesel generators	$ 208,000 over 20 years	$ 250,000	Yes

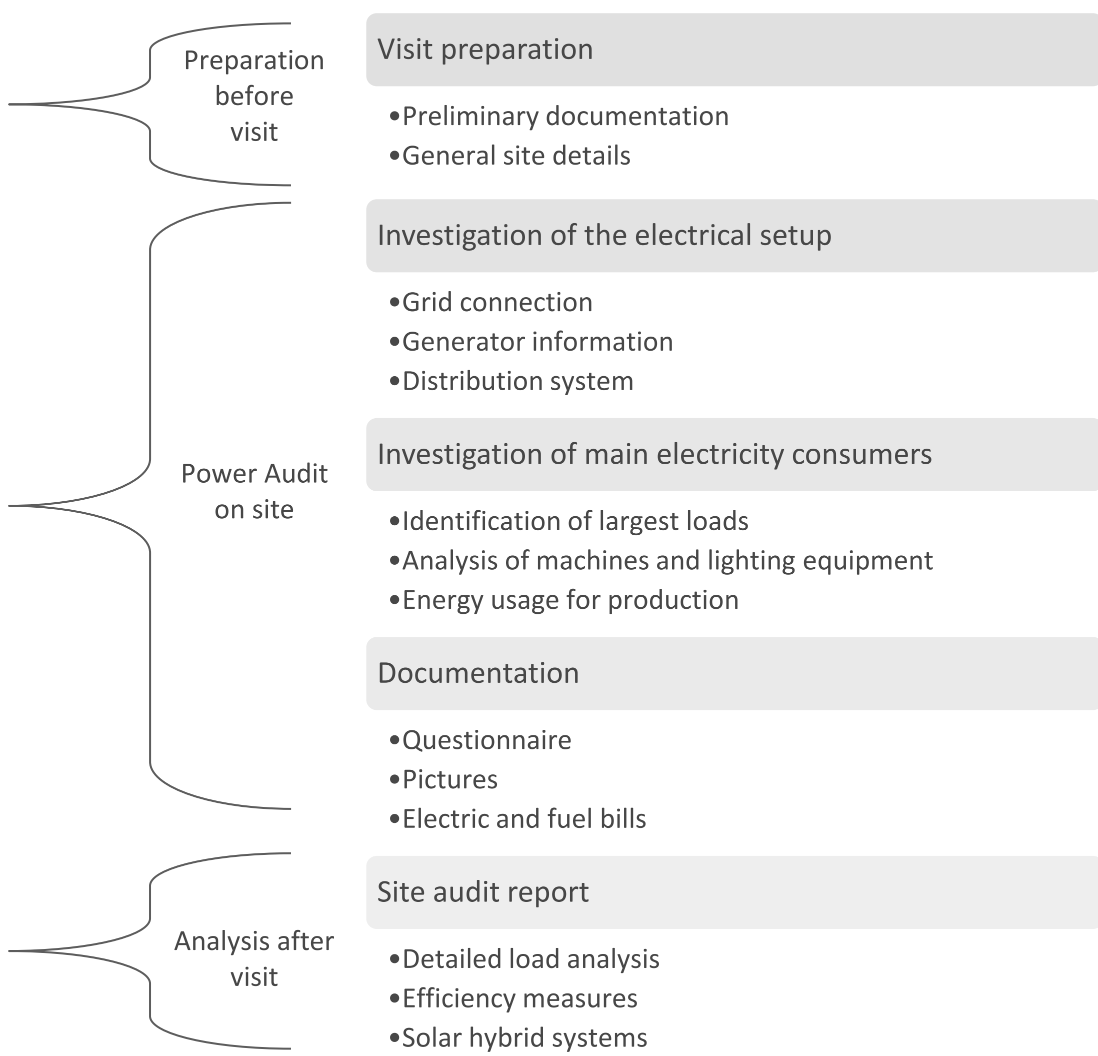
2. Site Visit Structure

2.1. Objective

To understand and document the power demand and electrical setup at Mother and Child Hospital through the implementation of power audit procedures as well as the installation of a data collection system to provide detailed measurement data.

2.2. Approach

The following diagram shows the OneShore procedure with a list of key deliverables for each step.



