Colegio Tecnológico de San Juan

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May 9, 2000

Dean Elsie Candelaria
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Colegio Tecnológico del Municipio de San Juan
180 Jose Oliver Street
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Dear Dean Candelaria:

Enclosed is our proposal entitled Alternate Energy Resources at Colegio Tecnológico. This proposal was completed at the Colegio Tecnológico del Municipio de San Juan during eight weeks while the team was in Puerto Rico. Preliminary work was completed prior to our arrival at the Colegio at Worcester Polytechnic Institute during the month of January through the beginning of March. This report is being simultaneously submitted to Professor Woods and Professor Menides for evaluation. Upon faculty review, the original will be catalogued in the Gordon Library of Worcester Polytechnic Institute. We thank you for the time and energy you devoted to this project.

Respectfully yours,

Dan Fontaine

Daniel L. Jacques

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Alternate Energy Resources at the Colegio Tecnológico

Report Submitted to:

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ALTERNATE ENERGY RESOURCES AT COLEGIO TECHNOLÓGICO

May 9, 2000

This project report is submitted in partial fulfillment of the degree requirements of Worcester Polytechnic Institute. The views and opinions expressed herein are those of the authors and do not necessarily reflect the positions or opinions of the Colegio Tecnológico del Municipio de San Juan or Worcester Polytechnic Institute.

This report is the product of an education program, and is intended to serve as partial documentation for the evaluation of academic achievement. The report should not be constructed as a working document by the reader.

Abstract

This report was prepared for the Colegio Tecnológico del Municipio de San Juan. The objective was to suggest an alternative to purchasing electric power from the local utility. Data was collected on every aspect of the alternatives. Budgeting information and investment costs were found. The team performed a cost analysis that compared the long-term cost of purchasing all power to the cost of multiple alternatives. We also performed interviews that investigated the concerns of faculty about power generation and future Colegio growth. Finally, the team used a decision matrix that lead to recommendations towards the best alternative for the Colegio as well as suggestions for future studies in the area of alternate energy resources.

Authorship Page

Each member of the group contributed equally to this proposal. Every person was able to contribute his expertise to each part of the report. In some cases, parts of the proposal were researched and written by one member of the group, each person's part is acknowledged here.

Sections written and researched by Dan Fontaine

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Acknowledgements Page

We would like to Acknowledge these persons because they offered support that was well above what was expected. These persons being recognized are just a few of the people who have been of assistance to us during this project.

Thank You

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Ramon Delgado, Contractor
Miguel Valez, Caterpillar
Idelfonso Acevedo, Cummins Diesel of Puerto Rico, Inc.
Feux Monserrate, M&C Electric, Inc.

Other Special Thanks:

Edward Clarke, Professor at WPI re.
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Executive Summary

Olga A. Benítez Garay, the Chancellor of the Colegio Tecnológico del Municipio de San Juan, commissioned this project. The Colegio grants associate degrees in nursing and industry and technology. Currently, power problems are limiting the growth of the Colegio community. These power problems include overloaded beakers and power outages. Additions to the Colegio cannot be considered until these power problems are fixed. The objective was to determine a cost effective alternative to purchasing all electricity from the utility. One motive for this is to decrease the amount of money the Colegio pays to the utility; the Colegio hopes to become autonomous from the municipality, from which it is funded. In order to do this, it is very important that the Colegio saves money so it can become self-sufficient. The executive summary discusses the data collected and the analyses performed during the project. It also summarizes the conclusions and recommendations that we developed.

Data Collection and Analysis

In the initial phase of this project, we collected data on solar power and diesel generators, and excluded other alternate forms of energy. This data was then used in a cost analysis; the initial investment costs and operating costs of the different alternatives were found. In addition to data on energy sources, we obtained the Colegio's electric bills and utility rates.

Diesel and solar power investment costs are comprised of different components. The investment costs includes the price of the generator set, installation, the housing for the generator, and a fuel tank. For solar power there is a high investment cost, which is the direct result of purchasing solar panels. Also included in the investment cost of a solar power system are batteries, inverters, and possibly a supplementary diesel engine.

The operating costs of diesel engines depend on the size and amount of time they are running. In the case of a standby or emergency generators the maintenance is substantially less because it will not be running nearly as much as a prime generator. Fuel is also a large operating cost. The generator that is best for the Colegio is dependant on what application they are looking for as well as what kind of future growth they expect. The most economical generator we analyzed was the 818 ekW Cummins generator, and the least economical alternative was a solar power generation system.

Once we obtained the necessary data, we were able to perform a life cycle cost analysis through a 20-year period. The internal rate of return (IRR), modified internal rate of return (MIRR), and the 20th year net present value that we obtained from the analysis were used to determine if an investment in an alternate energy source was cost effective. If the IRR, MIRR, and the net present value were high, than the use of that particular alternate energy source was cost effective compared to purchasing electricity from PREPA.

Conclusions and Recommendations

The final section of the report is the conclusions and recommendations section. The Colegio currently suffers from an electrical infrastructure that is inadequate and in disrepair. Under initial observations, we believed that the three substations could not supply the Colegio with sufficient power. However, the project team has determined the capacity of the substations is almost three times larger than the current demand. This suggests that even though the substations may be in disrepair, the real problem lies in the electrical infrastructure. One of our main recommendations to the Colegio is to repair and redesign the electrical infrastructure. This would be done with a detailed study that would explain what the best way to deliver power throughout the Colegio would be.

In the event that the electrical infrastructure at the Colegio was repaired, we have come to conclusions on the investitures of alternate energy sources. We determined that the use of a solar power system that could supply all the electricity at the Colegio is not cost effective because the investment is not paid off after 20-years. A hybrid system with solar power and a diesel engine would not be cost effective, but it is a more reasonable alternative compared to solar. A hybrid system still does not recover the initial investment cost after 20 years. The net present value (NPV) at the end of the 20-year life cycle was -$124,050 and the internal rate of return (IRR) and the modified rate of return (MIRR) were -2.55 and 5.69 percent respectively.

Over all, the most cost effective solution is to have a generator that runs during peak time and does not run during off-peak hours. The generator that would most economically supply the Colegio with all its on-peak power needs is an 818 ekW generator. The NPV for this alternative was $581,232 with an IRR and MIRR of 32.15 and 13.88 percent, respectively. This power generating system would save the Colegio money and be a worthwhile investment over purchasing all power form the utility the Puerto Rico Power Authority. The Cummins 818 ekW generator would run at 67.2 percent during average demand and at 79.7 percent during peak demand. This generator, like the others we researched, is not designed to run below 30 percent capacity. The Colegio's off-peak demands are very small, making every engine we studied unable to operate at night because they would all be operating below 10 percent.

There are several benefits that the Colegio would obtain from revamping the power system and installing an alternative power source. The Colegio would gain a consistent, stable system that would supply enough power to install needed air-conditioning, newer computers, and modern technology in the laboratories that cannot be run currently due to overloaded circuits. Air-conditioning would provide a comfortable learning and teaching environment that would increase the quality of education. This would also ensure that current equipment in laboratories and computers would not be damaged.

One last advantage to having an alternate source of energy with a well-designed infrastructure is the security it provides. During power failures, which would normally occur during a hurricane, the Colegio could provide power with its own generator. Classes would not be canceled during power emergencies and education at the Colegio would not be interrupted. During severe emergencies the Colegio could offer its campus as a shelter, which would provide benefits to the community.

Introduction

The Colegio Tecnológico del Municipio de San Juan[1] is a small college of technology currently operated by the Municipality of San Juan. Its enrollment has fluctuated between 900 and 1100 students each year over the last ten years. The Colegio grants Associates Degrees in a variety of majors such as nursing and electronics. The grounds of the campus contain six buildings. Three electrical substations distribute power throughout the campus.

The Colegio Tecnológico has problems with the electrical infrastructure that was installed in 1979 when the Colegio's buildings were constructed. The infrastructure has not been sufficiently maintained as the Colegio has increased its demand. The Colegio is interested in an alternate source of power production rather than in replacing the current system and continuing to purchase power. Our intention is to assess the Colegio's current power supply problems and recommend a solution that is economically and environmentally sound. Analyzing the current demands of the school and forecasting future demands allowed us to compare the cost of building an alternate source of energy to the cost of buying power from the Puerto Rico Electric Power Authority (PREPA). Currently, the Colegio is buying power from PREPA at a very high cost.

During the preliminary preparation phase of the project, the group researched multiple possibilities for power generation in Puerto Rico. Through our research, we will give an accurate assessment of the current problem. Researching details such as cost, environmental impacts, and efficiency will provide us with a background in alternative power production processes. With this knowledge we will provide a recommendation as to which energy option is best for the Colegio.

[1] The Colegio Tecnológico del Municipio de San Juan is a municipally funded college that grants associates degrees in nursing and technical sciences.

The Colegio's Chancellor, Olga A. Benítez Garay, commissioned this project. An alternate energy project was requested because the Colegio's infrastructure is in disrepair and does not allow enough power to supply current needs. An example of where the electrical problems impact the Colegio is that air-conditioning could not be installed in many classrooms.

Currently, the Municipality of San Juan funds the Colegio. Part of the strategic plan of the school is to become autonomous. The idea of autonomy is very important to the Colegio. The goal is to break away, and become independent from the municipality in the future. This means that the Colegio will be missing funds that were obtained in the past from the municipality. Autonomy is one reason the Colegio wants to look into an alternate source of energy. With the current electric rates as high as they are, the Colegio could potentially save money by producing their own power. The current situation limits the Colegio's growth due to an insufficient power supply from the infrastructure. If the Colegio had their own power generation, the utility companies rates would not be a barrier to growth. This flexibility would allow the Colegio to expand at a rate that is comfortable.

The Colegio will use the information we provide to decide whether they should build a power plant, continue buying power, or use a combination of both. The information provided by our report will contain recommendations and conclusions. Our study will identify power generating systems and their estimated costs. The project that we are conducting is broad; therefore, a more detailed investigation on the alternatives that we suggest must be done, before a final choice is made. Our objective is to produce a report that is as complete as possible and estimate the actual cost and benefits as accurately as possible.

This report is comprised of five main sections. They are, the literature review, interviews, data and results, life cycle cost analysis, and conclusions and recommendations.

The literature review contains all the research done on the alternatives we have studied. The background information gives the reader a better understanding of what alternate power sources are available and the advantages or disadvantages that they have. Contained in the literature review is information on environmental concerns, which includes the Environmental Protections Agency's rules and regulations. Information about PREPA, the local power utility, is also contained in this section.

The project team conducted interviews of the faculty and staff at the Colegio. The purpose of the interviews was to determine the feelings and concerns of the Colegio community about several issues related to our project. We identified the power problems that the Colegio currently suffers, their need for air-conditioning, and feelings about autonomy.

The data and results and cost analysis sections give detailed descriptions of how we accomplished our objectives. One main aspect of the project involved a detailed analysis of the cost of purchase, operation, and maintenance of a power system. Also the project team performed a life cycle cost analysis of each of the alternatives that enabled a comparison on a cost per kWh basis. The analysis determined the most appropriate power generation system for the Colegio.

We used a decision matrix to identify the most appropriate solution to the Colegio's electrical demands. We weighed the positives and negatives of each process of power generation. The decision matrix will contain our ratings for a variety of attributes of alternate sources of energy and the weights that the Colegio places on these attributes. The latter include pollution, size, and cost obtained from our research.

The results section of the report is where our acquired data is documented. It shows what each alternative costs to purchase and operate, as well as information on pollution, aesthetics and size. In this section, we discuss the costs of the different aspects of an alternate source of energy. Also, we will present the names of power suppliers and the quotations they provided. In our research it may be necessary for the team to make estimations because some data cannot be obtained or calculated. These will be clearly identified and explained. This part of the project is very important to the cost analysis and conclusions that we draw. We describe explicitly every aspect of our calculations in this section so that our recommendations can be used in the future. This is also the section where we determine the ratings for each of the categories we used in our decision matrix. From this data we formed conclusions and recommendations that we feel are best suited to the Colegio. Our recommendations will indicate to the Colegio what should be their next step in the search for an alternate source of energy. A good starting point for the Colegio in future studies is provided in this section as well.

The conclusions section of the proposal is possibly the most valuable part to the Colegio. This section contains our recommendations to the Colegio. We describe the results obtained from the decision matrix. Our conclusions provide the Colegio with what we feel are the best alternatives based on the relevant criteria. The criteria that guide our recommendations are cost, pollution, space, and aesthetics. This section also explains if the Colegio would be better off continuing to purchase power from PREPA or to explore an alternate source. Other aspects that we have not researched are the availability of grants from the Department of Energy and other government agencies.

Each student at Worcester Polytechnic Institute is required to complete an Interactive Qualifying Project (IQP). Our project is designed to fulfill the requirements of an IQP for Worcester Polytechnic Institute. The goal of all IQP projects is to integrate aspects of technology and society in solving problems on a self-selected topic that enables students to understand their place in society, as citizens, and as career professionals. The technological aspect of this project is an intricate study of alternate energy resources. The study includes research of the design and operation of numerous power generating systems. The social aspect of this project is to analyze what affect the installation of an alternate source of energy may have. Our study will investigate the financial impact on the Colegio by performing a cost analysis on alternate energy systems and the current system. Other characteristics of a power generating system that we investigated were pollution levels and aesthetic impacts. Also, the project team determined and reflected on the opinions of the Colegio community. The IQP is an interdisciplinary study of both engineering and social science. The engineering decisions that are made by our group must also reflect the social and environmental impacts. Providing unique opportunities for engineering majors in international education and pre-professional experience is a priceless part of education that the IQP provides. As students, we will see how our research affects the decision of the Colegio.

Members of Worcester Polytechnic Institute Puerto Rico Project Center prepared this report. The relationship of the Center to the Colegio Tecnológico del Municipio de San Juan and the relevance of the topic to the Colegio are presented in Appendix A.[2]

[2] This statement is required to appear in all Interactive Qualifying Projects that are completed in conjunction with Worcester Polytechnic Institute.

Literature Review

This chapter reflects the research done with respect to alternate sources of energy, the economic feasibility of alternate sources, and the environmental impacts of these sources. This review explains the concepts, advantages, and disadvantages of different types of power plants. Combined-cycle, diesel engines, and solar power generation are a few of the power systems that have been investigated by the group. The literature review also discusses the environmental legislation that governs power production, as well as the economics, and available resources. This research will help us identify reasonable solutions to the Colegio's power needs.

Combined-Cycle Power Generation

Combined-cycle power generation (CCP) produces energy by cogeneration. CCP generation is most commonly achieved in a process that combines multiple power generating cycles to form one efficient process. According to experts such as Ramage (1997), Boyle (1996), and Kehlhofer (1991), the goal of a combined-cycle system is to have the first stage use a large amount of heat and give the excess heat to the second stage to make further use of the resources. The most customary and accepted combined-cycle process at the present time is a power generator comprised of a gas turbine and a steam turbine. Figure 1 below illustrates the fundamental structure of such a system.

BOX 4.7 GAS TURBINES

One potential use for the clean fuel gas from biomass gasifiers is to run gas turbines for local power generation. A gas-turbine power station is similar to conventional steam plant except that instead of using heat from the burning fuel to produce steam to drive the turbine, it is driven directly by the hot combustion gases (Figure 4.9). Increasing the temperature in this way improves the thermodynamic efficiency, but in order not to corrode or foul the turbine blades the gases must be very clean – which is why nearly all present gas-turbine plants burn natural gas.

Substitution of gas from biomass gasifiers would serve a double purpose, conserving a premium fuel and reducing the emission of greenhouse gases – provided the biomass cycle is CO_2-neutral, of course. This route, gasification followed by power generation using gas turbines, is receiving attention as a potentially efficient use of wood from short rotation coppice (Sections 4.8 and 4.11).

In situations where the wastes from processing of vegetable material provide the input, the requirement is often for process heat (hot steam) as well as electric power, with the heat requirement often taking precedence. For this purpose the **steam-injected gas turbine** (STIG) is very suitable. As the name suggests, the turbine is driven by a combination of combustion gases and high-pressure steam, so the plant incorporates steam generators and can be operated much more flexibly in response to varying demands for heat. The system is therefore a biomass integrated gasifier/steam-injected gas turbine – a BIG/STIG.

Figure 4.9 Types of generating system (a) conventional steam turbine; (b) simple gas turbine; (c) steam-injected gas turbine

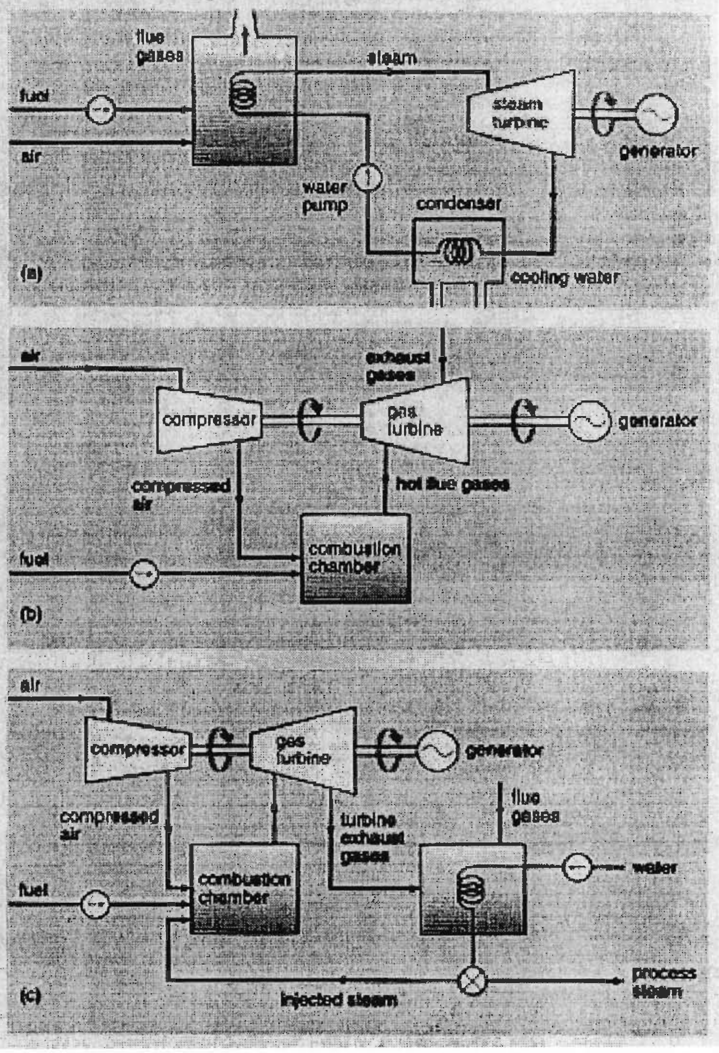

Figure 1: Structure of Generators

Source: Boyle, 1996: 150

As Ramage (1997), Boyle (1996), and Kehlhofer (1991) discuss, the dissipated heat from the gas turbine is not lost or wasted. In the second stage the steam turbine can take full advantage of the excess heat and greatly increase the efficiency compared to a system without a secondary cycle.

In a combined-cycle system, many fuels can generate the initial high temperatures; however, the use of gas is more efficient than the use of liquids and solid fuels (Ramage, 1997). If coal or other fuels such as oil are used, the blades of a turbine quickly become dirty due to the nature of these fuels and must be cleaned continuously and maintained for further use. Ramage (1997) says that the cleanest fuel known for use in turbine systems is natural gas, methane, or propane. The burning of natural gas is a clean process because of its chemical properties. Solid fuels can resemble gas fuels if they are altered in a process is called gasification.

Gasification is a process that transforms a solid fuel into a gaseous form so that it can be utilized in a gas turbine generator, as explained by Ramage (1997) and Boyle (1996). Instead of burning solid coal, burning a gasified form can be beneficial. Production of harmful materials is reduced during the burning of gasified forms compared to burning solid forms of fuel. Ramage (1997: 112) discusses that integrated gasification combined-cycle plants (IGCC) are not completely developed. These systems are very complicated and have low efficiencies. In most cases, gasification is accomplished in an independent plant; it is then transported to a separate plant where the fuel is burned in the combined-cycle plant.

Advantages of Combined-Cycle Gas Turbine Power Generation

Combined-cycle gas turbines (CCGT) have gained considerable attention and popularity in the power generation industry in recent years due to several reasons (Boyle, 1996; Ramage, 1991). One cause for the increase in use of gas turbines is the availability and cost of natural gas. Since prices of natural gas have decreased significantly, using it as the primary fuel for electric power generation has become feasible. Along with the availability of gas, the technology surrounding the development of its use has expanded and become a reality. Kehlhofer (1991: 9) notes that combined gas and steam turbine power systems are received well in practice because gas turbines and steam turbines have established reputations or reliability and efficiency in industry. These systems are readily available separately, and therefore have reasonable costs. As a result, the two systems can then be integrated together.

CCGT have low pollution concerns:

Ramage (1997), Boyle (1996), Flavin & Lenssen (1994), and Kehlhofer (1991) all mention that a principal advantage of CCGT systems, over coal and oil-based power plants, in addition to the availability of natural gas and CCGT's technological advantages, is the lack of adverse environmental effects. As mentioned previously, natural gas burns cleaner than coal or oil. When fuels are burned for power generation, pollutants are released into the air. These contaminates can be in the form of nitrogen oxides (NO, NO_2), carbon oxides (CO_2, CO), hydrocarbons (C_nH_n), and sulfur products. The emissions of a power plant can be dangerous to nature and humans, according to the Environmental Protection Agency (EPA).

Through the Clean Air Act of 1990, the Environmental Protection Agency (EPA) has enacted guidelines to minimize air pollution. Coal and oil burning plants create pollution that exceeds that of natural gas plants. If there are more harmful particles in the flue gasses, then it is difficult to treat and prevent them from escaping into the atmosphere.

A benefit of burning natural gas is the lack of pollutants compared to coal. Primarily only two pollutants exist, which are nitrogen monoxide and nitrogen dioxide (Flavin & Lenssen, 1994). Pollutants such as carbon dioxides and sulfur dioxides exist, but they are minimal because of the properties of natural gas. Kehlhofer (1991: 264) mentions that nitrogen oxide exhaust can be most damaging to the environment because it combines with rain to form acid rain.

A further advantage of CCGT generators is that nitrogen oxides can be reduced substantially through a dry low NO_x combustor (Kehlhofer, 1991: 264-274). This process is called selective catalytic reduction (SCR). SCR changes the chemical properties of NO and NO_2 by applying ammonia (NH_3), which results in the harmless elements of nitrogen and water. Flavin & Lenssen (1994: 100-104) and Kehlhofer (1991: 271) state that emissions of nitrogen oxides can be reduced up to 90 percent. The process of reducing NO_x can add costs to the system and reduce the efficiency of a power plant. Kehlhofer (1991: 264) points out that CCGT power plants are a feasible option for densely settled regions because the plants can be designed appropriately for low polluting emissions.

CCGT plants are used around the world:

Complete realization of the CCGT is still in progress, but it has been proved practical and is used in many locations. Some of these sites that Kehlhofer (1991: 305 – 352) describes are Korneuburg, Australia and California, USA.

Kehlhofer explains that the Korneuburg plant is a combination of an 80 MW/hr gas turbine and a 45 MW/hr steam turbine that produces 120 MW/hr. In that plant, efficiency of

46.6 percent is achieved. This efficiency occurs because the design of the plant has taken advantage of the extra heat left from the gas turbine and used it for the steam turbine.

The plant in California is an example of a cogeneration plant. Boyle (1996) discusses the purpose of a cogeneration process; it produces power along with heat. Cogeneration systems are very useful and efficient because they utilize excess heat from the gas turbine to create steam, and supply it to buildings for heat. In addition, cogeneration plants, especially the one in California, are designed to reduce outputs of harmful pollutants. Under the Public Utility Regulatory Policies enforced by the United States, the plant in California and other plants must comply with environmental protection policies. Since the climate of San Juan, Puerto Rico is warm; the excess steam is not needed to heat buildings as in other climates. However, this steam does have a use in warm climates. It can be used to turn compressors that power air-cooling systems.

Efficiency of CCGT

In an interview with Christopher Ganotis (2000), who works with Waste Management Incorporated in North Hampton, NH, the efficiency of CCGT systems was discussed in comparison to more conventional diesel generators. Gas turbines must run at full output unlike diesel engines. This means that if a gas turbine is designed to produce one megawatt per hour, the system must always produce this output. In diesel generation, a system designed for one megawatt per hour output can create that output as well as fractions of that output. Because of this limitation with the CCGT, inefficiencies are created in the production of energy. If a gas turbine is designed to deliver power during times of max load, the system will perform well. In times of average load, the system will be delivering more energy than is needed causing inefficient use of the system. According to Ganotis, using two smaller gas turbines, one of which would only run during times of peak demand can cure this problem. Another solution proposed by Ganotis is to sell the extra power, provided the revenue generated matches or exceeds the cost of operating the larger gas turbine.

Diesel Engines

In the opinion of Kehlhofer (1991: 241-242), a diesel-powered generator can be an alternate to the combined-cycle system. On a large scale diesel engines are able to produce electricity at an efficient rate, especially when the power plant is designed for low power output such as 20 to 30 MW. However, this system is not as environmentally sound as CCGT due to the production of NO_x and unburned hydrocarbon exhausts. Another disadvantage of diesel engines is cumbersome maintenance and high costs, especially as a system increases in size. Diesel power plants decrease in efficiency when they are designed for large power output; oppositely, combined-cycle power plants decrease in efficiency when lower power outputs are created as Kehlhofer (1991: 241-242) explains.

Case Study: Cogeneration at Clark University

Clark University in Worcester Massachusetts produces power for their needs and supplies the college with valuable heating for the buildings on campus. Roy Cordy is the Head Engineer at the Clark physical plant. During an interview with Cordy (2000) we learned about the workings of the cogeneration plant at Clark, and how much money the college has saved by using this plant.

There are numerous capabilities of the engine

The powerhouse was constructed in the early 1970's, and the cogeneration part was added in early 1980's. The plant is a cogenerator because it generates electricity and then uses the hot exhaust to create steam used to heat buildings on campus. A Fairbanks Morse engine drives the 1807 kW electric generator. This engine is able to run on diesel fuel, or natural gas. A nine-cylinder engine produces 2500 horsepower. The water-cooled engine, according to Cordy (Personal Interview, 2000), is very reliable. The reason for its reliability, Cordy (Personal Interview, 2000) says, is the fact that every part of the engine can be replaced; this particular engine does not have a block; it has individual piston jackets, making overhauls fast and cheap.

Some of the power that is generated by the system is sold back to the electric company. At average times of demand, the plant sells approximately 40 percent of the produced power back to the utility.

The efficiency of the power station without the cogeneration part is about 35 percent. Since the cogeneration part of the system was added, the system has increased its efficiency to about 70 percent. (Cordy Personal Interview, 2000)

The cogeneration plant uses exhaust heat from the engine to create steam that is used for heating buildings on campus. The hot exhaust gasses are piped to a Riley Beaird exhaust boiler where steam can be produced at 125 psi. Cordy (Personal Interview, 2000) explains that this hot water and steam provides domestic hot water. The steam provides approximately 1800 million BTU's of energy to the campus, which is about 20 percent of the college's heating needs.

At Clark, the power system has various costs and savings

The power plant at Clark University provides the college with many benefits according to the interview with Cordy (2000). The fuel savings alone are equivalent to 8,000 barrels of oil per year. These savings in fuel, in the first year of operation amounted to $250,000, says Cordy (Personal Interview, 2000). Records show the savings with the cogeneration compared to the costs without cogeneration at the College. Since the heat recovery system has been installed, the college saves approximately $20,000 per month. Cordy's data (Personal Interview, 2000) shows that the total electrical usage for the month of March in 1999 was 949,548 kWh. The heat usage was 7,862 million BTU's. Without the heat recovery system installed, the college would have to buy more electricity to produce heat for the college. The cost of generating 7,862 million BTU's for heat is $28,205. The cost of purchasing 949,548 kWh from the utility is $97,518, insists Cordy (Personal Interview, 2000).

At the Clark plant, there are operation, fuel, and maintenance costs

The data provided by Cordy (Personal Interview, 2000) gave us detailed breakdowns of fuel, maintenance, and operation costs the college incurs by running the power plant. Other costs include down time when the college must buy power from the utility. Cordy (Personal Interview, 2000) explains that maintenance costs increase at certain times of the year when the engine is overhauled. For one month every year, the engine is shut down and rebuilt in order to keep it running smoothly. During the downtime of the engine, Clark buys power from the utility.

During the month of March in 1999, the engine used $42,765 worth of fuel. The engine is known as a dual fuel engine, and it uses diesel fuel to start and Natural gas to run at normal loads. During the operation of the engine both fuels are always being consumed. The two forms of fuel that are used are high-pressure natural gas, and No 2 diesel fuel. Lube oil and other chemicals are used to keep the engine running smoothly. The breakdown of fuel costs is shown in the table below. As seen below the engine uses much more natural gas because the natural gas is cheaper. If diesel fuel was cheaper says Cordy then the engine would burn more diesel fuel.

Table 1: Costs of Fuels Used at the Clark Plant in the month of March 1999

Fuel type	Amount used	Cost per unit	Total cost in dollars
High Pressure Gas	111714 Therms	0.3398	37,960.42
Diesel Fuel	5443 gal	0.595	3,239
Lube oil	370 gal	3.26	1,206
Chemicals	719 hrs	0.5	360

The data supplied by Cordy (Personal Interview, 2000) illustrates the amount of power sold back to the utility during this month was 120,400 kW/h. Rates for on-peak and off-peak sales are different. On-peak rates are increased because the utility needs the power more during this time. For on-peak time, the utility will pay 0.02918 cents per kW/h, off peak is purchased from the college at 0.0212 cents per kW/h. The total revenue the college gained through power sales, in March of 1999, was $2,620.88.

Money was also saved by the college on the heat it gained from the heat recovery system in the plant. This savings of 1,877 million BTU's at $3.59 per million BTU's is worth $6,734.

The labor and maintenance costs were $6,734, which is part of the total operation cost for the month that amounted to $50,655. Because the college needed more power than the generator could provide at time the college needed to purchase power. Power purchased from the utility in this month was 8,709kw/h. Purchased electricity costs the college 22 cents per kW/h, which results in an expenditure of $1,914.65. The boiler for the college also is used for heating, and plays an important role in the heat recovery of the system. The cost to run and maintain the boiler used for heating was $34,391. Total expenditures to produce power and heat for the campus are then $83,890. The savings must then be subtracted from this cost. $6,734 on heat recovery, $2,620.88 in power sales, plus the $1,914.65 in purchased power. This makes the total maintenance cost $76,450 for the month.

The effect of noise pollution from the power plant is minimal

Noise pollution can be a serious concern for a power plant. The Clark University power plant is located in the center of the campus. As a result, it is very important to keep the noise pollution very low. The way Clark has solved this problem is by installing a muffler on the exhaust of the engine. Cordy (Personal Interview, 2000) says the muffler has made a large difference in the noise levels of the plant. The noise levels inside the engine room are very loud, and earplugs are necessary so no damage is caused to the ear. The sound does not escape the engine room because the room is about 12 feet below ground. This helps with vibrations as well as noise, says Cordy (Personal Interview, 2000). When our project group went to study the plant at Clark, we were surprised at the lack of noise the plant produced outside of the building.

Solar Energy

The sun is another valuable source of energy that can be harnessed. The conversion of solar power to electricity directly is known as the photovoltaic (PV) affect. Solar power is becoming more popular each year because of the depletion of fossil fuels. The first functional solar panel was created in the year 1945 and was capable of six- percent efficiency. Efficiency is the amount of the sun's energy converted into electricity. Today's solar PV can achieve efficiency of 15 percent, or in some cases up to 45 percent. (Markvart, 1994)

Photovoltaic Cell Types

There are three ways of making PV cells. According to Clarke (Personal Interview, 2000), these types are amorphous and crystalline-silicon cells, which can be single crystal or polycrystal. The majority of the solar cells on the market are the crystalline-silicon cells. The crystalline-silicon cells are the first tested in labs. The crystalline-silicon cell converts a good portion of light to electricity, but the process is high tech. Markvart (1994: 51) explains the general process of manufacturing crystalline-silicon solar panels. To make these solar panels, wafers of silicon are cut and etched. Because the silicon wafers are cut, they have to be made smooth, and then they are treated, and finally combined to construct a solar module. The technology-intensive and low volume process to make crystalline solar cells are expensive and make it hard to compete with other forms of electrical generation.

Clarke (Personal Interview, 2000) emphasized that amorphous cells have the greatest possibility of being mass-produced to compete with other forms of generation. These cells have potentially low manufacturing costs. The disadvantage to using the amorphous PV cell is that it has a very low conversion efficiency of less then ten percent. There is constant research to improve this efficiency.

Solar power advantages and disadvantages

A solar power plant has many advantages over other forms of electric generation. It does not have any moving parts, so it has little maintenance. No sound pollution is created. In addition, solar power is a free source of electricity. Photovoltaic systems are reliable, but depend upon available sunlight. They rely on the sun to generate power; hence, on overcast days power generation will be decreased. Edward Clarke (2000) stated during an interview that solar power production depends on the location of the photovoltaic modules. Solar cells depend on radiation of the sun to create power; the amount of radiation during the year varies. Clarke (Personal Interview, 2000) also mentioned that some kind of energy storage is needed for times that the solar panels cannot generate power, and needed to maintain power at night unless the solar system is connected as an interactive system with the grid.

Radiation

Markvart (1994) discusses that the sun's rays strike the earth in different amounts throughout the world. Radiation data for many locations of the world is categorized to give an estimate of the radiation in different zones of the world. Though the mean annual radiance in every region of the world is documented, the figures may not be accurate enough to estimate what energy could be harnessed from the sun.

Radiation tends to diverge through the atmosphere, and reflect off the ground. Constructing dual sided panels capable of collecting radiation from both sides will increase the amount of energy that can be collected in a smaller space. By doing so, the underside of the solar panels will collect the radiation that is reflected off the earth.

Tandem Cells

The tandem cell is one that is similar to the crystalline-cell, except that it is laminated internally to absorb a greater portion of the sun's radiation and convert it to electricity. This is one way to generate power without taking up as much space as other solar cells. Glob and Brus (1993) explain that the cells are transparent, and each layer or panel is created to absorb a different wavelength of the radiation that the sun emits. The first panel is made to retain a certain wavelength of the solar radiation. The radiation that the first panel did not absorb is transmitted to the following panel. This process is repeated to improve the use of the light available. Glob and Brus (1993) affirm that with a single PV cell, about 16 percent of the sunlight is converted into electricity. With layering, up to 40 percent of the radiation is transformed into electricity. Tandem is the most productive way to transfer the sun's rays into electric energy.

Concentrator Collectors

Another way to improve the power collection of the sun is to concentrate the sun's intensity by concentrating the light to a single small source. Concentrators can be mirrors or lenses. This method is generally less expensive than the use of solar panels that do not concentrate the sun, since fewer solar panels are needed to create the same power. With traditional systems, purchasing additional solar panels greatly increases the cost of electrical generation according to Clarke (Personal Interview). The costs of the reflectors and concentrators are inexpensive compared to the solar panels. In order to utilize this system, fully tracking systems are needed for the redirectors to obtain most effective use of the sun's radiation, but the cost of the tracking system makes this option uneconomical. Markvart (1994) points out that another disadvantage to magnifying the light in one place is that the PV panel would be at a higher temperature then it would under normal use, thus reducing the life of the panel. Cooling is necessary for panels with concentrators.

Case Study of Solar Energy in Schools

Ohio's Oberlin College is an example of a College that has constructed one building to be electrically self-sufficient through the use of solar electricity. The solar power system, finished in February 1999 is also designed to produce more energy for the building than it uses. This building is outfitted to receive 3,700 square feet of photovoltaic cells when the technologies for solar energy improve. The Institute of Energy Conservation estimates that a normal College in the climate of Ohio consumes 75,000 Btu/sf/yr, but this new building uses

16,499 Btu/sf/yr. In addition, the classrooms are built to use roughly 21 percent of the electricity that a normal classroom would utilize.

Fuel Cells

Fuel cells are similar to batteries because they both are electrochemical devices. The basic components of fuel cells are two electrodes, called the anode and cathode, separated by an electrolyte (Wolk, 1999: 1). Combining hydrogen and oxygen ions creates the electric current. The article Advanced Fuel Cell Power Systems (2000) says that fuel cells can be fueled by natural gas, coal-derived gas, landfill gas, biogas, or methanol. The figure below illustrates a complete fuel cell power plant.

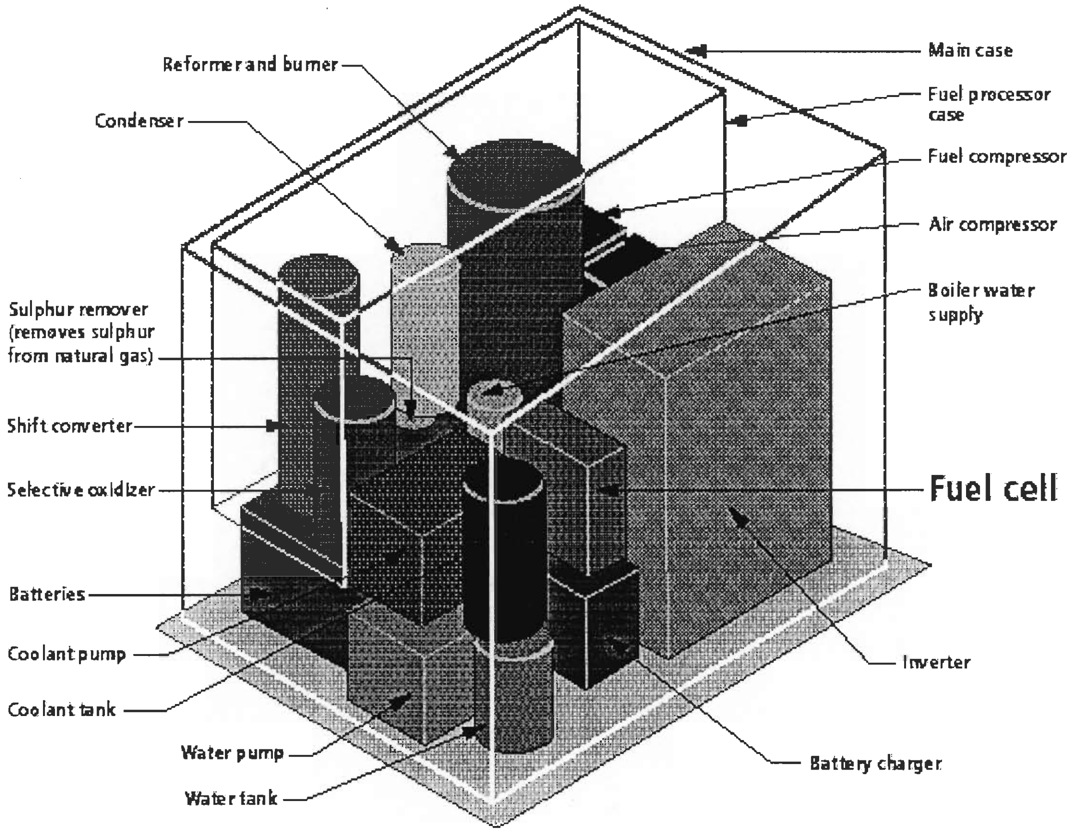

Figure 2: Fuel Cell Power Plant

Source: Wolk, 1999: 1

Fuel Cell Types

There are a variety of Fuel cell designs: phosphoric acid (PAFC), molten carbonate (MCFC), polymer electrolyte membrane (PEM), and solid oxide (SOFC). The following table displays the types of fuel cells and their respective characteristics.

Table 2: Fuel Cell Characteristics

Source: Advanced Fuel Cell Power Systems, 2000: 2

	Fuel Cell Type			
	Polymer Electrolyte Membrane	**Phosphoric Acid**	**Carbonate Acid**	**Solid Oxide**
Electrolyte	Ion Exchange Membrane	Phosphoric Acid	Alkali Carbonates Mixtures	Yttria Stabilized Zirconia
Operating Temp. °C	80	200	650	1,000
Charge Carrier	H^+	H^+	$CO_3^=$	$O^=$
Electrolyte State	Solid	Immobilized Liquid	Immobilized Liquid	Solid
Cell Hardware	Carbon- or Metal-Based	Graphite-Based	Stainless Steel	Ceramic
Catalyst	Platinum	Platinum	Nickel	Perovskites
Cogeneration Heat	None	Low Quality	High	High
Fuel Cell Efficiency, %LHV	<40	40-45	50-60	50-60

The PAFCs have been thoroughly studied and developed into practical devices, more than other types of fuel cells. Advanced Fuel Cell Power Systems (2000: 2-3) explains that MCFCs and SOFCs are well suited for combined-cycle systems. When the waste heat from either of these two fuel cells is utilized, efficiencies can extend to 85 percent; otherwise, the efficiency approaches 60 percent. PEMs have been developed primarily for the use in vehicles, but they have not been fully investigated for stationary power generation.