2.3. PROCEDURE

The site visit took place on the 28th of September 2017 with the assistance of site personnel and Nigerian solar company Solarmate. As part of the site visit, the following items were actioned:

1. Site inspection at Mother and Child Hospital
    a. Inspection of the grid connection and generator setup
    b. Identification of key electrical consumers
    c. Creation of a schematic of the electrical system
    d. Assessment of roof space and suitability for solar PV
    e. Visit through factory and quick identification of potential energy-saving measures
2. Installation and commissioning of a OneAnalyser load measurement device at the main electrical switchboard

2.4. DOCUMENTATION

The information collected for the electrical setup, power demand and production is summarized as part of the OneShore questionnaire. The following documents have been created during the site audit or been made available by the site for further analysis:

- ☑ Questionnaire
- ☑ Site plan drawing
- ☑ Electrical diagrams

3. DETAILED POWER AUDIT

3.1. LOCATION

The Mother and Child Hospital provides maternity care in the urban area of Akure, the capital of the Nigerian state of Ondo.

There is plenty of available roof space for a PV system on different buildings, adding up to approximately 600 m^2 on the patient and staff housing (see map and picture below). Further space is available on the main building, which can be used if required. Due to the distance of main building from power house a PV installation should be preferably placed on staff and patient housing.

Figure 1 - Map and plan of Mother and Child Hospital

Figure 2 - Hospital Mother and Child

There are already small PV systems on roof of the hospital's main building that have just recently been installed together with battery systems. Those are not connected to general power supply, but dedicated to providing continuous power to oxygen tanks. These are independent systems and hence have no impact on the solutions presented in this report. An old battery bank for backup was also found on site, however it is not operational anymore

3.2. Site Description

The hospital is funded by the Nigerian government. Some equipment, however, has been donated by private third parties, for example the oxygen tanks powered by a PV system with a battery bank. The hospital operates 24 hours a day, with office hours between 08:00 and 16:00. There is no much variability in the power demand throughout the year.

During the power audit, a OneAnalyser panel was installed to capture the electrical consumption on site from the grid and the diesel generator. As seen in the Single Line Diagram (SLD) below, the measurement device was installed to capture the consumption from all the production loads and a reference voltage measurement to distinguish whether the grid or the generator is supplying electricity. The supply from the gasoline generators are not measured by the OneAnalyser as they are not part of the main distribution system.

3.3. Electrical Setup

3.3.1. Grid Connection

The hospital is connected to the Benin Electricity Distribution Company 11 kV network through a 300 kVA transformer that provides 415 V on the low voltage side. The grid suffers heavily from power outages throughout the day, up to 18 hours a day on average. In addition to the low reliability of the network, the power quality is poor, commonly suffering from phase unbalances and voltage swells or dips that can lead to brownouts. The electricity tariff is 35.27 Naira (0.12 USD) per kWh. This follows the Nigerian regulated prices for special category "A", which is reserved for hospitals and other public and governmental institutions.

3.3.2. Diesel Generator

The diesel generator for on-site electrical generation are provided by the government, the hospital itself is responsible for their operation and maintenance as well as purchasing the fuel. Cost for electricity accounts for 40% of the entire hospital spending in a year. That cost is a mix of the fuel costs for on-site generation (60% diesel, 40% gasoline) as well as the electricity costs from the grid.

Due to the poor availability of the public grid, the hospital relies almost entirely on the 250 kVA diesel generator which provides power to the whole building including lighting, office equipment and medical equipment. This is a prime rated generator which means is designed to be the main power supply and provide constant power to a variable load with unlimited running hours as well as a 10% overload if required.

The diesel generator has the following technical specs:

	Generator
Manufacturer:	Mantrac (Caterpillar)
Model:	Olympian Power Systems GEP275-4
Operating Mode:	Prime
Apparent Power:	250 kVA
Real Power:	200 kW

There are also two broken generators on site that have not been repaired due to insufficient funds. A ComAp NT InteliLite controller is in place for the main generator that provides a wide range of applications such as remote start and online monitoring of power measurements and operation parameters.

Figure 3 – Mantrac Generator nameplate and InteliLite controller

For critical loads, such as blood bank, theatre, etc. the hospital deploys three small gasoline generators for up to 8 hours a day. The hospital takes the decision to operate these through a manual switch when the grid is not available and they want to save on fuel consumption. The price of gasoline at 145 Naira (0.40 USD) per litre is cheaper than diesel at 200 Naira (0.5 USD) per litre and they expect it to decrease. However, compared with the electricity price from the grid, a compounded diesel and gasoline fuel price (60% diesel and 40% gasoline) per kWh is still 89% more expensive.

Even though the cost per litre of gasoline is lower than for diesel, the cost of producing a kWh of electricity does not actually bring much savings due to the conversion inefficiency of these small generators. It is estimated that the specific electricity production for the diesel generator is 2.5 kWh / litre while for the gasoline generators goes down to 1.5 kWh / litre. This is why there is no real gain in replacing the large generator and does not provide a long term sustainable energy solution.

Figure 4 - Portable gasoline generators and datasheet for Thermocool model

The gasoline generators are connected to the critical equipment that is needed for operations in the hospital. Offices and housing cannot be supplied with power. For that reason, particularly in the evenings, the large generator runs to provide light and power to patient and staff housing.

It is estimated that the fuel consumption amount to approximately 40,000 to 60,000 Naira (111 to 160 USD) per day for both gasoline and diesel.

A 600 litre tank supplies fuel for the main generator and is refilled through a fuel pump from a 10,000 litre main fuel storage tank which is refilled every couple of weeks. There is no gasoline transported to site on a regular basis for the small portable generators; they are simply filled up when required.

3.3.3. Distribution Setup

The power supply is provided either by the grid, when available, or by the 250 kVA generator. A changeover switch is manually operated by a lever to select the generator whenever there is an outage.

The OneAnalyser device was connected to the load cables (see in Figure 5) to measure the power flow to the hospital. A reference voltage allows to distinguish between the grid and the generator. The power from the gasoline generators is not measured as they are connected through another changeover switch (see SLD diagram in the next page).