Fuel Cell Advantages

There are many advantages to electric power generation through fuel cells. One advantage to fuel cells is that they are extremely efficient. As discussed by Wolk (1999: 2), Turnkey is a manufacturer of 200-kw PAFCs that achieve efficiencies of over 40 percent or up to 80 percent if the waste heat is used to heat buildings and water.

The size range of fuel cells is wide

Flavin & Lenssen (1994: 100-102) and Wolk (1999: 2) state that fuel cells are versatile. They can be of any size, both in terms of physical properties and in terms of power generation. As mentioned by Advanced Fuel Cell Power Systems (2000: 4), a two MW fuel cell plant in Santa Clara, California occupies the size of a “tennis court”. Similar to conventional power plants, fuel cells can be designed to produce large amounts of energy. In contrast, they can be designed for use in hospitals, homes, and office buildings, which require smaller amounts of energy. As Advanced Fuel Cell Power Systems (2000: 3) mentions, high efficiencies are attained for large and small fuel cells. Also, the price per kilowatt of a fuel cell plant does not decline greatly with size. If the size of fuel cell plant doubles, the output in energy doubles but the price per kilowatt may remain about constant.

Fuel cell emissions are minimal

Many sources such as Advanced Fuel Cell Power Systems (2000: 3-4) and Wolk (1999: 1) indicates that fuel cells achieve low emissions. The primary byproducts that result in fuel cell power generation are water and carbon dioxide; these byproducts are common to nature and can be treated. When fuel cells generate electricity, pollutants such as nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide, and hydrocarbons are all exhausted at low levels. In an article from the Department of Energy (DOE), Solid Oxide Fuel Cell Reaches One Year of Operations (2000: 2), emissions at the Siemens-Westinghouse fuel cell plant in the Netherlands met air pollution requirements. NO_x emissions have been measured at 0.2 parts per million.

There are additional benefits for fuel cells

Advanced Fuel Cell Power Systems (2000: 4) and Wolk (1999: 1) explain that along with being environmentally friendly, fuel cells are quite, safe, and reliable. These benefits are the result of having minimal mechanical parts. Fuel cell systems also have low maintenance requirements.

Fuel Cell Disadvantages

The two main problems currently restricting the common use of fuel cells for electric power generation are high cost and primitive technology. Wolk (1999: 1) says that fuel cell systems cost approximately $3,000 per kW. This cost is substantially higher than conventional power plants, which range from $500 to $1,500 per kW. However, many analysts such as Wolk (1999: 1-8) and Flavin & Lenssen (1994: 102) are confident that prices will decline when fuel cells begin to sell on the market in volume. By 2001, GE Fuel Cell Systems plans to market fuel cells that can supply electricity to a large home. The price range for such a system is estimated to be between $7,500 and $10,000, but prices will decline to $3,500 after the system has been on the market and is mass-produced. The second problem with fuel cells is the technology. Fuel cells are in the early stages of use and have not been developed fully. Technological advancements in the design of fuel cell systems have been successful in recent years and continue to occur. Wolk (1999) explains that the fuel cell industry is open; there are a diverse number of fuel cell types. Many different companies and agencies can take advantage of the evolving fuel cell power generating systems.

U.S. Funded Fuel Cell Plants

In two U.S. Department of Energy articles, Solid Oxide Fuel Cell Reaches One Year of Operations (2000) and DOE Selects Four Projects to Begin Developing Ultra-Low Cost Fuel Cells (1999), the DOE discuses several new solid oxide fuel cell power plants. The goals of the DOE programs are to further develop the technology of fuel cell systems and to lower costs.

The plant in Westervoort, the Netherlands, is a 100 kW cogeneration plant that has been operating for two years under funding from the DOE and Siemens-Westinghouse Power Corp. The plant has sustained efficiency of 46 percent and has had minimal emissions. By the year 2004, Siemens-Westinghouse plans to make a range of fuel cells available from 250 kW to 1000 kW.

Other projects partially funded by the DOE include partnerships with McDermott Technology, Allied Signal Inc., NexTech Materials Ltd., and Technology Management Inc. (DOE Selects, 1999: 2). The projects with these companies range in the price range from

$18.6 million to $363,000. The principal purpose of these projects is to investigate particular fuel cell equipment such as electrolyte tape and fuel cell stacks.

Wind Energy

Wind energy is another source of energy that is also "environmentally friendly." It produces power without using fossil fuels. Windmills have often been used in the past to supply power in remote locations. Farmers who did not have any other means of electricity used windmills. According to Paul Gipe (1993), it is economical to produce power when the user lives more then a half-mile from any power grid. Gipe says, to make wind energy cheaper compared to other forms of generation, winds of approximately 9 miles per hour are required. If the wind has speeds of up to 12 miles per hour, power would be more financially beneficial as an alternative to buying utility power.

Some factors affect wind speed. Wind is created due to the heating of the earth from the sun. Peaks of mountains tend to have a higher velocity and long ridges create stronger winds.

Costs of Power Generation Systems and Fuel Costs

Beamon & Wade (1996) observe that the cost of a power generating system has a wide range due to several factors. The principal circumstances and issues that affect prices of a plant are the desired power output, the availability and cost of the fuel, online maintenance costs, and the costs of generators and equipment. Appendix I present a variety of manufactures and distributors of power generating systems.

Solar Costs

Applied Power Corporation is a company that deals with the sale of solar panels. They have a system manufactured by the Solar Electric Company that outputs 120 volts, 60 Hz, and 250 Watts. This model is designed to generate AC power. The current cost of a solar panel from this model is approximately $3,200. We are interested in larger systems that create more power. The Applied Power Corporation has much larger system that can produce up to 48,000 volts. The cost of the larger system is $38,967, but when comparing the price per volt between the smaller system and the larger, we can clearly see the larger is the less expensive per kWh.

Solarex is another company that sells solar cells. In practice Solarex charges approximately $3.50 per Watt uninstalled or $7.00 per Watt installed. The installed system includes balance of system components.

According to the North Carolina Solar Center, the cost of electricity is roughly three cents per kilowatt during the life of a system, and each square meter of flat photovoltaic system will cost $160. Ed Clarke (Personal Interview, 2000) informed us that solar energy would have to be reduced to around $1 per peak Watt for it to be competitive with other power generation plants, and that this price was only reduced to $3 per peak Watt. Our analysis will determine what the cost of this generation would be throughout the life of the solar panels.

Fuel Costs

As Roy Cordy (Personal Interview, 2000), the head engineer of the diesel engine power plant at Clark University in Worcester, MA, explained in an interview, fuel prices fluctuate from day-to-day and year-to-year. The price for No 2 diesel fuel will be affected by the price of crude oil. The fuel companies have different ways to charge the customer for fuel. Texaco uses a three-day average. This is the average price of oil in a three-day period and this will determine the cost of the fuel for the next three days. For instance the price of fuel will be averaged on Monday, Tuesday, and Wednesday and this will determine the price for the consumer on that Thursday, Friday, and Saturday. This is how the larger companies determine the cost of the fuel that they sell. Some other companies such as Exxon-Mobil use averages that span a week or depending on the quantity purchased even longer time periods.

Chillers and Air Conditioning

Air conditioning systems provide many functions. As Wang (1993) points out, air-conditioning controls air temperature, humidity, cleanliness, and airflow. Engines, electrical motors, or steam can drive cool water chillers. According to Carlos Benítez, the owner of Benítez Air-Conditioning, said that the most efficient for of air-conditioning is a piston driven cool water chiller.

How Air-Conditioners Work

The process of cooling air is simple. An air-conditioning system is made up of three components, according to Wang (1993). The compressor is a component that takes freon gas and compresses it into a liquid. This liquid is heated as it is compressed because the energy contained in the gaseous state is still stored in the compressed liquid. Marshal Brain (1999) explains that this hot compressed gas is brought to the outside environment so the stored heat can dissipate into the air. What is left is liquid freon gas that has dissipated most of its heat into the outside air. When this liquid is brought back through the system, the liquid is put through an expansion valve. When this liquid freon is expanded into a gas, Brain explains, it drops in temperature. This cold gas then absorbs heat from the room that is being air-conditioned. This is a cycle, he says, that constantly exchanges heat and cool air. The figure below shows the model of how this system works.

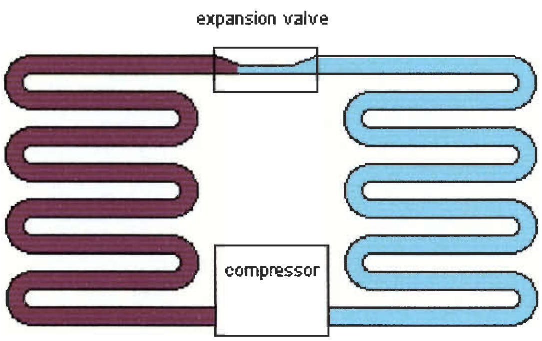

Figure 3: Model of How an Air-Conditioner Works
Source: Brain, 1999: 2

In large-scale applications it is necessary for cost and effective methods for cooling. One way to make the larger models more efficient is to use a water air conditioner. The process of cooling freon gas described above is similar as the process to cool water. As Wang (1993) explains, the use of water in a cooling system is called a chiller. The principal is the same for both devices as seen in the figure below.

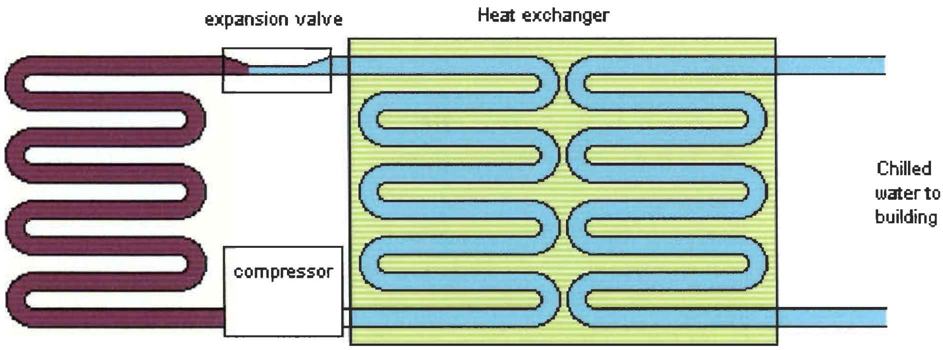

Figure 4: Chiller System that Cools Water and Delivers it to the Source.

Source: Brain, 1999: 5

Compressors and Fans

The driving mechanism for water chillers can be piston type compressors, screw compressors or centripetal driven compressors. The screw and centripetal driven types are only beneficial in very large applications and are very expensive. The water chiller uses a cooling tower to cool the water after the compressor compresses it. The water leaving the system is usually at 44 degrees, and the return is around 54 degrees. These systems use air handlers that are able to cool individual rooms using one chiller. The way this is accomplished is by installing separate water pipes to each room where an air handler is placed in each room. The air handler consists of a fan, and a drainage pipe for condensation. Heat from the room is absorbed through a heat transfer process into the pipe. This process will cool the room while the water in the pipe absorbs the heat from the room. The efficiency of this system results from the use of one large chiller as opposed to separate smaller systems. Chillers have many small compressors inside them that allow them to run at different loads during times of need. For example if only a few rooms are in need of air conditioning a chiller can run at 25, 50, or 75 percent of its max capacity. Typically Chillers have a minimum operating percentage and it is around 12 to 16 percent.

Air conditioning systems are measured with an energy efficiency rating or EER. The larger this number, the more efficient the system is. Expensive centripetal driven chillers can achieve EER ratings as high as 16, but most air chillers run at around 9.4, which is more cost effective comp aired to the 16 EER unless huge systems are installed.

The expense in running air conditioning systems is the airflow and the compressor systems. As Hansen (1985) states, fans are needed to move the warm air across the cool pipes in order to have heat exchange work efficiently. These air-moving systems take electrical energy. The other large load in an air-conditioning systems and chillers are the compressors. Compressors create a large load on an electrical system, he says.

Cogeneration and Air-Conditioning

Chillers can be driven in three ways. The electricity developed from a generator can power an electric chiller. Chillers can run directly off the mechanical drive of an engine or turbine. A third method is that the chiller can be run off of steam that is recovered from an engine, gas turbine, boiler, or cogeneration plant. As Wang (1993) points out, these chillers are being used very often in hospitals, public buildings, industrial facilities, and college campuses. He also says, a heat recovery system can increase efficiencies in the power generation process. As discussed in combined-cycle gas generators, the steam is used to produce electricity in a steam turbine. The steam after it leaves the turbine can still have sufficient pressure to operate a steam driven compressor. With this setup, Wang (1993) says, efficiency of 45 percent can be achieved.

Environmental Protection Agency

Clean Air Act

The Clean Air Act (CAA) was created by the Environmental Protection Agency (EPA) and serves many purposes. According to Section 160, five reasons exist for enacting this legislation. This legislation will: protect the health and welfare of the public from the effects of air pollution, protect nature and parks, ensure that economic growth keeps the environment in mind while it expands, make sure the pollution from one state will not interfere with another, and will sure that air pollution will occur only after all of these potential adverse consequences have been examined.

The original CAA was introduced in 1970, and amended in 1990 by President George Bush. The original Clean Air Act set standards for only six pollutants: sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), ozone, lead, and particulate matter (PM-10). The amended version of the CAA listed 193 pollutants listed in section 112 of the Clean Air Act. This list is updated no less then every eight years as stated in the CAA. The purpose for adding a new pollutant to the Clean Air Act list is to avoid a harmful pollutant from entering the human body. To remove a pollutant from the list, the risk of cancer in a human must be shown to increase by less than one millionth as a result of the pollutant; also, the pollutant cannot effect the environment negatively.

The Clean Air Act also sets regulations on stack height for buildings that produce pollution. Stacks that were built before the 1970s are exempt from these height regulations.

The CAA sets regulatory guidelines that the states enforce. This is why the CAA does not define a definite stack height requirement. According to Section 123 of the CAA (1990), stack heights have to be the height "necessary to insure that emissions from the stack do not result in excessive concentrations of any air pollutant in the immediate vicinity of the source." Section 123 also says that stack heights should not exceed two and a half times the height of the building giving off the emissions unless it is proven necessary for the reduction of air pollutants.

The class designation of a geographic area will determine the quality of the air in that region. There are three defined classes that define where buildings can be built. Currently three classes determine the amount of building that can go on in that area. Class 1 areas are national parks, in these areas the air is considered very clean. The majority of areas are in Class 2. In these regions, pollution is controlled and monitored. In Class 3 areas, the pollution is a concern to the area and possibly the areas it surrounds. It is easiest to construct plants that produce pollution in Class 2 areas. See Appendix H, which displays Section 163 of the Clean Air Act. This section of the Clean Air Act shows the maximum allowable emission of pollution.

The states are responsible for the enforcement of the Clean Air Act legislation. They impose fines of up to $25,000 a day per violation; each chemical that exceeds its limit is considered a separate violation. For large companies, the EPA has the authority to double or triple fines to ensure action. The consequences for not adhering to the EPA's Clean Air Act regulations can be severe. In addition to fines, administrators of companies can be sentenced to jail.

Some fees also are included in the CAA. A company must pay a minimum of $25 per ton of pollutant discharged into the air. This fee is paid to the state, and it can be higher according to the state's discretion. For large companies, these fees can be about $200,000 per pollutant per year.

EPA Construction Sanctions

One step necessary to initiate construction of a power plant is to obtain a permit from the EPA. Bruce Maillet who is a consultant in air pollution for the IT Group says (Personal Interview, 2000) that the EPA must give authorization of the particular design of the plant. The Clean Air Act of 1990, which was written by the EPA, outlines many regulations that must be followed in order to be eligible for a permit. He states that depending on the type of power generation and the location of a proposed plant, other environmental factors are reviewed by the EPA, in addition to air pollution. These environmental concerns include water and land conservation. Two situations that show the EPA's impact on power plants in Puerto Rico are Ecoelectrica's proposed plant in Penuelas, PR and the Puerto Rico Electric Power Authority's (PREPA) plant in San Juan, Puerto Rico.

EPA Case Studies:

The EPA approved the Ecoelectrica power company's plan to construct a combined-cycle co-generation plant in Puerto Rico (EPA Gives, 1996: 1). This power company was given a permit to construct a plant because it adheres to the Clean Air Act regulations. Natural gas turbines run the first cycle in this combined-cycle system and steam turbines operate the second cycle. As mentioned in an EPA's news release (EPA Gives, 1996: 1), the use of natural gas will result in a minimal amount of harmful pollutants. Under federal agreement, the Ecoelectrica plant minimizes the nitrogen oxides given off during the burning of the natural gas through advanced technology methods. Existing power plants in Puerto Rico are primarily fueled by oil. The Administrator of EPA Region 2, Jeanne M. Fox, notes that Ecoelectrica's plant adds variety into the power generation industry of Puerto Rico (EPA Gives, 1996:1).

A second study by the EPA deals with the Puerto Rico Electric Power Authority (PREPA). Consideration for the installation of new turbines to replace the older existing ones at PREPA's power plant in San Juan has been discussed in a recent EPA news Release (EPA Proposes, 1999: 1). The new turbines would run by gas generated from burning concentrated fuel oil. The EPA has authority to grant PREPA a permit if the site meets all environmental regulations. The boilers at the San Juan plant are not in operation because they are old and inefficient according to PREPA. Gas turbines will replace the old boilers if the EPA approves PREPA to do so. PREPA has agreed to comply and exceed the limits set by the regulations of the EPA's Clean Air Act. The EPA PREPA news release (EPA Proposes, 1999: 1) mentions several advantages of the use of the new gas turbines over the boilers. One aspect is that the turbines would be more efficient. The boilers, PREPA says, are outdated; whereas, the gas turbines would be technologically advanced. The power plant would incorporate anti-pollutants methods to reduce harmful environmental effect using enhanced techniques. An example of an advanced process is called selective catalytic reduction (SCR), which diminishes nitrogen oxide emissions. Other improvements in PREPA's proposed power-generating system are monitors and regular system checks of emissions (EPA proposes, 1999: 2).

EPA Violation Consequences

The EPA's enforcement of regulations can be seen from their actions toward several of the power companies in Puerto Rico such as PREPA. As described in a news release by the EPA (PREPA to, 1997: 1), PREPA settled with the EPA and the United States Department of Justice (DOJ) for environmental offenses. PREPA was found guilty for "air, water, underground storage tank and spill regulations, and hazardous substance reporting requirements" (PREPA to, 1997:1). As a result PREPA must pay six million dollars to rectify its actions. The EPA and the Department of Justice (DOJ) has set objectives for PREPA to maintain the air quality standards stated in the Clean Air Act. The power company will establish projects to prevent future environmental violations from occurring and to ensure that current environmental conditions improve.

Power and Energy: How it Works

Electrical energy is a very common entity that is common in everyday life. Electricity can be produced in many ways and transmitted in equally as many ways. Power is distributed in large consuming industries and commercial buildings in a much different way than the power is distributed in homes. The most common way in which power is produced and will be produced at the Colegio is known as three-phase power. The method of power production and transmission for the Colegio is described here as simply as possible.

Three Phase Power, its Production and Use

A Russian scientist named Nicola Testler discovered the benefits of three-phase power. His studies in electricity made three-phase power the more effective way to produce and transport electricity over Direct Current, commonly known as DC power. According to Miller (1982), he points out that the reason for the advances in power were because of the ease in which three-phase power can be produced and most importantly the distance three-phase power can be transmitted. DC current is an electric charge that flows through a conductor. The current is constant or has a frequency equal to zero. Alternating Current or AC takes the form of a sinusoid and can have any frequency other than zero. In the case of the United States including Puerto Rico, the standard frequency is 60htz AC. In most other countries the frequency is 50 Htz. The frequency is the number of times the wave goes from its highest value to it lowest value in one second says Miller & Culpepper (1988). The figure below shows AC current.

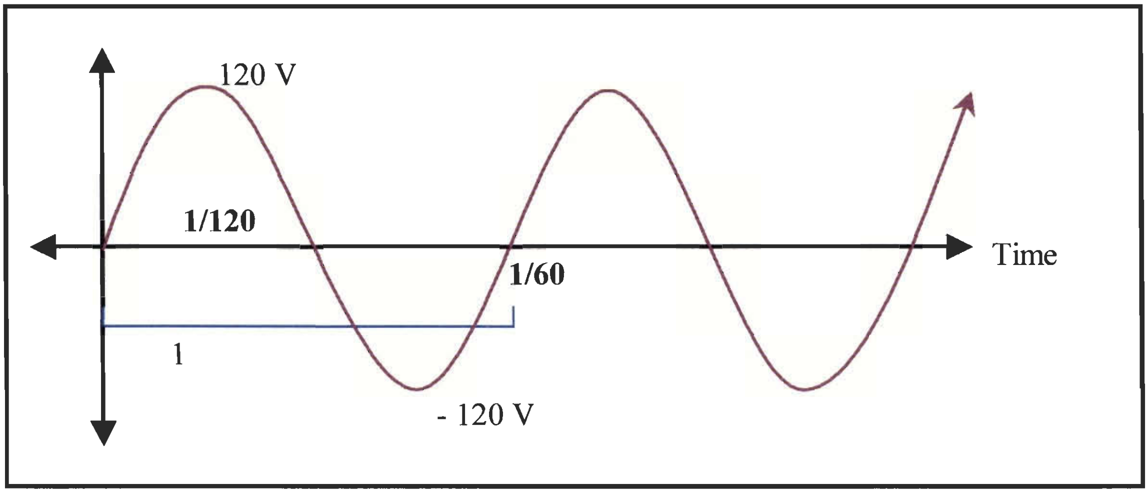

Figure 5: A 60 Htz sin wave with amplitude of 120 Volts

AC current can travel over large distances without any real loss in strength compared to DC. Fardo & Patrick (1979) explains that three-phase power is made up of four lines. Three lines carry AC current, each offset by 60 degrees. The figure below illustrates three-phase power.

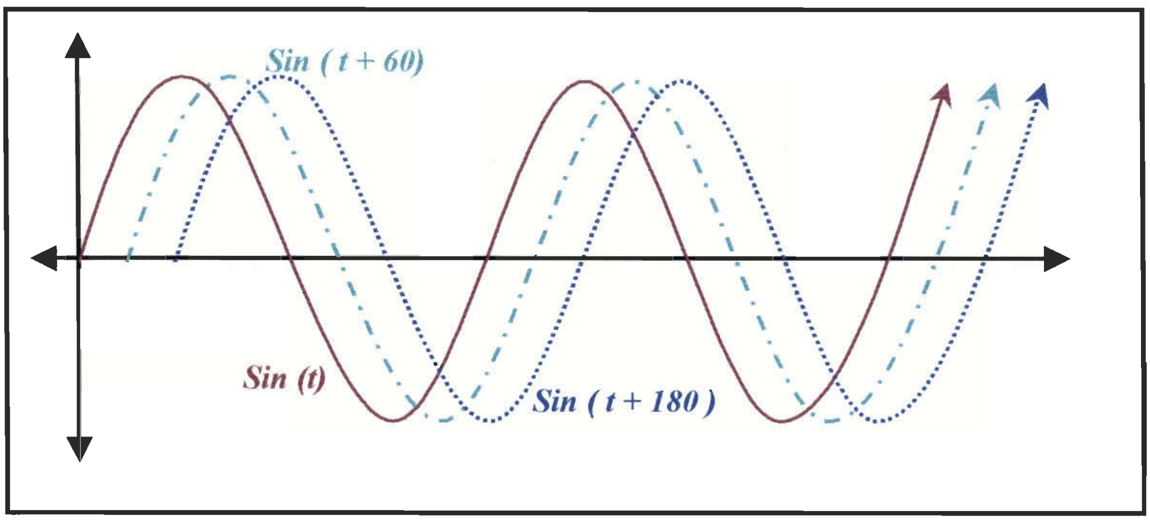

Figure 6: Three-Phase power as transmitted through a system

The fourth line is known as a neutral or as a ground. The Colegio has a three-phase power supply going to most of the breakers and transformers. In order to use the three-phase power for conventional lighting, computers, and projectors, the three-phase power must be converted to single-phase power. In order to explain the convention in three-phase power, some terms must be defined. The wires that carry the current are called lines, and the fourth wire is known as the neutral according to Fardo & Patrick (1979). Voltages can be measured from line to line (VLL) or from the line to neutral (VLN). The writing convention in circuit breakers and transformers is to display the VLN followed by the VLL, depending on what voltage the supply line is carrying. The VLN and VLL in three-phase systems are always proportional to each other by a factor of $\sqrt{3}$. The figure below illustrates the voltages in a 277V/480V three-phase system.

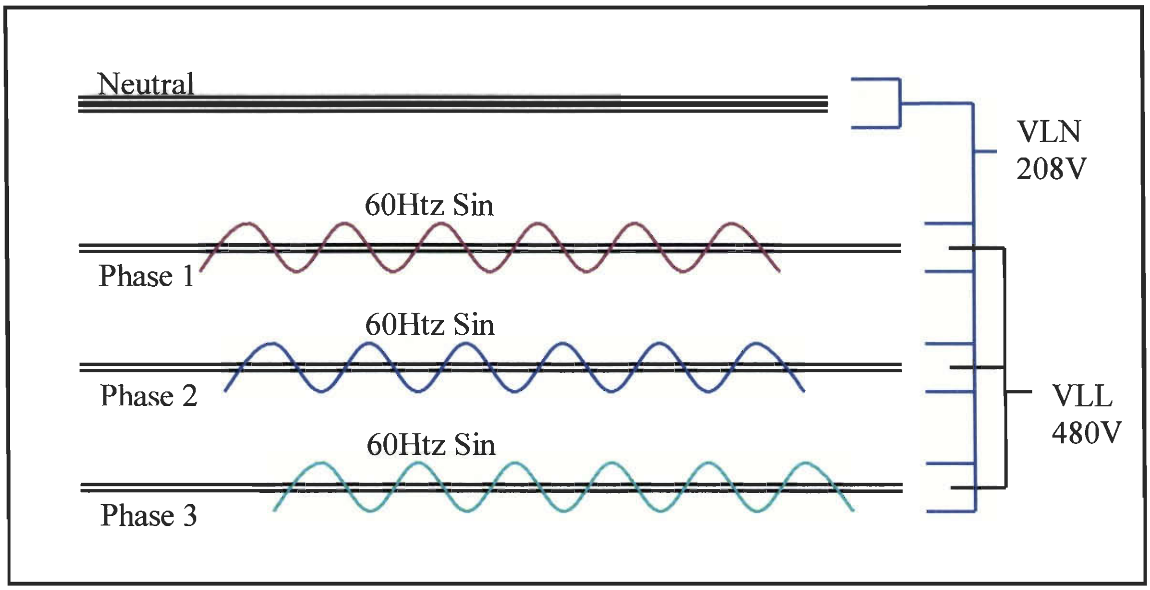

Figure 7: Voltage as measured through a three-phase system

Miller (1982) explains that the voltages in three-phase systems are mathematically shown by the formula $VLL \times \sqrt{3} = VLN$. VLN is single-phase power that can supply lights, computers, and other equipment. The most common voltages found in commercial or industry is 347/600 277/480 or 120/207. The Colegio uses both of these voltage supplies.

Generator Specifications

An added generator set that is chosen should supply the previous system with the same voltage types. For this reason, the supply of the already installed system does not need to be changed. Many terms apply to the production of power through a generator, and some can be very mathematical and complex. In order to simplify the discussion of the technical aspect of power generation, the mathematical explanations will be avoided.

In a specification sheet provided by Caterpillar power generators, there are three categories called Standby, Continuous, and Prime. In order to explain these types of power, it is important to understand a term known as load. Load is the amount of energy required by a circuit says Miller & Culpepper (1988). The entire electrical system is a circuit and depending on what is running, the demand for electricity changes. This electrical change corresponds to a fluctuation in load. Generators that cannot provide a varying load can only supply a specified output. Standby generators are used as backup generators and are designed to work at nearly maximum capacity for a short amount of time. These generators can provide a varying load. Continuous generators are designed to run all the time but are unable to provide power to a varying load; this limits the use of continuous generators. These generators are good because they are much cheaper to purchase. If the Colegio was to use a generator to charge batteries used in a solar hybrid system, a continuous generator could be considered. A prime generator is the type of generator the Colegio would be most interested in because it supplies power all the time and can handle varying loads.

Generators have four ways that they characterize their outputs. The first way and the most common way is by kilowatts. A kW is a measure of power that comes from an electrical engineering law known as Ohm's Law says Fardo & Patrick (1979). Ohm's Law states that voltage equals the current times the resistance or V=IR. Power is defined as current times the voltage or VI=P. Kilovolts Apparent is also a common way to define generator outputs. The kVA of a system is slightly more complex to calculate because it deals with a type of resistance known as impedance that affects the power. In simple terms kVA explains the reaction a generator has to varying loads and how fast a generator can supply a varying load. As shown in a specification sheet provided by Caterpillar a good kVA should be 25 percent higher than the ekW output of the generator.

Puerto Rico Electric Power Authority

The Puerto Rico Electric Power Authority (PREPA) currently has a monopoly on the power producing industry in Puerto Rico. As Alfaro (1999) states in an article in Caribbean Business, PREPA generates 98 percent of the island's power and is the only distributor. Recently, independent contracts have been granted to private businesses to build power plants for Puerto Rico to satisfy the island's power needs. Future demands for power are expected to increase, and PREPA must find a way to meet these demands says Alfaro (1999). In order to tackle this problem, PREPA is involved in many research and retrofitting projects that will allow the utility company to continue providing power for the entire island.

Current Power Production

Alfaro (1999) said the main type of fuel in Puerto Rico used in power production is oil. Oil is responsible for 97.6 percent of the total energy consumption. Coal and hydroelectric power are responsible for the remaining 2.4 percent. PREPA, as of 1999, has seven power generating facilities that produce 4,421 megawatts of power. The two power generating giants are the Aguirre and the South Coast plants producing over 1000 MWh each. In 1999, PREPA used approximately 80 percent of its total capacity, and PREPA says it uses 90 percent of total capacity during peak demand times. PREPA estimates that the annual demand growth is about 3.4 percent. The Energy Information Administration (EIA) (1999) predicts that by the year 2008, the demand will increase by 1,725 MWh increasing the total demand to 6,146 MWh.

Cost of Power in Puerto Rico

Alfaro (1999) says consumers are billed according to usage. Depending on usage a consumer is put into one of three brackets, residential, commercial, and industrial. The cost of power in Puerto Rico is very high compared to the mainland price for power in the respective customer classes. In 1999, the cost per kilowatt-hour for the industrial classes was 7.71 cents, for the commercial classes, the cost was 10.24 cents, and for the residential classes, the cost was 7.93 cents according to Alfaro (1999).

Ganotis of Waste Management explained (Personal Interview, 2000) that there are three fees incurred for the purchasing of power in Puerto Rico. The first charge he says is use. This charge is competitive with most other parts of the US, approximately 3 cents per kW/h. The second cost, which is also competitive according to Ganotis, is the transmission cost. The third cost, the demand cost, is what makes the price for power in Puerto Rico so high. Demand cost, he explains, is determined by the maximum power in kW a consumer demands in a fifteen-minute interval for the entire year. The consumer must pay for this demand cost every month. The demand cost is reasonable, because the power company must produce the power for this demand, even though it may not be used. The result is very high cost for power per kW/h. Ganotis (Personal Interview, 2000) mentioned that the sugar cane industry is most directly affected by this demand cost. During the harvest season he says, the demand is very high, but during the growing season, the power consumption is very low. As a result, the industries are paying for their high consumption even when they are not using it.

Billing Structure in PREPA

PREPA has a billing structure similar to that of the utilities in the United States, as Ganotis (Personal Interview, 2000) explained. There is a rate per kW/h of consumption. This price is reasonable; it is about 3 cents per kW/h. There is also a transmission charge added to this cost that is about 2 cents per kW/h, he adds. The real expense is hidden in the demand charge. This demand charge is based on the peak demand in a fifteen-minute interval for a one-year period. The consumer pays the cost of this demand charge for every month. This makes the average electric cost in Puerto Rico 8.9 cents.

If a company is producing its own power, Ganotis adds, but needs to purchase power for peak time, or down time, PREPA is going to charge for this every month. The reason for this charge is because of the reserve that PREPA must have to supply these demands. This can be devastating to a company, and Ganotis believes that this is how PREPA prevents businesses from producing their own power. Some businesses on the island have power stations called peaking plants that simply drive their peak demand down to avoid paying high costs. Ganotis suggested that the Colegio could invest in two plants, both of which could supply the Colegio during average demand times. During peak demand times, both generators would be operating together, and in off-peak demand times only one generator would be running. This would also allow maintenance to be done on one generator while the other is still producing power.

Investments

In order to meet future power consumption demands, PREPA must depend on several large investments. According to an article by Alfaro (1999), PREPA will need to produce 5800 MWh of power by 2001. To do this, PREPA will invest almost two billion dollars. The Department of Energy (DOE) has also been investing time and money into PREPA (EIA, 1999). Various research projects pertaining to renewable energy resources have received funding from the DOE. According to the DOE (EIS, 1999), sugar cane is a possible source of biomass energy, and studies on resource recovery facilities are underway.

PREPA's Future Projects

PREPA is planning to invest $200 million in their San Juan electric power plant. This upgrade will add two new turbines that will more than double the plant's original output. In addition to power generation, PREPA also controls the distribution of power. PREPA wants the ability to track the growing infrastructure that results from increased population. In order to do this, PREPA has granted the company Intergraph a $26.4 million contract to provide

Puerto Rico with an integrated resource management system (Utility Watch, 1999). By using models and monitoring equipment, Intergraph will map the power grid, show new construction and repairs, and deal with dispatches and outages. This will create better response to consumers when outages occur, in addition to resource management and efficient control for the new plants according to Utility Watch (1999).

Private Power Production

Alfaro (1999) explains that in order to produce the amount of power expected for the future in Puerto Rico, private industries have begun building power plants and selling the power to PREPA. Those private industries are now beginning to produce power on the island. One reason for private power generations is that the demand for energy is increasing Puerto Rico. As Alfaro (1999) points out, the demand has been increasing and will continue to increase due to technology. Currently, PREPA is able to supply adequate power to the island, but they are not prepared to keep up on the huge infrastructure that will result from expansion. Ganotis (Personal Interview, 2000) says the means are not present for PREPA to fix the problem of the growing infrastructure, and so they will have great difficulty in keeping up with the expansion necessary to supply the island. An article from the EPA (EPA Proposes, 1999) and Alfaro (1999) notes that PREPA is planning many expansion projects, some which have already started.

Ana (1999) explains that in December of 1999, PREPA began buying power from a privately funded natural gas plant owned by Ecolectrica. The plant produces 507 MWh that provides Puerto Rico with an increase of ten percent the total production. According to Ana

(1999), PREPA has also allowed the construction of an 800 million-dollar power plant. This clean-coal burning plant proposed by AES Puerto Rico will be online in 2002; the new plant will provide 454 MWh of power to the system. An article by the Energy Information Administration (1999) mentions that other investors have proposed waste-to-energy facilities. These plants would burn between 2,000 and 3,300 tons of solid waste and produce 50 to 72 MWh of power respectively. As Ganotis (Personal Interview) explained, the proposed waste-to-energy plants have not been contracted yet, but discussion is underway.

Energy Consumption and Construction Space at the Colegio

Consumption and Cost of Energy at The Colegio

Professor Marcus Droz from the Colegio Tecnológico del Municipio de San Juan obtained the electricity consumption and cost data for the Colegio through the last six months. He estimated an average consumption of 142,770 kWh per month. The average cost of on-peak, off-peak, demand, plus transport is approximately 0.12 cents per kW/h resulting in an expense for electricity of $17,170 per month.

Space Available for Construction at the Colegio

The Colegio has an estimated 400 square meters vacant. This parcel of land is located between two existing Colegio building. The land is flat with grass and trees. The Colegio has declared this area available for a possible power generating system.

Data, Results, & Analysis

The data, results, and analysis section of this report includes information obtained during the project in three subsections. It explains what information was received and its significance. By conducting interviews, we became knowledgeable about the Colegio campus' power issues as documented in the first subsection. The second subsection called "Power Requirements and Alternatives" includes information on the current electrical conditions and future power generation needs at the Colegio. The final subsection deals with the life cycle cost analysis. This subsection deals with the economics of all the alternatives.

Opinions of Faculty and Staff Concerning the Colegio's Power Needs

We investigated the views of the faculty and staff at the Colegio in regards to the power issue. The opinions of the faculty influenced but did not determine the alternative power recommendations to the Colegio because we felt that the faculty could not be considered experts in the field of power generation. We asked the faculty questions that did not deal with the alternatives directly, but rather questions that focused on their feelings towards the current system and how changes would effect education and the Colegio's atmosphere. The results of the interviews were documented and summarized to present the concerns of the community members of the Colegio.

Members of the Colegio Interviewed

Dean Elsie Candelaria, our liaison at the Colegio, explained the views she and her department have. Following our initial communication with Dean Candelaria, we spoke with other faculty members of the Colegio. Using a list of faculty at the Colegio, a sample of interviewees was chosen. People outside of academics such as executive members of the Colegio were also questioned. Our liaison, Elsie Candelaria or Carmon Andreu, a secretary in the academics department, arranged the interviews.

Interviewing Process

The project team worked in teams of two or three when interviewing faculty and administrative members of the Colegio. The purpose of the interviews was to learn about the power needs of the faculty and to see if they have any problems with the current power supply. We also wanted to learn if the professors at the Colegio would be able to use the power plant as a source of education. In each interview, the interviewee was ensured that the interview would remain confidential. We did not use the recorder or an interviewee's name in any reports unless we were authorized.

During an interview, one member of the group addressed a list of questions while the other members of the group took notes on the responses given by the interviewee. A sample list of questions that was used for interviews can be seen in Table 3. We interviewed seven of the faculty and staff. The interviewees included a member from each academic department. The interviewing technique was structured, which means that the same questions were asked of all participants. However, unstructured methods were used as well.

The project team asked participants to elaborate on their answers. We probed in order to obtain comprehensive feelings, attitudes, and ideas of the interviewee.

Post Interview Phase

When an interview had completed, the interviewers thanked the participant for their time and efforts. Our group then documented and analyzed each interview to determine the interviewee's feelings on such topics as environmental issues, economics, and noise. These topics will be used in the results and conclusions section to let the Colegio know about concerns of the faculty.

Interview Summaries

Each of our interviews lasted nearly 25 minutes. We asked each interviewee the questions presented in Table 3 below and asked the interviewee to elaborate on each subject that we felt necessary.

Table 3: Faculty Interview Questions

1	Have you noticed power problems or failures in lighting, equipment, or air-conditioning? If so, how frequently and how severe?
2	Do you think that these power problems affect the students' ability to learn?
3	Have you had any difficulty teaching under the current conditions?
4	Do you feel the heat has an impact on the students' ability to learn or be productive?
5	Would you be able to benefit from an air-conditioning system?
6	How do you think the school would be affected as a whole if air-conditioning became used in all classrooms?
7	Do you feel that air-conditioning is essential at the Colegio for maximum learning and teaching?
8	Are you familiar with the schools plan to become autonomous?
9	Do you have any preference towards the Colegio becoming autonomous?
10	Are you familiar with the fact that the school is looking into generating its own power?
11	If the school were to carry out this plan, would you be able to use this as an educational tool?

We interviewed five faculty and then two administrators. The information obtained during the interviews did not greatly impact the power decisions and recommendations that we made. However, we thought that it was necessary to identify the Colegio community's concerns and feelings that relate to all aspects of the power issue.

Mariamelia González (4/10/00 9:15 AM)

Mariamelia González is a professor at the Colegio who teaches word processing. She mentioned that there were power outages at least once a week. The power problems affect the student's education. Students complain of equipment that is malfunctioning because voltage spikes damage the equipment. According to Mariamelia González, the power fluctuations cause damage to the computers and the air conditioners.

The air-conditioning in the room that she teaches does not work. Because of the lack of air conditioning, the students have shorter attention spans in the afternoon because it is warmer. There is a noticeable change in the students when trying to teach them when the temperature outside is high.