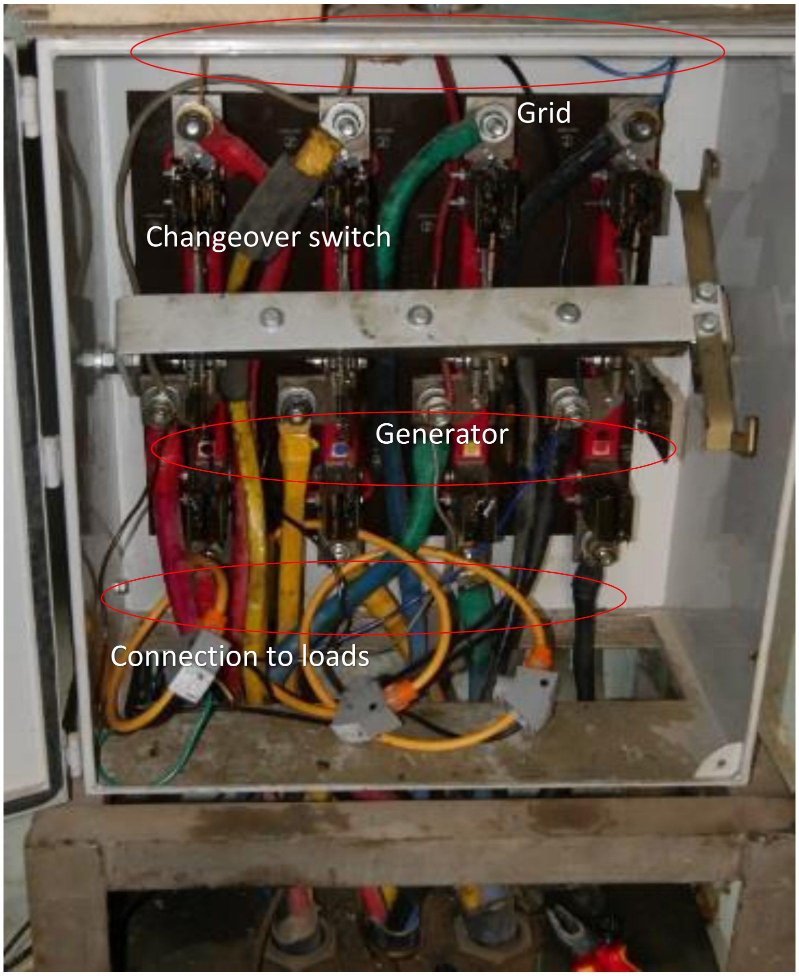


Figure 5 - Main electrical distribution panel

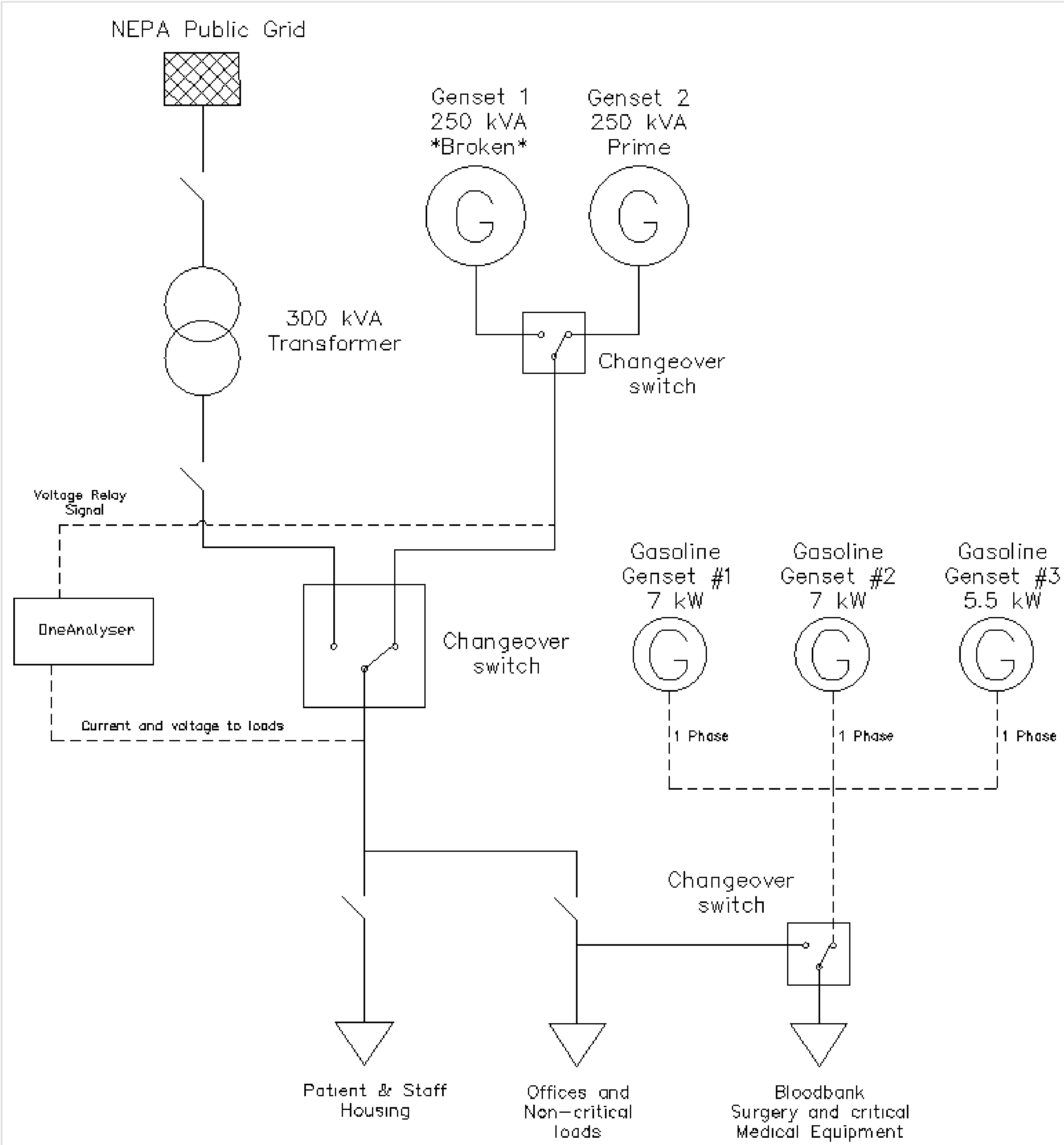


Figure 6 - SLD for Mother and Child hospital

3.3.4. Electrical loads

The largest loads on site are the medical equipment such as the bloodbank. However, no specific details for their rated consumption could be captured during the visit. Lighting is composed mainly of energy-saving lamps, CFL type with wattage equivalent to 85 to 130 Watts traditional incandescent lamps. There are at least 80 lamps of this type in the factory, however during the visit it was noticed that many of the were not working.

3.4. Power Demand

3.4.1. Load Profile

The load profile of the site can be obtained through the measurements from the OneAnalyser installed on site. It captures the current running through each of the wires as well as the voltage on each phase. This provides an accurate measurement of the power demand in each time of 1 minute.