Mariamelia González is aware of the Colegio's interest in becoming autonomous. She expects that the school will be separate from the municipality in three years. She explained that the teacher's were unable to obtain the funds that they requested because it was an election year for the Municipality of San Juan. Mariamelia González approves of autonomy because it will give the Colegio the freedom to make their own budget and not be subject to the Municipality's approval. It will also make it faster for the Colegio to get needed equipment and supplies without the long delay that the Municipality currently causes.

Mariamelia González further told us that our alternate energy source could also be used for educational purposes. It could be used for a planning and design course when it is built and it could also be used for electrical classes.

Antonio Bacenet (4/10/00 11:00 AM)

Antonio Bacenet teaches classes in computer repair. Antonio Bacenet told us that he has not experienced power problems at the Colegio. He stated that he has air conditioning in the room that he teaches. He indicated that his room is one of the only rooms that continually have air conditioning. He said that other classrooms that have wall unit air conditioners often malfunction. He also stated that other professors constantly ask him when he has classes and when he does not so that they may use the classroom when he is not.

At times, there are air conditioning problems in his classroom. About five to six times a year the air conditioning will be down in his room. When this happens he notices that it is much harder to teach and it is harder to keep the students attention. There is a huge attitude change when the air conditioning malfunctions he said.

Antonio Bacenet has measured the voltage from outlets in his room at different times. He found a fluctuation from 119 volts to 125 volts at the Colegio. He said that this should not damage the computers in the labs at the Colegio.

As for the autonomy issue, Antonio Bacenet said that it would be beneficial for the Colegio. Currently the Colegio runs under a bureaucracy, which he mentioned is inefficient. The process to acquire equipment takes three times longer then it should.

He thinks that strategic planning will have to take place before the school will be able to become autonomous. The school budget will be very important because the Colegio will have higher financial responsibilities that they currently do not have. All bills are sent to the municipality for payment. The Colegio is currently under the Municipality's shadow.

Antonio Bacenet also said that the power alternative would be an educational tool for students, as well as a marketing tool to increase enrollment. He said that students could manage a power plant if it was built on campus.

Ana I. Landrón (4/10/00 12:00 PM)

Ana I. Landrón is an English teacher at the Colegio. Aggregative noises easily travel from the outside to the classrooms. She has concerns with the lack of air-conditioning and outside noise. She must stop her class at times because of planes flying; she is unable to compete with the loud noises.

Ana I. Landrón experienced constant disruptions in her classrooms. The heat creates problems by making her and the students both uncomfortable. She says that air conditioning would greatly be beneficial for her classroom.

There are some power problems. She says that the lights flicker about once a month because of low voltage. She also said that they have a power outages a couple times a month.

Ana Landrón is aware of the autonomy issue at the school although she says she does not know what stage they are in currently. She thinks that it is a very good idea. She feels that autonomy is needed because Municipal processes are lengthier than needed. Materials are received late because of the long process to obtain materials through the Municipality. The Colegio does not control its own the fiscal budget and funds are limited; therefore, autonomy is needed to relieve the restrictions.

Sinthia C. Fernández (4/11/00 11:00 AM)

Sinthia C. Fernández is part of the Nursing department. She has a problem with the Colegio's power supply. Sinthia C. Fernández says that the lights are not adequate in the room that she teaches in. The lighting she said will go out on a regular basis. The lab equipment that the student nurses use is manual, rather than electric because of the lack of electricity consistency. She would like to put electrical equipment in the labs because that is what they will be using in practice when the graduate.

She explained that the air-conditioning units are loud and disrupt teaching and learning. Sinthia explained that the sun puts the students to sleep because of the heat.

Sinthia Fernández understood the autonomy issue. She understood that the money to pay bills came from the Municipality and that the Colegio would have to begin to pay their own bills when it becomes autonomous. She also said that it takes a long time to receive equipment and needed supplies when dealing with the Municipality. She said that the Colegio budget limits the nursing department and insufficient funds are received for necessary equipment.

Edwin Marrero (4/13/00 9:00AM)

Edwin Marrero is the head maintenance supervisor. He has worked at the Colegio for five years.

Mr. Marrero described the existing infrastructure. He said that the current system was built to accommodate the Colegio when it first built. The college was built over twenty years ago and now it has outgrown its original power needs.

The Colegio is unable to increase the equipment that it currently has. It cannot put in more computers and it is unable to get air conditioning in the rooms that do not currently have air conditioning according to Marrero.

As for the existing electrical system he says that it has only gone down completely once in the five years that he has worked at the Colegio. This is when one of the substations went down. He did say that the school goes low on voltage about two or three times per month.

According to Mr. Marrero, there is generally no problem with the power except for the low supply in voltage at times.

Air conditioning is not necessary for the classrooms at the Colegio, but it is necessary for the labs at the college. He thought that wind was enough to cool the classrooms.

The autonomy should take place according to Mr. Marrero. He said that the college does currently not set up the fiscal budget. Because the Municipality controls the Colegio, there are long delays in ordering items. He said there was no freedom for the school. They always had to ask the Municipality for money on projects that they intended to accomplish.

Antonio Isaac (4/13/00 9:30AM)

Antonio Isaac is a professor at the Colegio who teaches electronics and semiconductors.

Antonio Isaac has had problems with the power in the past. He says that the power fluctuates and fails a couple of times throughout each semester. The lighting in the room in which he teaches, fluctuates and this is a concern. Unlike most teachers at the Colegio he has air conditioning. His room is not open to the outside elements so the sun does not provide enough light to compensate for the fluctuation in the lighting. If air conditioning were to be used in the school, voltage fluctuations would not be tolerable.

Since Professor Isaac is an electronics professor we asked him about a specific electrical question we had. Professor Isaac explained what happens when low and high voltages occur during the operation of electrical equipment. He said that high voltage would cause an electronic device to fail. It could ruin resisters, diodes, and other electrical components. Low voltage will cause the electronic components to not work properly. This is currently a problem at the Colegio he said.

Antonio Isaac believes that air conditioning is very important for the students and the professors at the Colegio. He says that it is difficult to teach and it is harder for the students to learn in conditions where the temperature is too warm. Also the sounds from the outside distract the class. Planes cause noise pollution.

As for the autonomy issue, Professor Isaac believes that it would be beneficial for the school to become autonomous. He has a problem with getting parts or equipment from the Municipality. For instance he said that he needed to get some fuses for some electrical meters, which are not by any means expensive. He said that he had to go through a pile of paperwork just to be able to get these fuses. It was a much harder and longer process than it had to be. He mentioned times when he had to wait months and sometime years before getting equipment that he needed. He expressed his feeling that autonomy was necessary.

Dr. Olga A. Benítez Garay (4/25/00 9:00 AM)

Olga A. Benítez Garay is the Chancellor for the Technological College of San Juan. She believes that there is a power problem at the Colegio. She said that the lights constantly flicker and that there are short lives for the light bulbs due to poor power. Power goes out once every couple of weeks. Sometimes the lights have to be turned on and off in order to get them to turn on.

Olga Benítez Garay said that the power problem is also affecting the students in their studies. She says that the power failures are bad for the labs. When the power goes off during the day, it is still possible to teach according to Benítez, but when the power fails at night, then it is impossible to teach due to the lack of lighting. Because of these problems, the power affects the students learning.

Benítez also said that air conditioning is necessary for every classroom. She says that it is difficult for the students to work in the heat during the afternoon. She believes that students have a harder time staying awake during the hotter part of the day. Air conditioning is needed in the summer because of the heat and humidity.

As for the Autonomy issue, Benítez agrees with everyone else we have talked to. She believes that it is necessary to "remove politics from education". Politics affect the school directly; they are unable to make their own budget, making it hard to purchase in needed equipment. Benítez said that there is no way of knowing what will happen to the Colegio in the future, due to the politics within the Municipality. She said that Autonomy for the Colegio would be beneficial to education.

Power Requirements and Alternatives

Our objectives during this project were to determine the best option for the Colegio to obtain power to meet their current and future needs. The criterion upon which the assessments were based, were those identified in our literature review. These decisive factors included cost, pollution, aesthetics, and size of plant. The goal was to determine whether the Colegio should continue to purchase power from the local utility PREPA or seek an alternative source of power generation. We assessed which alternative was most cost effective and which was most environmentally sound.

This section reports information and calculations we made to evaluate various power production alternatives. The material in this section reflects the information we obtained while on site in Puerto Rico. The project team has included explanations of how and why this information was obtained. We describe the motives for choosing certain alternatives and why other alternatives were determined to be unavailable or unrealistic. We described the methods we used to estimate the cost of every aspect of every alternative. The information in this chapter is based on current prices and therefore may be imprecise for alternatives adopted in the future.

Electrical System

We toured the Colegio campus on March 21st. In our original study, we had assumed that the current electrical system was in good operating condition. However, after observing the electrical system, we determined that it would need extensive repair. Professor Marcus Droz, the Director of Industry and Technology at the Colegio, as well as Professor Bonilla, a professor in the Industry and Technology Department and a licensed electrician, both recommended replacing the electrical infrastructure.

There are three substations, which supply the Colegio with power. The amount of electricity that these substations distribute roughly equals three times the Colegio's needs. The rated kVA of the three substations is approximately 1500 kVA. The electrical bills obtained from PREPA show that the maximum kVA that the Colegio demands is 582 kVA and the average kVA is equal to 229 kVA. We originally believed the substations did not have the capacity to support the Colegio. Once we discovered that the substations could supply the Colegio with three times its needs, as described above, we knew the problem was not with the substations capacity. The problem must be in the infrastructure of the school. The substations may need to be maintained; however for the time they are not directly responsible for the power problems.

The Colegio is supplied with a 13.2-kilovolt three-phase supply. This voltage is stepped down as it goes through the three substations. As stated in the literature review the voltages are 277/480 and 120/208. From the substations the Colegio is supplied with all of its energy. The Colegio is suffering from an unbalanced distribution of the load. A balanced system is when each phase has an equal current. Due to this unbalanced load, the current in one phase is not equal to the other two phases. The only way to fix this problem is to study the system and determine what phase is overloaded, and then engineer a way to redistribute the power through the other two phases.

When dealing with three-phase power distribution, the concept of a balanced load is very important. Unlike a home that is supplied by two 120V lines, the current in one line is not dependant on the other as in three-phase power systems. Three phase systems have a current in each line that is offset by 60 degrees. In a home the phase shift in the two lines is zero, for this reason when the two lines are combined, a voltage of 240 can be obtained. In a three-phase system, the voltage across two lines is not twice the voltage in the first line, but it is $\sqrt{3}$ times the voltage. Refer to the Literature Review section entitled Power and Energy: How it Works, for more details. In a home, every time an air-conditioned or refrigerator turns on; one may notice a quick flicker in the lights. The reason for this is because the compressor added a phase shift to the current in the line. This concept is shown in the figure below.

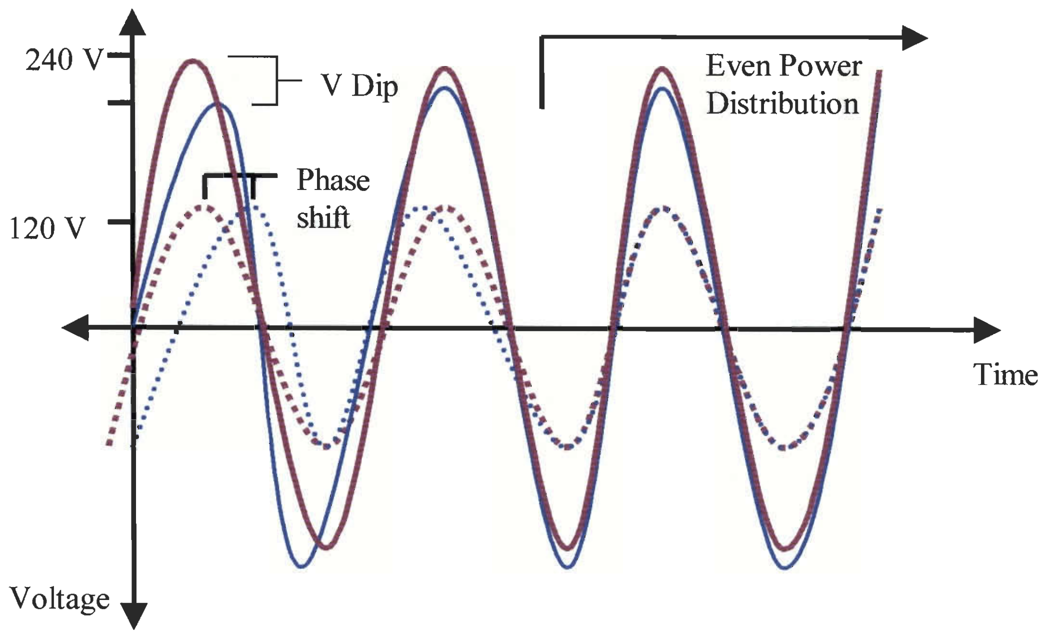

Figure 8 Power anomalies due to phase shifts

The red dotted line is a single 120V current like would be found in a home and the solid red line is when two lines are used together to produce 240 V. The dotted blue line is what happens to the current when an air-conditioner or a refrigerator turns on, which is a small shift in the position of the current for a short time in one of the two lines. The addition of the voltages is no longer 240V but slightly less as seen in the blue line. This voltage dip, as it is called, is what causes a flicker in the lights. This shift only lasts for a brief moment, but can cause damage to computers or other electronic equipment.

In a three-phase system, this problem is magnified greatly. The reason for this is because there are three lines and two of them can shift causing a larger voltage dip than could occur in a normal home. Usually systems that use three-phase power are much larger than a home and air-conditioning units are much large. In Large systems with large compressors for air-conditioning or sizeable motors for machinery, the shifts that appear only for a short time in the home may be permanent. When this happens, the system is known to be unbalanced. In a balanced system the current in each of the phases should be relatively equal. If this is not the case, then the system is unbalanced. One reason for this is because the load is not properly distributed. The distribution of load is known as load shed. If each phase is supplying an equal load, the load is distributed well; however, if this is not the case, the problem is evident by measuring the fluctuations in current through each phase at different areas of the system.

Our first clue to the load being unbalanced at the Colegio was when we measured the current through one of the supply lines coming from one of the substations. We also took measurements from one of the panels that supplied the air-conditioning for the administrative building and the current in one of the panels that supplies the second floor classrooms. Below is a table that displays the measurements through each phase.

Table 4 Current through certain areas supplying three-phase power

	Substation Panel 1	Substation Panel 2	AC supply panel
Phase 1	28 Amp	50 Amp	193 Amp
Phase 2	32 Amp	34 Amp	177 Amp
Phase 3	27 Amp	36 Amp	161 Amp

As the table shows, the substation measurement on the first panel had good distribution; the fluctuation was only five Amperes. On the second panel, the maximum deviation between two lines was 16 Amperes, which is a substantial variation. The air-conditioning supply was also very poorly balanced; the deviation was 32 Amperes. According to Marcus Droz, this is enough to show that the system is not balanced. The solution to this is to have the load redistributed. The task of balancing the load distribution in the Colegio is even more important with the addition of air-conditioning, because this increase in load will only magnify the power problems.

From our interviews we were informed that many faculty and staff have experienced power outages due to overloaded circuits. This is due to both the problems stated above as well as circuits not being able to supply enough current.

To obtain a cost estimate for such a project, the project team collected a variety of electrical information from the Colegio. This information included a list of all of the transformers and circuit breaker panels at the Colegio and their respective specifications. To obtain this list, we examined the electrical blueprints and surveyed the Colegio with the assistance of a Don Ramon, a staff member who is a licensed electrician and is experienced with Colegio's electrical infrastructure.

It is essential to have an efficient electrical system. An efficient infrastructure would save the Colegio money in the future as a result of having fewer power losses. An efficient system would include appropriate lighting and wiring. Electrical contractors estimated the cost of increasing the efficiency as well as revamping the transformers and circuit breaker system.

Air conditioning

Air-conditioning is a main concern for the Colegio. As a result we determined the increased power load and cost that air-conditioning would impose. The first step was to determine all of the specifications of the building that would have air-conditioning installed. These specifications included the volume of each room, type of windows and doors, number of lights, and the number of people. Once we obtained the necessary information, the project team inputted the data into a heat transfer program that calculated the BTU's (British Thermal Units) necessary for cooling. After determining an estimate for the tons of cooling, air-conditioning suppliers and contractors determined the cost and the power consumption of such a system. When we determined the increased power load, we added it to the current load to approximate the total consumption of the Colegio with air-conditioning.

In order to accurately determine a system that is economically viable and efficient, we found it necessary to study the air conditioning system as well as the electrical system. It was made clear to us that only a handful of the 30 classrooms were air-conditioned and these rooms were predominantly labs. We concentrated on the non air-conditioned building containing the classrooms and did not investigate the existing air conditioning system in the other buildings. Inefficient wall units that run at full capacity predominantly cool the classrooms that are currently air-conditioned. Some of the laboratories have split air-conditioning units which are generally more efficient than wall units; however, these split units did not condition the entire building or even an entire floor which also is an inefficient way to cool the buildings. By considering a single source of air-conditioning, we hope to cut back on the schools electricity load demands. The Colegio has also expressed a desire to air-condition all the classrooms; this requirement must be taken into consideration when determining the size of the power alternative we recommend.

We studied the air conditioning needs extensively for each individual classroom. Air-conditioning units are measured in two ways: BTU's of cooling power and tons of compression. Normally chillers, because of their scale, are measured in tons. Air conditioners also have an Energy Efficiency Rating (EER). Typically air conditioners have an EER between 9.1 and 10.4, where 10.4 is more efficient. New, very high efficient air handlers and chillers can have an EER up to 16, but these units are extremely expensive and are only cost effective for systems above 400 tons according to Carlos Benítez of Benítez Air-Conditioning in Puerto Rico.

In order to find the size of the air-conditioning unit needed to cool the classrooms, we used a program called "BTU Analysis Plus" written by David Ostler, which is designed for such tasks. The program was written by Enchanted Tree software. It is a powerful program used by air-conditioning contractors to determine the size of air-conditioning units. The tables at the end of the air-conditioning section show the data the program gave for each room of the Colegio. The data inputted into the program included square footage, wall height, window area and direction, window types, door types, number of people, perimeter, and ceiling and floor insulation. The program then uses heat transfer equations and tables to calculate the amount of BTUs and tons of cooling needed for each building.

The entire building that houses the classrooms and laboratories will need a total of approximately 1.3 million BTUs of cooling power and 125 tons of compression. The classrooms require from 27,183 to 69,064 BTU's each. The reason air conditioning demand was calculated was that air-conditioning will increase the electrical power demand of the Colegio. The load required for 130-ton Carrier cool water chiller system that consumes 1.259kW/ton at 100 percent capacity is 163.67 kW according to the specifications on the cool water chiller given to us by Arco Air-Conditioning Supply. The load is found by multiplying the consumption, in kW/ton, by the size of the system in tons. Because the system is approximately 5 tons larger than is necessary the system will never reach 100 percent under the Colegio's current demands. By taking the required size and dividing it by the actual size needed we found the capacity in percent that the system would use at maximum output. Finally we could calculate the actual demand by multiplying the max consumption by the percentage used by the system. The consumption is found by multiplying 163.67kW by $\frac{125tons}{130tons} = 157kW$, this is a very large number and greatly increases the Colegio's power consumption. The Colegio currently has an average kW demand of 195.09 kW as shown below in the section entitled Current Electric Cost. With an air-conditioning system the Colegio's demand would increase to 352.465 kW. Arco Supply provided a quote for a 130-ton Carrier cool water chiller and air handling system. The price for a 130-ton system is $47,000 uninstalled.

In performing our cost analysis, our liaison Elsie Candelaria informed us that air conditioning would be installed in the future. For this reason, we chose to price generators that were large enough to handle the extra load consumed by air conditioning.

Table 5, seen below, shows the air conditioning needs of each of the classroom at the Colegio. This table shows the results of the analysis done for each individual classroom.

Table 5: Air-Condition Data & Analysis

Building A Floor 1	BTU's	Tons	CFM's
Room Number			
100	29,181	2.4	778
101	19,119	1.6	1,019
102	19,119	1.6	1,019
103	19,119	1.6	1,019
104	19,119	1.6	1,019
105	19,119	1.6	1,019
106	19,119	1.6	1,019
108	23,000	1.9	622
109	23,000	1.9	622
110	39,984	3.3	1,066
111	23,000	1.9	622
112	57,965	4.8	1,546
113	30,482	2.5	778
Bath	25,635	5.8	1,866
Individual Total	*366,961*	*34.1*	*14,014*
Building A Floor 2	**BTU's**	**Tons**	**CFM's**
Room Number			
200	31,888	2.7	850
201	31,888	2.7	850
202	31,888	2.7	850
203	31,888	2.7	850
204	31,888	2.7	850
205	31,888	2.7	850
206	31,888	2.7	850
208	30,901	2.6	824
209	30,901	2.6	824
210	45,151	3.8	824
212	43,501	3.6	1,160
213	42,501	3.6	1,160
Bath	25,635	5.8	1,866
Total individual	*409,918*	*38.2*	*11,758*

Building A floor 3	BTU's	Tons	CFM's
Room number			
300	27,731	2.5	793
301	27,183	2.7	724
302	27,183	2.7	724
303	27,183	2.7	724
304	27,183	2.7	724
305	27,183	2.7	724
306	27,183	2.7	724
307	40,835	3.4	1,089
308	46,277	3.8	1,234
309	46,277	3.8	1,234
310	46,277	3.8	1,234
311	46,277	3.8	1,234
312	46,277	3.8	1,234
313	69,064	5.8	1,842
Bath	25,635	5.8	1,866
Individual Total	*557,748*	*52.8*	*16,104*
Building Total	1,334,627	125.1	41,876

Air Conditioning System with Power Load Requirement				
Size tons	Size Required tons	Percentage Used	Energy Use kW/ton	Total Energy Consumption
130.00	125.00	0.96	1.26	157.38kw

PREPA Rate structure

Determined Current Power Needs

Since the Colegio is a municipally funded school, it was very difficult to obtain the records of the schools power consumption. The most important part of our cost analysis was to determine Colegio's cost for power, as well as the current electricity requirements. Eventually, the project team was able to obtain the Puerto Rican Electric Power Authority (PREPA) electricity rates and the electric bills for the Colegio. From these electric bills, we were able to breakdown the cost structure. We used PREPA's tariffs, which can be seen in Appendix E, to determine the rates and charges the Colegio pays.

Current Electric Costs

The Colegio is currently purchasing power from PREPA under the designation known as GSP or Primary Distribution Voltage. By obtaining the account number for the Colegio we were able to retrieve the cost and consumption breakdown for the last ten months. Shown below is a table of the information we received from PREPA.

Table 6: Electric Bill as Obtained from PREPA

Colegio Tecnológico del Municipio de San Juan		**Power Factor = .85**
Account Number =	**013-0377194-001**	
Contract	**GSP-Commercial District Primary, Contracted Load = 650 kVA**	

Amount Billed	Day of Billing	Consumed kWh	Days	peak kVA
$18,097.51	3/27/00	138,600	32	524
$17,622.41	2/24/00	140,250	30	505
$13,700.80	1/25/00	103,950	32	505
$16,573.76	12/24/99	125,400	30	544
$17,911.50	11/24/99	150,150	30	582
$18,971.93	10/25/99	155,100	31	582
$18,965.58	9/24/99	166,650	30	582
$17,161.89	8/25/99	152,450	28	582
$15,910.69	7/28/99	151,800	33	524
$16,786.30	6/25/99	143,350	30	563

There are a couple of terms that must be understood when dealing with electricity. To begin, we will first describe kilowatts (kW) and kilowatt-hours (kWh). The kW and kWh are used in the measurement of electricity. To use an analogy, the kW is like a velocity. If one travels at 20 miles per hour constantly for one hour, then they would have traveled 20 miles. Similarly, if the Colegio's demand were a constant 20 kW for an hour, then they would consume 20 kWh of electricity. Kilowatts are known as real power.

The total power that is dissipated in a system cannot be completely measured in the real measurement of kW, and so the convention is to use a measurement known as apparent kilovolt (kVA). kVA includes a measurement of power dissipated in transformers and motors that cannot be completely measured with kW. The relationship between kW and kVA is known as the power factor. Power factor is the ratio of kW to kVA. For example a system with a power factor of 80 percent that consumes 500 kW will have an apparent power rating of 625 kVA.

In the Table 7 below we were able to estimate the current demand at the Colegio. In the PREPA bills we were given the Amount billed, the Day of billing, the Consumed kWh during each month, the Peak kVA, and the cost each month. From this information we were able to determine the average demand by taking the total kWh per month and dividing by the number of hours in that month. Then to get an average cost for the electricity that the Colegio uses, we took the total bill for each month and divided by the consumed kWh for that month. To calculate the peak kW, we took the peak kVA and divided this number by the given power factor of 85 percent.

Table 7: Cost and Consumption breakdown for the Colegio in the last ten months

Colegio Tecnológico del Municipio de San Juan	Power Factor = .85
Account Number = 013-0377194-001	
Contract GSP-Commercial District Primary, Contracted Load = 650 kVA	

Amount Billed	Day of Billing	Consumed kWh	Days	peak kVA	peak kW
$18,097.51	3/27/00	138,600	32	524	445.40
$17,622.41	2/24/00	140,250	30	505	429.25
$13,700.80	1/25/00	103,950	32	505	429.25
$16,573.76	12/24/99	125,400	30	544	462.40
$17,911.50	11/24/99	150,150	30	582	494.70
$18,971.93	10/25/99	155,100	31	582	494.70
$18,965.58	9/24/99	166,650	30	582	494.70
$17,161.89	8/25/99	152,450	28	582	494.70
$15,910.69	7/28/99	151,800	33	524	445.40
$16,786.30	6/25/99	143,350	30	563	478.55

Average kW Demand per month	Price per kWh including all charges
180.47	$0.13
194.79	$0.13
135.35	$0.13
174.17	$0.13
208.54	$0.12
208.47	$0.12
231.46	$0.11
226.86	$0.11
191.67	$0.10
199.10	$0.12

The information on the top of the table shows some designations that are used in determining what charges the Colegio is subject to. The power factor is shown which allows us to determine the kW demand from the kVA that is measured by the meter. The contracted load and rate designation is also shown as a contracted load of 650kVA and General Service at Primary Distribution Voltage or GSP designation respectively. If the Colegio uses more than this contracted load they are subject to very high fees. As seen in the Peak kVA column, these numbers are not greater than 650kVA, so the Colegio is not incurring these charges.

We wanted to determine the breakdown for each of the charges the Colegio is paying, and in order to do this we looked at the legal documents provided by PREPA to explain the rate GSP seen in Appendix E. Under the GSP contract the customer is subject to four charges: a Monthly Demand Charge, Monthly Energy Charge, Fixed Charge, and a Fuel Adjustment Charge.

The Monthly Demand Charge is comprised of three separate charges, and the Colegio is subject to whichever of these three charges is highest.

a. $8.10 per KVA of 60% of the contracted load
b. $8.10 per KVA of 60% of the maximum demand established during the 12 months that end with the current month.
c. $8.10 per KVA of the maximum demand during a period of 15 consecutive minutes during the month.

The contracted load is 650 kVA, and 60 percent of that load is 390 kVA. Charge A says $8.10 per kVA of 60 percent the contracted load, so:

Equation 1

$$(ContractedLoad\,0.60)\$8.10 = \$3,159.00$$

This rate remains constant until the contracted load changes. The second charge deals with the maximum kVA demand in the last twelve months. Because we could only receive data for the last ten months we used the most recent month and took the largest kVA demand for the previous ten months. As seen in the table, the largest kVA demand in the last ten months of the billing data was 582 kVA. Taking 60 percent of this number and multiplying it by the rate we have:

Equation 2

$$(Peak \rightarrow kVADemand \cdot 0.60)\$8.10 = \$2828.52$$

The third way to calculate the demand charge is to take the maximum kVA demand for a continuous fifteen-minute period in one month. Using 60 percent of the peak kVA documented in Table 8 and multiplying this by the rate determines this charge. This charge is clearly the most expensive of the demand charges and so every month the Colegio pays this amount. The table below shows each of the rates for the Demand Charge.

Table 8 Demand Charge, Colegio pays whichever charge A, B, C is highest

Day of Billing	Calculation of each demand charge, Colegio is subject to whichever is highest		
	Demand A	*Demand B*	*Demand C*
3/27/00	$3,159.00	$2,828.52	$4,244.40
2/24/00	$3,159.00	$2,828.52	$4,090.50
1/25/00	$3,159.00	$2,828.52	$4,090.50
12/24/99	$3,159.00	$2,828.52	$4,406.40
11/24/99	$3,159.00	$2,828.52	$4,714.20
10/25/99	$3,159.00	$2,828.52	$4,714.20
9/24/99	$3,159.00	$2,828.52	$4,714.20
8/25/99	$3,159.00	$2,828.52	$4,714.20
7/28/99	$3,159.00	$2,828.52	$4,244.40
6/25/99	$3,159.00	$2,828.52	$4,560.30

The second Charge is the Monthly Energy Charge; this is the charge per kWh consumed. It is calculated in a way that seems very confusing, however with the use of a table we hope to make the explanation as clear as possible. The charge is stated as:

a. 4.1 cents for each of the first 300 KWH of consumption per KW of the maximum monthly demand.

b. 3.3 cents per each KWH of additional consumption.

Part A of this charge says that for the first 300 kWh the rate is 4.4 cents. The charge under part A is calculated by multiplying the rate times the 300kWh times the kW demand, as seen below.

Equation 3

$$300 \cdot 0.041 \cdot Peak\_kWdemand = Charge\_A$$

Part B of the charge is found by taking the entire amount of kW's consumed and subtracting 300 from this value, this value is then multiplied by 3.3 cents to obtain that charge. Below is the formula that calculates part B of the energy charge.

Equation 4

$$(Total\_kW - 300) \cdot 0.031 = Charge\_B$$

The addition of these two charges makes up the complete Energy Charge; the table below shows the total charge the Colegio pays for energy consumption.

Table 9 The Energy Charge per month paid by the Colegio

Day of Billing	Calculation of Energy Demand Charge		Total Energy Charge Per Month
	Energy Demand A	*Energy Demand B*	
3/27/00	$5,478.42	$4,563.90	$10,042.32
2/24/00	$5,279.78	$4,618.35	$9,898.13
1/25/00	$5,279.78	$3,420.45	$8,700.23
12/24/99	$5,687.52	$4,128.30	$9,815.82
11/24/99	$6,084.81	$4,945.05	$11,029.86
10/25/99	$6,084.81	$5,108.40	$11,193.21
9/24/99	$6,084.81	$5,489.55	$11,574.36
8/25/99	$6,084.81	$5,020.95	$11,105.76
7/28/99	$5,478.42	$4,999.50	$10,477.92
6/25/99	$5,886.17	$4,720.65	$10,606.82

The Monthly Fixed Charge is the most straightforward of the four charges. This charge is $200 per month per customer.

After determining three of the four charges, and knowing the total amount billed, we will be able to calculate the Fuel Adjustment Charge. Subtracting the sum of the three known charges from the total bill gives the Fuel Adjustment Charge. The reason for not calculating the Fuel Adjustment Charge is because the Charge is based on the price of crude oil, the cost of refining, and other variables defined by PREPA based on power output, Power Factor, and maximum Demand. Because this charge is so difficult to calculate we find this value as a residual. The table below shows the total charges that amount to the total bill paid by the Colegio each month.

Table 10: Total cost and Charge breakdown per month

Month	Fuel Adjustment	Energy Charge ($ Per Month)	Fixed Charge ($ per month)	*Demand Charge ($ per month)*	Total Bill ($ per Month)
3/27/00	$3,610.79	$10,042.32	$200.00	$4,244.40	$18,097.51
2/24/00	$3,433.79	$9,898.13	$200.00	$4,090.50	$17,622.41
1/25/00	$710.07	$8,700.23	$200.00	$4,090.50	$13,700.80
12/24/99	$2,151.54	$9,815.82	$200.00	$4,406.40	$16,573.76
11/24/99	$1,967.44	$11,029.86	$200.00	$4,714.20	$17,911.50
10/25/99	$2,864.52	$11,193.21	$200.00	$4,714.20	$18,971.93
9/24/99	$2,477.02	$11,574.36	$200.00	$4,714.20	$18,965.58
8/25/99	$1,141.93	$11,105.76	$200.00	$4,714.20	$17,161.89
7/28/99	$988.37	$10,477.92	$200.00	$4,244.40	$15,910.69
6/25/99	$1,419.19	$10,606.82	$200.00	$4,560.30	$16,786.30

Electric Cost with Added Air-Conditioning

Now that the cost structure has been determined we can determine a similar cost breakdown for the Colegio with the expected air conditioning system factored in. The air-conditioning system will add a substantial load to the current system and as a result will add a significant increase in cost to the monthly bill. This increase in load will subsequently cause an increase in peak kVA. In order to make the Colegio's rates as low as possible and to prevent the Colegio from incurring added charges due to consuming over the current contracted load, the Colegio will have to change their contracted load. The present system has a contracted load of 650 kVA. This contracted load will have to be increased to at least 800 kVA in order to avoid added charges.

The air-conditioning system at maximum capacity will consume 157.375 kW. The air conditioning system will not be running at all times however, therefore we must determine the consumption per month based on how much it is expect to run. To begin with, the air conditioning system is only running during the day and during night classes. We assume the system to be running at maximum load from 11:00AM to 4:00PM every day of the week. From 7:00AM to 11:00PM and from 4:00AM to 8:00PM the system runs at 75 percent load. From 9:00PM to 6:00AM the system will be off. The system will also be off during weekends.

The system will be off approximately 10 days in a regular month for weekends. This leaves 20 days of operation. In 20 days there are 480 hours. The system is at maximum load for five hours a day or 100 hours per month. The system is at 75 percent load for eight hours a day or 160 hours per month. This leaves a remaining 220 hours where the system is not running or is at zero percent load. Multiplying the load by the hours at that load and summing gives the total kWh per month. The table below shows the calculations.

Table 11: Total kWh consumption per month of AC system

	Hours of operation at specified load	kW consumption at specified loads per month	kVA consumption at specified loads per month	kWh
75 percent	160	118.375	139.264	18940
100 percent	100	157.375	185.147	15737.5
0 percent	460	0	0	0
		Total kWh consumption per month =		34677.5

Now that we have calculated the kWh and kVA consumption we can start reevaluating the cost breakdown for PREPA. By adding the maximum kW demand, and kVA demand at 100 percent load, we can recalculate the peak kW and kVA. By multiplying the kW consumption by the amount of hours at each load, we found the additional consumption per month for the Colegio. Assuming the average price per kWh of 12 cents we can then determine how much the Colegio will have to pay each month with an air-conditioning system. The table below shows the revised costs and usages.

Table 12: New electrical bill with cost of air-conditioning

Colegio Tecnológico del Municipio de San Juan				Power Factor = .85	
Account # =	013-0377194-001				
Contract	GSP-Commercial District Primary, Contracted Load = 850 kVA				
Amount Billed	**Day of Billing**	**Consumed kWh**	**Days**	**Peak kVA**	**Peak kW**
$21,139.86	3/27/00	173,277.50	32	709.147	602.775
$21,341.16	2/24/00	174,927.50	30	690.147	586.625
$16,912.56	1/25/00	138,627.50	32	644.264	547.625
$19,529.46	12/24/99	160,077.50	30	729.147	619.775
$22,548.96	11/24/99	184,827.50	30	767.147	652.075
$23,152.86	10/25/99	189,777.50	31	767.147	652.075
$24,561.96	9/24/99	201,327.50	30	767.147	652.075
$22,829.56	8/25/99	187,127.50	28	767.147	652.075
$22,750.26	7/28/99	186,477.50	33	709.147	760.15
$21,719.36	6/25/99	178,027.50	30	748.147	635.925

As seem on the above table the contracted load was changed to accommodate the increase in kVA consumption. This is very important because the charge for going over the contracted load is $10 per kVA. In order to escape this extremely high penalty charge the Colegio will have to renegotiate their contracted load. The demand charges are calculated in the same manner as the Colegio's bill. These modified charges are shown below.

Table 13 Cost of each charge and total charge per month with air-conditioning

Month of Billing	Fuel Adjustment	Energy Charge ($ Per Month)	Fixed Charge ($ per month)	*Demand Charge ($ per month)*	Total Bill ($ per Month)
1	$2,073.37	$13,122.39	$200.00	$5,744.09	$21,139.86
2	$2,572.77	$12,978.20	$200.00	$5,590.19	$21,341.16
3	$193.42	$11,300.60	$200.00	$5,218.54	$16,912.56
4	$527.47	$12,895.89	$200.00	$5,906.09	$19,529.46
5	$2,025.13	$14,109.93	$200.00	$6,213.89	$22,548.96
6	$2,465.68	$14,273.28	$200.00	$6,213.89	$23,152.86
7	$3,493.63	$14,654.43	$200.00	$6,213.89	$24,561.96
8	$2,229.83	$14,185.83	$200.00	$6,213.89	$22,829.56
9	$1,312.46	$15,493.70	$200.00	$5,744.09	$22,750.26
10	$1,772.48	$13,686.89	$200.00	$6,059.99	$21,719.36

This total cost adjusted for air-conditioning is as accurate as it can be given the current estimations. The only part of the equation that may cause some inaccuracies is the amount of time the system is running and at what load. We decided on these numbers with the help of our liaison Elsie Candelaria.

Cost Paid to PREPA after Generator is Online

Once the Colegio begins to produce their own power, but remains connected to PREPA the Colegio becomes known as a co-generator. During times when the generator is not operating the Colegio will need to purchase power from the Authority. Due to the predictability of down time, the Colegio is able to pay PREPA a fee substantially less than under a contract that does not include co-generation. Most contracts specify the lowest rate possible, but we will use the standard rates defined under the SBS rate. This rate is known as Standby Service at Transmission or Primary Distribution Voltage. PREPA will supply the Colegio with power when it is needed at a varying load.

Under the SBS Rate the Colegio can request four different types of service: Supplementary Service, Auxiliary Service, Service for Maintenance, and Interruptible Service. Below each type of service is defined.

1. Supplementary service - This is the service required by the customer to supply load, which is in excess of customer's installed generation capacity.
2. Auxiliary Service – This is the service-required by the customer to supply the load normally served by his generating units, during forced outages of his equipment.
3. Service for Maintenance – This is the service required by the customer during defined periods of time equivalent to the maintenance period of this generating units, upon prior coordination with the Authority.
4. Interruptible Service – This service is provided to supply the customer's load under the condition that it will be subject to reductions or curtailments at the request of the Authority or to automatic interruption by under frequency relays, controlled by the Authority. This load shall be delivered only upon the availability of sufficient capacity in the Authority's generation and transmission system.

As seen from the rates defined above the Colegio would try to operate under the Service for Maintenance rate. Under certain cases when the generator goes down unexpectedly for whatever reason, the Colegio would be subject to Auxiliary Service that is a much higher rate.

Under the Service for Maintenance rate the Colegio would have to notify PREPA in advance of the expected length of down time, as well as the date when the generator would be down. This can be easily determined because the generators preventative maintenance is scheduled. During the scheduled down times PREPA would supply the Colegio with power. The charges for electricity during these down times are clearly defined by PREPA. The bill for the Service of Maintenance will be made up of four charges: Fixed Monthly Customer Charge, Monthly Fuel Adjustment Charge, Monthly Energy Charge, and Monthly Demand Charge.

The Fixed Monthly Customer Charge is taken from the general service rates of GSP or GST. The Colegio will be subject to the GSP or Primary Distribution Voltage rate because the GST rate is for industries that sell power to other industries. All of the charges are the same as the Colegio currently pays, however the amount of kW consumed is substantially less. The amount of peak kVA could still be the same unless maintenance on the engine was done on off hours, such as at night or on weekends. According to most generator dealers, it is not a problem for them to do maintenance on weekends. The reason for this is because many power-producing industries want preventative maintenance done on off hours to keep their charges down. This analysis will assume that all preventative maintenance will be done on weekends, except overhauls because these typically take 10 to 15 working days.

Every 250 hours of operation the engine will be down during off-peak for three hours. This means that the engine will be down for 8.64 hours per month. As for the overhaul time, we used a method exactly the same as was used in the section on diesel downtime and maintenance. The average amount of down time per year is equal to 314.643 hours. In order to calculate the number of hours on--peak and off-peak we must assume that the downtime for oil changes is off-peak. With these assumptions we can determine the number of kW consumed during this time. The average consumption during off-peak is 30kW, since the generator is down for three hours the number of kWh consumed for the downtime is 90kWh.

This number multiplied by the 36 oil changes per year makes a total consumption of 3,240 kWh per year.

As for the downtime for overhauls, these hours are just regular consumption hours that are made up of both on and off-peak hours. For this time we can assume the same kVA peak and kW demand as would exist without a power generator. It is important to calculate the consumption for this downtime. We assume that the Colegio has 16 hours per day of on-peak consumption. Per year the engine is down for overhaul an average of 15 days including one weekend. In one day there are 16 on-peak hours which means the total on-peak hours is found by:

Equation 5

$$16 \cdot \left(15 - 2_{off-peak\_weekends}\right) = 208 hours$$

Off-peak is then found by:

Equation 6

$$\left((24-16) \cdot 13\right) + 48_{weekend} = 152 hours$$

The average on-peak and off-peak demand is 549.63 kW and 30 kW respectively. By multiplying the demands by the hours of on and off-peak we find the total consumption in kWh per year as a result of overhaul downtime. These number are shown below:

Equation 7

$$off\_peak = 208hr \cdot 30kW = 6{,}240 \,{}^{kWh}\!/_{year}$$

Equation 8

$$on\_peak = 152hr \cdot 549.63kW = 83{,}543.76 \,{}^{kWh}\!/_{year}$$

By adding these two values we get a total consumption of 89,783.76 kWh per year due to overhauls. Added to this is the consumption due to oil changes, which makes the total consumption during down time for one year equal to 96,911.76kWh per year.

The cost of 96,911.76kWh per year can be found very easily using the average cost per kWh that we calculated from the bills. The rates under SBS use the same charges as the GSP rate, as long as the downtimes are scheduled. By taking the average 12 cents per kWh and multiplying the consumption by this rate we obtain a yearly expenditure of $11,629.94.

Estimated Off Peak Power Demand

To determine the demands of the Colegio we first estimated the power demand during off peak hours when the Colegio is closed. During off peak hours, the Colegio is shutdown and little power is consumed. All air-conditioning units are off, as well as lab equipment and computers. We assumed that the only power being used during off peak hours is from external lighting and refrigerator units. Elsie Candelaria, our liaison at the Colegio, informed us that the Colegio uses under ten percent of the on peak demand. To obtain a more accurate off peak power demand, we calculated the amount of power used by external lights. Once we determined the load from the outdoor lights we estimated the power consumption for refrigerators and any other small power consumption devices so we could have a total power demand during off peak hours.

We determined the power demand of the external lighting system by counting the two different types of lights and multiplying them by their respective power demand. The following table shows the number of each type of light fixture, the power rating of the fixture, and a total power demand due to the lights.

Table 14: External Lights

Number of Exterior Lamps at Colegio	Number of Tubes per Lamp	Watts per Tube from Exterior Lamps	Watts from Exterior Lamps	Number of Outdoor Fixtures	Watts per Outdoor Fixture	Watts from Exterior Lamps	Total Watts	Total kilowatts
134	2	36	9648	36	384	13824	23472	23.472

The estimated power demand during off peak hours from the external lights is 23.47 kW, which can be seen underlined in the above table. To take into account the power from refrigerators and other small power consuming items during the night, we rounded the power due to the lights to 30 kW. This 30 kW gives us the total power demand during the off peak hours.

Estimated On Peak Power Demand

From the electric bills of the Colegio, we were able to estimate the power consumption in kilowatt-hours (kWh) with air-conditioning. Multiplying the average consumed kWh per month by 12 months gave us an estimated consumption over a one-year period. This consumption was 2,005,157 kWh. Along with the total consumption, we had the off peak demand of 30 kW, which was determined in the previous section. The next step in our analysis was to determine the average on peak demand of the Colegio. For the analysis of a diesel engine, we assume that it would be running at an average on peak load during the normal operating hours at the Colegio. The average on peak demand occurs during the weekday hours of 6:00 AM to 10:00 PM, which is 16 hours per day. The total hours a year that the engine would be running at peak load would be 3360. The off peak demand occurs during all other times, which includes nights, weekends, and holidays. The number of hours a year that the engine would be running at off peak load would be 4896. The number of hours the engine would be running at on and off peak hours has been explained further in the "Cost Paid to PREPA after Generator is Online" section of this report.

Once we had the total consumption, the number of on and off peak operating hours of the engine, and the off-peak demand, we were able to solve the following equation for the average on peak demand.

Equation 9

$$CP\left(\frac{kWh}{year}\right) = O_fPT\left(\frac{hr}{year}\right) * O_fPD(kW) + O_nPT\left(\frac{hr}{year}\right) * O_nPD(kW)$$

$$2005156.75\left(\frac{kWh}{year}\right) = 4896\left(\frac{hr}{year}\right) * 4896(kW) + 3360\left(\frac{hr}{year}\right) * O_nPD(kW)$$

$$OnPeakDemand = 553.0586kW$$

$$\begin{aligned} &WHERE: \\ &CP = ConsumedPower \\ &O_nPT = On - PeakTime \\ &O_fPT = Off - PeakTime \\ &O_fPD = Off - PeakDemand \\ &O_nPD = On - PeakDemand \end{aligned}$$

We obtained 553.06kW as the average on peak power demand for the Colegio. From this demand we sized diesel engines and performed a variety of analyses. As mentioned previously, our estimated off peak demand was 30 kW. This demand is 5.42 percent of the average on peak demand and 4.60 percent of the peak demand. Since our liaison estimated that less than ten percent of the normal operating demand is used during off peak, we assumed that 30 kW was a reasonable estimate.

Solar Possibility

The project team calculated the total roof space available in squared feet. The total space may not all be usable, but it was an appropriate estimate that was used by solar energy contractors to size an energy system. A system that uses solar power is much more complex than the system that uses diesel. This is because solar power creates DC power which must be converted to 60 Hz AC with inverters. The cost of battery backups was also considered when looking at solar energy, as all solar systems require backup. In order to make a solar system cost effective, it is important to use high efficiency lighting and controls. Solar power data was obtained from contractors that perform installations so we could avoid determining the cost of each aspect of this alternative.

After we were on the Colegio campus, we calculated the area of roof space and the amount of sun that the area receives. As stated in our literature review, Puerto Rico has a very good potential for solar power. Our initial calculations showed approximately 70,000 square feet exist on the roof for solar panels. It should be mentioned that not all of this space is necessarily usable because structural concerns may be a factor.

Solar for the Colegio

The initial investment cost of solar power is very large, as we had originally estimated; however, it is important to realize that the operation and maintenance costs are low compared to other forms of energy. Other costs for other forms of electricity generation are fuel and maintenance, which solar has little. One main reason for this is the free source of fuel for solar panels, the sun. The maintenance costs are also very inexpensive compared to diesel generation.

We discussed solar cells in depth with an installer and contractor of ETS Technical House in San Juan. Jorge Denato, the owner of ETS, explained the many options that the Colegio could pursue in the way of renewable energy resources. The system that has worked best for him in the past is a combination of solar, wind, and a backup diesel generator. This system is powered completely by batteries that are charged by the three types of generation Denato said. The system would use a series of inverters that transfer the DC current of the solar and wind into 60htz AC. This current would then be distributed though the Colegio in the same manner that conventional power. The batteries would be supplying the power to the Colegio and the solar and wind generators would charge them. During times of high demand, the diesel generator would be used to charge the batteries. The generator could be controlled to turn on during the evening to charge the batteries or at times during the day when the expected battery charge is low. A processor that monitors each aspect of the system to determine the most effective and efficient way to manage the power distribution in the Colegio would control this entire system.

Denato also made it clear that the best way to optimize this system is to replace all the lights in the classrooms with high efficient lights that can save on current power demand. These types of additions are critical to making the solar power system more cost effective according to Denato. He also suggested installing motion sensors in the classrooms so that the lights would go off when the room is not in use. This would further save on electrical cost.

To replace all of the lighting in the school with the high efficiency lighting is going to cost $186,130. Denato estimated the cost to both buy and install the solar panels, and the backup generator. The backup Cummins 455 ekW diesel generator is going to cost $65,000.

The Solar portion of this alternative will produce 43.2 kW of electricity, and will cost $392,200. The table below shows the investment cost of the solar portion of the hybrid system. This alternative is also included in a cost analysis seen in the 'Solar Cost Analysis with Purchasing Additional Electricity from PREPA' table.

Table 15: Solar Investment Costs

Cost to revamp the system with high efficient lighting:	
Motion sensors for classrooms	$6,300.00
144 relays	$13,680.00
108 fixtures	$37,800.00
classroom light fixtures	$117,600.00
Outdoor fixtures	$7,000.00
Additional Equipment	$3,750.00
Subtotal lights =	$186,130.00
PV equipment	
PV panels installed with hardware	342,200.00
Additional hardware equipment and supplies	50,000.00
Subtotal PV =	392,200.00
Total cost=	$578,330.00

Diesel Engines

Overview of Diesel Generation Investigation

Some of the cost issues for diesel power generation were fuel, a fuel tank, fuel pipes, and housing for a generator, as well as the generator itself.

The type and amount of lubrication oil also was considered because this was a factor in fuel costs. The project team obtained price estimates from local fuel distributors such as Texaco and Exxon-Mobil. Diesel fuel price is dependent on the price of crude oil. Currently the price of crude oil is high. As the price of crude oil increases, the refined oil or NO. 2 diesel fuel the Colegio would use for generating electricity will also increase. We take this into account by using an escalation rate. This data is documented in our literature review and escalation rates for fuel prices were found from the Department of Energy.

The fuel must be stored in a tank whose cost was also estimated. In order to do this we obtain a proposal from the diesel fuel supplier Texaco, as well as Alonso & Carus Iron Works Inc. Because Texaco includes the fuel tank and delivery in the price per gallon, we used this number to remain consistent throughout our analyses. There was a lot to consider in the purchase of a fuel tank. Texaco supplies a tank under a contract of service, however other factors such as insurance for fuel spills and permitting were not investigated.

The engines we looked at to provide the Colegio with power were all similar in size and options. The size of diesel generators was nearly 800 kW. According to Kevin Donahue, a maintenance expert in the United States working for Detroit Diesel, if the engine is run at greater then 75 percent capacity, then the life of the engine will decrease while the cost of maintenance increases. All the engines have been prime operation, three-phase power generators. Prime generation means that the generator runs all the time continuously and can provide a varying load as described earlier.

The supply is 277/408 Volts at 60 Htz. Diesel generators have many standard options that are supplied with the generator quotations from engine distributors. Some of these options include coolant and engine oil heater for better starts, usually used on standby generators or generators operating in cold climates. Also included are fuel filters and a fuel tank. The day storage tank is supplied by the manufacturer and is usually small. For a generator operating at prime, an additional fuel tank is required because there are large volumes of fuel being burned. An important option for the Colegio is the exhaust silencer, which is also an option with generator sets. Since the generator would be installed close to the buildings at the Colegio, the generators we investigated must be as quiet as possible.

Diesel Engine Housing

To determine the investment cost of a diesel generator, one of the aspects of the system that was investigated was the housing for the system. Table 16 below illustrates the cost of housing for a diesel generator. There are four options for the housing of the generator. The buildings are soundproof and weatherproof. The housing is made from 14-gauge steel and can be fabricated from either stainless steel or galvanized steel. The costs are shown below along with insulation. The benefit of stainless steel over the galvanized steel is the stainless steel's resistance to corrosion. Generators that are positioned near the ocean are recommended to have stainless steal enclosures. The galvanized steel is just as strong as the other enclosure and if the generator is in a dry climate it is more affordable to use the galvanized enclosure. A plastic covering can also be purchased for protection of these steel housings. This enclosure provides no extra sound control, but it does offer added protection against corrosion and denting. This cover is $10 per foot to install and should cost between $750 and $800 dollars.

Ramon Delgado, who is the preferred contactor on the island for Cummins generators, provided us with all of these costs that can be seen in the table below.

Table 16: Diesel Engine Housing Prices

Housing type		Housing Cost ($)	Installation Cost ($)	Cost w/o Plastic	Plastic protective cover ($ / ft^2)	Building area (ft^2)		Protective Cost ($)		Total Cost ($)	
						$\leq$ 500 kW	650 kW	$\leq$ 500 kW	650 kW	$\leq$ 500 kW	650 kW
Sound proof	Stainless steel (G14)	$28,000	$5,000	$33,000	10	$740	$800	$7,400	$8,000	$40,400	$41,000
Sound proof	Galvanized Steel (G14)	$23,000	$5,000	$28,000	10	$740	$800	$7,400	$8,000	$35,400	$36,000

Installation Costs

In addition to housing costs, Ramon Delgado provided us with installation estimates for a generator set with all its components. Because the Colegio has three substations running at different kVA and current loads, Delgado suggests that the way to utilize one generator is to have the generator supply the main feeder line that supplies the three sub-stations. If this were not done then one generator would have to be purchased for each of the substations. Delgado says, it is also important to have three transfer switches, one for each of the sub-stations.

Transfer switches are used to select the electricity source, for example, if PREPA has a power outage, then the transfer switch will allow the generator to power the Colegio. Conversely, if the generator stops running, then the switch will use PREPA as its supply.

According to M&C electric, the installation can be done using a single transfer switch. Both installations will provide the same service, however, the cost will vary.

There are two places where the diesel engine can be placed. One place is the place originally stated in the literature review. The second place is near the meter room in the back of the Colegio near the student parking lot. Both places will be well suited for construction of the diesel generator. It was suggested by Delgado to place the engine closer to the meter room to reduce costs and M&C said it was better to have the engine closer to the substations outside.

According to Delgado, the main cost in supplies and installation comes from the feeder line that will run from the generator to the meter room. The feeder line must be buried, and encased in concrete and sand. The line itself is also very expensive; it is a 2,500-Ampere line, parallel three-phase connection. The installation also includes two distribution panels, the three transfer switches, one rated at 600 Amperes, one at 900 Amperes, and one rated at 1000 Amperes. The installation of the generator and with all the above accessories will cost $38,000 as quoted by Ramon Delgado, the preferred installer for Cummins.

Because of the discrepancies between the two installers and for the reason that the installation of the M&C quote was not broken down in detail, we will use the installation cost from M&C only for the engine they supplied. All other quotes we used Delgado's installation cost.

Generator Investment Costs

For this study, the investment costs that are included are the price of the generator set, installation, and housing for engine and fuel tank. An estimate of the wiring for the generator and installation is $38,000. We obtained this price from Ramon Delgado. His installation experience includes other installations for different manufacturers of diesel generators and he said his estimate for a generator could be used for any type of the generators with the standard options. The cost of the installation of the diesel tank and its housing will also be included in the investment cost. Overall investment cost of the diesel generator is not changed due to price of a fuel tank. The reason for this is that the diesel tank is included with the delivery of diesel fuel for a contracted amount of time by Texaco.

The determination of the investment cost for one diesel engine is described in the following paragraphs for a Cummins engine. The generator set is rated at a 1250 kW, 1100 ekW, 1563 kVA, and it is a three-phase system that could produce 1692 Amperes. This set comes with a main 2000-Ampere breaker panel with digital meters, two mufflers to dampen exhaust noise, radiator and coolant heater, twelve vibration isolators, and a 1000-gallon fuel tank. This generator set, not unloaded, was quoted at $165,000. This quote includes most of the options that other engine dealers provide and the prices are similar to each other.

The following table illustrates the total investment cost for a variety of diesel generators that we have investigated for this project.

Table 17: Investment Cost of Diesel Engines

Tank housing and Protective Dike Cost =	$1,400

Engine Distributor	Cummins
Power Rating (ekW)	1100
Power Rating (kVA)	1375
Generator & Parts ($)	$165,000
Installation ($)	$38,000
Tank Housing ($)	$1,400
Subtotal:	$204,400
Housing Stainless ($)	$33,000
Total Cost:	$237,400
Housing Galvanized ($)	$28,000
Total Cost:	$232,400
Housing Stain w/ Plastic ($)	$40,400
Total Cost:	$244,800
Housing Galv w/ Plastic ($)	$35,400
Total Cost:	$239,800
High Investment Cost ($) =	$244,800

Engine Distributor	Onan (West India)
Power Rating (ekW)	1100
Power Rating (kVA)	1375
Generator & Parts ($)	$159,500
Installation ($)	$38,000
Tank Housing ($)	$1,400
Subtotal:	$198,900
Housing Stainless ($)	$33,000
Total Cost:	$231,900
Housing Galvanized ($)	$28,000
Total Cost:	$226,900
Housing Stain w/ Plastic ($)	$40,400
Total Cost:	$239,300
Housing Galv w/ Plastic ($)	$35,400
Total Cost:	$234,300
High Investment Cost ($) =	$239,300

Engine Distributor	Onan(West India)
Power Rating (ekW)	900
Power Rating (kVA)	1125
Generator & Parts ($)	$149,500
Installation ($)	$38,000
Tank Housing ($)	$1,400
Subtotal:	$188,900
Housing Stainless ($)	$33,000
Total Cost:	$221,900
Housing Galvanized ($)	$28,000
Total Cost:	$216,900
Housing Stain w/ Plastic ($)	$40,400
Total Cost:	$229,300
Housing Galv w/ Plastic ($)	$35,400
Total Cost:	$224,300
High Investment Cost ($) =	$229,300

Engine Distributor	Caterpillar
Power Rating (ekW)	820
Power Rating (kVA)	1025
Generator & Parts ($)	$127,650
Installation ($)	$38,000
Tank Housing ($)	$1,400
Subtotal:	$167,050
Housing Stainless ($)	$33,000
Total Cost:	$200,050
Housing Galvanized ($)	$28,000
Total Cost:	$195,050
Housing Stain w/ Plastic ($)	$40,400
Total Cost:	$207,450
Housing Galv w/ Plastic ($)	$35,400
Total Cost:	$202,450
High Investment Cost ($) =	$207,450

Engine Distributor	Cummins
Power Rating (ekW)	818
Power Rating (kVA)	1023
Generator & Parts ($)	$128,800
Installation ($)	$38,000
Tank Housing ($)	$1,400
Subtotal:	$168,200
Housing Stainless ($)	$33,000
Total Cost:	$201,200
Housing Galvanized ($)	$28,000
Total Cost:	$196,200
Housing Stain w/ Plastic ($)	$40,400
Total Cost:	$208,600
Housing Galv w/ Plastic ($)	$35,400
Total Cost:	$203,600
High Investment Cost ($) =	$208,600

Engine Distributor	Cummins
Power Rating (ekW)	455
Power Rating (kVA)	570
Generator & Parts ($)	$65,000
Installation ($)	$38,000
Tank Housing ($)	$0
Subtotal:	$103,000
Housing Stainless ($)	$0
Total Cost:	$103,000
Housing Galvanized ($)	$0
Total Cost:	$103,000
Housing Stain w/ Plastic ($)	$0
Total Cost:	$103,000
Housing Galv w/ Plastic ($)	$0
Total Cost:	$103,000
High Investment Cost ($) =	$103,000

Other Concerns with Diesel Engines

All diesel generators that operate at 1800 rpm's cannot run below 30 percent. If they run below 30 percent the engine life will greatly decrease. All of the engines that we are looking at cannot operate at night because every generator we are studying will produce far too much electricity at 30 percent for the Colegio to consume during these off peak hours.

Miguel Hernandez from Caterpillar explains that the reason that the engine cannot go below 30 percent is because it would have unburned fuel in the cylinder that would ignite in the wrong cycle. On the second cycle when the piston compresses, the air/fuel mixture in the cylinder would ignite and it would not drive the piston. This manifold is open in this cycle, and so the blast will go through the exhaust causing a loud bang, and damages the engine.

Any engine that we have looked at cannot be run at night because the engine would be damaged. For all our analyses, we operated the diesel engines during on peak hours and the electricity was purchased from PREPA during the night.

Estimated Diesel Engine Downtime and Price of Maintenance

We called the Detroit Diesel Corporation in Florida to get prices on maintenance costs of the diesel generator for which we received quotes. We did receive a verbal estimate on the maintenance cost for a 500 kW prime generator.

A V12-2000 engine drives a 500 kW prime operation generator. We looked at the cost of the oil, oil filter, and fuel filter change that were lumped together for this particular generator as a single cost. We also looked at the cost of a complete overhaul.

Kevin Donahue from Detroit Diesel of Florida estimated that it would cost $400 every 250 hours to replace the oil and filters of the 12V-2000 engines. This process would take five hours, and three of these hours would cause downtime where the Colegio would have to purchase power from PREPA. The three hours of downtime is the time the generator would not be running. The school would have to purchase power for three hours every 250 hours of running this diesel generator. The added two hours are for maintenance purposes only. While the engine is running the old oil must be disposed of and various checks must be performed on the engine while it is running.

Replacing the oil and filters would take place about three times every month and each month the cost would be about $1,200, which is about $14,400 to change the oil and filters for one year. The downtime will be 108 hours and during this time the Colegio will have to buy power.

A complete overhaul on this engine will cost about $30,000. The overhaul, according to Kevin Donahue, would take 10 to 15 working days to complete, and would have to take place every 10,000 hours. The overhaul includes the changing of belts, and air filters as a standard procedure in the cost of the overhaul.

The overhaul will not take place every year. In a year there are 8,760 hours. From 8,760 hours the time it takes to perform the oil changes every year must be subtracted, the result is 8,652 hours of running time per year. Since the overhaul takes 10 to 15 working days to complete, time out of each year also needs to be deducted from the yearly running time. Every 1.1416 years the generator will be down for an overhaul. The generator will be down for about 360 hours during an overhaul. That time divided by 1.14155 will give an average of 315.36 hours of downtime each year for overhauls. To find the total time the generator will be running each year we took the running time with oil changes and subtracted the down time due to overhauls per year to find the total running time per year. The number that was calculated was 8336.64 hours of running time per year for the generator. The overhaul will cost $30,000 total, but will average yearly less than this amount. The annual cost of an overhaul will be the ratio of running hours per year to that of the amount of running hours between overhauls. This will be:

Equation 10

$$\$30{,}000\left(\frac{8{,}336.64}{10{,}000}\right) = \$25{,}009.92 \text{ per year}$$

Taking the cost of the overhaul and adding the cost of the oil and filter change gave us the total cost for maintenance for a year of running the engine generator. The total cost of maintenance for the 500 kW engine for the first year would be $39,409.92 on average.

Maintenance Cost Adjustment

The maintenance operations and maintenance costs data that we have obtained was for an engine of power rating 500 kW. The data that we had for maintenance stated that every 250 hours, oil and filter changes were required. In addition to preventative maintenance, an overhaul of the engine less than once a year was required. The maintenance cost that we determined was for an engine running constantly for all hours per year. The cost per year to maintain the engine was calculated for oil and filter changes and yearly overhaul.

Since most of the engines that we have used in our final cost analyses were larger than 500 kW, we needed to adjust the yearly cost of maintenance. For the larger engines of 800 kW and 1100 kW, M&C Electric, a Perkins engine distributor, and Cummins of Puerto Rico have informed us that engines of larger size must also have preventative maintenance for every 250 hours of engine operation. We were not able to obtain the cost for the preventative maintenance or overhauls for the larger engines; therefore, we multiplied the yearly maintenance cost of the 500 kW engine by an assumed cost increase percentage.

We did not feel that if an engine power rating doubled in size that the resulting maintenance cost would also double. Therefore we formed the following table that shows the percentage increase of yearly maintenance cost for a variety of engine power ratings. The first column represents the size of the engine that we have more closely investigated. The second column displays the increased power percentage above a 500 kW engine. The last column represents the percentage maintenance cost increase.

Table 18: Maintenance Increase per Generator Set Size

Engine Size (KW)	Percentage Increase Over 500 kW Engine	Maintenance Price Increase Over 500 kW Engine
820	39.0%	20%
900	44.4%	28%
1100	54.6%	40%

In the life cycle cost analysis tables found in the "Cost Analysis" chapter of this report, the increased maintenance cost due to increased engine size can be found. The percentage increase was then multiplied by the 500 kW maintenance cost and added to the original 500 kW maintenance cost in order to get an increase of the assumed percentage. The following equation was used.

Equation 11

$$C_M = C_{M-500kw} * (1 + P)$$

Where: C_M = Cost of Maintenance for Larger Engine
$C_{M\text{-}500kW}$ = Cost Maintenance for 500 kW Engine
P = Percentage Maintenance Cost Increase

Maintenance Adjustment for Operating Engine Only at On Peak Hours

Once we obtained the maintenance cost for an engine at all hours, we needed to adjust the cost if the engine was only running during peak hours. The number of on peak hours that an engine would run was 80 hour per week. Since the total hours in a week are 168, we determined the proportion of hours the engine would run during on peak compared to all the time. This proportion was the following.

Equation 12

$$P = \frac{On - Peak\_Time\_Per\_Week}{Total\_Time\_per\_Week}$$

$$P = \frac{80}{168}$$

$$P = 0.467$$

Where: P = The proportion of on peak hours in week to the total hours in week

Since the maintenance hours and costs are directly related to the hours the engine is operation, we multiplied the yearly maintenance cost for running an engine at all hours by the above proportion P.

Diesel Engine Power Ratings

Each engine has three power ratings. These power ratings are measured in kVA, ekW, and kW. The power rating kVA stands for apparent kilovolts. Generally, the power authority measures the peak power demand uses in kVA. The ekW stands for effective kilowatts. The effective power rating is the power that is given to the system under continuous load. The last power rating, kW or kilowatts, is the peak output that is supplied when a spike in power use occurs. This peak output is only generated for a short time and cannot be maintained continuously. Most engines will measure the peak output by measuring the short circuit voltage for a time of ten minutes. The current is not a concern in this measurement because the transfer switch supplied with the generator can withstand this large current.

To determine the appropriate engine for the Colegio, we needed an engine that could supply the average on peak demand at a continuous rate. As a result, we used the effective kilowatts power rating of each engine to determine if an engine could supply the necessary power. Also, from the ekW rating, we determined the corresponding maximum power output, kW, the kVA power rating, the fuel consumption of different generators at different loads, as well as the maximum and minimum target load. The calculation of these variables is explained further in the following paragraphs and the results are shown in Table 19.

The specification sheets of each engine supplied us with the maximum kW output and the maximum ekW output, which is used for continuous loads. From these two power ratings, we were able to calculate the peak percent output. The peak percent output is calculated by the following formula:

Equation 13

$$PeakPercentOutput = \frac{(PeakOutput - EffectiveOutput)}{EffectiveOutput}$$

We used the peak percent output to calculate the peak output at different effective output ratings. In simple terms, this measurement in percent explains the amount of power the engine can supply over its normal output. This is important when discussing large air-conditioning units that require large voltages to start. An example of a peak percent output can be seen in the following expression for the Cummins 1250 kW / 1100 ekW engine.

Equation 14

$$PeakPercentOutput = \frac{(1250kW = 1100ekW)}{1100ekW}$$

$$PeakPercentOutput = 13.64\%$$

The peak percent output and the different power ratings of the engines that we investigated can be seen in the tables at the end of this section.

To convert from the kVA of a diesel engine to kW, the equation below was used.

Equation 15

$$y = 0.80 * x$$

Where:

y = The value in kVA
x = The value in kW
0.80 = The Power Factor for Diesel Engines

The power factor for a diesel engine is 0.80 due to the design and physical characteristics of an engine. For each diesel engine we investigated, a power factor of 0.80 was given in the engine specifications. For all the varying loads at which the engine may operate, we took the ekW rating and divided it by 0.80 to obtain the kVA rating. The corresponding ratings can again be seen in Table 19. An example of this conversion can be seen in the following calculation of Cummins 1100 ekW engine.

Equation 16

$$P_{kVA} = \frac{1100ekW}{0.8}$$

$$P_{kVA} = 1375kVA$$

Where: P_{kVA} = Peak kilovolts Apparent
1100 = Power Rating in effective kilowatts
0.8 = Power Factor for Diesel Engines

For all other engines, the same method was also used. We were given the power rating in ekW and the power factor, therefore we were able to solve for the unknown kVA value. The reason that we needed a conversion from kVA and kW is that engines are sometimes supplied in one or the other. Also, the power company PREPA often measures electricity in kVA so we wanted to be consistent through out all our calculations.

Engine Load Percentage to Meet On Peak Demand at the Colegio

We obtained the percentage that each generator would need to run to supply the necessary on peak average demand with air-conditioning at the Colegio of 549.63 ekW. The average demand for the Colegio was determined from the PREPA electric bills, which has been explained in further detail in the section "Estimating Power Demand". The percentage that the engine would be needed to run to supply the Colegio was calculated by dividing the average required load of the Colegio by the effective power rating (ekW) of each specific engine. Below is an example of the calculation of the percentage load required for the Cummins 1100 ekW engine.

Equation 17

$$L = \frac{ColegioDemand(kW)}{MaxSupplyfromEngine(ekW)}$$

$$L = \frac{549.63kW}{1100eKW}$$
$$= 49.27\%$$

Where L = Percentage Load of the engine needed to run the Colegio's power needs

The second to last column in Table 19 shows what percentage of the average on peak demand that an engine is producing at different loads. The Cummins 1100 ekW engine runs at 49.27 percent to produce the average on peak demand of 549.63kW, which was determined in the last equation. Now, looking at the second to last column in the power ratings table, we see that when the engine is running at 49.27 percent, the engine is producing 100 percent of the average on peak demand. To determine the percentage of the on peak demand produced at a given engine load, we divided the average on peak demand of the Colegio by the power rating of the engine at the given load. As another example for the Cummins 1100 ekW engine, when it runs at 75 percent, it produces 185 percent of the average on peak demand. This was determined by the following expression.

Equation 18

$$P_{AVG} = \frac{OnPeakAverageDemand}{PowerRatingofEngine}$$

$$P_{AVG} = \frac{553kW}{825ekW}$$

$$P_{AVG} = 185.04\%$$

Where: P_{AVG} = Percent of Average On Peak Demand Supplied by Engine at Specific Power Rating

The last column in Table 19, the power ratings table, is similar to the second to last column. The difference is that that last column represents the percentage of the maximum instead of the average demand that an engine can produce at a given power rating. Using the Cummins 1100 ekW engine again, and at an engine load of 50 percent, we obtain that the engine is producing 84 percent of the maximum demand of 652 kW. This is done by the following equation.

Equation 19

$$P_{MAX} = \frac{PeakDemnd}{PowerRatingofEngine}$$

$$P_{MAX} = \frac{652.1kW}{550ekW}$$

$$P_{MAX} = 84.35\%$$

Where: P_{MAX} = Percent of Peak Demand Supplied by Engine at Specific Power Rating

An important value that we used to size a generator for this project was the percentage that an engine would run to meet the average on peak demand. In Table 19, the row that is highlighted in blue illustrates the specifications of the engine that will supply the Colegio with the average on peak demand. Similarly, there is a column highlighted in red, which represents the engine running at certain load to meet the minimum demand of the Colegio during off peak hours. A final row is highlighted in green. This row represents at what percentage an engine must run to meet the peak demand that the Colegio may reach. If an engine must run at 110 percent in this row, then it is not capable of producing the peak demand of the Colegio even if it may meet the average on peak demand.

Engine Load Percentage to Meet Off Peak Demand of the Colegio

After discussing the power issue with our Liaison Elsie Candelaria, we determined that the power load at night, when the Colegio is shutdown, is significantly lower than the maximum demand during open school hours. Most equipment including air-conditioning is shutoff when the school is not in operation, and as a result, the power consumption is less. With the assistance of our liaison, we estimated that less than 10 percent of the Colegio's maximum demand must be supplied during the off peak hours. As described earlier, the off peak demand with air-conditioning is 30 kW. We calculated each engine to meet 30 kW, which is the average off peak demand. We did this by dividing the low load required by the Colegio by the maximum effective kilowatt output of the engine. This gave us the percentage at which the engine would need to be run to meet the low demand. An example of the calculation of this percentage can be seen in the following equation for the Cummins 1100 ekW engine.

Equation 20

$$PL = \frac{LowDemandofColegio}{MaximumEffectiveSupplyofEngine}$$

$$PL = \frac{30kw}{1100ekW}$$

$$PL = 2.73\%$$

Where: PL = Percentage that the engine must run to meet off peak demand of Colegio

This technique was used for other engines as well.

The following table illustrates the data discussed in the previous section on diesel engine power ratings. The table shows a variety of diesel engines and their operating characteristics at different loads.

Table 19: Diesel Engine Varying Power Ratings and Characteristics

The Load value in BLUE represents the percentage that a specific engine must be run at to supply the Colegio with the Average On Peak Demand of 549.6 kW of power
The Load value in RED represents the percentage that a specific engine must be run at to supply the Colegio with the Minimum Demand during off peak hours
The Load value in Green represents the percentage that a specific engine must be run at to supply the Colegio with the Peak Demand of 652 kW

Colegio Demand

Average Off Peak Demand (kW) =	30.0
Average On-Peak Demand (kW) =	549.630
Peak Demand with AC (kW)=	652.075

Cummins 1250 kW, 1100 ekW, 1375 kVA

Power Factor = 80.0%

Peak Percent Output = 13.64%

Engine Load	Power Rating (kW)	Power Rating (ekW)	Power Rating (kVA)	Fuel Consumption (Gal/hr)	Percent of Colegio's Average Power Supplied at Given Loads	Percent of Colegio's Peak Power Supplied at Given Loads
25.00%	312.5	275.0	343.8	26.4	50.03%	42.17%
50.00%	625.0	550.0	687.5	41.1	100.07%	84.35%
75.00%	937.5	825.0	1031.3	56.5	150.10%	126.52%
100.00%	1250.0	1100.0	1375.0	72.3	200.13%	168.69%
49.97%	624.6	549.6	687.0	41.1	100.00%	80.00%
2.73%	34.1	30.0	37.5	4.6	5.46%	4.60%
59.28%	741.0	652.1	815.1	46.8	118.64%	100.00%

Onan (West India) 1250 kW, 1100 ekW, 1563 kVA

Power Factor = 80.0%

Peak Percent Output = 13.64%

Engine Load	Power Rating (kW)	Power Rating (ekW)	Power Rating (kVA)	Fuel Consumption (Gal/hr)	Percent of Colegio's Average Power Supplied at Given Loads	Percent of Colegio's Peak Power Supplied at Given Loads
25.00%	312.5	275.0	343.8	26.4	50.03%	42.17%
50.00%	625.0	550.0	687.5	41.1	100.07%	84.35%
75.00%	937.5	825.0	1031.3	56.5	150.10%	126.52%
100.00%	1250.0	1100.0	1375.0	72.3	200.13%	168.69%
49.97%	**624.6**	**549.6**	**687.0**	**41.1**	**100.00%**	**80.00%**
2.73%	**34.1**	**30.0**	**37.5**	**4.6**	**5.46%**	**4.60%**
59.28%	**741.0**	**652.1**	**815.1**	**46.8**	**118.64%**	**100.00%**

Onan (West India) 990 kW, 900 ekW, 1125 kVA

Power Factor = 80.0%

Peak Percent Output = -21.78%

Engine Load	Power Rating (kW)	Power Rating (ekW)	Power Rating (kVA)	Gas Consumption (Gal/hr)	Percent of Colegio's Average Power Supplied at Given Loads	Percent of Colegio's Peak Power Supplied at Given Loads
25.00%	176.0	225.0	281.3	23.4	40.94%	34.51%
50.00%	352.0	450.0	562.5	36.6	81.87%	69.01%
75.00%	528.0	675.0	843.8	50.1	122.81%	103.52%
100.00%	704.0	900.0	1125.0	63.3	163.75%	138.02%
61.07%	**429.9**	**549.6**	**687.0**	42.3	**100.00%**	**80.00%**
3.33%	**23.5**	**30.0**	**37.5**	4.4	**5.46%**	**4.60%**
72.45%	**510.1**	**652.1**	**815.1**	48.6	**118.64%**	**100.00%**

Caterpillar 900 kW, 820 ekW, 1025 kVA

Power Factor = 80.0%

Peak Percent Output = 10.00%

Engine Load	Power Rating (kW)	Power Rating (ekW)	Power Rating (kVA)	Gas Consumption (Gal/hr)	Percent of Colegio's Average Power Supplied at Given Loads	Percent of Colegio's Peak Power Supplied at Given Loads
25.00%	225.5	205.0	256.3	17.90	37.30%	31.44%
50.00%	451.0	410.0	512.5	32.90	74.60%	62.88%
75.00%	676.5	615.0	768.8	46.90	111.89%	94.31%
100.00%	902.0	820.0	1025.0	61.80	149.19%	125.75%
67.03%	**604.6**	**549.6**	**687.0**	**42.43**	**100.00%**	**80.00%**
3.66%	**33.0**	**30.0**	**37.5**	**2.87**	**5.46%**	**4.60%**
79.52%	**717.3**	**652.1**	**815.1**	**49.47**	**118.64%**	**100.00%**

Cummins 900 kW, 818 ekW, 1023 kVA

Power Factor = 80.0%

Peak Percent Output = 10.02%

Engine Load	Power Rating (kW)	Power Rating (ekW)	Power Rating (kVA)	Gas Consumption (Gal/hr)	Percent of Colegio's Average Power Supplied at Given Loads	Percent of Colegio's Peak Power Supplied at Given Loads
25.00%	225.0	204.5	255.6	12.7	37.21%	31.36%
50.00%	450.0	409.0	511.3	27.9	74.41%	62.72%
75.00%	675.0	613.5	766.9	40.0	111.62%	94.08%
100.00%	900.0	818.0	1023.0	54.6	148.83%	125.45%
67.19%	**604.7**	**549.6**	**687.0**	**36.2**	**100.00%**	**80.00%**
3.67%	**33.0**	**30.0**	**37.5**	**0.6**	**5.46%**	**4.60%**
79.72%	**717.4**	**652.1**	**815.1**	**42.5**	**118.64%**	**100.00%**

Fuel

Natural Gas

Before arriving at the Colegio we were unable to determine the availability of natural gas on the island. We researched the possibility of using natural gas extensively during the background research for this project. However, natural gas is not available commercially in San Juan. As a result, the project team eliminated natural gas combined cycle systems and fuel cells as viable options for alternate energy.

Liquid Petroleum Gas

Liquid Petroleum Gas (LPG) is a type of fuel that is similar to Liquid Natural Gas (LNG). LPG is stored under pressure in a liquid form. LPG is made up of propane and has other fuels mixed in with it. These other fuels include butane and depending on the manufacturer a number of other fuels in small quantities. LPG is typically of more expensive than diesel fuel. One reason for this is that ten percent more LPG must be burned in order to create the same number of BTUs as diesel fuel. The transport and storage is also much more costly. In order to make the use of LPG cost effective, large quantities must be used in highly efficient gas turbines or combined cycle systems. It is also not cost effective to have this fuel trucked to the site, but better to have a dedicated pipe line. For these reasons, LPG is not a good option for the Colegio. Other issues that were not apparent before we arrived to Puerto Rico were the safety and reliability issues that are associated with the company that controls distribution of LPG on the island, San Juan Gas. Numerous people on the island, such as our liaison Elsie Candelaria and Carlos Cruz from Caribe Detroit Diesel-Allison, expressed concern when we discussed dealing with the local gas company on the island.

Diesel Fuel

When operating a generator set of approximately 800 kW, a large tank is needed to store the fuel. Each different engine has a unique fuel consumption rate. For the purpose of selecting a tank size, we took the average consumption for a variety of generator sets. Assuming a generator that consumes between 30 and 40 gallons per hour at prime power rating, we were able to obtain quotations of fuel prices from Texaco. The quotation given to us by Texaco was $1.022 per gallon. Under a contract with Texaco, the cost included the delivery of the diesel fuel and fuel tank.

<u>Diesel Fuel Consumption by Engines</u>

We wanted to calculate the percentage that each engine would be run and the fuel consumption to meet the Colegio's power needs. This data can be seen in Table 19. Once we had determined the percentage that each engine would run to meet the low and on peak average demand of the Colegio, we were able to estimate the fuel consumption per year. The reason why we needed the low power demand is that at nights and weekends, the Colegio would be using a constant amount of electricity that is the low of the school. We also determined the average on peak demand, which varies during a weekday. We used the specifications given by each engine on fuel consumption. Depending on the load of the engine, the engine burns a different amount of fuel. Table 19 displays the fuel consumption for each engine at the varying loads in gallons per hour. For example, the Cummins 1100 ekW engine burns 72.3 gallons per hour at 100 percent load and 41.1 gallons per hour at 50 percent load. Also, since we calculated the percentage load that the engine would run at for the on peak hours and the off peak hours, we displayed the fuel consumption at these two respective loads. These hourly fuel consumptions were then used to estimate the yearly fuel consumption used by each engine.