Based on this measurement, the following figures can be determined:

- Load profile during week days
- Load profile during weekends
- Energy consumed from the diesel generator (250 kVA)
- Energy consumed from the grid

During the measurement period (30/09/2017 until 17/12/2017) that this report is based on the following consumption was measured:

Generator consumption:	16,435 kWh	51 %
Grid consumption:	7,657 kWh	24 %
*Gasoline gensets consumption:	8,218 kWh	25%
*Total consumption:	32,210 kWh	

*The consumption from the gasoline generators is not covered with the measurements but was derived through the fuel cost information gathered during the visit. This allows to calculate the total electricity consumption for large genset, grid and gasoline generators.

3.4.2. Electricity Consumption

The calculations derived previously allow to calculate an expected consumption and electricity costs for a year with the current setup. This forms the base case to which the renewable scenarios are compared in order to propose solutions that are affordable for the hospital. In summary, the annual costs for electricity for the proposed energy solutions should not be higher than the current annual expenses for electricity generation. The following are the expected annual values to establish the base case:

Total annual consumption	**172,695 kWh**		**$ 33,864**
Annual diesel generator consumption:	85,698 kWh	50 %	$ 17,140
Annual grid consumption:	44,148 kWh	26 %	$ 5,298
Annual gasoline gensets consumption:	42,849 kWh	25%	$ 11,426

Figure 1Figure 7 below shows the combined consumption from the grid and the diesel generator as captured by the OneAnalyser for a tpical week. The gaps in the profile represent the load that is not being supplied by the main generator or the grid. The hospital tries to save fuel costs during outages by not using the large diesel generator and uses the gasoline backup generators instead. A combined generating capacity of 19.5 kW from the three gasoline generators (7 kW, 7 kW and 5.5 kW) is then enough to cover the demand at these times.

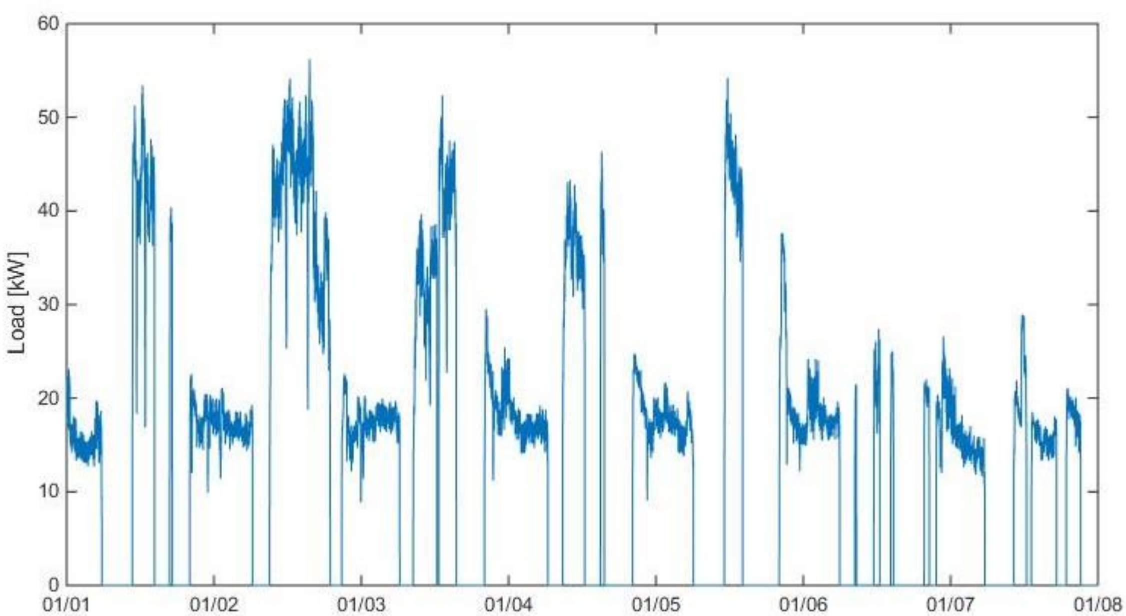


Figure 7 - Weekly load profile example from current demand

The consumption of the hospital has been recreated to show the true load profile according to their power requirements. Currently they must resort to the diesel generator and the gasoline gensets to ensure there is power supply at least for the most critical equipment when needed. An energy solution should enable them to cover the entire demand without additional costs and provide reliability of supply. The measurements are interpolated to complete the load profile as shown in the figure below. This is the load used for the renewable simulation case to find the most economical system that could provide the entire load demand.

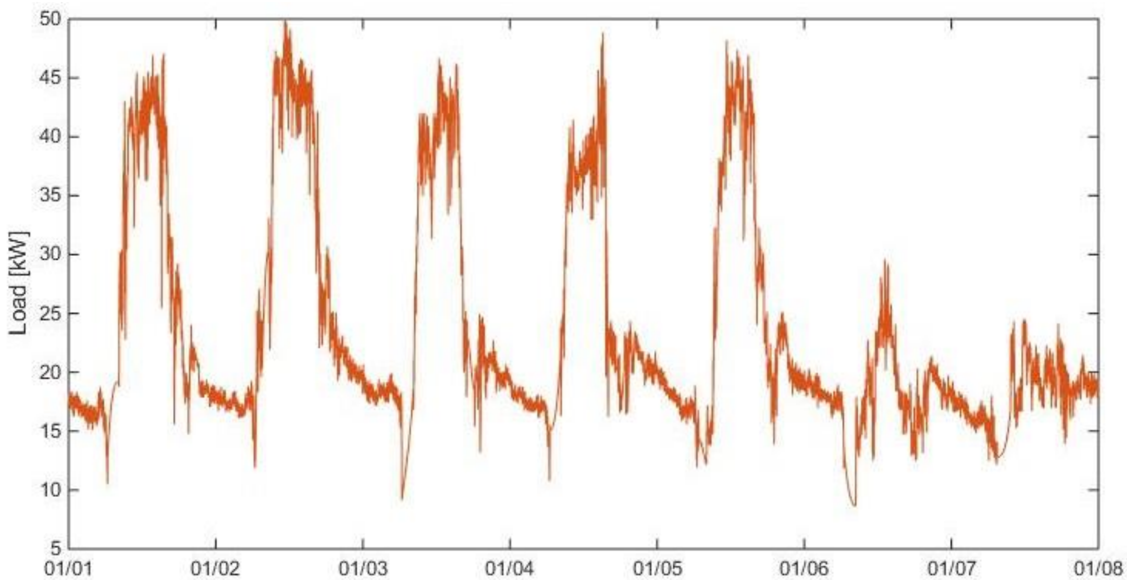


Figure 8 – Average weekly load profile with complete load demand

The expected total annual consumption based on this profile would be higher than the calculated annual total based on the measurements, as the site would have uninterrupted power and the consumption would be expected to be higher.

The simulations for a renewable case as detailed in section 4.3 and 4.4 provide the energy share between the grid and on-site generation systems (diesel generator or PV system). The gasoline generators in this case would no longer be required.

4. ENERGY EFFICIENCY OPTIONS

In its goal to reduce the power demand at Mother and Child Hospital, various options can be considered. Below a list of these energy-savings or on-site generation options to reduce the electricity bill are presented in more detail. All options are compared after this chapter, with regards to their energy-savings and the attached cost.

4.1. REPLACEMENT OF EQUIPMENT

Lighting on site is provided mainly by approximately 80 Concentrated Fluorescent Lighting (CFL) lightbulbs, one of the most efficient types of lighting in the market. As seen during the power audit, it is assumed that 40 are operational. A replacement of these lights with LED lighting would be possible to further reduce electricity consumption.

	CFL lighting	**LED lighting**
Brightness	1,650 lumens	1,600 lumens
Temperature	6,500 k	5,000 k
Lamp Wattage (equivalent for 100W traditional lighting)	23 W	16 W
Lamp Cost	$ 3	$ 9
Expected Lamp lifetime	12,000 hours	15,000 hours

The electricity cost is assumed to be 0.20 USD/kWh, a compounded value from grid costs of 0.12 USD/kWh, diesel cost of 0.50 USD/litre. The operating hours for lighting is assumed to be 24 hours. For the hospital it is a requirement that the lights are sufficiently bright, therefore there would not be a possibility to downgrade the equipment to increase the potential savings. From the replacement, annual electricity savings of $ 9 saving per lightbulb can be expected. For a replacement of 40 lamps the following savings (including replacement savings) could be achieved:

Annual Savings	$ 364
Total Savings (expected lifetime of LED)	$ 623
Implementation Cost	$ 360
Simple Payback	1 year

Total savings are calculated based on the lifetime of the LED lighting with the same operating hours, in total 1.7 years. A more in-depth lighting audit would be required to find detailed information about the current lighting system and to provide realistic cost estimates. These are the assumed conditions for the lighting based on the available information from site.