Since we had the fuel consumption in gallons per hour, we were able to estimate the diesel fuel used in gallons per year. Again, with the assistance of Elsie Candelaria, we estimated that from 6:00 AM to 10:00 PM each weekday, or 16 hours per weekday, the Colegio would have the potential to be running at maximum load. The power demand of the school was estimated to be the average on peak demand during these hours; therefore, the engine would supply the entire school. These 16 hours of peak power demand were used, and can be seen in the fuel consumption tables for each engine. The fuel consumption per gallon for the on and off-peak hours can also be seen in these tables. An example of the fuel consumption for on-peak hours was 41.1 gallons per hour for the Cummins 1100 ekW diesel engine. The on and off-peak hour fuel consumption rates were determined and described in the Diesel Engine Power Ratings section. For all times that did not fall into the peak demand hours, we used the low fuel consumption rate of each engine. Low power demand times included weekends, weekday hours from 10:00 PM to 6:00 AM, or 8 hours, and days when the school was not open. An example of the fuel consumption for off-peak hours was 4.6 gallons per hour for the Cummins 1100 ekW diesel engine.

The next step in the analysis of fuel consumption was to determine the amount of hours per year that the Colegio was operating. We obtained the number of hours per year that the engine would be running for on and off peak hours without any downtime hours for maintenance. These hours, along with the downtime hours were determined and explained in the "Cost Paid to PREPA after Generator is Online" section of this report. The number of total on and off-peak hours would be 3600 and 5160 hours per year, respectively. We also needed the number of hours that the engine would not be operating because of maintenance. The number of on and off peak hours that the engine would be off would be 208 and 466.643 hours per year, respectively.

Once we had the hours that the engine would be down due to maintenance, we were able to find the number of running hours for both on peak time and off peak time. This is shown in the equations below.

Equation 21

$$3600\left(\frac{SchoolHoursOn-Peak}{Year}\right)-208\left(\frac{On-PeakHours}{Year_{for}Downtime}\right)=3392\left(\frac{On-PeakOpperation}{Year}\right)$$

Equation 22

$$5160\left(\frac{SchoolHoursOff-Peak}{Year}\right)-466\left(\frac{Off-PeakHours}{Year_{for}Downtime}\right)=4694\left(\frac{Off-PeakOpperation}{Year}\right)$$

After determining the number of hours per year at both on and off peak demand, we calculated the total number of gallons used by the engine per year. Depending on the engine, there was different fuel consumption per hour at each high and low demand. As mentioned previously, the fuel consumption for on and off peak for the Cummins 1100 ekW engine was 41.1 and 4.6 gallons per hour respectively. To determine the gallons per year used at each load, we multiplied the total number of hours by the fuel consumption. An example of this can be seen in the following calculation for the Cummins 1100 ekW engine.

Equation 23

$$41.1\frac{\text{gallons}}{\text{hour}}*3392\frac{\text{hour}}{\text{year}}=139411.2\frac{\text{gallons}}{\text{year}}\text{Due to On Peak}$$

Equation 24

$$4.6\frac{\text{gallons}}{\text{hour}}*4694\frac{\text{hour}}{\text{year}}=21592.4\frac{\text{gallons}}{\text{year}}\text{Due to On Peak}$$

The total gallons used in a year for this Cummins 1100 ekW engine was 207004.8 gallons. The last step in our fuel consumption tables was to multiply each year's fuel consumption by the price per gallon of fuel at each year. Since the fuel price had an escalation rate, the fuel price each year went up while the same number of gallons was used to produce electricity by the engine.

Power Outputted by Engine

In addition to fuel consumption and price, the tables at the end of this "Fuel Consumption by Engine" section display the total kilowatt-hours (kWh) outputted by the engine, including on and off peak. To obtain the number of kWh, we found the kWh outputted during on and off peak separately and then added the two together. We calculated the number of kWh outputted during on and off peak outputted by multiplying the power demand at on and off peak by the number of hours the engine would run at during their respective peaks. The following equation displays the calculation.

Equation 25

$$On-Peak \quad 3{,}392hrs(549.6kW)=1{,}864{,}243.2kW$$

Equation 26

$$Off-Peak \quad 4{,}694hrs(30kW)=140{,}820kWh$$

Finally, we added the outputs during on peak and off peak to obtain a total of 2,005,156.75 kWh. This kWh output is equal to the total consumption that would have to be paid for if the Colegio purchased all its electricity; therefore, the engine would supply all the necessary power.

Fuel Consumption for On Peak Generator Only

To perform a cost analysis and a fuel consumption analysis on an engine that would only operate during the on peak hours, we set the number of off peak hours of engine output to zero, along with the fuel consumption rate and the number of off-peak hours. The result of this gave the total number of power consumed, the gallons used, and the total cost of the fuel per year. The fuel cost for each year was then inputted into the cost analysis table as it was for all diesel engine analysis. The result of only operating the engine during on peak hours reduced the number of gallons per year as well as the cost of fuel per year. All the engines we studied could not supply the off-peak demands without running below 30 percent, so we performed all cost analyses on generators running on on-peak hours only.

Table 20: Fuel Consumption for Caterpillar 1100 ekW Producing All Power, Assuming Off-Peak Operation is Possible

Fuel Escalation Rate =	3.50%
Initial Price ($/gallon) =	$1.02
Average On-Peak Demand (kW) =	549.6275796
Average Off-Peak Demand (kW) =	30

Total Running Time per Year of Engine (hr) =	8336.64
Downtime during On Peek periods (hr) =	208
Downtime during Off Peek periods (hr) =	466

Year	Peek Running time per day (hr)	Off Peek Running time per day (hr)	Price for Fuel ($/gal)	Fuel consumption per hour peak (Gal/hr))	Fuel Consumption per hour off Peek (Gal/hr)	School days per year	Off Peek hours per year	On Peek hours per year	Power Consumption in a year (kW-H)	Gallons used in a year	Fuel cost per year
1	16	8	$1.022	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$164,363.92
2	16	8	$1.058	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$170,116.66
3	16	8	$1.095	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$176,070.74
4	16	8	$1.133	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$182,233.21
5	16	8	$1.173	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$188,611.38
6	16	8	$1.214	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$195,212.77
7	16	8	$1.256	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$202,045.22
8	16	8	$1.300	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$209,116.80
9	16	8	$1.346	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$216,435.89
10	16	8	$1.393	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$224,011.15
11	16	8	$1.442	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$231,851.54
12	16	8	$1.492	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$239,966.34
13	16	8	$1.544	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$248,365.16
14	16	8	$1.598	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$257,057.95
15	16	8	$1.654	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$266,054.97
16	16	8	$1.712	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$275,366.90
17	16	8	$1.772	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$285,004.74
18	16	8	$1.834	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$294,979.91
19	16	8	$1.898	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$305,304.20
20	16	8	$1.965	41.08	4.58	225	4694	3392	2005156.75	160825.7515	$315,989.85

Power Consumption in a year estimated by electric bills (kW-H) =	2005156.75

Operating Engine Only During On Peak Hours

Fuel Consumption for On Peak Generator Only

To perform a cost analysis and a fuel consumption analysis on an engine that would only operate during the on peak hours, we set the number of off peak hours of engine output to zero, along with the fuel consumption rate and the number of hours. The result of this gave the total number of power consumed, the gallons used, and the total cost of the fuel per year. The fuel cost for each year was then inputted into the cost analysis table as it is for all diesel engine analysis. The result of only operating the engine during on peak hours reduced the number of gallons per year as well as the cost of fuel pear year. The following tables illustrate the fuel consumption for an engine that is producing power for the Colegio only during the on peak hours. For engine downtime and all off peak hours, the Colegio would purchase additional electricity. The following tables show the 20-year fuel cost for all engines running during on-peak hours only.

Table 21: Fuel Consumption for Onan West India 900 kW Generator Running On-Peak Only

Fuel Inclination Rate =	3.50%
Initial Price ($/gallon) =	$1.02
Average On-Peak Demand (kW) =	549.63
Average Off-Peak Demand (kW) =	30

Total Running Time per Year of Engine (hr) =	8336.64
Downtime during On Peek periods (hr) =	208
Downtime during Off Peek periods (hr) =	466

Year	Peek Running time per day (hr)	Off Peek Running time per day (hr)	Price for Fuel ($/gal)	Fuel consumption per hour peak (Gal/hr))	Fuel Consumption per hour off Peek (Gal/hr)	School days per year	Off Peek hours per year	On Peek hours per year	Power Consumption in a year (kW-H)	Gallons used in a year	Fuel cost per year
1	16	0	$1.022	42.32	0.00	225	0	3392	1864344.96	143549.4759	$146,707.56
2	16	0	$1.058	42.32	0.00	225	0	3392	1864344.96	143549.4759	$151,842.33
3	16	0	$1.095	42.32	0.00	225	0	3392	1864344.96	143549.4759	$157,156.81
4	16	0	$1.133	42.32	0.00	225	0	3392	1864344.96	143549.4759	$162,657.30
5	16	0	$1.173	42.32	0.00	225	0	3392	1864344.96	143549.4759	$168,350.30
6	16	0	$1.214	42.32	0.00	225	0	3392	1864344.96	143549.4759	$174,242.57
7	16	0	$1.256	42.32	0.00	225	0	3392	1864344.96	143549.4759	$180,341.05
8	16	0	$1.300	42.32	0.00	225	0	3392	1864344.96	143549.4759	$186,652.99
9	16	0	$1.346	42.32	0.00	225	0	3392	1864344.96	143549.4759	$193,185.85
10	16	0	$1.393	42.32	0.00	225	0	3392	1864344.96	143549.4759	$199,947.35
11	16	0	$1.442	42.32	0.00	225	0	3392	1864344.96	143549.4759	$206,945.51
12	16	0	$1.492	42.32	0.00	225	0	3392	1864344.96	143549.4759	$214,188.60
13	16	0	$1.544	42.32	0.00	225	0	3392	1864344.96	143549.4759	$221,685.20
14	16	0	$1.598	42.32	0.00	225	0	3392	1864344.96	143549.4759	$229,444.18
15	16	0	$1.654	42.32	0.00	225	0	3392	1864344.96	143549.4759	$237,474.73
16	16	0	$1.712	42.32	0.00	225	0	3392	1864344.96	143549.4759	$245,786.35
17	16	0	$1.772	42.32	0.00	225	0	3392	1864344.96	143549.4759	$254,388.87
18	16	0	$1.834	42.32	0.00	225	0	3392	1864344.96	143549.4759	$263,292.48
19	16	0	$1.898	42.32	0.00	225	0	3392	1864344.96	143549.4759	$272,507.72
20	16	0	$1.965	42.32	0.00	225	0	3392	1864344.96	143549.4759	$282,045.49

Power Consumption in a year estimated by electric bills (kWh) =	2005156.75

Table 22: Fuel Consumption for Cummins 1100 kW Generator Running On-Peak Only

Fuel Inclination Rate =	3.50%
Initial Price ($/gallon) =	$1.022
Average On-Peak Demand (kW) =	549.63
Average Off-Peak Demand (kW) =	30

Total Running Time per Year of Engine (hr) =	8336.64
Downtime during On Peak periods (hr) =	208
Downtime during Off Peak periods (hr) =	466

Year	Peak Running time per day (hr)	Off Peak Running time per day (hr)	Price for Fuel ($/gal)	Fuel consumption per hour peak (Gal/hr))	Fuel Consumption per hour off Peek (Gal/hr)	School days per year	Off Peek hours per year	On Peek hours per year	Power Consumption in a year (kW-h)	Gallons used in a year	Fuel cost per year
1	16	0	$1.022	41.08	0.00	225	0	3392	1864344.96	139338.7497	$142,404.20
2	16	0	$1.058	41.08	0.00	225	0	3392	1864344.96	139338.7497	$147,388.35
3	16	0	$1.095	41.08	0.00	225	0	3392	1864344.96	139338.7497	$152,546.94
4	16	0	$1.133	41.08	0.00	225	0	3392	1864344.96	139338.7497	$157,886.08
5	16	0	$1.173	41.08	0.00	225	0	3392	1864344.96	139338.7497	$163,412.10
6	16	0	$1.214	41.08	0.00	225	0	3392	1864344.96	139338.7497	$169,131.52
7	16	0	$1.256	41.08	0.00	225	0	3392	1864344.96	139338.7497	$175,051.12
8	16	0	$1.300	41.08	0.00	225	0	3392	1864344.96	139338.7497	$181,177.91
9	16	0	$1.346	41.08	0.00	225	0	3392	1864344.96	139338.7497	$187,519.14
10	16	0	$1.393	41.08	0.00	225	0	3392	1864344.96	139338.7497	$194,082.31
11	16	0	$1.442	41.08	0.00	225	0	3392	1864344.96	139338.7497	$200,875.19
12	16	0	$1.492	41.08	0.00	225	0	3392	1864344.96	139338.7497	$207,905.82
13	16	0	$1.544	41.08	0.00	225	0	3392	1864344.96	139338.7497	$215,182.53
14	16	0	$1.598	41.08	0.00	225	0	3392	1864344.96	139338.7497	$222,713.92
15	16	0	$1.654	41.08	0.00	225	0	3392	1864344.96	139338.7497	$230,508.90
16	16	0	$1.712	41.08	0.00	225	0	3392	1864344.96	139338.7497	$238,576.71
17	16	0	$1.772	41.08	0.00	225	0	3392	1864344.96	139338.7497	$246,926.90
18	16	0	$1.834	41.08	0.00	225	0	3392	1864344.96	139338.7497	$255,569.34
19	16	0	$1.898	41.08	0.00	225	0	3392	1864344.96	139338.7497	$264,514.27
20	16	0	$1.965	41.08	0.00	225	0	3392	1864344.96	139338.7497	$273,772.27

Power Consumption in a year estimated by electric bills (kWh) =	2005156.75

Table 23: Fuel Consumption for Onan West India 1100 kW Generator Running On-Peak Only

Fuel Inclination Rate =	3.50%
Initial Price ($/gallon) =	$1.022
Average On-Peak Demand (kW) =	549.63
Average Off-Peak Demand (kW) =	30

Total Running Time per Year of Engine (hr) =	8336.64
Downtime during On Peek periods (hr) =	208
Downtime during Off Peek periods (hr) =	466

Year	Peek Running time per day (hr)	Off Peek Running time per day (hr)	Price for Fuel ($/gal)	Fuel consumption per hour peak (Gal/hr))	Fuel Consumption per hour off Peek (Gal/hr)	School days per year	Off Peek hours per year	On Peek hours per year	Power Consumption in a year (kW-h)	Gallons used in a year	Fuel cost per year
1	16	0	$1.022	41.08	0.00	225	0	3392	1864344.96	139338.7497	$142,404.20
2	16	0	$1.058	41.08	0.00	225	0	3392	1864344.96	139338.7497	$147,388.35
3	16	0	$1.095	41.08	0.00	225	0	3392	1864344.96	139338.7497	$152,546.94
4	16	0	$1.133	41.08	0.00	225	0	3392	1864344.96	139338.7497	$157,886.08
5	16	0	$1.173	41.08	0.00	225	0	3392	1864344.96	139338.7497	$163,412.10
6	16	0	$1.214	41.08	0.00	225	0	3392	1864344.96	139338.7497	$169,131.52
7	16	0	$1.256	41.08	0.00	225	0	3392	1864344.96	139338.7497	$175,051.12
8	16	0	$1.300	41.08	0.00	225	0	3392	1864344.96	139338.7497	$181,177.91
9	16	0	$1.346	41.08	0.00	225	0	3392	1864344.96	139338.7497	$187,519.14
10	16	0	$1.393	41.08	0.00	225	0	3392	1864344.96	139338.7497	$194,082.31
11	16	0	$1.442	41.08	0.00	225	0	3392	1864344.96	139338.7497	$200,875.19
12	16	0	$1.492	41.08	0.00	225	0	3392	1864344.96	139338.7497	$207,905.82
13	16	0	$1.544	41.08	0.00	225	0	3392	1864344.96	139338.7497	$215,182.53
14	16	0	$1.598	41.08	0.00	225	0	3392	1864344.96	139338.7497	$222,713.92
15	16	0	$1.654	41.08	0.00	225	0	3392	1864344.96	139338.7497	$230,508.90
16	16	0	$1.712	41.08	0.00	225	0	3392	1864344.96	139338.7497	$238,576.71
17	16	0	$1.772	41.08	0.00	225	0	3392	1864344.96	139338.7497	$246,926.90
18	16	0	$1.834	41.08	0.00	225	0	3392	1864344.96	139338.7497	$255,569.34
19	16	0	$1.898	41.08	0.00	225	0	3392	1864344.96	139338.7497	$264,514.27
20	16	0	$1.965	41.08	0.00	225	0	3392	1864344.96	139338.7497	$273,772.27

Power Consumption in a year estimated by electric bills (kWh) =	2005156.75

Table 24: Cummins 818 ekW Engine Outputting Only During On Peak Hours

Fuel Inclination Rate =	3.50%
Initial Price ($/gallon) =	$1.022
Average On-Peak Demand (kW) =	549.63
Average Off-Peak Demand (kW) =	30

Total Running Time per Year of Engine (hr) =	8336.64
Downtime durring On Peek periods (hr) =	208
Downtime durring Off Peek periods (hr) =	466

Year	Peek Running time per day (hr)	Off Peek Running time per day (hr)	Price for Fuel ($/gal)	Fuel Consumption on on-peak (Gal/hr)	Fuel Consumption on off-Peek (Gal/hr)	School days per year	Off-Peak hours per year	On-Peak hours per year	Power produced in a year (kW-H)	Gallons used in a year	Fuel cost per year
1	16	0	$1.022	36.16	0.00	225	0	3392	1864345	122657.4	$125,355.84
2	16	0	$1.058	36.16	0.00	225	0	3392	1864345	122657.4	$129,743.29
3	16	0	$1.095	36.16	0.00	225	0	3392	1864345	122657.4	$134,284.31
4	16	0	$1.133	36.16	0.00	225	0	3392	1864345	122657.4	$138,984.26
5	16	0	$1.173	36.16	0.00	225	0	3392	1864345	122657.4	$143,848.71
6	16	0	$1.214	36.16	0.00	225	0	3392	1864345	122657.4	$148,883.41
7	16	0	$1.256	36.16	0.00	225	0	3392	1864345	122657.4	$154,094.33
8	16	0	$1.300	36.16	0.00	225	0	3392	1864345	122657.4	$159,487.63
9	16	0	$1.346	36.16	0.00	225	0	3392	1864345	122657.4	$165,069.70
10	16	0	$1.393	36.16	0.00	225	0	3392	1864345	122657.4	$170,847.14
11	16	0	$1.442	36.16	0.00	225	0	3392	1864345	122657.4	$176,826.79
12	16	0	$1.492	36.16	0.00	225	0	3392	1864345	122657.4	$183,015.73
13	16	0	$1.544	36.16	0.00	225	0	3392	1864345	122657.4	$189,421.28
14	16	0	$1.598	36.16	0.00	225	0	3392	1864345	122657.4	$196,051.02
15	16	0	$1.654	36.16	0.00	225	0	3392	1864345	122657.4	$202,912.81
16	16	0	$1.712	36.16	0.00	225	0	3392	1864345	122657.4	$210,014.75
17	16	0	$1.772	36.16	0.00	225	0	3392	1864345	122657.4	$217,365.27
18	16	0	$1.834	36.16	0.00	225	0	3392	1864345	122657.4	$224,973.06
19	16	0	$1.898	36.16	0.00	225	0	3392	1864345	122657.4	$232,847.11
20	16	0	$1.965	36.16	0.00	225	0	3392	1864345	122657.4	$240,996.76

Power Consumption in a year estimated by electric bills (kWh) =	2005157

Cost to Purchase Electricity if Generator Only Supplies On Peak Power

For a power generating system that only produces power during the day, or a part of the on peak demand, the off peak power consumption of the Colegio must be supplied by PREPA. In the above section, we described how many kWh an engine outputs per year. If the kWh output per year is not equal to the needed 2,005,156.75 kWh per year, then the average cost per kWh would be charged by PREPA. In the example of the Cummins 1100 ekW engine that is run only during peak hours, it produces all the power during on peak hours minus 208 hours per year due to maintenance downtime. The table below shows the number of kWh needed by the Colegio, the number of kWh produced by the Cummins engine during on peak, the additional electricity that must be purchased, and the cost to purchase it.

Table 25: Additional Electricity for Cummins 1100 ekW On Peak Generator

Needed Power for Colegio per year (kWh)	Average On Peak Demand (kW)	Engine Runtime during on peak per year (h)	Engine Output (kWh)	Difference between Outputted and Needed per year (kWh)	Price of Additional Electricity ($/kWh)	Cost of Additional Electricity per year ($)
2005156.8	549.6	3392	1864243	140913.55	$0.12	$16,909.63

The additional cost of power that engine does not produced was then added into the life cycle cost analysis for each particular engine as an operating cost. Whether an engine produces power during on and off peak or only on peak, electricity must be purchased due to downtime of the engine

Smart Usage

We know that the price to purchase electricity from PREPA is estimated to be 12 cents per kWh. Each of the engines we have researched creates prime power, so they are able to support varying loads. There is a different fuel consumption that corresponds to the changing output percentages. However, some output percentages make generating power not a cost effective choice. When the cost to purchase power per kWh is less than the cost of generating the power, then purchasing electricity is the best option. This happens on some of the generators that run at low percentages, because the generator is not as efficient at very low outputs.

The cost to produce electricity with an engine is determined by using the fuel cost and cost of maintenance per kWh. To factor in maintenance, we took the cost of maintenance and divided by the number of kWh the Colegio uses per year. This will give the cost of maintenance for a generator in cents per kWh.

To determine the total cost per kWh, we added the cost of the fuel and cost of maintenance per kWh. This varies for each output of the generator depending on the percentage output. It was important to estimate fuel consumption for each output percentage. Specification sheets only provide fuel consumptions for generators at 25, 50, 75, and 100 percent. We plotted these points for each of the possible generators, and extracted a best-fit 6-term polynomial that would interpolate fuel consumption for any percent usage we inputted. By knowing the fuel consumption, and the price of fuel (currently $1.022/Gal.) we were able to multiply the fuel cost for one hour, and then divide this number by the output the generator at that fuel consumption. These calculations gave us a price per kWh due to fuel cost.

By adding the fuel price per kWh, and the maintenance price per kWh, we determined the price to generate electricity with each varying load. Since the price to purchase power from PREPA is 12 cents per kWh, the price of generating power must be less than this in order to be cost effective. If at a particular operating percentage the cost to produce is more than the cost to buy then the generator should be turned off.

A programmable logic controller (PLC) could monitor and decide when generation will be cost effective can control the generator and when it is not effective, the computer will turn off the generator. When the demand is again larger to make the generator cost efficient, it will turn on.

Pollution Concerns

In our literature review, we studied emission controls and what guidelines a plant must follow. We interviewed Bruce K. Maillet (2000), a private consultant for The It Group, to see what types of costs and legislation a plant would be subject to. We studied legislation such as the Clean Air Act, and the Best Available Control Technology (BACT), as well as fees for emitting pollutants into the air. A case study of Clark University in Worcester, MA gave us valuable information on pollution and noise levels. If properly constructed, a plant can be very quiet to the surrounding environment. We studied the Colegio's requirements for space and appearance and saw if the same techniques used at Clark University were applicable to the Colegio.

Sound Pollution

Sound levels, as a standard are measured at a number of db(A) per seven meters. The Perkins generator distributed by M&C electric has a sound level of 68 db(A) measured at seven meters. The houses that would be used for all other the generators we are researching would offer similar sound proofing. Engines and housing for engines are designed so that as little noise pollution is emitted as possible. Along with low sound outputs, a diesel generator can be installed between the theater and the student parking lot at the Colegio. This area is a fair distance from the main academic building, and as a result the engine would not be a disruption to education.

Air Pollution

The Environmental Protection Agency (EPA) will charge a company per ton of air pollution. There is a minimum charge of $25 per ton of pollution. We received air pollution data from Cummins Diesel of Puerto Rico and Rimco, the Caterpillar engine distributor in Puerto Rico. Using this data, we extrapolated to obtain how much pollution would be emitted in the environment per gallon of fuel burned. The following table shows the tons of each pollutant emitted in exhaust for every gallon of diesel fuel burned.

Table 26: Emissions Exhausted

Component	Emissions in grams per gallon	Tons in 1 gram	Tons of emission per gallon burned
HC	3.9332	1.1023E-06	4.3356E-06
NO_x	213.6259	1.1023E-06	2.3548E-04
CO	8.9083	1.1023E-06	9.8196E-06
Particulate matter	1.7983	1.1023E-06	1.9823E-06
SO2	12.8900	1.1023E-06	1.4209E-05

Due to lack of data, we could not calculate the pollution output of each specific generator. Because pollution varies with fuel consumption, temperature, and fuel type; we were unable to get an accurate pollution output for each generator set. Our decision matrix places a large weight on pollution, so we had to calculate the pollution output based on the known pollution outputs of engines for which we had this information. By taking an average of the pollution given in grams power horsepower-hour, we could divide this by the fuel consumption in gallons per hour, which gave us pollution output in grams per gallon. This information is seen in the Emissions Exhaust table above.

By knowing the fuel consumption in gallons per year, we were able to determine the pollution output in tons per year. Our concern is not which engine is most efficient in terms of pollution, but rather which engine will produce the least amount of pollution under the operating condition that we recommended. In this way the engines that have the least pollution output will stand ahead in the decision matrix. The Colegio wants to produce minimal amounts of pollution on the campus and in the environment, so the alternative emits low amounts of pollution into the environment will be the preferred engine in this respect. The method we selected to calculate the pollution outputs reflect this very well.

Since we knew the number of gallons an engine would use per year to supply the Colegio with sufficient power and the tons of pollution per gallon of fuel burned, we calculated the total number of tons of pollution emitted per year. Once we determined the tons of emissions given off each year by an engine, we were able to calculate the total cost per year that would need to be paid. We multiplied the $25 per ton by the tons of pollution emitted to obtain the pollution charge.

The Colegio would not be producing much air pollution if they were to generate their own power using a diesel engine. We received air pollution data from Cummins Diesel of Puerto Rico and Rimco, the Caterpillar engine distributor in Puerto Rico. Using this data we were able to interpolate how much pollution would be emitted in the environment per gallon of fuel.

The following table displays the tons of each pollutant emitted by each engine and the cost that would be paid to the EPA.

Table 27: Pollution of Diesel Generators based on Fuel Consumption per Year

Cummins 1100		Cummins 818	
Component	**tons per year**	**Component**	**tons per year**
HC	0.604	*HC*	0.532
NO_x	32.811	*NO_x*	28.883
CO	1.368	*CO*	1.204
Particulate matter	0.276	*Particulate matter*	0.243
SO2	1.980	*SO2*	1.743
total =	**37.040**	**total =**	**32.606**
EPA minimum charge ($25 ton per year) =	**$926.00**	**EPA minimum charge ($25 ton per year) =**	**$815.14**

Hybrid Cummins 455		Caterpillar 820	
Component	**tons per year**	**Component**	**tons per year**
HC	0.494	*HC*	0.624
NO_x	26.849	*NO_x*	33.890
CO	1.120	*CO*	1.413
Particulate matter	0.226	*Particulate matter*	0.285
SO2	1.620	*SO2*	2.045
total =	**30.309**	**total =**	**38.257**
EPA minimum charge ($25 ton per year) =	**$757.73**	**EPA minimum charge ($25 ton per year) =**	**$956.43**

Onan 1100		Onan 900	
Component	**tons per year**	**Component**	**tons per year**
HC	0.604	*HC*	0.622
NO_x	32.811	*NO_x*	33.803
CO	1.368	*CO*	1.410
Particulate matter	0.276	*Particulate matter*	0.285
SO2	1.980	*SO2*	2.040
total =	**37.040**	**total =**	**38.159**
EPA minimum charge ($25 ton per year) =	**$926.00**	**EPA minimum charge ($25 ton per year) =**	**$953.98**

Life Cycle Cost Analysis

Determined the Cost Effective System

To explain the life cycle costing of each alternative, we investigated the cost of purchasing power and compared it to the cost of generating the power over a 20-year span. This comparison told us how cost effective generating power could be for the Colegio. In order to conduct this cost analysis, we obtained PREPA's rate structure. Also, the project team spoke with Ecolectrica and Abott representatives who are private power generators in Puerto Rico about electric rates.

It was our goal to find out if the initial investment would become a gain for the Colegio Tecnológico. Cost was an important criterion that we used in our decision. If the Colegio cannot pay for a particular energy source, then it makes that option infeasible.

Compound interest plays a part in the decision to invest. In a loan, the amount owed will increase due to interest. If the Colegio decided not to invest their money in a power plant, they could gain interest in their favor. Interest was calculated using the formula:

Equation 27

$$L(1+k)^n$$

Where:
L = Initial loan amount
k = Cost of Capital
n = number of years

This formula assumes that the interest is not paid out at the end of each year and it is compounded yearly.

Present Value

Another basic concept employed in our cost analysis was that of present value. To determine the time for an initial investment to be paid off, this concept of present value was used. To obtain the present value, we used the formula:

Equation 28

$$PV = \frac{F_n}{(1+k)^n}$$

Where:
- PV = Value at time of investment
- F_n = Future cash flow
- k = Cost of Capital
- n = number of years after investment before that future cash flow is received

The equation above was used to translate future earnings in dollar values at the time the money was invested. Each year's profit was translated into its value at the time of investment so that we could accurately estimate the return on the Colegio's investment.

The concept of present value was one step used to see if an investment would be economical. This process would pertain to the Colegio because we could project savings that the power plant would provide every year. If the dollar amount calculated was greater than the amount to be invested, at the end of the 20th year, then that investment made money. We inputted the estimated savings or F_n of each year into Equation 12 above that translated the net savings into an equivalent dollar value on the day of investment.

The concept of present value was used to see if an investment that generates future cash flows or net savings would be beneficial. The present value theory applies to the Colegio's power alternative because it results in savings as an independent generator compared to purchasing power from PREPA every year. The savings were determined by subtracting the annual operating costs, using an alternate energy source, from the annual cost of purchasing electricity exclusively from the utility PREPA. The annual operation costs were composed of fuel cost, the maintenance cost, and the cost to of electricity during engine downtimes.

Future Cash Flow

To find the future cash flow (F_n), otherwise known as Net Savings, we took the cost of not buying the power from the electric company and subtracted all operation costs that the Colegio would pay as an independent power generator. The calculation of the net savings value, F_n, can be seen in the equation below.

Equation 29

$$F_n = P_C - O_C$$

Where: F_N = Future Cash Flow
P_C = Cost to Buy All Necessary Power
O_C = Operations Cost as Independent Generator

We estimated how the Colegio would benefit in present dollar values over 20 years. If the dollar amount saved over 20 years was greater than the amount invested, then that investment made money. We inputted the estimated savings, or F_n, of each year into the Equation 12, seen earlier, which translated the net savings into an equivalent dollar value on the day of investment.

Cost of Capital

In order to perform a proper life cycle cost analysis on this given project, it necessary to compute the cost of capital k. For the life cycle cost analysis of each energy alternative, the cost of capital remained the same. We assumed that the investment rates would remain the same on all alternatives so an equal k was used for analysis. The Colegio is a non-profit organization and it does not pay income taxes and is municipally funded. In financial theory, k is assumed equal to be the risk free interest rate plus a risk premium. Every project has a measure of risk, which is determined by the stock market risk premium and by the variable Beta. Beta measures the risk of the project relative to the market. The variable k is determined from the formula below.

Equation 30

$$k = T + \beta_P * M$$

Where k = Cost of Capital
T = Risk Free Rate
β_P = Project Beta
M = Market Risk Premium

The variables that determine the cost of capital, k, are explained below.

Risk Free Interest Rate

For the Alternate Energy Resources project for the Colegio, we chose the current long term Municipal Bond rate of Puerto Rico for the risk free rate in place of the long term US Treasury Bond that is typically used. The Municipal Bond rate was obtained from the local newspaper *The San Juan Star*. The rate was 5.91 percent. We used the Municipal Bond Rate as risk free rate because it was a risk and tax-free rate and we assumed that the Colegio could borrow at this rate.

Risk Factor

The coefficient β_P is the project Beta or the risk of the project compared to the stock market. Beta is determined from the following formula below

Equation 31

$$\beta_P = \rho_{PM} * \frac{\sigma_P}{\sigma_M}$$

Where ρ_{PM} = the correlation coefficient between the return on the project and the stock market

σ_P = the standard deviation of returns on the project

σ_M = the standard deviation of returns on the market

For our project, we assumed the ratio of σ_P and σ_M to be equal to one.

Stock market returns are highly variable. We did not believe that the variability of returns on this project was likely to exceed that of the stock market. To be conservative we assumed them to be equal. The major cause of potential variation away from the project return will be unexpected changes in the rate of escalation of fuel prices and electricity rates. These changes are likely to be poorly correlated with variations in the stock market returns and therefore we assumed that the correlation coefficient between the returns on the two types of investments was only 0.5 percent.

For the estimate of the Beta for this project we obtained:

Equation 32

$$\beta_P = \rho_{PM} * \frac{\sigma_P}{\sigma_M}$$

$$\beta_P = 0.5 * \frac{1}{1}$$

$$\beta_P = 0.5$$

The market risk premium is the long-term difference between the total return on the stock market and the risk free rate. Researchers have estimated this rate to be historically 7.5 percent.

After determining the variables of the cost of capital, k, were able to estimate its value for the cost analysis.

Equation 33

$$k = T + \beta_P * M$$

$$k = 5.91\% + 0.5 * 7.5\%$$

$$k = 9.65\%$$

Where
k = Cost of Capital
T = Risk Free Rate
β_P = Project Beta
M = Market Risk Premium

Net Present Value

The net present value was used to show us the net value of the investment decision. For the year zero of the analysis, the Net Present Value was equal to the initial investment cost, I. For each other year, taking the Net Present Value of the preceding year and adding the savings in present value of the current year and subtracting any investment, determined the Net Present Value. The Net Present Value for every year other than year zero can be seen in the equation below.

Equation 34

$$NPV_n = NPV_{n-1} + PV - I$$

Where:
n = Current Year
NPV_n = Net Present Value of Year n
NPV_{n-1} = Net Present Value of Previous Year
PV = Present Value
I = Investment

Internal Rate of Return

Internal rate of return is another way to tell if an investment will result positively compared to other investments. The internal rate of return will show the annual interest rate that an investment will return. For this reason, if the IRR is negative, then the reinvested savings will yield negative returns; this is a slightly inaccurate measure if the IRR is low. Normally an investor would not reinvest money in something that would give a negative return, but rather a reinvestment at the cost of capital. The equation to calculate internal rate of return is seen in the equation below:

Equation 35

$$I = \frac{F_1}{(1+r)} + \frac{F_2}{(1+r)^2} + ... + \frac{F_n}{(1+r)^n}$$

Where:
I = Investment
F_n = Future Cash Flow
r = Internal Rate of Return

When the cost of capital is less than the internal rate of return, the result is that the return for this investment is larger; hence the investment should be made. This method of evaluation shows the annual rate of return that the investment will provide. For our purposes, if the internal rate of return is larger then 9.65 percent then this investment will benefit the school. To assist our calculations of IRR we used an excel function.

Modified Internal Rate of Return

Modified Internal Rate of Return (MIRR) is similar to the Internal Rate of Return. The MIRR will give a more realistic investment analysis. MIRR takes into account reinvestment of the savings at the cost of capital. This is a better measure of an investment when comparing it to IRR. In our case we calculated the MIRR using the cost of capital for both the reinvestment and to pay interest on a loan that would be taken out to pay for an investment. To perform the cost analyses we used an excel formula, as we did for the IRR.

Escalation Rates and CPI

Accurately predicting the price of fuel twenty years from now is not an exact science. Predictions are based on a multitude of factors that all affect the future course of fuel and electricity sales, fuel and electricity consumption, labor force growth in the energy industry, fuel production rates, and many other predictions. We investigate data from various groups and felt that the Annual Energy Outlook 2000's forecasts for escalation rates were suitable. The Annual Energy Outlook 2000 (AEO2000), The

WEFA Group, Standard & Poor's DRI, and the Gas Research Institute GRI all create detailed forecasts for energy into the year 2020, (except for GRI which only projects to the year 2015). There are numerous other groups that do these forecasts, such as the International Energy Agency (IEA), Energy Information Administration (EIA), and Petroleum Industry Research Associates inc. (PIRA), just to name a few. The data provided by these reports is very important to our cost analysis because the fuel escalation rate, as well as the escalation rate for electricity and labor on maintenance will affect the NPV that we calculate in the cost analysis.

Our Cost analysis required the escalation rates for diesel fuel, maintenance, and electricity prices. One of the most important factors in forecasting the escalation rates defined above is the Consumer Price Index (CPI), or inflation rate. The calculation of the CPI is in itself a very complex calculation that depends on many factors such as The Gross Domestic Product. There can be slight variations between the CPI used in one study to the next. We used the CPI found in the Annual Energy Outlook 2000. The value of the CPI according to this source will be 2.7 percent per year through 2020.

Diesel Fuel Escalation Rate

From the Department of Energy, we determined an inflation rate that can be used for estimating future diesel prices. From the Annual Energy Outlook 2000, we found that the estimated annual escalation rate for the price of Number 2 diesel fuel was 0.8 percent per year from 2000 to 2020. This escalation rate was determined for real constant 2000 dollars. Since the rate was constant for 2000 dollars, we added the general rate of inflation of 2.7 percent to put the diesel fuel escalation rate into current dollars. The

Annual Energy Outlook estimated the inflation rate or the Consumer Price Index (CPI) at 2.7 percent from 1998 to 2020. The adjusted escalation rate that was used for the 20-year cost analyses was 3.5 percent.

To obtain the fuel cost estimates to perform the life cycle cost analysis, we have used $1.022 per gallon as the initial diesel fuel price. This price of fuel was used as the current or initial price for the analysis. From the initial price of fuel, we increased the fuel price by the escalation rate of 3.5 percent every year. By multiplying the fuel price each year by the compound value interest factor, $(1+e)^t$ where 'e' is the escalation rate and 't' is the number of years in the future, we obtained a forecasted price for future years. The interest rate, e, was set equal to the escalation rate of 3.5 percent per year. The following equation illustrates the calculation of the forecasted diesel fuel price.

Equation 36

$$F_P = 1.022 * (1.035)^t$$

Where F_P = Fuel Price in Year t
t = year
1.022 = Initial Diesel Fuel Price for Year Zero
1.035 = The Annual Escalation Rate of Diesel Fuel

A table showing 20 years of fuel price per gallon can be seen below.

Table 28: Fuel Price for 20 Years

Year	Fuel Cost ($ per Gallon)
1	$1.022
2	$1.058
3	$1.095
4	$1.133
5	$1.173
6	$1.214
7	$1.256
8	$1.300
9	$1.346
10	$1.393
11	$1.442
12	$1.492
13	$1.544
14	$1.598
15	$1.654
16	$1.712
17	$1.772
18	$1.834
19	$1.898
20	$1.965

Escalation Rate of Maintenance Prices:

The cost of the maintenance will increase each year by an estimated 3.6 percent. This will take into account the increase of the cost of maintenance in the future. Labor price increase of 0.9 percent every year for the next 20-years from Annual Energy Outlook 2000 plus the Consumer Price Index (CPI) of 2.7 percent was used to determine the maintenance escalation. We then used the maintenance escalation to more accurately perform the life cycle cost analysis on each alternative.

Escalation Rate of Electricity Prices

The electricity escalation rate is also very important to our analysis because if the cost of purchasing energy from PREPA goes up, then the investment will be more likely to recover. Conversely, if the escalation rate is negative, the investment may be affected negatively because cost of electricity would become cheaper. AEO2000 projects an annual escalation rate for electricity cost of -0.6 percent until the year 2020. This number is forecasted for the continental United States, Alaska and Hawaii, but Puerto Rico is not part of the model. The number may not be accurate in terms of Puerto Rico because there currently is no competition that would drive the cost down. Other factors that would affect future electricity rates is that the system is running inefficiently due to the bureaucracies that exist within the company. Also, there are inefficiencies in the production of power, due old outdated systems that burn oil instead of new generators that utilize natural gas and co-generation technology. This would suggest that the escalation rate for electricity cost in Puerto Rico would not be negative, at least not for a few years. Because the rate given by AOE2000 could be considered a worst case for Puerto Rico, we decided to use this value.