4.2. Replacement of Diesel Generator

There is currently one main genset on site which is deployed during outages and covers 50% of the total annual demand. According to the measurement data, the average demand is 21 kW and the highest peak demand is 61 kW. The diesel generator is supposed to be designed to cover the maximum demand. In this case it is about 3 times larger than it would be required.

As seen in the histogram below, the generator is operating for 80% of the time under 25 kW, this is an equivalent loading of 13%. As a prime generator it is designed to work as the main power supply at an average loading of 70-80% which shows that is not correctly sized for the demand and it cannot be utilized in its most efficient designed conditions.

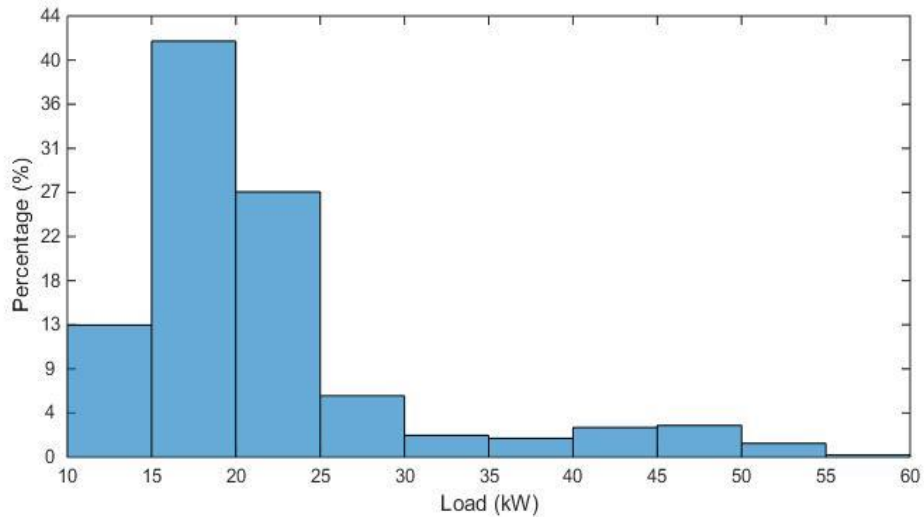


Figure 9 - Genset loading distribution

The 250 kVA generator could be downsized by approximately 66% to 85 kVA, with a 10% buffer capacity over the current peak 61 kW. The CAPEX for a new diesel generator would lie around 19,760 USD including shipment and installation compared to anticipated cost of 55,900 USD for the large genset. The investment for the new genset then would give 36,140 USD of replacement savings.

After a replacement, a 54% in diesel savings could be achieved annually based on the current electricity consumption and considering the average loading and the fuel consumption efficiency of the old and new generator. For an average power demand of 21 kW, the savings would amount to approximately 9,240 USD annually for the lifetime of the system, expected to be 7 years.

Instead of keeping the current operational principles the new resized generator could also replace the gasoline generators and produce a reduced output dedicated to critical loads when required. It is estimated that the diesel cost in this case would still be about 9,000 USD lower than total fuel cost (diesel and gasoline) for the present way of operation. This option would require disconnecting all other loads of the hospital during the times that typically the gasoline gensets are used.

4.3. Solar Diesel Hybrid System

The current power system with an oversized diesel generator means that the generator always runs inefficiently. To ensure grid stability in a PV hybrid system without storage, the genset must provide a baseload to balance fluctuating solar energy. It is recommended therefore to resize the generator according the proposed solution in section 4.2 to a 100 kVA generator. This setup would ensure that a new PV hybrid system is based on an efficient operation of the generator that the PV assets are optimally utilized.

A PV system is well suited to the load profile of the hospital, as the highest demand occurs during daylight hours from 08:00 to 16:00. As the data has shown, outages are a common occurrence. The goal is to add a PV hybrid system that (together with diesel generator and grid power) can provide the hospital with a permanent supply of power without increasing annual electricity costs for the hospital.