All the values presented above for escalation rates are measured in current US dollars, this means that the adjusted yearly growth is the CPI plus the escalation rate for the given category in question. To summarize, the table below shows the yearly escalation rates for fuel, electricity, and labor growth.

Table 29 DOE Escalation Rates in Percent

Forecast Study	CPI	Diesel Fuel	Electricity	Labor Force
AOE 2000	2.7 %	0.8 %	-0.6 %	0.9 %

Specific Calculations for Each Alternative

After determining the necessary data, we inputted the prices and rates into a spreadsheet to analyze. Each life cycle cost analysis for the different energy alternatives was calculated over a 20-year period. In order to make adjustments of data simple, we initialized a variable in its own cell in the spreadsheet. At any point, we were able to change a variable and the rest of the calculations in the spreadsheet changed accordingly. The main purpose of setting up adjustable variables was that at some points during this project some pieces of information were estimates. As the project team determined precise data, the overall cost analysis became more accurate.

Each alternative was comprised of different data, however the cost analysis tables were all established in the same manner using the same equations and theories. These life cycles cost analysis methods have been described in the above sections. Numerous tables for each alternate energy source's life cycle cost analysis can be seen in the tables that follow. The most detailed discussion of the deviations of the values in these tables is provided below for the Cummins 818 ekW diesel as this generator performed best of all the alternatives. The results of its life cycle cost analysis are shown in Table 32.

Table 30: Solar Cost Analysis with Purchasing Additional Electricity from PREPA

Cost of capital =	9.65%
Maintenance escalation =	3.60%
Electricity escalation =	2.1%

Year	Investment cost	Maintenance cost	Money Saved	Present value	Net present value
0	$578,330.00			-$578,330.00	-$578,330.00
1	$0.00	$500.00	$28,034.12	$25,566.92	-$552,763.08
2	$0.00	$518.00	$28,529.74	$23,729.06	-$529,034.03
3	$0.00	$536.65	$29,033.95	$22,023.19	-$507,010.84
4	$0.00	$555.97	$29,546.90	$20,439.83	-$486,571.00
5	$0.00	$575.98	$30,068.74	$18,970.20	-$467,600.80
6	$0.00	$596.72	$30,599.61	$17,606.13	-$449,994.66
7	$0.00	$618.20	$31,139.66	$16,340.05	-$433,654.61
8	$0.00	$640.45	$31,689.04	$15,164.92	-$418,489.70
9	$0.00	$663.51	$32,247.92	$14,074.21	-$404,415.49
10	$0.00	$687.40	$32,816.44	$13,061.86	-$391,353.63
11	$0.00	$712.14	$33,394.76	$12,122.25	-$379,231.37
12	$0.00	$737.78	$33,983.05	$11,250.16	-$367,981.21
13	$0.00	$764.34	$34,581.46	$10,440.74	-$357,540.48
14	$0.00	$791.86	$35,190.17	$9,689.48	-$347,851.00
15	$0.00	$820.36	$35,809.34	$8,992.22	-$338,858.78
16	$0.00	$849.90	$36,439.14	$8,345.07	-$330,513.71
17	$0.00	$880.49	$37,079.75	$7,744.44	-$322,769.27
18	$0.00	$912.19	$37,731.34	$7,186.98	-$315,582.28
19	$0.00	$945.03	$38,394.08	$6,669.61	-$308,912.68
20	$0.00	$979.05	$39,068.16	$6,189.42	-$302,723.25

IRR =	Negative
MIRR =	Negative

Table 31: Solar and Cummins 455 ekW Diesel Engine Hybrid

Cost of capital =	9.65%
Maintenance escalation=	3.60%
Electricity escalation=	2.10%

Years	Investment cost	Fuel Cost ($)	Maintenance cost	Cost to purchase power during maintenance	Future cash flow	Present value	Net present value
0	$723,130.00					-$723,130.00	-$723,130.00
1	$0.00	$116,526.79	$40,000.00	$9,000.00	$76,473.21	$69,743.01	-$653,386.99
2	$0.00	$120,605.22	$41,440.00	$9,189.00	$75,847.78	$63,084.92	-$590,302.06
3	$0.00	$124,826.41	$42,931.84	$9,381.97	$75,130.51	$56,988.92	-$533,313.14
4	$0.00	$129,195.33	$44,477.39	$9,578.99	$74,316.70	$51,410.51	-$481,902.64
5	$0.00	$133,717.17	$46,078.57	$9,780.15	$73,401.46	$46,308.58	-$435,594.06
6	$0.00	$138,397.27	$47,737.40	$9,985.53	$72,379.67	$41,645.18	-$393,948.87
7	$0.00	$143,241.17	$49,455.95	$10,195.23	$71,246.02	$37,385.24	-$356,563.64
8	$0.00	$148,254.61	$51,236.36	$10,409.33	$69,994.97	$33,496.37	-$323,067.27
9	$0.00	$153,443.52	$53,080.87	$10,627.92	$68,620.75	$29,948.68	-$293,118.58
10	$0.00	$158,814.05	$54,991.78	$10,851.11	$67,117.37	$26,714.59	-$266,403.99
11	$0.00	$164,372.54	$56,971.49	$11,078.98	$65,478.56	$23,768.63	-$242,635.36
12	$0.00	$170,125.58	$59,022.46	$11,311.64	$63,697.82	$21,087.30	-$221,548.07
13	$0.00	$176,079.97	$61,147.27	$11,549.19	$61,768.38	$18,648.93	-$202,899.14
14	$0.00	$182,242.77	$63,348.57	$11,791.72	$59,683.19	$16,433.54	-$186,465.60
15	$0.00	$188,621.27	$65,629.12	$12,039.35	$57,434.91	$14,422.69	-$172,042.90
16	$0.00	$195,223.01	$67,991.77	$12,292.17	$55,015.90	$12,599.41	-$159,443.50
17	$0.00	$202,055.82	$70,439.47	$12,550.31	$52,418.24	$10,948.02	-$148,495.48
18	$0.00	$209,127.77	$72,975.29	$12,813.86	$49,633.65	$9,454.11	-$139,041.37
19	$0.00	$216,447.25	$75,602.40	$13,082.96	$46,653.54	$8,104.39	-$130,936.97
20	$0.00	$224,022.90	$78,324.09	$13,357.70	$43,468.96	$6,886.63	-$124,050.35

	Internal Rate of Return =	-2.55%
	Modified Internal Rate of Return =	5.69%

Table 32: Cost Analysis for Cummins 818 ekW Diesel Engine

Cummins On Peak Generator **Power Rating: 900 kW / 818 ekW / 1023 kVA**
Cost of Purchasing all Power = What they would pay to PREPA to purchase all electricity
Initial Investment = all investments made to the system prior to startup

Cost of capital =	9.65%
Diesel Fuel Escalation =	3.50%
Electric Price Escalation =	2.10%
Maintenance Escalation =	3.60%
Cost to Purchase Power per Month	$21,648.60
Maintenance Cost Adjustment due to increased engine Size =	20.00%

Year	Maintenance Cost ($)	Fuel Cost ($)	Initial Investment ($)	Electricity cost due to downtime ($)	Cost of purchasing all power ($)	Fn = Net Savings ($)	Present Value ($)	Net Present Value ($)
0			$208,600.00			-$208,600.00	-$208,600.00	-$208,600.00
1	$22,848.00	$125,355.84	$0.00	$17,179.04	$259,783.14	$94,400.26	$86,092.35	-$122,507.65
2	$23,670.53	$129,743.29	$0.00	$17,539.80	$265,238.59	$94,284.97	$78,419.70	-$44,087.94
3	$24,522.67	$134,284.31	$0.00	$17,908.13	$270,808.60	$94,093.49	$71,372.95	$27,285.01
4	$25,405.48	$138,984.26	$0.00	$18,284.20	$276,495.58	$93,821.63	$64,903.55	$92,188.56
5	$26,320.08	$143,848.71	$0.00	$18,668.17	$282,301.98	$93,465.02	$58,966.58	$151,155.14
6	$27,267.60	$148,883.41	$0.00	$19,060.20	$288,230.33	$93,019.11	$53,520.52	$204,675.66
7	$28,249.24	$154,094.33	$0.00	$19,460.47	$294,283.16	$92,479.13	$48,526.98	$253,202.64
8	$29,266.21	$159,487.63	$0.00	$19,869.14	$300,463.11	$91,840.13	$43,950.46	$297,153.10
9	$30,319.79	$165,069.70	$0.00	$20,286.39	$306,772.83	$91,096.95	$39,758.15	$336,911.24
10	$31,411.31	$170,847.14	$0.00	$20,712.40	$313,215.06	$90,244.21	$35,919.73	$372,830.97
11	$32,542.11	$176,826.79	$0.00	$21,147.37	$319,792.58	$89,276.31	$32,407.18	$405,238.15
12	$33,713.63	$183,015.73	$0.00	$21,591.46	$326,508.22	$88,187.41	$29,194.63	$434,432.78
13	$34,927.32	$189,421.28	$0.00	$22,044.88	$333,364.90	$86,971.42	$26,258.16	$460,690.94
14	$36,184.70	$196,051.02	$0.00	$22,507.82	$340,365.56	$85,622.01	$23,575.70	$484,266.64
15	$37,487.35	$202,912.81	$0.00	$22,980.49	$347,513.24	$84,132.59	$21,126.85	$505,393.48
16	$38,836.90	$210,014.75	$0.00	$23,463.08	$354,811.01	$82,496.29	$18,892.80	$524,286.28
17	$40,235.03	$217,365.27	$0.00	$23,955.80	$362,262.05	$80,705.95	$16,856.16	$541,142.44
18	$41,683.49	$224,973.06	$0.00	$24,458.87	$369,869.55	$78,754.13	$15,000.92	$556,143.36
19	$43,184.09	$232,847.11	$0.00	$24,972.51	$377,636.81	$76,633.09	$13,312.27	$569,455.64
20	$44,738.72	$240,996.76	$0.00	$25,496.93	$385,567.18	$74,334.77	$11,776.58	$581,232.22

Internal Rate of Return =	32.15%
Modified Internal Rate of Return =	13.88%

Table 33: Cost Analysis of Caterpillar 820 ekW Diesel Engine

Caterpillar On Peak Generator **Power Rating: 900 kW / 820 ekW / 1023 kVA**
Cost of Purchasing all Power = What they would pay to PREPA to purchase all electricity
Initial Investment = all investments made to the system prior to startup

Cost of capital =	9.65%
Diesel Fuel Escalation =	3.50%
Electric Price Escalation =	2.10%
Maintenance Escalation =	3.10%
Cost to Purchase Power per Month	$21,648.60
Maintenance Cost Adjustment due to increased engine Size =	20.00%

Year	Maintenance Cost ($)	Fuel Cost ($)	Initial Investment ($)	Electricity cost due to downtime ($)	Cost of purchasing all power ($)	*Fn = Net Savings ($)*	*Present Value ($)*	*Net Present Value ($)*
0			$207,450.00			-$207,450.00	-$207,450.00	-$207,450.00
1	$22,848.00	$147,083.85	$0.00	$17,179.04	$259,783.14	$72,672.25	$66,276.56	-$141,173.44
2	$23,556.29	$152,231.79	$0.00	$17,539.80	$265,238.59	$71,910.71	$59,810.35	-$81,363.09
3	$24,286.53	$157,559.90	$0.00	$17,908.13	$270,808.60	$71,054.03	$53,896.78	-$27,466.32
4	$25,039.42	$163,074.50	$0.00	$18,284.20	$276,495.58	$70,097.46	$48,491.74	$21,025.42
5	$25,815.64	$168,782.10	$0.00	$18,668.17	$282,301.98	$69,036.07	$43,554.48	$64,579.90
6	$26,615.92	$174,689.48	$0.00	$19,060.20	$288,230.33	$67,864.72	$39,047.41	$103,627.31
7	$27,441.02	$180,803.61	$0.00	$19,460.47	$294,283.16	$66,578.07	$34,935.80	$138,563.12
8	$28,291.69	$187,131.74	$0.00	$19,869.14	$300,463.11	$65,170.55	$31,187.62	$169,750.74
9	$29,168.73	$193,681.35	$0.00	$20,286.39	$306,772.83	$63,636.37	$27,773.31	$197,524.05
10	$30,072.96	$200,460.19	$0.00	$20,712.40	$313,215.06	$61,969.50	$24,665.60	$222,189.65
11	$31,005.22	$207,476.30	$0.00	$21,147.37	$319,792.58	$60,163.69	$21,839.34	$244,028.99
12	$31,966.38	$214,737.97	$0.00	$21,591.46	$326,508.22	$58,212.41	$19,271.34	$263,300.33
13	$32,957.34	$222,253.80	$0.00	$22,044.88	$333,364.90	$56,108.87	$16,940.23	$280,240.56
14	$33,979.02	$230,032.68	$0.00	$22,507.82	$340,365.56	$53,846.03	$14,826.30	$295,066.86
15	$35,032.37	$238,083.83	$0.00	$22,980.49	$347,513.24	$51,416.55	$12,911.40	$307,978.26
16	$36,118.37	$246,416.76	$0.00	$23,463.08	$354,811.01	$48,812.80	$11,178.81	$319,157.07
17	$37,238.04	$255,041.35	$0.00	$23,955.80	$362,262.05	$46,026.85	$9,613.12	$328,770.19
18	$38,392.42	$263,967.80	$0.00	$24,458.87	$369,869.55	$43,050.46	$8,200.16	$336,970.35
19	$39,582.59	$273,206.67	$0.00	$24,972.51	$377,636.81	$39,875.04	$6,926.87	$343,897.22
20	$40,809.65	$282,768.90	$0.00	$25,496.93	$385,567.18	$36,491.70	$5,781.25	$349,678.47

Internal Rate of Return =	21.68%
Modified Internal Rate of Return =	12.13%

Table 34: Cost Analysis of Onan 900 ekW Diesel Engine

Onan (West India) On Peak Generator **Power Rating: 990 kW / 900 ekW / 1125 kVA**

Cost of Purchasing all Power = What they would pay to PREPA to purchase all electricity

Initial Investment = all investments made to the system prior to startup

Cost of capital =	9.65%
Diesel Fuel Escalation =	3.50%
Electric Price Escalation =	2.10%
Maintenance Escalation =	3.60%
Cost to Purchase Power per Month	$21,648.60
Maintenance Cost Adjustment due to increased engine Size =	27.00%

Year	Maintenance Cost ($)	Fuel Cost ($)	Initial Investment ($)	Electricity cost due to downtime ($)	Cost of purchasing all power ($)	*Fn = Net Savings ($)*	*Present Value ($)*	*Net Present Value ($)*
0			$229,300.00			-$229,300.00	-$229,300.00	-$229,300.00
1	$24,190.48	$146,707.56	$0.00	$17,179.04	$259,783.14	$71,706.06	$65,395.40	-$163,904.60
2	$25,061.33	$151,842.33	$0.00	$17,539.80	$265,238.59	$70,795.13	$58,882.48	-$105,022.12
3	$25,963.54	$157,156.81	$0.00	$17,908.13	$270,808.60	$69,780.11	$52,930.47	-$52,091.65
4	$26,898.23	$162,657.30	$0.00	$18,284.20	$276,495.58	$68,655.84	$47,494.46	-$4,597.19
5	$27,866.57	$168,350.30	$0.00	$18,668.17	$282,301.98	$67,416.94	$42,532.99	$37,935.80
6	$28,869.76	$174,242.57	$0.00	$19,060.20	$288,230.33	$66,057.79	$38,007.76	$75,943.56
7	$29,909.07	$180,341.05	$0.00	$19,460.47	$294,283.16	$64,572.57	$33,883.45	$109,827.00
8	$30,985.80	$186,652.99	$0.00	$19,869.14	$300,463.11	$62,955.18	$30,127.45	$139,954.45
9	$32,101.29	$193,185.85	$0.00	$20,286.39	$306,772.83	$61,199.31	$26,709.69	$166,664.14
10	$33,256.93	$199,947.35	$0.00	$20,712.40	$313,215.06	$59,298.37	$23,602.41	$190,266.55
11	$34,454.18	$206,945.51	$0.00	$21,147.37	$319,792.58	$57,245.52	$20,780.05	$211,046.60
12	$35,694.53	$214,188.60	$0.00	$21,591.46	$326,508.22	$55,033.63	$18,219.00	$229,265.60
13	$36,979.54	$221,685.20	$0.00	$22,044.88	$333,364.90	$52,655.28	$15,897.53	$245,163.13
14	$38,310.80	$229,444.18	$0.00	$22,507.82	$340,365.56	$50,102.75	$13,795.60	$258,958.73
15	$39,689.99	$237,474.73	$0.00	$22,980.49	$347,513.24	$47,368.03	$11,894.76	$270,853.49
16	$41,118.83	$245,786.35	$0.00	$23,463.08	$354,811.01	$44,442.76	$10,178.01	$281,031.50
17	$42,599.11	$254,388.87	$0.00	$23,955.80	$362,262.05	$41,318.27	$8,629.69	$289,661.19
18	$44,132.68	$263,292.48	$0.00	$24,458.87	$369,869.55	$37,985.52	$7,235.40	$296,896.60
19	$45,721.45	$272,507.72	$0.00	$24,972.51	$377,636.81	$34,435.13	$5,981.88	$302,878.48
20	$47,367.42	$282,045.49	$0.00	$25,496.93	$385,567.18	$30,657.34	$4,856.93	$307,735.40

Internal Rate of Return =	17.88%
Modified Internal Rate of Return =	11.42%

Table 35: Cost Analysis of Cummins 1100 ekW Diesel Engine

Cummins On Peak Generator **Power Rating: 1250 kW / 1100 ekW / 1375 kVA**

Cost of Purchasing all Power = What they would pay to PREPA to purchase all electricity

Initial Investment = all investments made to the system prior to startup

Cost of capital =	9.65%
Diesel Fuel Escalation =	3.50%
Electric Price Escalation =	2.10%
Maintenance Escalation =	3.60%
Cost to Purchase Power per Month	$21,648.60
Maintenance Cost Adjustment due to increased engine Size	40.00%

Year	Maintenance Cost ($)	Fuel Cost ($)	Initial Investment ($)	Electricity cost due to downtime ($)	Cost of purchasing all power ($)	*Fn = Net Savings ($)*	*Present Value ($)*	*Net Present Value ($)*
0			$244,800.00			-$244,800.00	-$244,800.00	-$244,800.00
1	$26,656.00	$142,404.20	$0.00	$17,179.04	$259,783.14	$73,543.90	$67,071.50	-$177,728.50
2	$27,615.62	$147,388.35	$0.00	$17,539.80	$265,238.59	$72,694.82	$60,462.52	-$117,265.99
3	$28,609.78	$152,546.94	$0.00	$17,908.13	$270,808.60	$71,743.74	$54,419.95	-$62,846.04
4	$29,639.73	$157,886.08	$0.00	$18,284.20	$276,495.58	$70,685.56	$48,898.57	-$13,947.47
5	$30,706.76	$163,412.10	$0.00	$18,668.17	$282,301.98	$69,514.95	$43,856.61	$29,909.14
6	$31,812.20	$169,131.52	$0.00	$19,060.20	$288,230.33	$68,226.40	$39,255.51	$69,164.65
7	$32,957.44	$175,051.12	$0.00	$19,460.47	$294,283.16	$66,814.13	$35,059.67	$104,224.32
8	$34,143.91	$181,177.91	$0.00	$19,869.14	$300,463.11	$65,272.15	$31,236.24	$135,460.56
9	$35,373.09	$187,519.14	$0.00	$20,286.39	$306,772.83	$63,594.21	$27,754.91	$163,215.48
10	$36,646.52	$194,082.31	$0.00	$20,712.40	$313,215.06	$61,773.83	$24,587.71	$187,803.19
11	$37,965.80	$200,875.19	$0.00	$21,147.37	$319,792.58	$59,804.23	$21,708.85	$209,512.04
12	$39,332.57	$207,905.82	$0.00	$21,591.46	$326,508.22	$57,678.37	$19,094.55	$228,606.59
13	$40,748.54	$215,182.53	$0.00	$22,044.88	$333,364.90	$55,388.95	$16,722.87	$245,329.46
14	$42,215.49	$222,713.92	$0.00	$22,507.82	$340,365.56	$52,928.33	$14,573.62	$259,903.08
15	$43,735.24	$230,508.90	$0.00	$22,980.49	$347,513.24	$50,288.60	$12,628.16	$272,531.24
16	$45,309.71	$238,576.71	$0.00	$23,463.08	$354,811.01	$47,461.51	$10,869.35	$283,400.58
17	$46,940.86	$246,926.90	$0.00	$23,955.80	$362,262.05	$44,438.48	$9,281.38	$292,681.96
18	$48,630.73	$255,569.34	$0.00	$24,458.87	$369,869.55	$41,210.60	$7,849.71	$300,531.67
19	$50,381.44	$264,514.27	$0.00	$24,972.51	$377,636.81	$37,768.59	$6,560.95	$307,092.62
20	$52,195.17	$273,772.27	$0.00	$25,496.93	$385,567.18	$34,102.81	$5,402.78	$312,495.40

Internal Rate of Return =	16.86%
Modified Internal Rate of Return =	11.24%

Table 36: Cost Analysis of Onan 1100 ekW Diesel Engine

Cummins On Peak Generator **Power Rating: 1250 kW / 1100 ekW / 1375 kVA**
Cost of Purchasing all Power = What they would pay to PREPA to purchase all electricity
Initial Investment = all investments made to the system prior to startup

Cost of capital =	9.65%
Diesel Fuel Escalation =	3.50%
Electric Price Escalation =	2.10%
Maintenance Escalation =	3.60%
Cost to Purchase Power per Month	$21,648.60
Maintenance Cost Adjustment due to increased engine Size	40.00%

Year	Maintenance Cost ($)	Fuel Cost ($)	Initial Investment ($)	Electricity cost due to downtime ($)	Cost of purchasing all power ($)	*Fn = Net Savings ($)*	*Present Value ($)*	*Net Present Value ($)*
0			$239,300.00			-$239,300.00	-$239,300.00	-$239,300.00
1	$26,656.00	$142,404.20	$0.00	$17,179.04	$259,783.14	$73,543.90	$67,071.50	-$172,228.50
2	$27,615.62	$147,388.35	$0.00	$17,539.80	$265,238.59	$72,694.82	$60,462.52	-$111,765.99
3	$28,609.78	$152,546.94	$0.00	$17,908.13	$270,808.60	$71,743.74	$54,419.95	-$57,346.04
4	$29,639.73	$157,886.08	$0.00	$18,284.20	$276,495.58	$70,685.56	$48,898.57	-$8,447.47
5	$30,706.76	$163,412.10	$0.00	$18,668.17	$282,301.98	$69,514.95	$43,856.61	$35,409.14
6	$31,812.20	$169,131.52	$0.00	$19,060.20	$288,230.33	$68,226.40	$39,255.51	$74,664.65
7	$32,957.44	$175,051.12	$0.00	$19,460.47	$294,283.16	$66,814.13	$35,059.67	$109,724.32
8	$34,143.91	$181,177.91	$0.00	$19,869.14	$300,463.11	$65,272.15	$31,236.24	$140,960.56
9	$35,373.09	$187,519.14	$0.00	$20,286.39	$306,772.83	$63,594.21	$27,754.91	$168,715.48
10	$36,646.52	$194,082.31	$0.00	$20,712.40	$313,215.06	$61,773.83	$24,587.71	$193,303.19
11	$37,965.80	$200,875.19	$0.00	$21,147.37	$319,792.58	$59,804.23	$21,708.85	$215,012.04
12	$39,332.57	$207,905.82	$0.00	$21,591.46	$326,508.22	$57,678.37	$19,094.55	$234,106.59
13	$40,748.54	$215,182.53	$0.00	$22,044.88	$333,364.90	$55,388.95	$16,722.87	$250,829.46
14	$42,215.49	$222,713.92	$0.00	$22,507.82	$340,365.56	$52,928.33	$14,573.62	$265,403.08
15	$43,735.24	$230,508.90	$0.00	$22,980.49	$347,513.24	$50,288.60	$12,628.16	$278,031.24
16	$45,309.71	$238,576.71	$0.00	$23,463.08	$354,811.01	$47,461.51	$10,869.35	$288,900.58
17	$46,940.86	$246,926.90	$0.00	$23,955.80	$362,262.05	$44,438.48	$9,281.38	$298,181.96
18	$48,630.73	$255,569.34	$0.00	$24,458.87	$369,869.55	$41,210.60	$7,849.71	$306,031.67
19	$50,381.44	$264,514.27	$0.00	$24,972.51	$377,636.81	$37,768.59	$6,560.95	$312,592.62
20	$52,195.17	$273,772.27	$0.00	$25,496.93	$385,567.18	$34,102.81	$5,402.78	$317,995.40

Internal Rate of Return =	17.52%
Modified Internal Rate of Return =	11.37%

Alternatives Compared

The above tables show the results of the life cycle cost analyses carried out for each alternative. Using these we are able to tell which of the options are most cost effective. These specific calculations allowed us to determine values in the decision matrix in the economics column.

<u>Solar</u>

The Solar Cost Analysis with Purchasing Additional Electricity from PREPA was found to be the least cost effective out of all the alternatives. With an initial investment of $578,330, this alternative did not pay itself off. It had a net present value of -$302,723.25 at the end of the 20-year life cycle. This solar generation alternative uses the utility as its backup to take the place the battery. The solar panels are taking the place of a peaking generator. This option takes into account replacing the lighting in each of the classrooms, which will reduce the amount of consumed electricity. It also uses solar power for approximately 40 kW of electric production at the Colegio.

We took the total kWh of consumed electricity at the Colegio, and subtracted what they still purchased while using a solar power alternative. Then by multiplying this kWh saved by the price per kWh for each specific year, we determined the "future cash flow" column in the solar cost analysis table above. By taking future cash flow, and subtracting the maintenance cost, we are able to find the "money saved" column.

There is going to be maintenance that will have to be done on this system. There will be an escalation growth associated with maintenance cost from year to year. The maintenance escalation is 3.6 percent due to the increase in cost of labor. We do not have accurate values for the "maintenance cost" column, so the calculations are estimations. But with such a large debt at the end of the 20 years, one can easily see that the maintenance has little effect on the outcome.

The saved money in present value each individual year is shown in the second to last column in Table 30. It is then used in the calculation of the net present value shown in the last column of the table. The net present value is what we are using to access the economics of this particular alternative since excel was unable to compute IRR and MIRR.

Solar/Diesel Hybrid

This is similar to the last analysis, except this that this option includes a diesel generator. The diesel generator greatly increases the maintenance cost, and there is an added cost for fuel.

It turns out that the combination of diesel and solar are slightly better then solar alone. The system consists of solar panels on the roof of the Colegio, efficient lights, and also a diesel generator. The diesel generator is a 455 ekW Cummins generator that will run both day and night to give the Colegio a constant internal supply of electricity. The only time the Colegio should have to purchase power from PREPA is when the diesel generator is receiving maintenance. The maintenance, the fuel, and electricity have escalations of 3.6, 3.5, and 2.1 percent respectively. The future cash flow is calculated each individual year. The future cash flow is brought to the dollar amount at the time of investment, and then with this information the net present value is calculated.

The net present value for this hybrid system is -$124,050.35. This shows that the Colegio would not make money and at a return that they would have if they had invested elsewhere. The internal rate of return was -2.55 percent, and the modified internal rate of return, which is more realistic, was 5.69 percent. This option is not the most economical investment. It would be less expensive to purchase electricity from PREPA.

It is clear from our analyses that any system that contains solar as a large part of the power output, as the two systems above; the investment cost is too large to make the investment worthwhile. It is very difficult to recover the large investment cost requires to do solar, making solar uneconomical.

Cummins 818 ekW Cost Analysis

The same procedure and format was used to develop the cost analysis for all the alternatives, except for the solar alone table that was designed in a slightly different manner that has been described earlier. The following discussion describes the cost analysis table for the Cummins 818 ekW engine alternative.

All columns in the table represent data in dollar except the year's column, which is the first column. Year zero for the Cummins 818 ekW engine has an initial investment cost of $208,600. The initial investment column only has a value in the zero year because the initial startup cost was the only investment over the 20-year analysis. There were no operating costs in year zero; therefore, the net savings, present value, and net present value columns were equal to the negative of the initial investment cost.

The remaining columns begin for the year zero when the engine would be operating. The first column is the maintenance column. The first years maintenance cost was given as $22,848 and it was then increased each year by 3.6 percent due to maintenance escalation rate. One can see that in the 20th year of the analysis, the maintenance cost for the 818 ekW engine would be $44738.72, which is significantly higher than the first year cost. The fuel cost column represents the fuel purchased to drive the diesel engine over a one-year period. Similarly to the maintenance column, we obtained the first year's fuel cost of $125,355.84 and escalated the cost each year after that by 3.5 percent.

The center two columns deal with the electricity purchased from the local electric company, the Puerto Rico Power Authority (PREPA). For the column "electricity cost due to downtime" we obtained the first year cost to buy electricity from PREPA when the Cummins 818 ekW engine was not operating, which was during nights, weekends, and when the Colegio is closed for holiday and other events. The first year's electricity cost to purchase electricity that this engine would not produce was $17,179.04. Again, we took the first year cost and escalated it by the electricity escalation rate of 2.1 percent. The "cost of purchasing all power" column is constant for all tables. This column shows the cost the Colegio would have to pay in a year for buying all electricity. This means that there would be no alternative energy source producing electricity. For the first year in the table, the cost was $259,783.14 to purchase all electricity.

The definitions and precise calculations of net savings, present value, and net present value have been explained in detail in the earlier sections of this report. To make the cost analysis table clear, we briefly explained how we obtained each of these values.

The "F_n = Net Savings" column was determined for each year in the analysis individually, but in the same manner. As an example, we will discuss the tenth year in the Cummins 818 ekW cost analysis table. Each other year in the analysis was determined by the same procedure. To obtain the net savings in the tenth year of $90,244.21, we subtracted the "cost of purchasing all power" value, $313,215.06, from the following columns: the "maintenance cost" equal to $31,411.31, the "fuel cost" equal to $170,847.14, and the "electricity cost due to downtime" equal to $20,712.40. Next, we determined the present value for the tenth year, which was $35,919.73. The "present value" column took the net savings and converted it into the dollar value at the year of the initial investment. Finally, the "net present value" column was determined. Following the above example, the "net present value" for the Cummins 818 ekW in the tenth year of the analysis was $372,830.97. The "net present value" for each year was calculated by adding the "present value" for the given year in question with the previous year's "net present value". Since this value is positive in this case, the initial investment of $208,600 has been paid off and the Cummins 818 ekW alternative has saved this much money compared to solely purchasing electricity from PREPA.

The size of this engine is large enough to supply the entire Colegio with all its power needs. This generator like the others is running only during on-peak hours, 16 hours per day. This makes the fuel consumption per year less. This engine has the best IRR and MIRR of 32.15 and 13.88 percent respectively. The net present value after the 20 years is $581,232.22, which is a very good return on the investment. This generator set preformed the best in all of our analyses.

Caterpillar 820 ekW Cost Analysis

This Caterpillar engine is very similar to the Cummins 818 ekW engine, but it performed slightly worse than the Cummins generator set. The initial investment cost was lower in this engine by approximately $1,100, however the fuel efficiency of this engine is slightly, less than the Cummins. The net present value after 20 years is $349,687.47, which shows that it is still a good investment, but it does not make quite as much as the Cummins. For this generator the IRR is 21.68 percent and the MIRR is equal to 12.13 percent. These numbers prove that this generator is also a good investment.

Onan 900 ekW Cost Analysis:

The cost analysis for the Onan 900 ekW contained a higher initial investment rate than the two 800 ekW engines and higher maintenance cost because the engine has a larger power rating and as a result, the Onan 900 ekW was not as cost effective. This engine did however make money over the 20-year life cycle. The net present value in the 20th year was $307,735.40. The IRR and the MIRR were 17.88 and 11.42 percent, respectively. This engine only runs at 61 percent to meet the average on peak demand and 72 percent to meet the peak demand; therefore this engine has more power output than needed for the Colegio.

Cummins 1100 ekW Cost Analysis:

The Cummins 1100 ekW, as the 900 ekW engine discussed previously, could supply much more power to the Colegio than needed. It would operate at only 50 percent to supply the average on peak demand and 59 percent to meet the peek demand. This 1100 ekW engine had a net present value of $312,495.40. The IRR and MIRR were 16.86 and 11.24 percent, respectively. This engine still made money even though it was larger than needed.

Onan 1100 ekW Cost Analysis:

This engine has the same specification as the above Cummins 1100 ekW engine because Cummins/Onan manufactures them. The reason why the analyses were not identical was that the engines were distributed by different organizations. West India Machinery and Supply Company distributed the Onan 1100 ekW engine. Cummins of Puerto Rico distributed the Cummins 1100 ekW engine. The investment cost of the engine distributed by West India Machinery and Supply Company was $5,500 less expensive. As a result of having a lower investment cost, the Onan 1100 ekW engine had slightly higher net present value, IRR, and MIRR. The net present value for this engine was $317,995.40. The IRR and MIRR were 17.52 and 11.37 percent.

The only benefit to the above two engines is their added capacity. If the Colegio was expecting large growth in the future, these engines could be considered. These engines are wasteful for the Colegio's current and future needs even with increased air-conditioning.

Decision Matrix for Analysis

One method of analysis that we used in this project was a decision matrix. There were five steps involved in conducting the matrix which were: prepare the matrix, rate the concepts, rank, combine and improve the concepts, select one or more concepts, and reflect on the results and the process.

The idea of the decision matrix was to weigh each category, such as economics, environmental impacts, and size of the alternatives. Each concept, or in this case a power generating alternative, was rated in every category. The ratings were multiplies by the weights. A total score was obtained for each category. Then, the results of the scores were examined to determine the best option for power generation.

To determine the weight of each category, we consulted with our liaison Dean Elsie Candelaria. Weights for pollution, economics, and size of plant were determined.

Table 37: Criterion and their Weights

Criteria	*Weight*
Economics	19
Pollution	20
Aesthetics	11
Size	5

The weights represent the importance of the respective criteria. If a criterion has a higher weight, then it is more important to the Colegio than a criterion with a lower weight. A criterion was chosen to be higher than another criteria if it was more important to the final decision for an alternate energy source.

Once we established the weights for each criterion, we were able to rate each alternative under each criterion. The rating was out of 100 for every alternative and every category. In this way each matrix and each alternative will be proportional to each other. To obtain the rating, we examined all alternatives simultaneously. If an alternative was better than another alternative in a given criteria, than it received a higher rating for that particular criteria. To make a fair decision, each member of the project team ranked each different alternative for the four categories of economics, pollution, aesthetics, and size. After each member ranked all the concepts, and discussed the reasoning behind the ranking, the average rank was chosen as the final.

After the project team ranked each alternative under all the categories, we summed the weighted scores of the categories for the specific alternative. The result that we obtained was a total weighted score for each alternative. The following is the decision matrix that we developed.

Table 38: Decision Matrix

Criteria	Weight	Alternative 1: Cummins 1100 Rating	Alternative 1: Cummins 1100 Weighted score	Alternative 2: Cummins 818 Rating	Alternative 2: Cummins 818 Weighted score
20 Year Life-Cycle Cost	19	70	1330	100	1900
Pollution	20	43.2	864	54.8	1096
Aesthetics	11	50	550	50	550
Size	5	50	250	70	350
Total Weighted Score:			**2994**		**3896**

Criteria	Weight	Alternative 3: Hybrid Cummins 455 Rating	Alternative 3: Hybrid Cummins 455 Weighted score	Alternative 4: Caterpillar 820 Rating	Alternative 4: Caterpillar 820 Weighted score
20 Year Life-Cycle Cost	19	20	380	90	1710
Pollution	20	60.8	1216	40	800
Aesthetics	11	40	440	50	550
Size	5	80	400	70	350
Total Weighted Score:			**2436**		**3410**

Criteria	Weight	Alternative 5: Onan 1100 Rating	Alternative 5: Onan 1100 Weighted score	Alternative 6: Onan 900 Rating	Alternative 6: Onan 900 Weighted score
20 Year Life-Cycle Cost	19	70	1330	70	1330
Pollution	20	43.2	864	40.3	806
Aesthetics	11	50	550	50	550
Size	5	50	250	60	300
Total Weighted Score:			**2994**		**2986**

Criteria	Weight	Alternative 7: Solar Rating	Alternative 7: Solar Weighted score
20 Year Life-Cycle Cost	19	0	0
Pollution	20	100	2000
Aesthetics	11	70	770
Size	5	60	300
Total Weighted Score:			**3070**

The alternative with the best economics was the Cummins 818 ekW engine and as a result, it was given a "20 Year Life-Cycle Cost" rank of 100. Along with the best economics, this power generating system had the best overall score of 3896. This engine matches the Colegio's needs best. This engine is running close to the percent where its efficiency is highest; this means the generator burns less fuel per kW generated. A high rating on pollution indicates low levels of pollution for diesels, the pollution rating is inversely proportional to fuel consumption.

The second best overall alternative and the second best rank in economics was the Caterpillar 820 kW engine. This alternative was given a rank of 90 for economics and obtained a total score of 3,410, which was 340 points higher than the next best option of using only solar power. The reason why the Caterpillar engine was not as cost effective as the Cummins 818 ekW engine is that it consumes more fuel per year to produce the same power. As a result of the higher fuel consumption, this generator produces higher pollution.

The Onan 900 ekW engine was similar in most categories with the Cummins 818 ekW and Caterpillar 820 ekW except for pollution and economics. This engine burns more fuel than these two, so naturally it costs more to run and creates more pollution. This engine would be a good option if the Colegio for expected large growth in the future. If the Colegio increases its demand in the future this engine would run at a more efficient level and prove to be more cost effective.

The alternative that was least cost effective was the alternative that did not break even at the end of the end of the 20-years. This alternative was given a rank of zero. The option that had the worst cost analysis was the solar alternative. From the matrix it is seen that the total weighted score ranks it third. The reason for this is because the Colegio wanted to place the highest weight on pollution, and solar had the highest rating in this category.

Overall the worst option turned out to be the hybrid system. This system combines the expense of solar power, with the pollution of a generator. The size is also large, because the roof space has solar, and the ground has a generator. In the decision matrix, this option had the worst performance.

The Cummins and Onan 1100 kW generators should also be looked at as an option. The generator did recover its payment and had a decent payback, however because of its size, the engine lost ratings in economics and pollution. This option should only be considered if the Colegio is expecting rapid expansion in a few years.

We obtained the total weighted score for each alternative from the decision matrix and then compared the alternatives. The higher the total weighted score, the better an alternative and these are ranked in order from best alternative to lease in the table below.

Table 39: Decision Matrix Ranking Results

Alternative	Score	Rank
Cummins 818	3896	1
Caterpillar 820	3410	2
Solar	3070	3
Onan 1100	2994	4
Cummins 1100	2994	4
Onan 900	2986	6
Hybrid	2436	7

From the decision matrix and the other data and analysis we obtained, the project team was able to give their conclusions and recommendations that can be read in the following section.

Conclusions and Recommendations

This section of the report will explain our recommendations concerning where future efforts should be focused, and our conclusions about alternative power sources. The views presented in this section were derived from our data collection and analysis. We feel that if the Colegio follows our recommendations then there will be a reduction in energy costs in the future, as well as a future for the Colegio that will not suffer from power deficiencies.

Faculty Interviews

The project group is able to make some general comments and conclustions about the interviews that took place during this project. The first couple of questions that we asked the interviewees dealt with the impact of education due to the power failures that occur at the Colegio. We noticed that all interviewees had some problems with power at the Colegio. They all also said that the electrical difficulties affect the students education. The installation of a power generator would make the power supply more reliable, thus improving education at the Colegio.

The next couple questions delt with concerns about air conditioning. Every professor said that air conditioning is necessary at the Colegio. Not only will it make it better for the students to learn, but also it would make it better for the teachers. Air-conditioning, according to almost all people at the Colegio that we talked to, is a necessity. We recomend that air conditioning be installed to the Colegio.

The third set of questions dealt with the autonomy issue. We asked each interviewee their feelings about the autonomy issue that the Colegio is currently facing. Each interviewee said that the Colegio would be better off if they were not part of the Municiplaity of San Juan. They believed that there would be a great imporvement if the Colegio would become seperate because politics would be removed from education. Each person we talked to said that the Colegio was being held back by the Municipality. There were budget problems due to being part of the Municipality and there were long delays when the employees at the Colegio ordered equipment because it had to be approved by the Municipality before the order could be sent.

The last set of questions dealt with the Colegio using the power source that might be installed as some kind of educational value. All interviewees said that there was an eduactional value to using the system we may recommend for education.

We conclude from the interviews that the electrical system must be improved to make the system more reliable, and to have a larger capacity for air conditioning. This will improve the Colegio so that it would be able to be independent from the Municipality, which everyone believes should be done.

Repairing the Infrastructure of the Colegio

As stated in the chapter on "Data, Results, & Analysis", our original assumption that the three substations must be overloaded proved to be false. With the addition of air-conditioning the average kVA demand of the Colegio will be 303 kVA, with a peak demand of 767 kVA. The Colegio has a capacity of 1500 kVA, which is well above the current and projected maximum demand of the school. This is not to say that the substations could not use maintenance and repair to prevent future collapse; however, for the present time the substations do not appear to be the main electrical problem at the Colegio.

A solution to this problem, which was offered by Marcus Droz, is to perform a detailed study to see where the load in the Colegio distributed and from what source and phase each load is powered. Measuring the current at each transformer and at each breaker box will give some idea of the load distribution. Refer to the Results chapter for a detailed explanation of the load distribution. Once the load distribution is determined and the current measurements are made, a system can be designed to deliver power to more efficiently and evenly throughout the Colegio.

We feel that the best way to go about engineering the repairs to the system is to divide the Colegio into areas that all have similar current demands. Once this is done, a simple block diagram can be designed that will show where each phase must be brought to and distributed from. Close attention must be paid to the substations as well; from each substation equal amounts of current must be taken. This will give the most versatility for future load demands, as well as allow future distributions to be balanced and distributed evenly. With a block diagram of the current demands, the diagram can be compared with the current system to determine which existing parts can be used and what parts will have to be replaced or added.

If the Colegio were to have a balanced system, their power problems would most likely be solved, and future additions would have enough power to run without any power problems as reported by the interviewees. We feel that one of the most important steps in correcting the Colegio's problems is to complete this study and repair the infrastructure.

Our recommendation for the Colegio's power problems lies in the repair, and replacement, if necessary, of the current infrastructure. A new infrastructure should be able to supply the Colegio with their current power needs, and future needs. Additional loads that will be demanded by air-conditioning, and future additions in buildings, or labs must be carefully considered.

Educational Value

Educational Value due to Repairing the Infrastructure

Many benefits can be attained with the repair of the infrastructure. The benefits are the result of having proper electricity distribution. For instance, added technology could be utilized in the labs and classroom, which previously could not be powered. This technology will better prepare students as they enter their respective professional fields. Because of the poorly distributed load in the infrastructure, circuit breakers can become overloaded and can cause power outages. In addition, lights often flicker due to air-conditioner compressors, which would not occur if the circuits were not overloaded. If the infrastructure were repaired, these anomalies would not occur. This would cause less disruption for teachers, students, and administrators. The unbalanced load in the Colegio also affects lab equipment and computers. Computers especially, are subject to voltage spikes and dips. In the current system, computers and lab equipment can be damaged due to these voltage irregularities that can cause equipment to be damaged and prevent students and faculty using the equipment. Through the changes in the electrical infrastructure of the Colegio, students and faculty would be more productive, which is important to the educational system.

Curricular Value

A benefit to using an alternate form of energy, such as a diesel generator and solar electricity, is the educational value. Whether alternate forms of energy are cost effective or not it could be used as an educational tool. Academic classes or projects could be centered on this potential energy source. This point is supported by the results of the interviews conducted by the project team. All Colegio professors interviewed, and especially Industry and Technology professors, agreed that a new electrical generation plant could be used in the curriculum for classes or projects.

Value to the Academic Environment With Air Conditioning

We believe that the Colegio should include air conditioning with any investment in their electrical system with or without electric generation. Air-conditioning would improve the environment of the classrooms. Productivity is difficult to achieve for students and faculty in warmer temperatures. Attention spans diminish during the warmer part of the day. We believe that adding air conditioning to the classrooms at the Colegio would improve the quality of the education.

Solar Energy Alternative

Initially, solar panels could be placed on the roof in low concentration, because it would be very expensive to purchase and install 70,000 square feet of solar panels. The most appropriate strategy for the Colegio would be to have multiple stages of solar power installations. If solar power were to be used for the Colegio, the Colegio would start with an affordable amount of solar panels that would power one area of the infrastructure, such as lights. Then in the future, the Colegio could add more panels to provide more energy. Solar energy is not cost effective compared to buying all electricity from PREPA. The reason for this is because of the huge investment cost. To produce only a fraction of the Colegio's power needs with solar, the initial investment would be $578,330. Using this solar alternative would still not produce a quarter of the Colegio's power needs; therefore, additional electricity would have to be purchased from the utility. Over a 20-year life cycle analysis, we determined that the solar alternative would not be paid off and therefore did not have positive returns. The net present value for the 20th year of analysis was -$302,723. Again, the benefit of using a renewable resource has value apart from the economics. The power created is 100 percent pollution free.

Solar and Diesel Engine Combination

Since using only solar energy to produce power at the Colegio was determined not to be cost effective and sufficient for the power demands, we decided to investigate a hybrid system of solar power and a diesel generator. After performing a 20-year cost analysis on the hybrid system, we determined that it was still not cost effective as using solely solar. The net present value of this alternative was -$124,050. The internal rate of return was -2.55 percent and the modified rate of return was 5.69 percent; this means that over the 20-year cycle did not make money and it was well below the cost of capital of 9.65 percent. The money invested could have been put to better use in a different investment.

Diesel Engine Operating Types

Independent power generation leads to many options for the Colegio. Prime independent generation is the option of using a generator to produce all of the Colegio's power and depend on the utility to supply the school with power only during engine downtime. The Colegio also has the option to have a generator for emergency use only, which would come online in the case of a power failure, or brownout. The third option is to use a generator as a supplement to purchasing power from the utility.

The purpose of a supplementary generator is to drive the utility charges down. This generator runs only during times of peak demand, for example, during the day. The generator would still be a prime generator, but it would only run for approximately 16 hours per day, while the Colegio is experiencing peak demand. During the remaining eight hours and on weekends and holidays the Colegio would be purchasing power form the utility.

Under the option of becoming independent of the utility, the Colegio would install a large prime generator that would run 16 hours a day and would supply the Colegio with all their power needs. The generator would run at its optimum percent output during peak hours, and it would not run during off-peak hours. During this time the Colegio would purchase power from PREPA to meet the low power demand.

Emergency power generation is also an option for the Colegio. Under this option the Colegio would have a generator that would be able to supply the Colegio with enough power to operate during times of energy failures. This generator would produce enough electricity to operate essential equipment such as lights, lab equipment, and outlets. Air-conditioning, for example, would not be run during the times when this generator is online. The cost effectiveness of an emergency generator is difficult to evaluate. The emergency generator would only run during time of failure, which makes the price of buying power from PREPA irrelevant, because PREPA would not be supplying power during this time. The investment cost is very difficult to recover because the generator may only operate once a year, or every few years, and the running time may never be more than one day, unless a hurricane were to cause serious damage to the electrical system. Hurricanes that are this devastating only occur every 30 years or so, which makes the literal payback time not worth the investment. What makes this option worthwhile is the security of having a generator that will be able to provide power during times of crisis. The Colegio would not have to cancel classes during power failures and in times of hurricanes the Colegio could be used as a shelter if necessary. The money saved in dollars may not be cost-effective, but the humanitarian aspect and the aid to the community that the energy can provide have a priceless return on the investment.

A generator that can supply all the Colegio's needs such as the prime generator described above also has the benefits of the emergency generator. A prime generator that operates during on peak hours is cost effective, and it can also be used as an emergency generator.

All of the above options provide security to the Colegio. By installing a generator of some type the Colegio will be able to have a more reliable system. Each option gives an unseen asset to the Colegio, because, if PREPA goes down classes will not have to be cancelled, and this is a great benefit to the school and the students.

Cost Effectiveness of Diesel Power Generators

We found that diesel engines are not capable of running at less than 30 percent because the engine would be damaged. The Colegio uses very little power during nights and weekends compared to on peak hours when the school is in full operation. The engines that would meet the on peak demands of the school would have to run well below 30 percent to supply the off peak demands. Since an engine is not capable of operating below 30 percent, we performed analyses for engines producing the on peak power demand while purchasing needed electricity at night.

The generator that was most cost effective while working only during on peak hours was the Cummins 818 ekW engine. We recommend that the Colegio use this power generating system as their alternative. The 20th-year net present value was $581,232, which was substantially higher than all other alternatives. The Cummins 818 ekW was the most economical also for the reason that the internal rate of return (IRR) and modified internal rate of return (MIRR) were the highest at 32.15 and 13.88 percent respectively. The investment returns using the Cummins 818 ekW alternative was shown better than all other alternatives.

The second most cost effective alternative was the Caterpillar 820 ekW engine. The investment cost was $1,100 less than the Cummins 820 ekW engine, but the 20-year analysis was higher for the Caterpillar engine. The Caterpillar generator set burns more fuel per hour and therefore has a higher cost for fuel than the Cummins 818 ekW engine. The Caterpillar engine had the second highest net present value of $349,678, which was $321,554 lower than the Cummins 818 ekW engine. The IRR and MIRR for the Caterpillar engine were 21.68 and 12.13 percent, respectively. The investment returns from using the Caterpillar 820 ekW engine were above the cost of capital at 9.65 percent so using this alternative would be lucrative; however the Cummins 818 ekW engine had slightly higher returns.

The following table summarizes the net present value, the IRR, and the MIRR for the diesel engines that we have analyzed.

Table 40: Economic Data for Diesel Engines

Diesel Engine	20th Year NPV	IRR	MIRR
Cummins 818	$581,232	32.15%	13.88%
Caterpillar 820	$349,678	21.68%	12.13%
Onan 900	$307,735	17.88%	11.42%
Onan 1100	$317,995	17.52%	11.37%
Cummins 1100	$312,496	16.86%	11.24%

Where: NPV = Net Present Value, how much money the investment made
IRR = Internal rate of return
MIRR = Modified internal rate of return

Recommended Alternatives From Decision Matrix

When we obtained the total weighted score for each alternative, we compared and contrasted all alternatives, especially alternatives that had similar total scores. The total scores for each alternative are based on economics, pollution, size, and aesthetics. The higher the total weighted score, the better an alternative. The alternatives are ranked from the best to the worst, and are listed in the table below.

Table 41: Decision matrix Ranking Results

Alternative	Score	Rank
Cummins 818	3896	1
Caterpillar 820	3410	2
Solar	3070	3
Onan 1100	2994	4
Cummins 1100	2994	5
Onan 900	2986	6
Hybrid	2436	7

The alternative with the highest weighted score was the Cummins 818 ekW generator with a score of 3,896. Since this alternative had the highest score, it is the best option for the Colegio. The next best energy system was the Caterpillar 820 ekW generator with a score of 3,410, which was 486 points behind. The Caterpillar 820 ekW alternative resulted in lower total weighted score for the main reason that the economics were not as good as the Cummins 818 ekW. The Caterpillar 820 ekW engine burns more fuel per hour and as a result has a higher cost per year for fuel. These two options are what we recommend to the Colegio if they decide to generate their own electricity.

Contacts for Future Reference

Throughout our work in San Juan, we found that some of the people we contacted were very willing to help. Some vendors, and installers provided quotes in very short times. Other vendors were slower or provided quotes that were not complete, or inaccurate. For this reason we decided to acknowledge the names and companies who proved to be helpful and fast in processing our requests. Below is a list of their names and companies. If any questions or future studies are expected for the future, we recommend these people as helpful contacts.

Caterpillar-Rimco, Puerto Rico
Ricardo Diaz, Sales representative
Miguel Hernandez, Head of sales division

Cummins Diesel de Puerto Rico Inc.
Idelfonso Acevedo, Sales representative
Carlos Cruz, Sales representative

M&C Electric
Feux Monserrate, Sales representative

Preferred Installer for Cummins Diesel
Ramon R. Delgado, P.E. Private installer/contractor

M&C Electric
Feux Monserrate, Installer

Texaco
Alejandro Santiago, Fuel sales department

ETS Technical House (Solar)
Jorge Denato, Owner

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Appendix A: Information about The Colegio Tecnológico del Municipio de San Juan

The information for this appendix was obtained from Elsie Candelaria, Dean of Academic Affairs for the Colegio Tecnológico del Municipio de San Juan. She provided us the institution's strategic plan and mission statement, as well as historical background pertaining to the Colegio.

Mission Statement

"The Colegio's Mission is to offer post-secondary education and innovative educational programs geared toward promoting a holistic development of its students and the community, insuring access to residents of socio-economically disadvantaged sectors of the Municipality of San Juan. Our commitment is to the development of an educated individual that is competent on a personal, social and professional level." This statement is taken directly from the Colegio's strategic plan.

Philosophy

The Colegio is a higher education institution that integrates technological and humanistic movements. Discovering new possibilities and investigating alternatives is one goal the institute strives for. Problem solving, self-improvement, and teamwork are what the Colegio community is based on.

Autonomy

The Colegio Tecnológico is currently under the control and authorization of the Municipality of San Juan. Since the Colegio is part of the Municipality, the Colegio receives funds and support from the Municipality of San Juan. Accompanying the benefits of financial support, the Colegio has difficulties with the operations of the Municipality. These constraints include money management problems and delays, as well a not receiving desired funding. The Municipality makes the processes to obtain equipment for the Colegio very lengthy and time consuming. Many members of the Colegio would like to break away from the Municipality of San Juan and operate independently in the near future. Autonomy would allow the Colegio to grow and operate completely under the discretion and judgment of the Colegio. The Colegio would then be able to manage their own money and budgeting issues, which would make the processes move much faster and with less effort.

Historical background

As the need for technically experienced personnel increased in the city of San Juan, a need and a means for training new people who would be entering the workforce became clear. Consequently, the City of San Juan established the Colegio Tecnológico del Municipio de San Juan. The Colegio was built under ordinance #45 of the Municipal Assembly, Series 1971-72, under the name of "Colegio Tecnológico de la Comunidad." The "Colegio Tecnológico" is the first post-secondary institution developed by a municipality in Puerto Rico. The name of the Colegio was then changed to "Colegio

Tecnológico del Municipio de San Juan" under Ordinance, Number 37 of the Municipal Assembly, Series 1981-82. The Colegio grants certificates and associate degrees in many fields of study. Those fields are Electronics, Computer Programming, Secretarial Sciences, Architecture, Construction, and Nursing. Other courses have been offered from time to time.

The school has gained many accreditations. In June of 1978, the Middle States Association of Colleges and Schools accredited the institution. It was reaccredited in 1983 and in 1987. Later, the Council of Higher Education extended accreditation. It received an additional accreditation by the National League for Nursing in June of 1990 and was reaccredited by the league last May 1996.

Colegio's Current Layout and Enrollment

The size of the Colegio's campus is approximately an acre and half. The campus is comprised of three main buildings. Two large buildings are used for academics and administration. There is also a third, smaller building used primarily for administrative purposes. Accompanying the main buildings at the Colegio is a gymnasium and a theater that holds approximately 500 people. One last building contains the library and the cafeteria. Over the last ten years, the number of students attending the Colegio has fluctuated between 900 and 1100.

Goals and Objectives

The Colegio Tecnológico del Municipio de San Juan has three goals, each with its respective objectives. These goals and objectives were taken directly from the Colegio's Strategic Plan (1998).

GOAL1: To promote a holistic development of students.

Objectives:

1. To cultivate in the student self-esteem, self-assurance, and self-determination.
2. To develop a person with communication skills.
3. To develop a person that establishes positive interpersonal relationships in their daily life.
4. To develop a person with logical and quantitative reasoning skills.
5. To enable the student to make value judgment, make decisions and adapt to society's changes.
6. To develop in the learner appreciation for their cultural and historical heritage.
7. To cultivate the appreciation, preservation, and improvement of the environment. The natural world and personal health.
8. To develop a person that assumes leadership, fulfills its civic duties and responsibilities, and contributes to the economy of their country.
9. To develop in the student technological knowledge and its applications.

GOAL 2: To provide varied, flexible and updated programs that respond to the needs of the community.

Objectives:

1. To facilitate access to study programs to students coming from socioeconomically disadvantaged areas.

2. To offer interdisciplinary education based on competencies in both regular and evening sessions.

3. To offer special programs dedicated to reinforce knowledge that allows the student to improve its background and complete a study program.

4. To offer academic programs in the areas of General Education, Business Administration, Health Related Sciences, Industry and Technology and others that may arise as a result of needs assessment.

5. To offer re-training opportunities to the Institution's personnel, graduate and members of the community, preferably from San Juan, through the Continued Education Program and professional development activities.

6. To direct investigations leading to improvement in the teaching quality of the institution.

7. To promote the evaluation and continuous review of academic programs and administrative processes.

8. To maintain the standards of excellence required by higher education accrediting agencies.

GOAL 3: To maintain an academic and professional climate that stimulates a constant desire to improve among the members of the Colegio community.

Objectives:

1. To propitiate dialogue between members of the Colegio community and the external community.

2. To promote positive attitudes that guarantee respect to divergent opinions and the rights of others.

3. To recognize excellence in performance to members of the institution.

5. To sponsor extracurricular and cultural events for both the collegiate community and the external community.

6. To provide institutional security to members of the Colegio Community.

Organizational Structure of the Colegio

The governing structure is a Board of Trusties. In addition, the Municipal Assembly serves in an advisory capacity. The mayor, with the recommendations of the Board of Trusties and the Municipal Assembly appoints the Chancellor. The Chancellor assures that the Colegio is striving towards the goals and objectives of the Colegio. Nine members make up the Board of Trusties. These members represent the faculty, student body, and public interests. The function of the board is to guide the development of the Colegio; it also deals with matters dealing with student affairs.

Appendix B: Colegio's Infrastructure

Electrical Investigation: Circuit Breakers and Transformers Count at Colegio, 2000

The Colegio Tecnológico del Municipio de San Juan is interested in determining the cost to revamp the electrical infrastructure. The following is a list of transformers and circuit breakers that are currently in operation at the Colegio. The Colegio currently is not able to distribute enough power for its needs; therefore additional units should be installed. Replacing the entire electrical system, as well as efficient lighting and wiring would increase the power efficiency at the Colegio.

Outside, Behind Theater and Cafeteria

Primary Sub-Station

This sub-station is the where high voltage of 13.2 kilovolts is supplied by the Puerto Rico Power Authority, PREPA. This substation contains transformers and a meter by which the Colegio is billed for power usage.

Outside, West Side of Building "A"

(I) Primary Sub-Station

(A) Panel: MDP-2 277/480 V
Breakers:
(1) Name: Transformer > 175 A
(2) Name: HF-Panel > 225 A
(3) Name: Panel-H > 225 A

(II) Secondary Sub-Station

Current Measurements were performed for the following Panels (A) and (B)

(A) Panel: Bus Duct, 1st Floor
Brand: FPF Cat No. 3232
240 V
200 A
3 Phase

(A) Panel: Bus Duct, 2nd Floor
Brand: FPF Cat No. 3232
240 V

200 A
3 Phase

Roof, Above Building "B"

(I) Breaker Panel
GE, Cat No. TFJ236200WL
3 Phase
Adding up all breakers in Panel there is 610 A

Roof, Above Building "A"

(I) Breaker Panel
Underwriters Laboratories Inc. (UL) No. FZ392159
3 Phase, 4 Wire
480/277 V
225 A Max
There are nine 30 A breakers in Panel

Building "A", 1st Floor

Electrical Room

(T1) Transformer
Cat No. 752-415-3A
75 kVA
480 A-208/120
3 Phase
60 Hz

Dry Type Transformer

(T2) Transformer
Cat No. SE1R
30 A Breaker

Breaker Panels:
(A) Panel HA
U.L. File E-16314 Plant 1
277/480 V

(B) Panel RA
U.L. File E-16314 Plant 1
120/208 V

(C) Breaker
Sylvania, Cat No. S3LB12 (12-24) C
120/208 V
125 A Max

Room 113

(T1) Transformer
Sylvania
15 kVA
3 Phase
60 Hz

(A) Breaker Panel
Sylvania SLB12 (12-24) C
120/208 V

Building "A", 2nd Floor

Electrical Room

(A) Breaker Panel (for Air-Conditioning)
Enclosed Panel, No. EZ 917823
220 V

Electrical Supplies Storage Room, Next to Room 204

(A) Breaker Panel
U.L. File E-16314 Plant 1
120/208 V
This is for Electrical Labs on 2nd Floor and Labs on 1st Floor

Building "A", 3rd Floor

Electrical Room

(T1) Transformer
30 kVA
480 A-208/120
3 Phase
60 Hz
Dry Type Transformer

Breaker Panels:

There is a "Jumper" between the two circuit breakers

(A) Panel
U.L. File E-16314 Plant 1
277/480 V

(B) Panel
U.L. File E-16314 Plant 1
120/208 V

Building "B", 1st Floor
Electrical Room

Measurements of Current were taken for this section of the Colegio from the roof.

(T1) Transformer
Sylvania
75 kVA
480-208/120

Circuit Breakers Panels

(A) Main Breaker 1200 A
Breakers:
(1) Elevator > 60 A
(2) Panel HD > 150 A
(3) Panel HE > 175 A
(4) AC P1 > 125 A
(5) Panel ACP2 > 300 A
(6) Panel HB > 300 A

(B) Panel RB
U.L. File E-16314 Plant 1
120/208 V
For Theater, Library, AC, Building "B"

(C) Panel HB
U.L. File E-16314 Plant 1
277/480 V
42 Breakers

Building "C"

Breakers from the electrical room in Building "B" control part of Building "C"

2^{nd} Floor

(T1) Name: TB-3 Transformer
Cat No. 302-415-3A
30 kVA
3 Phase
60 Hz
Voltage: 480-208Y/120

(A) Panel RB-3
U.L. File E-16314 Plant 1
120/208 V

Building "D", 3^{rd} Floor

(A) ACP 1 Breaker Panel
U.L. File E-16314 Plant 1
277/480 V
AC for 1^{st}, 2^{nd}, and 3^{rd} Floor
Outlets and Lights

Building "E", 1^{st} Floor

(T1) Transformer
45 kVA
3 Phase
60 Hz

(A) Panel HE
277/480 V

(B) Panel RE
120/208 V

Building "F", 1^{st} Floor

Back Corridor

(T1) Transformer
No Label: Approximately 75 kVA

Breaker Panels
(A) Panel SKA
U.L. File E-16314 Plant 1
120/208 V

(B) Panel SKB
U.L. File E-16314 Plant 1
120/208 V

(C) Panel SKB
U.L. File E-16314 Plant 1
120/208 V

(D) Panel EFP
U.L. File E-16314 Plant 1
120/208 V

<u>Backroom</u>

(T1) Transformer
No Label: Approximately 45 kVA

Breaker Panels
(A) U.L. File E-16314 Plant 1
480 V
Amp Section 220

(B) U.L. File E-16314 Plant 1
240 V
Amp Section 125

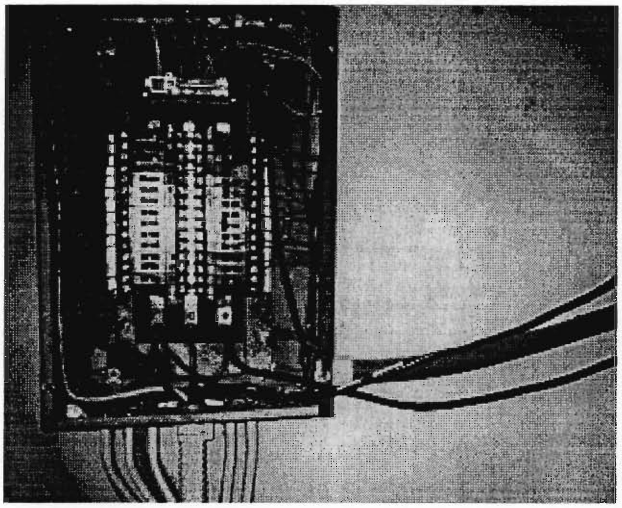
Electrical Room (<u>Locked -> Approximations</u>)

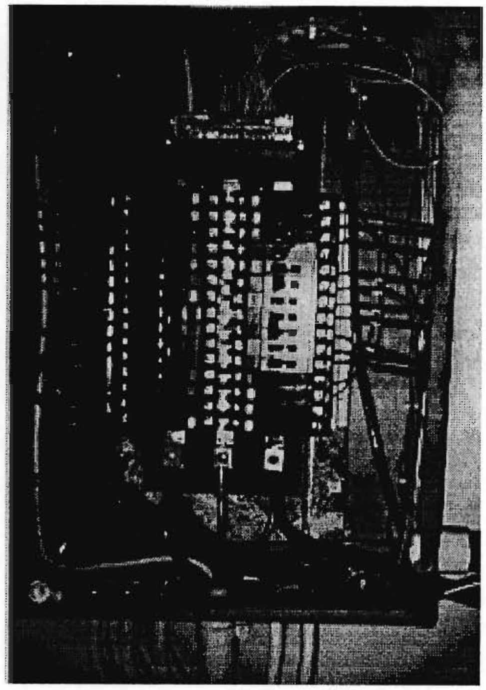
(T1) Transformer
30 kVA
3 Phase
60 Hz

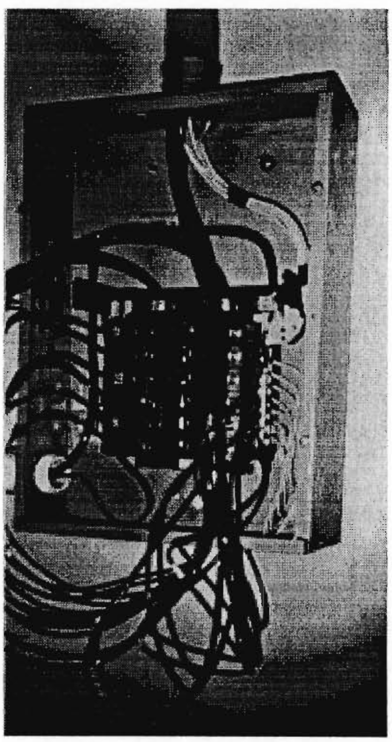
Breaker Panels:
(A) Panel
U.L. File E-16314 Plant 1
277/480 V
(B) Panel
U.L. File E-16314 Plant 1
120/208 V

Appendix C: Pictures from Colegio

Figure 9: Electrical Wiring Examples







Appendix D: Volumes of Colegio Buildings by Room

Room #	Area (square feet)	Height (feet)	Volume (Cubic feet)
101	638.25	11	7020.75
102	644	11	7084
103	644	11	7084
104	644	11	7084
105	644	11	7084
106	644	11	7084
107	638.25	11	7020.75
108	149.25	11	1641.75
109	756	11	8316
110	1134	11	12474
111	756	11	8316
112	1883.25	11	20715.75
113	1249.5	11	13744.5
120	263.375	11	2897.125
121	263.375	11	2897.125
201	638.25	11	7020.75
202	644	11	7084
203	644	11	7084
204	644	11	7084
205	644	11	7084
206	644	11	7084
207	638.25	11	7020.75
208	749.25	11	8241.75
209	756	11	8316
210	1134	11	12474
211	378	11	4158
212	1134	11	12474
213	1127.25	11	12399.75
214	1249.5	11	13744.5
221	263.375	11	2897.125
222	263.375	11	2897.125
300	638.25	11	7020.75
301	644	11	7084
302	644	11	7084
303	644	11	7084
304	644	11	7084
305	644	11	7084

306	638.25	11	7020.75
307	1512	11	16632
308	756	11	8316
309	756	11	8316
310	756	11	8316
311	756	11	8316
312	756	11	8316
313	1249.5	11	13744.5
320	263.375	11	2897.125
321	263.375	11	2897.125
Building B			
Floor 1	3823.75	11	42061.25
Floor 2	3823.75	11	42061.25
Floor 3	3823.75	11	42061.25
Building C			
Floor 1	6378.46	11	70163.06
Floor 2	6378.46	11	70163.06
Floor 3	6378.46	11	70163.06
Building D			
Floor 1	3577	11	39347
Floor 2	3577	11	39347
Floor 3	3577	11	39347
Building F			
Floor 1	15432.66	11	169759.26
Floor 2	4576	11	50336
		Total:	1049548.94
	Volume needs to be conditioned:		931507.94

Appendix E: Puerto Rico Electric Power Designation and Electric Rates

General Service At Primary Distribution Voltage

DESIGNATION	:	GSP
AVAILABLE	:	In all parts of Puerto Rico
APPLICABLE	:	This rate shall apply to industrial costumers for all general purposes and to commercial costumers with large energy demands (such as office buildings, stores, hotels, restaurants, clinics and private hospitals, private schools, clubs, movie houses, radio stations, etc.), for general use including lighting, refrigeration, cooking, air-conditioning, water heating, and motive power. Service shall be through only one meter.

Two or more industrial firms can contract electrical service through one meter, and remain under this rate, if they meet the following requirements without exception:

The industrial firms shall be the property of one owner or parent corporation.
The factories are located in the same building or adjacent buildings in the same lot.
The industries manufacture the same product or interrelated complementary products that form part of the same article.
The industries to contract through one meter cannot have debts with the Authority at the time they request this benefit.

To receive service under this rate schedule, the customers must comply with the requirement of providing the required electrical facilities. Measurement shall be performed and established in this rate, and in accordance with the existing terms and conditions.

Service shall be rendered and billed to the sole responsibility of the owner or legal entity responsible for assuming the prompt payment of the service rendered as well as the deposit of the respective bond.

CHARACTER OF SERVICE: Alternating current, 60 hertz, 3 or 4 wire, three-phase; 2,300; 4,000; 4,160; 8,000; 13,200 volts or another voltage at the Authorities option. The costumer shall provide transformers and substations or may rent them from the Authority, if the equipment is available upon payment of a monthly charge of 1.4% of the total cost of said equipment, including the materials used and equipment installed, plus the full labor charges and other cost incidental to the installation and eventual dismantling of the same.

RATE : Monthly Demand Charge:

Whichever of the following is highest:

a. $8.10 per KVA of 60% of the contracted load.
b. $8.10 per KVA of 60% of the maximum demand established during the 12 months that end with the current month.
c. $8.10 per KVA of the maximum demand during a period of 15 consecutive minutes during the month.

If the maximum demand established during the month is higher than the contracted demand, the excess over the latter shall be billed at $10 per KVA.

Monthly Energy Charge

a. 4.1 cents for each of the first 300 KWH of consumption per KW of the maximum monthly demand.
b. 3.3 cents per KWH of additional consumption.

Monthly Fixed Charge

$200 per month per customer

Plus an adjustment for any change in the fuel price, as described below.

MINIMUM BILL	:	$605 per month plus fuel adjustment.
TERM OF CONTRACT	:	No less than one year, or for the term necessary to justify the costs incurred in providing the service. Can be canceled thereafter with sixty (60) days prior notice by either party.
EFFECTIVE DATE	:	November 15, 1989

General Service at Secondary Distribution Voltage

DESIGNATION: GSS

AVAILABLE: In all parts of Puerto Rico

APPLICABLE: This rate shall apply to non residential, commercial and industrial customers in general (such as offices, stores, restaurants, hotels, ice plants, cold storage packing houses, ball parks charging admission, boarding houses, hospitals and clinics, orphanages, private schools and colleges, clubs, cafes, libraries, community houses, rooming houses, stair and hall lighting in office or apartment buildings, sign and show window lighting, churches, pump installations, and other general industrial uses) with a connected load of 50 KVA or less. Service shall be through one point of delivery and one metering point.

Non-residential customers that at the effective date of this rate schedule have a connected load greater then 50kVA and are being served at secondary distribution voltages, can opt for this rate schedule.

Two or more industrial firms can contract electric service through on meter and remain under this rate schedule if they meet the following requirements without exception:

1. The industrial firms shall be the property of one owner or parent corporation.
2. The factories are located in the same building or adjacent buildings located in the same lot.
3. The industries manufacture the same product or interrelated complementary products which form part of the same article.
4. The industries to contract through on meter cannot have debts with the Authority at the time they request this benefit.

comply with the requirement of providing the required electrical To receive service under this rate, the customer must comply with the requirement providing the required electrical facility.

Measurement shall be performed as established in this rate and in accordance with the existing terms and conditions.

Service shall be rendered and billed to the sole responsibility of the owner or legal entity responsible for assuming the prompt payment of the service rendered as well as for the deposit of the respective bond.

CHARACTER OF SERVICE:	Alternating current 60 hertz, single or three phase, 120, 208,240,440 volts, at the Authority's option.
RATE:	Monthly energy charge: 8.15 cents per kWh of monthly consumption Monthly Fixed Charge: \$5.00 per month per customer Plus an adjustment for any charge in the fuel price, as described below
MINIMUM BILL:	20% of the highest bill during a regular billing period, registered during the last six months or \$5.00 plus energy and fuel adjustment charges, whichever is highest.
EFFECTIVE DATE:	November 15,1989

Standby Service at Transmission or Primary Distribution voltage

DESIGNATION: SBS Rate

AVAILABLE: In all parts of Puerto Rico

APPLICABLE: This rate shall apply to industrial or commercial customers which operate generating equipment, owned by the customer, and which utilizes the Authority's electric service to supplement their internally generated electrical energy, or which require service during outages or maintenance periods of their generating equipment. The customer's generating units may operate in parallel with the Authority upon previous consent of the Authority and subject to the terms and conditions provided for this type of operation. Services shall be rendered through one point of delivery for each industry and one or more meters, as required. Energy produced by the customer shall not be for resale to another entity. The customer shall have the option of requesting the following services which are defined below.

1. Supplementary Service
2. Auxiliary Service
3. Service for Maintenance
4. Interruptible Service

The first three services will be provided on a firm basis and through only one meter. The interruptible service will be metered separately from any other customer load.

CHARACTER OF SERVICE: Alternating current, 60 hertz, 3 or 4 wire, three se, transmission or primary distribution voltage the Authority's option. Transformers and substation facilities are to be furnished by customer.

DEFINITIONS: For the application of this rate schedule the following terms are defined:

1. Supplementary service - This is the service required by the customer to supply load, which is in excess of customer's installed generation capacity.
2. Auxiliary Service – This is the service-required by the customer to supply the load normally served by his generating units, during forced outages of his equipment.
3. Service for Maintenance – This is the service required by the customer during defined periods of time equivalent to the maintenance period of this generating units, upon prior coordination with the Authority.
4. Interruptible Service – This service is provided to supply the customer's load under the condition that it will be subject to reductions or curtailments at the request of the Authority or to automatic interruption by under frequency relays, controlled by the Authority. This load shall be delivered only upon the availability of sufficient capacity in the Authority's generation and transmission system.

RATE: The total bill shall consist of the following charges in accordance with the supply voltage.

1. Fixed Monthly Customer Charge – The fixed monthly customer charge shall be as established in the general service rates at primary distribution voltages(GSP) or Transmission voltage (GST), or in the time of use rates, (TOU-P or TOU-T), whichever is applicable.
2. Monthly Fuel Adjustment Charge – The charge is for kWH will be as established in the Fuel Adjustment clause for primary distribution or Transmission voltages, whichever is applicable.
3. Monthly Energy Charge – The charge for each kWH consumed, for all services, shall be as established in the General Service Rates Primary Distribution voltage (GST), or in the time of use rates, (TOU-P or TOU-T), whichever is applicable.
4. Monthly Demand Charge:

a. For the firm services (auxiliary supplementary and maintenance) measured by only one meter, the charge per kVA will be computed according to the General service Rates GSP or GST, or the Time of Use Rates, (TOU-P or TOU-T), whichever applies. The maximum demand established during the maintenance periods, duly coordinated with the Authority, will not be considered to calculate 60% of the maximum demand established during the 12 months that end with the current month.

b. For Interruptible Service, the charge will be whichever of the following is the highest:
   i. $4.60 per kVA of interruptible contracted load, or
   ii. $4.60 per kVA of the established maximum demand in a 15 minute period during the month

MINIMUM BILL: The minimum charge will be as defined in the GSP, GST, TOU-T, or TOU-P rates, whichever applies, according to the service voltage.

SPECIAL REQUIREMENTS: In all cases in which firm (supplementary, auxiliary, or maintenance service) and interruptible service are supplied at the same time through a single connection, the customer shall segregate the auxiliary portion from the interruptible portion, with separate feeders at the secondary bus of the substation for interconnection with the Authority. Generating equipment operating in parallel with the Authority's service shall be disconnected from the interruptible load. The Authority shall install and maintain an under frequency relay, which will automatically disconnect the customer's interruptible load if system frequency drops below 59.5 hertz during 20 seconds, or 59 hertz without any time delay. The customer shall, at his own expense, install a load limiter device at the firm load feeder (or feeders) in order to prevent the occurrence of a load 110% higher than the contracted load.

For service for maintenance, a designated maintenance period schedule shall be specified, upon previous request of not less then three months, and subject to the Authority's approval.

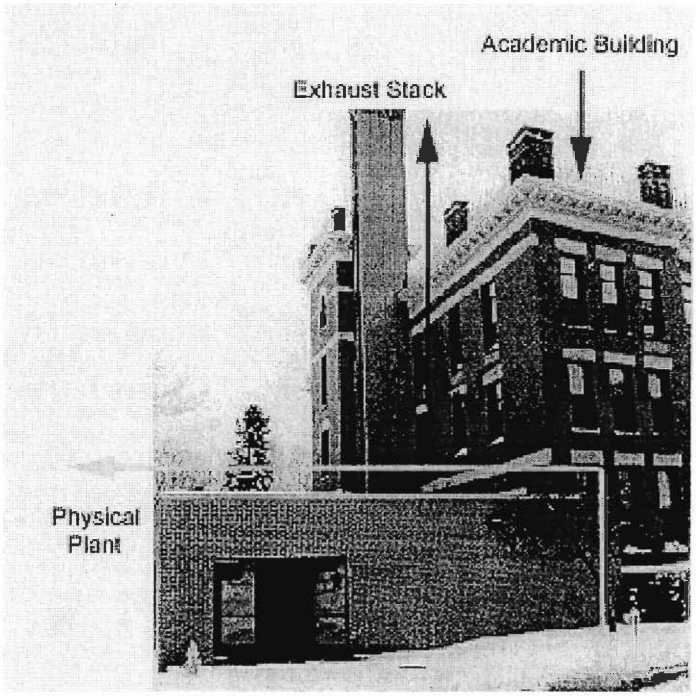
If meter readings of both energy and demand are performed at the secondary side of the customer's substation, the readings shall be referred to the primary side, which is the point of delivery, including a correction factor to account for transformer losses.