This scenario is simulated using the expected total demand profile which the hospital would have if power availability was not a problem. The grid is used when available and the diesel generator switched on during each outage. The electricity production of the PV system displaces energy from grid and generator respectively. Hence, even though total consumption is expected to rise when power is permanently available, overall expenses for grid power and diesel should remain constant over the year.

This can be achieved with a 30 kW PV system, which provides a solar share of 17% of the total demand on site without incurring in higher annual electricity costs. See the table in the next section for a summary of the key technical and financial indicators for the selected system in comparison with the other scenarios.

The investment of 60,000 USD for the system is not considered in the analysis. The hospital itself does not have the funds to purchase such a solution themselves. Hence it would need to be realised by the government or private donors. Such possibilities need to be investigated further.

4.4. Solar Diesel Battery System

The addition of batteries to the setup with PV and diesel allows to raise the share of solar energy by enabling the integration of larger PV systems. Any PV power that cannot be directly used can be stored in the battery and discharged later. It is required to use a battery inverter that is grid forming, allowing the PV and the battery to operate on their own without having to run the diesel generator in parallel.

Technical simulations showed that a battery capacity of 100 kWh in combination with an 80 kW PV system is suitable to switch off the diesel generator during daytime on most days. This leads to a total share of 50% of annual consumption of the site being supplied by solar energy and over 90% utilization of the PV system. Compared to the PV diesel scenario this system is larger, more complex and more expensive. However, it also offers a greater benefit, with higher fuel savings thanks to the better utilization of the PV system through energy storage.

Similarly to the PV diesel hybrid system, this on-site generation system would need to be funded by a public or private entity. In addition to the provision of a reliable and continuous supply of power significant savings could be achieved for the hospital.

	Base case	PV with diesel	PV with diesel and battery
Size diesel generator	200 kW	80 kW	80 kW
Size PV	-	30 kW	80 kW
Size battery	-	-	100 kWh
Solar energy share	-	17 %	50 %
Investment cost	-	$ 60,000	$ 250,000
Annual grid cost	$ 5,298	$ 3,582	$ 2,604
Annual diesel cost	$ 17,140	$ 28,448	$ 16,650
Annual gasoline cost	$ 11,426	-	-
Total annual cost	$ 33,864	$ 32,150	$ 19,254
Continuous power	**No**	**Yes**	**Yes**
Annual cost savings	**-**	**$ 1,714**	**$ 15,150**
Total Savings	**-**	**$ 46,467**	**$ 208,000**

5. CONCLUSION

5.1. COMPARISON OF ENERGY EFFICIENCY OPTIONS

Several energy-saving measures and solutions have been investigated in this report. A list of the recommended options that should be further analysed are presented in the table below.

Case	Total Savings (USD)	Total Investment (USD)	Allows continuous power for hospital
Lighting replacement	$ 623 over 1.7 years	$ 360	No
Replacement of large generator	$ 88,200 (fuel) over 7 years $ 31,720 (on replacements)	$ 24,180	No (only possible with increased fuel cost)
PV with diesel generators	$ 46,467 over 20 years	$ 60,000	Yes
PV with battery and diesel generators	$ 208,000 over 20 years	$ 250,000	Yes

A low-investment energy saving measure for the replacement of lighting could be paid relatively fast but also brings low savings, as the contribution to the total electricity consumption, around 1.4%. A more in-depth lighting audit could help identify further savings possibilities.

Another option is to replace current equipment is to downsize the large 250 kVA generator which is currently being used to cover the power demand during high season. An appropriately sized generator of 100 kVA brings fuel and OPEX savings which makes this an interesting option. This option also allows for renewable generation to be integrated more efficiently into the system.

Finally, two options for the installation of on-site PV hybrid generation systems are simulated and analysed. Deployment of these systems would allow the hospital to operate with a permanent supply of power.

A 30 kW PV system along with the resized 100 kVA diesel generator could provide the hospital with a larger and continuous amount of power at around the same electricity costs per year as per current operation. With this setup, it is no longer necessary to deploy inefficient gasoline generators, saving in fuel costs and providing a reliable power system that covers the full demand of the hospital whenever the grid is not available.

A second PV hybrid option with energy storage was also discussed in this report. An 80 kW PV system can contribute a high share of electricity for the hospital, however this also increases the required investment. The 100-kWh battery allows to best utilize the output of the PV plant and reduce dependency on diesel generators. This would have a great impact in terms of fuel savings leading to a significant cost reduction for the hospital.