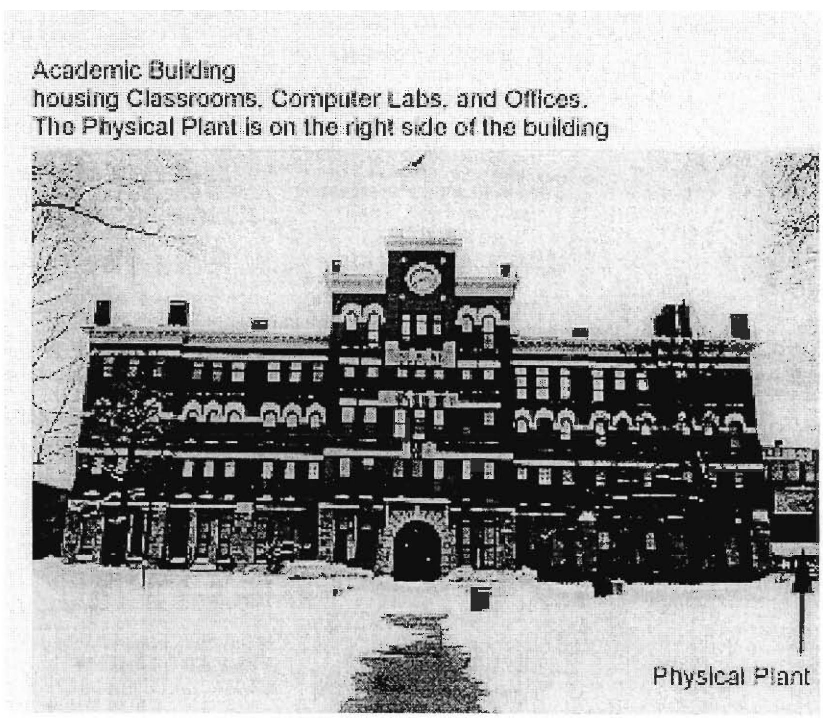
CONTACT PERIOD:	One year minimum, renewable yearly, thereafter
EFFECTIVE:	November 15, 1989

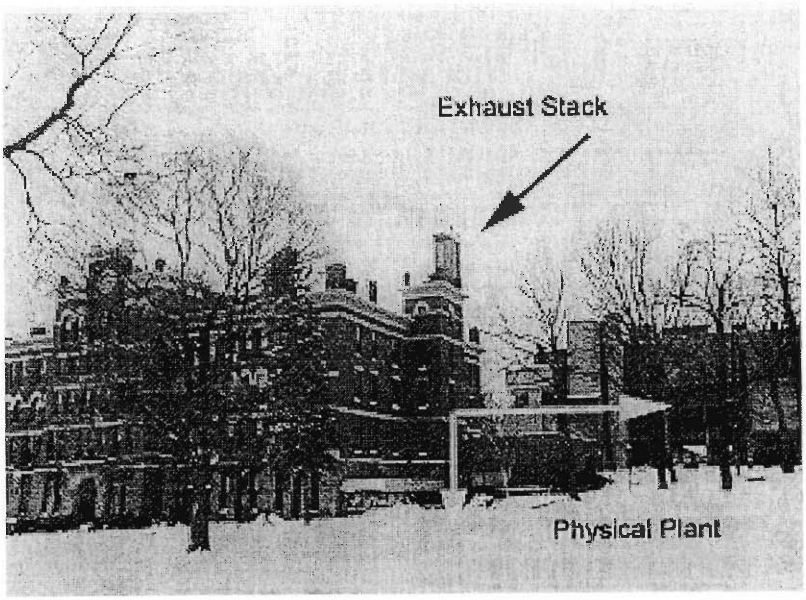
Appendix DF

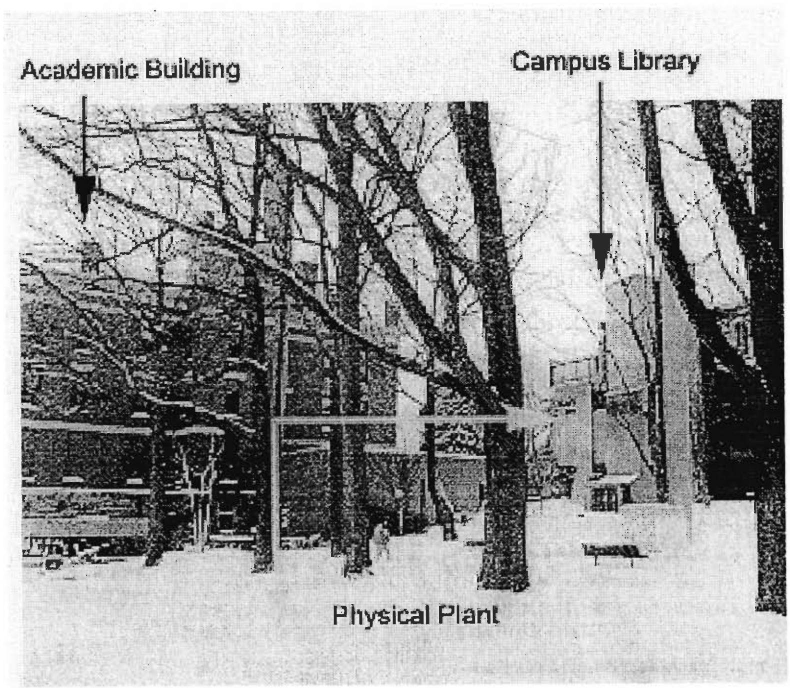
Appendix F: Pictures of Clark University's Power Plant

Worcester, Massachusetts






Exhaust Stack
Physical Plant


Academic Building
Campus Library
Physical Plant

Appendix G: Energy Data from Worcester Polytechnic Institute

Worcester, Massachusetts

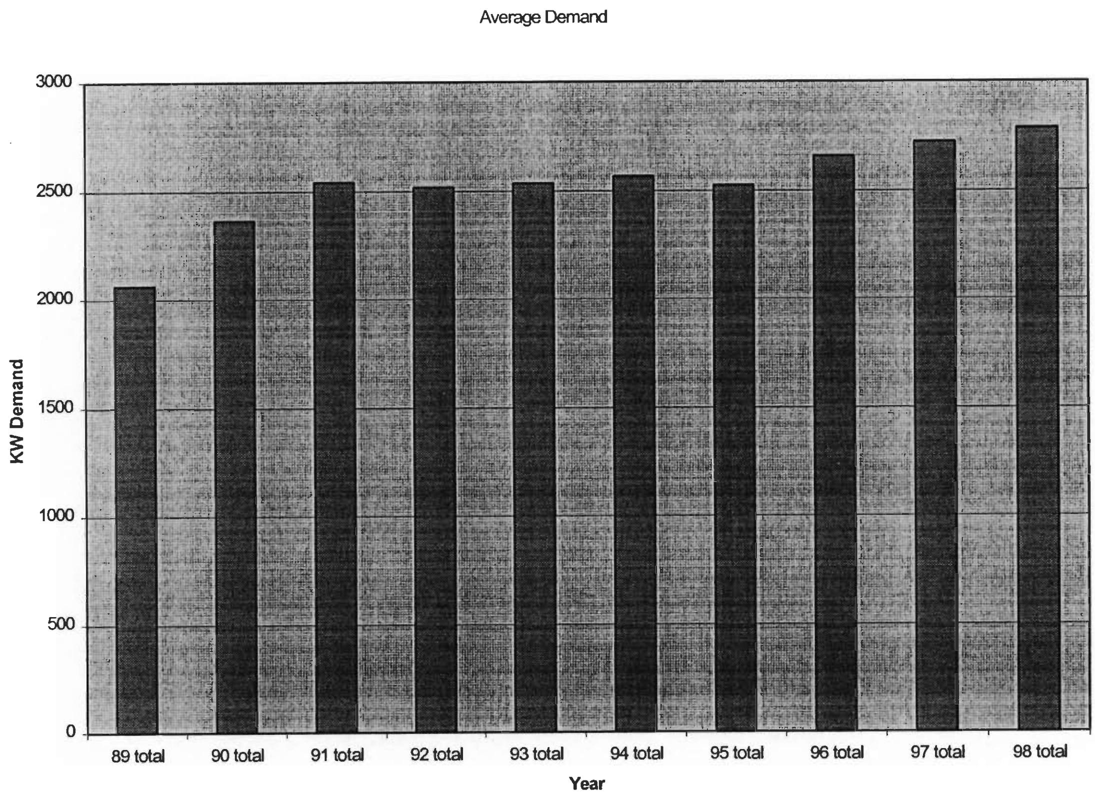
Spreadsheet of WPI's Power Consumption 1989 - 1990

Month Year	Peak	Off Peak	Total	KW Demand	Cost	% Increase from previous year
Jan-89	396000	448800	844800	1793	43406	
Feb-89	442800	438000	880800	1884	45442	
Mar-89	427200	460800	880000	1884	45636	
Apr-89	451200	438000	889200	1836	47054	
May-89	375600	387600	763200	1890	44225	
Jun-89	397200	480000	877200	1976	51046	
Jul-89	423600	458400	882000	2041	53255	
Aug-89	428400	447600	876000	2052	53067	
Sep-89	490800	511200	1002000	2268	60229	
Oct-89	460800	520800	981600	2268	58921	
Nov-89	512400	526800	1039200	2400	63284	
Dec-89	556800	55600	1112400	2472	67862	
89 total			11028400		633427	
Average			919033.3	2063.666	52785.58	
Jan-90	439200	564000	1003200	2136	62030	
Feb-90	538800	5436000	1082400	2304	67987	
Mar-90	513600	601200	1114800	2220	71238	
Apr-90	552000	544800	1096800	2220	69313	
May-90	499200	512400	1011600	1800	61435	
Jun-90	454800	538800	993600	2311	64450	
Jul-90	511200	529200	1040400	2559	71992	
Aug-90	567840	532800	1100640	2624	76187	
Sep-90	702720	748800	1451520	2572	93575	
Oct-90	491520	566640	1058160	2860	77925	
Nov-90	506400	560880	1067280	2380	77863	
Dec-90	536880	600480	1137360	2380	81873	
90 total			13157760		875868	
Average			1096480	2363.833	72989	0.161833
Jan-91	442800	516960	959760	2272	74665	
Feb-91	537360	640320	1177680	2306	88057	
Mar-91	501120	509760	1010880	2255	76350	
Apr-91	571200	562800	1134000	2577	83536	
May-91	512640	575520	1088160	2412	78323	
Jun-91	518400	565680	1084080	2539	80058	
Jul-91	518160	528720	1046880	2592	87159	
Aug-91	612240	681600	1293840	2873	101264	
Sep-91	624720	655920	1280640	3024	101610	
Oct-91	557760	618960	1176720	2892	87345	
Nov-91	558960	695520	1254480	2323	85327	
Dec-91	551040	607200	1158240	2453	81820	

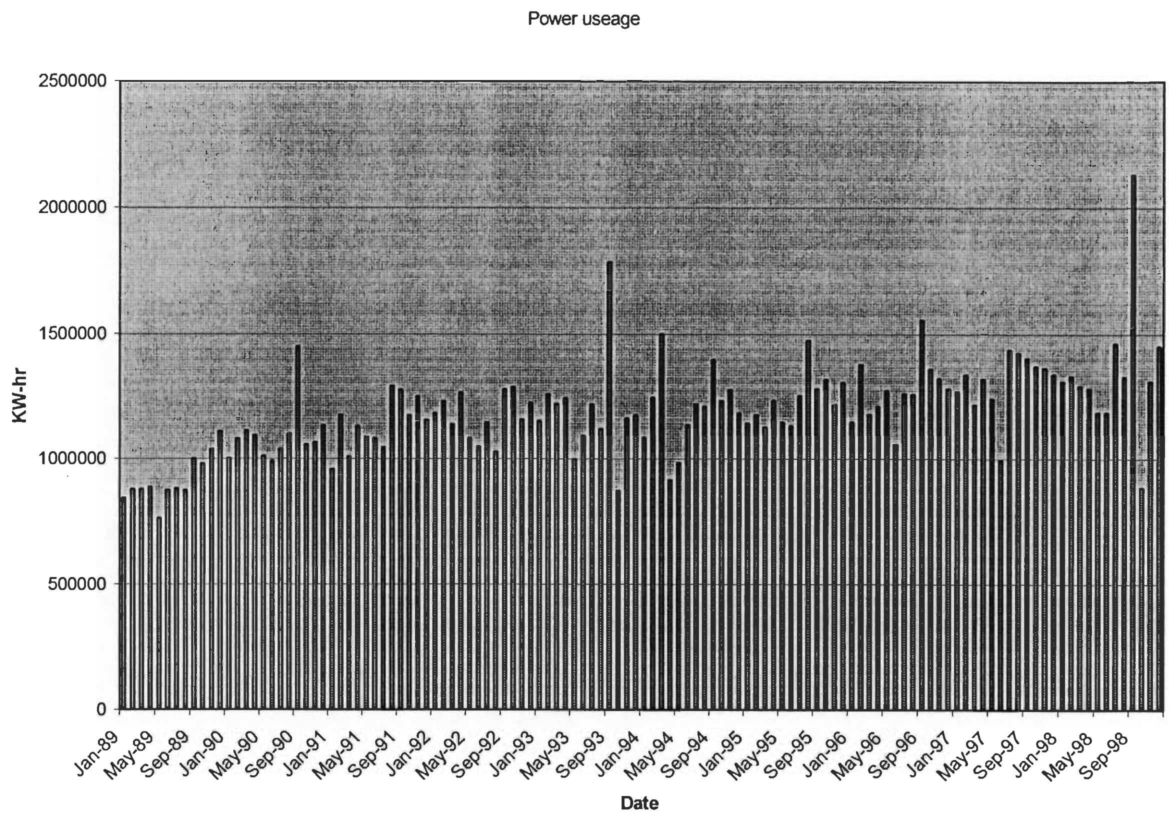
91 total			13665360		1025514	
Average			1138780	2543.166	85459.5	0.037145
Jan-92	502080	682560	1184640	2380	84298	
Feb-92	581760	653520	1235280	2407	88229	
Mar-92	556080	586800	1142800	2462	85405	
Apr-92	593280	675600	1268880	2347	93058	
May-92	530160	553680	1083840	2458	83707	
Jun-92	509760	540000	1049760	2472	82342	
Jul-92	540000	608400	1148400	2575	90029	
Aug-92	519360	510480	1029840	2402	81916	
Sep-92	628080	653760	1281840	3009	102050	
Oct-92	58640	712080	1290720	2848	100238	
Nov-92	543600	617520	1161120	2371	88258	
Dec-92	585360	642960	1228360	2503	93248	
92 total			14105480		1072778	
Average			1175456.6	2519.5	89398.16	0.031202
Jan-93	488400	667200	1155600	2455	85485	
Feb-93	594480	668400	1262880	2510	92250	
Mar-93	560640	663363	1224003	2460	89595	
Apr-93	626880	620160	1247040	2392	94419	
May-93	488880	512160	1001040	2344	79615	
Jun-93	495630	599040	1094670	2409	85763	
Jul-93	605040	618000	1223040	2693	96061	
Aug-93	555120	568080	1123200	2698	91060	
Sep-93	838080	947280	1785360	2986	149574	
Oct-93	401040	472800	873840	2592	68328	
Nov-93	547200	617040	1164240	2539	91004	
Dec-93	524640	652800	1177440	2354	88481	
93 total			14332353		1111635	
Average			1194362.7	2536	92636.25	0.015829
Jan-94	526320	560640	1086960	2512	82438	
Feb-94	601440	647520	1248960	2498	87400	
Mar-94	680640	821520	1502160	2407	106236	
Apr-94	464160	453600	917760	2422	66537	
May-94	483600	502320	985920	2512.8	75808	
Jun-94	529920	608400	1138320	2491	84540	
Jul-94	581040	641760	1222800	2777	91363	
Aug-94	612480	601200	1213680	2897	92289	
Sep-94	642960	756000	1398960	2791	100504	
Oct-94	598800	638400	1237200	2608	90050	
Nov-94	570720	709200	1279920	2464	90373	
Dec-94	560640	623760	1184400	2436	85323	
94 total			14417040		1052861	
Average			1201420	2567.983	87738.41	0.005874
Jan-95	488640	657360	1146000	2352	80481	
Feb-95	539520	639120	1178640	2311	82894	
Mar-95	542160	587280	1129440	2318	80069	
Apr-95	599760	637680	1237440	2455	89503	
May-95	519600	629520	1149120	2426	84185	
Jun-95	527760	607920	1135680	2542	85657	
Jul-95	568320	688560	1256880	2704	97021	
Aug-95	664320	810720	1475040	2755	101609	
Sep-95	577920	706320	1284240	2854	99913	
Oct-95	613680	707760	1321440	2611	96254	

Nov-95	567360	652520	1219880	2477	90681	
Dec-95	566640	742800	1309440	2506	94546	
95 total			14843240		1082813	
Average			1236936.6	2525.916	90234.41	0.028713
Jan-96	491760	659280	1151040	2538	87605	
Feb-96	597840	780960	1378800	2523	102011	
Mar-96	548640	633840	1182480	2577	91576	
Apr-96	568800	644400	1213200	2549	96050	
May-96	579840	696240	1276080	2959	103278	
Jun-96	466800	592080	1058880	2698	87694	
Jul-96	576720	687360	1264080	2739	101741	
Aug-96	586080	675360	1261440	2762	101913	
Sep-96	667200	888720	1555920	3069	122045	
Oct-96	616800	745440	1362240	2600	103350	
Nov-96	546480	780480	1326960	2480	102124	
Dec-96	571200	712800	1284000	2412	99507	
96 total			15315120		1198894	
Average			1276260	2658.833	99907.83	0.030811
Jan-97	513360	757920	1271280	2412	95153	
Feb-97	591840	747600	1339440	2473	99826	
Mar-97	559440	659280	1218720	2440	92767	
Apr-97	575760	746640	1322400	2590	105531	
May-97	596880	648960	1245840			
Jun-97	426960	571440	998400	2758	1088336	
Jul-97	653040	785280	1438320	3145	119221	
Aug-97	618720	805440	1424160	3039	115755	
Sep-97	618480	786960	1405440	3080	108727	
Oct-97	636720	735120	1371840	2985	113266	
Nov-97	582720	783360	1366080	2509	107944	
Dec-97	618720	721680	1340400	2527	108512	
97 total			15742320		2155038	
Average			1311860	2723.454	195912.5	0.027137
Jan-98	547200	765360	1312560	2426	103185	
Feb-98	605760	727920	1333680	2434	103764	
Mar-98	570720	723600	1294320	2455	96063	
Apr-98	610800	674400	1285200	2873	95465	
May-98	560160	627360	1187520	2851	87426	
Jun-98	541440	646320	1187760	3070	88860	
Jul-98	657600	805680	1463280	3063	106500	
Aug-98	610800	720480	1331280	2904	99428	
Sep-98	965760	1165680	2131440	3154	145617	
Oct-98	371520	514080	885600	2685	57454	
Nov-98	566880	747360	1314240		86125	
Dec-98	677680	774000	1451680	2727.5	94661	
98 total			16178560		1164548	
Average			1348213.3	2785.681	97045.66	0.026964

Graph of Average Power Demand Over 1989 – 1998



Graph of Power Usage 1989 -1990



Appendix H: Clean Air Act: Section 163

"For any Class I area, the maximum allowable increase in concentrations of sulfur dioxide and particulate matter over the baseline concentration of such pollutants shall not exceed the following amounts:"

Maximum allowable increase
[Micrograms per cubic meter]

Pollutant	
Particulate matter:	
Annual geometric mean	5
Pollutant	
Twenty-four-hour maximum	10
Sulfur dioxide:	
Annual arithmetic mean	2
Twenty-four-hour maximum	5
Three-hour maximum	25

For any class II area, the maximum allowable increase in concentrations of sulfur dioxide and particulate matter over the baseline concentration of such pollutants shall not exceed the following amounts:

Maximum allowable increase
[Micrograms per cubic meter]

Pollutant	
Particulate matter:	
Annual geometric mean	19
Twenty-four-hour maximum	37
Sulfur dioxide:	
Annual arithmetic mean	20
Twenty-four-hour maximum	91
Three-hour maximum	512

For any class III area, the maximum allowable increase in concentrations of sulfur dioxide and particulate matter over the baseline concentration of such pollutants shall not exceed the following amounts:

Pollutant	Maximum allowable increase [Micrograms per cubic meter]
Particulate matter:	
Annual geometric mean	37
Twenty-four-hour maximum	75
Sulfur dioxide:	
Annual arithmetic mean	40
Twenty-four-hour maximum	182
Three-hour maximum	700

Appendix I: Quotations from Vendors

All the following quotations were received from vendors who we contacted during our research on alternate energy resources. The quotes were used to calculate investment costs for each diesel alternative. These quotations were accurate at the time of analysis; however for future studies these quotes may not be considered as accurate estimations from each vendor.

CUMMINS DE
PUERTO RICO, INC.

Onan

PO Box 2121
San Juan PR 00922-2121
Tel. (787)793-0300
Fax (787)793-1072

May 2, 2000

Mr. Antonio Troncoso
Colegio Tecnologico de SJ
180 José Oliver Street
San Juan, P.R. 00918

Ref: Quote # 2K 1235
800KW Genset
Colegio Tecnologico de SJ

Dear Mr. Troncoso:

We are most pleased to quote you the following equipment as per your request. Material will consist of one (1) Cummins/Onan Diesel generator set model DFJC with the following rating and options for the **PRIME** application:

- *Kw: 800* — *Volts: 277/480*
- *Kva: 1000* — *Amps: 1354*
- *Phase: 3*
- *Wires: 4*

The following options are included with the proposed equipment:

- One (1) Alternator with a 125°C temperature rise.
- One (1) Main line circuit breaker, U.L. listed rated at 1250 amps, 3 poles and 600 volts.
- One (1) Power Command control panel with AC meters.
- One (1) 50°C ambient temperature radiator.
- One (1) Low coolant level shutdown.
- Four (4) 8D model, 12 volts lead acid battery with cables and rack.
- One (1) 1000 Gallons above ground fuel tank.
- One (1) Fuel level gauge.
- One (1) 100 Gallons fuel day tank.
- One (1) Oil drain extension.

Price at FOB job site not Unloaded...$128,800.00

Page 2 Ref. # 2K1235

Start up will include one man at job site at the time engine is going to be started for the first time. All the connections and installations must be completed before the start up.

Factory warranty for two (2) years or 6000 hours from the day of start up against workmanship and material defects as per manufacturer published warranty if the equipment is exclusive for the standby application.

Our terms and conditions are as follows:

- ✓ Net 30 days. (subject to credit approval)
- ✓ Financing and leasing programs available through bank institutions.
- ✓ *Excise taxes are included.*
- ✓ A late penalty fee of 1.5% per month will be charged if necessary.
- ✓ Delivery time is 10-12 weeks from factory with a possibility of improvement after we receive a written purchase order or an approved submittal.
- ✓ Price quoted includes only the items numbered above.
- ✓ Contractor shall supply any other item required.
- ✓ INSTALLATION BY OTHERS.
- ✓ This quote is valid for 30 days.

We would like to emphasize that *Cummins de Puerto Rico, Inc.* is the exclusive distributor for Cummins engines products in *Puerto Rico* and as such we keep a complete inventory of parts for *all Cummins type engines and generators sets*. In addition we have factory-trained mechanics and technicians.

Please let us know your decision and if we can be of further assistance, do not hesitate to contact us.

Sincerely,

Carlos Cruz
Generator Sales Department

PO Box 2121, San Juan PR 00922-2121 • Tel. (787) 793-0300 Fax (787) 793-1072

CUMMINS DE PUERTO RICO, INC.

PO Box 2121
San Juan PR 00922-2121
Tel. (787)793-0300
Fax (787)793-1072

April 5, 2000

Mr. Antonio Troncoso
Consultant
Colegio Tecnologico San Juan
180 Jose Oliver Street
San Juan, P.R. 00918

Ref: Quote # IA-2055-500kw Genset

Dear Mr. Troncoso:

We are most pleased to quote you the following equipment as per your request. Material will consist of one (1) ***Cummins/Onan diesel generator set model DFED*** with the following rating and options for the *prime application;*

- *Kw : 450* *Volts: 277/480*
- *Kva: 563* *Amps: 678*
- *Phase: 3* *Engine: Cummins K19, 6 Cyls.*
- *Wires: 4*

The following options are included with the proposed equipment:

- One (1) 12 leads alternator with 125°C temperature rise.
- One (1) Digital Power Command Control panel with AC meters.
- One (1) 800 amps main line circuit breaker 3 poles, U.L. listed.
- Two (2) critical mufflers with flexible package.
- One (1) 50°C ambient temperature engine mounted radiator.
- Two (2) 8D model, 12 volts lead acid battery with cables.
- One (1) coolant heater rated at 480 volts.
- One (1) set of eight vibration isolators.
- One (1) SCR battery Charger rated at 10 amps, 24 volts.
- One (1) 560 gallons single wall above ground fuel tank.

Price at JOB SITE NOT UNLOADED...$65,000.00

One (1) trip start up will include one man at job site at the time engine is going to be started for the first time. All the connections and installations must be completed before the start up.

CUMMINS DE PUERTO RICO, INC.

Onan

PO Box 2121
San Juan PR 00922-2121
Tel. (787)793-0300
Fax (787)793-1072

Page 2 Ref. # IA-2055 – 500 Kw Genset

Factory warranty is for two (2) years or 1500 hours which ever occur first from the day of start up against workmanship and material defects as per manufacturer published warranty if the equipment is exclusive for the standby application.

Our terms and conditions are as follows:

- ✓ Net 30 days(Subject to credit approval).
- ✓ ***Delivery time is 10-12 weeks from factory.***
- ✓ *Excise taxes are included.*
- ✓ Price quoted includes only the items numbered above.
- ✓ Contractor shall supply any other item required.
- ✓ This quote is valid for 30 days.

We would like to emphasize the fact that *Cummins de Puerto Rico, Inc.* is the exclusive distributor for the Cummins engines products in *Puerto Rico* and as such we keep a complete inventory of parts for ***all Cummins type engines and Onan generators sets.*** In addition we have factory-trained mechanics and technicians.

Please let us know your decision and if we can be of further assistance, do not hesitate to contact us.

Sincerely,

Idelfonso Acevedo
Engines Sales Department

CUMMINS DE PUERTO RICO, INC.

Onan

PO Box 2121
San Juan PR 00922-2121
Tel. (787)793-0300
Fax (787)793-1072

Wednesday, April 26, 2000

Mr. Antonio Troncoso
Consultant
Colegio Tecnologico San Juan
180 Jose Oliver Street
San Juan, P.R. 00918

Ref: Quote # IA-2055A-1250kw Genset – Colegio Tecnologico

Dear Mr. Troncoso:

We are most pleased to quote you the following equipment as per your request. Material will consist of one (1) ***Cummins/Onan diesel generator set model DFLC*** with the following rating and options for the *prime application:*

♦ *Kw : 1250**	*Volts: 277/480*
♦ *Kva: 1563*	*Amps: 1692*
♦ *Phase: 3*	*Engine: Cummins K50, 16 Cyls.*
♦ *Wires: 4*	

**1100 Kw prime rated.*

The following options are included with the proposed equipment:

- One (1) 12 leads alternator with 125°C temperature rise.
- One (1) Digital Power Command Control panel with AC meters.
- One (1) 1600 amps main line circuit breaker 3 poles, U.L. listed.
- Two (2) critical mufflers with flexible package.
- One (1) 50°C ambient temperature engine mounted radiator.
- Two (2) 8D model, 12 volts lead acid battery with cables.
- One (1) coolant heater rated at 480 volts.
- One (1) set of fuel/water filters.
- One (1) set of twelve (12) vibration isolators.
- One (1) SCR battery Charger rated at 10 amps, 24 volts.
- One (1) 1000 gallons single wall above ground fuel tank.
- One (1) 100 gallons standard day Tank.

Price at JOB SITE NOT UNLOADED..$165,000.00

CUMMINS DE PUERTO RICO, INC.

PO Box 2121
San Juan PR 00922-2121
Tel. (787)793-0300
Fax (787)793-1072

Onan

Page 2 Ref. # IA-2055A –1250 Kw Genset - Colegio Tecnologico San Juan

One (1) trip start up will include one man at job site at the time engine is going to be started for the first time. All the connections and installations must be completed before the start up.

Factory limited warranty is for two (2) years or 6000 hours which ever occur first from the day of start up against workmanship and material defects as per manufacturer published warranty.

Our terms and conditions are as follows:

- ✓ Net 30 days(Subject to credit approval).
- ✓ ***Delivery time is 12-14 weeks from factory.***
- ✓ *Excise taxes are included.*
- ✓ Price quoted includes only the items numbered above.
- ✓ Contractor shall supply any other item required.
- ✓ This quote is valid for 30 days.

We would like to emphasize the fact that *Cummins de Puerto Rico, Inc.* is the exclusive distributor for the Cummins engines products in *Puerto Rico* and as such we keep a complete inventory of parts for ***all Cummins type engines and Onan generators sets.*** In addition we have factory-trained mechanics and technicians.

Please let us know your decision and if we can be of further assistance, do not hesitate to contact us.

Sincerely,

Ildefonso Acevedo
Engines Sales Department

COMPLETE STOCK OF
CONTRACTOR - INDUSTRIAL - AGRICULTURAL
EQUIPMENT

West India Machinery and Supply Co.

TEL. (787) 721-7640
FAX: (787) 721-6192

PO BOX 364308
SAN JUAN, PUERTO RICO 00936-4308

SKID-LOADERS
FORKLIFTS
LOADERS
WATER PUMPS
GRADERS
LAWN MOWERS
COMPRESSORS
VIBRATORY ROLLERS
CONCRETE MIXERS
ELECTRIC PLANTS
ASPHALE PAVERS
QUARRY EQUIPMENT

MAIN OFFICES AT
MARGINAL SUR MIRAMAR
SANTURCE, P.R. 00908

QUOTATION FORM

TO:
COLEGIO TECNOLOGICO
MUNICIPIO DE SAN JUAN
180 JOSE OLIVER STREET
SAN JUAN, PR 00918

Sheet No.	No. of Sheets	Quotation No. H-3752
1	2	26-ABRIL-2000
Terms: NET.		Customer's inquiry

Item No.	Quan.	DESCRIPTION	Price	Total
1	ONE	ONAN MODEL 1100.0DFLB DIESEL ELECTRIC GENERATOR		

PRIME POWER
900KW; 1125KVA

POWER OUTPUT AT 1800 RPM:
277/480 volts 3 Phase
1654 amperes 60 Hertz

CONTROL DETAIL:
Detector 2 Control: Run-Stop-Remote switch; Remote starting, (2-wire, 24 volt); Oil pressure gauge; Coolant temperature gauge; DC Voltmeter; Running time meter; Fault reset switch; Lamp test switch; Cycle cranking; 7-light engine monitor with individual 1/2 amp relay signals, and common alarm contact indicating each of the following conditions: Run (green light); Pre-warning for low oil pressure (yellow light); Pre-warning for high coolant temperature (yellow light); Low oil pressure shutdown (red light); High coolant temperature shutdown (red light); Overcrank shutdown (red light); Overspeed shutdown (red light).

STANDARD EQUIPMENT:
Diesel Engine; AC Alternator with PMG; Structural Steel Skid Base; Mounted Control Panel on Isolators; Battery Cables; Flexible Fuel Lines; Dry Element Air Cleaner; Oil Drain Valve with Hose Extension; Full Flow Oil Filters; Radiator with Air Discharge Duct Adapter Flange; Battery Charging Alternator(24V). Mounted Battery Rack within Skid.

F.O.B. | Delivery

QUOTATION FORM

TO: COLEGIO TECNOLOGICO
MUNICIPIO DE SAN JUAN
180 JOSE OLIVER STREET
SAN JUAN, PR 00918

SHEET NO.	NO. OF SHEETS	QUOTATION NO. H-3752
2	2	26-ABRIL-2000
TERMS		CUSTOMER'S INQUIRY
NET.		

ITEMS NO.	QUAN.	DESCRIPTION	PRICE	TOTAL
		ADDITIONAL EQUIPMENT:		
		ONE MOD H-530 Power Command Control		
		ONE MOD H-389 Low Coolant Level Shutdown		
		ONE MOD KH-43 Main Line Breaker 2000A.		
		ONE MOD H-556 Engine Coolant Heater		
		ONE MOD C-127 Separator-Fuel/Water		
		ONE MOD H-393 By-pass Oil Filter		
		ONE MOD D-36 Heavy Duty Eng. Air Cleaner		
		TWO 155-2342-3 Critical Muffler		
		TWO 155-2554 Pipe Package		
		TWELVE 402-0427 Vibration Isolators		
		FOUR 416-0439 Batteries		
		ONE 1000 Ga. Fuel Tank (Single Wall)		
		ONE 1329 Petrometer		
		LITERATURE WITH ADDITIONAL SPECIFICATIONS INCLUDED		
		PRICE DELIVERED-TAXES INCLUDED------------------------		$149,500.0
		DELIVERY: 90 DAYS APPROX. - SUBJECT TO PRIOR SALE		
		WARRANTY: TWO (2) YEARS OR 6000 HOURS (PRIME POWER) AGAINST DEFECTIVE PARTS & WORKMANSHIP		
		NOTES:		
		PRICE & DELIVERY VALID FOR 30 DAYS.		
		PRICE QUOTED ABOVE INCLUDES ONLY THE ITEMS LISTED. ANY OTHER ITEMS REQUIRED ARE THE RESPONSIBILITY OF THE CONTRACTOR/OWNER.		
		WEST INDIA MACHINERY & SUPPLY CO.		
		JORGE ELIAS OPERATIONS MANAGER		

F.O.B.

DELIVERY

ALL PRICES QUOTED SUBJECT TO CHANGE WITHOUT NOTICE. EQUIPMENT, MATERIALS AND/OR PARTS WILL BE INVOICED AND PAID FOR AT PRICES IN EFFECT ON DATE OF DELIVERY. TIME OF DELIVERY SUBJECT TO DELAYS DUE TO CAUSES BEYOND OUR CONTROL.

RIMCO, INC.

CAT

BOX 362529 SAN JUAN, P.R. 00936-2529 • TEL.: (809) 792-4300 • FAX: (809) 783-8180 / 782-1044

QUOTATION NO. 0754-E-2K May 2, 2000

TO : **COLEGIO TECNOLOGICO DE SAN JUAN**

ATTENTION : Mr. Dan Jacques

SUBJECT : **Quotation for a Caterpillar Generator Set 3508 - 820 KW**

Dear Mr. Jacques:

We are pleased to present this quotation based in our interpretation of your requirements for a generator set. We offer the following:

One (1) **CATERPILLAR DIESEL GENERATOR SET, MODEL 3508 - 820 KW (PRIME POWER) @ 0.8 Power Factor, 480/277 Volts, 3 Phase, 4 Wires, 60 Hertz at 1800 RPM**, with the following standard accessories:

AIR INLET SYSTEM
Aftercooler core, Material: copper nickel
Air cleaner, Regular duty, with service indicators
Two Turbocharger, Rear Mounted

CONTROL SYSTEM
Governor, 2301A speed control with EG6PC actuator, RH, installed

COOLING SYSTEM
Blower fan, fan drive, and fan guard
Thermostats and housing, Full open temperature 90 C (198 F)
Radiator, Single Core, Single circuit radiator
Jacket water pump, gear driven, centrifugal

EXHAUST SYSTEM
Exhaust manifold, dry, single (8 in) ID round flange outlet (center)

FLYWHEELS AND FLYWHEEL HOUSINGS
Flywheel, SAE No. 00, 183 teeth
Flywheel housing, SAE No. 00
SAE Standard Rotation

FUEL SYSTEM
Fuel filter, RH
Fuel transfer pump
Mechanical unit injectors

GENERATORS AND GENERATOR ATTACHMENTS
Brushless self excited SR4B generator. Includes VR3 voltage regulator and 4 terminal for load connections.
Space Heater

INSTRUMENTATION

Control panel, rear facing, mounted on generator terminal box. Includes:
- Standard generator controls and monitoring:
  - Digital Ammeter, voltmeter, and frequency meter
  - Ammeter/voltmeter phase selector switch
  - Voltage adjust rheostat
- Standard engine controls and monitoring:
  - Automatic/manual start stop control
  - Engine control switch for off/reset, auto/start stop, manual start, cooldown stop
  - Cycle cranking
  - Cooldown timer
- Safety shutdown protection and LED indicators for:
  - Low oil pressure, alarm & shutdown
    - High coolant temperature,
    - Overcrank, shutdown
    - Overspeed
    - Emergency Stop
    - Spare alarm, spare shutdown
  - Digital display for:
    - Coolant temperature
    - Oil pressure
    - Service Hours
    - Engine RPM
    - System DC volts
    - System diagnostic codes

LUBE SYSTEM

Crankcase breather, top mounted, 51 mm (2in) OD outlet
Oil cooler
Oil filler and dipstick, LH
Oil filter, spin on, RH
Oil pump, gear type,
Shallow oil pan

MOUNTING SYSTEM

Rails engine-generator-radiator mounting, 330 mm (13 in), industrial type

POWER TAKE-OFFS

Accessory drive, upper RH rear of front gear housing, 1.3:1 gear drive ratio

PROTECTION SYSTEM

Manual shutoff, RH
Safety shutoff protection electrical
Energized to run

STARTING SYSTEM

Single 24 volt electric starting motor

GENERAL

Paint, Caterpillar yellow
Vibration damper
Literature

ADDITIONAL EQUIPMENT INCLUDED:

*Electronic Modular Control Panel II+
*Battery Charger 10 A
*24 Volt Battery Set
*Battery Rack & Cables
*Charging Alternator 24V, 35A
*Flexible Fitting
*Flange and Exhaust Expander
*Muffler
*Fuel Priming Pump
*Flexible Fuel Lines
*Lubricating Oil
*Vibration Isolators
*Vibration Isolators-Radiator
*Flange
*Antifreeze
*Fumes Disposal
*Fuel Cooler
*Jacket Water Heater – Dual
*Coolant Loss Sensing
*Primary Fuel Filter
*Circuit Breaker 1600 A, 3 Poles with Auxiliary Switch

TOTAL PRICE F.O.B. JOBSITE OUR TRUCK, TAXES ARE INCLUDED:	**$ 127,650.00**

DELIVERY : 10 to 12 weeks from factory,

WARRANTY : 2 years after initial start-up.

VALIDITY : Quotation is valid for 30 days.

We will arrange for initial start-up services at no additional charge. These services include a check of wiring continuity, safety shutoffs and controls; including automatic transfer switches, on and related to the unit that we supply.

Thank you for the opportunity of quoting this project. If additional information or assistance is needed, please feel free to contact us.

Best Regards,

RICARDO DIAZ
Sales Representative
Engine Division

RIMCO, INC.

BOX 362529 SAN JUAN, P.R. 00936-2529 • TEL.: (809) 792-4300 • FAX: (809) 783-8180 / 782-1044

QUOTATION NO. 0755-E-2K

May 2, 2000

TO : **COLEGIO TECNOLOGICO DE SAN JUAN**

ATTENTION : Mr. Dan Jacques

SUBJECT : **Quotation for a Caterpillar Generator Set Model 3512B – 1275 EKW**

Dear Mr. Jacques:

We are pleased to present this quotation based on our interpretation of your requirements for a generator set. We offer the following:

One (1) **CATERPILLAR ENGINE GENERATOR SET MODEL 3512B – 1275 KW (Prime Power Application) @ 0.8 Power Factor, 277/480 Volts, 3 Phase, 4 Wire, 60 Hertz at 1800 RPM,** with the following standard accessories included:

AIR INLET SYSTEM

Air cleaner, Regular duty, with service indicators
Aftercooler core, Material: copper nickel
Two turbochargers – rear mounted

CONTROL SYSTEM

ADEM control, electronic engine controls 10 amps at 24 volts DC for operation.

COOLING SYSTEM

Blower fan, fan drive, and fan guard
Engine Jacket Water Coolant Thermostats
(Full open temperature 92 C (198 F)
Jacket water pump, gear driven, centrifugal
Low Emissions PGS – SCAC
Single core, single circuit, engine only radiator
Aftercooler water pump – gear driven – centrifugal
Aftercooler cooling pump circuit contains thermostat to keep
Aftercooler water from falling below 30 C (85 F)
Requires: Customer supplied cooling to supply system 30 C (85 F)
Cooling water to aftercooler system for best emissions.
Emissions Certified PGS-SCAC
Split core, Two circuit, engine only radiator
Aftercooler water pump – gear driven – centrifugal
Aftercooler cooling pump circuit contains thermostat to
Keep aftercooler water from falling below 60 C (140 F)
Requires: 60 C (140 F) for certification and have split core two
Circuit radiator

EXHAUST SYSTEM

BVBVBNExhaust manifold, dry, single, 203 mm (8 in) ID round flange outlet on 1500 rpm and 1800 rpm

FLYWHEELS AND FLYWHEEL HOUSINGS

Flywheel, SAE No. 00, 183 teeth
SAE Standard Rotation
Flywheel housing, SAE No. 00

FRONT HOUSING

Two sided front housing

FUEL SYSTEM

Fuel transfer pump
Fuel filter RH
Electronic controlled unit injectors

GENERATORS AND GENERATOR ATTACHMENTS

Brushless SR4B generator 4 terminals for load connections.
Space heaters

INSTRUMENTATION

Electronic Modular Control panel
- Mounted on generator terminal box.

Standard generator controls and monitoring:
- Digital ammeter, voltmeter, frequency meter
- Ammeter/voltmeter phase selector switch
- Voltage adjust rheostat

Standard engine controls and monitoring:
- Automatic/manual start stop control
- Four position engine control switch:
  - Off/reset
  - Auto start/stop
  - Manual start
  - Cooldown/stop
- Cycle cranking
- Cooldown timer
- Emergency stop pushbutton

Safety shutdown protection and LED indicators for:
- High coolant temperature alarm and shutdown
- Low oil pressure alarm and shutdown
- Emergency stop
- Overcrank and Overspeed shutdowns
- Spare alarm and spare shutdown

Digital display for:
- Coolant temperature & Oil pressure
- Service Hours
- Engine RPM
- System DC volts & System diagnostic codes

LUBE SYSTEM

Oil pump -gear type
Crankcase breather
- Top mounted 51 mm (2 in) OD outlet(s)

Oil cooler
Shallow oil pan
Oil filter RH

MOUNTING SYSTEM
Rails – engine/generator/radiator mounting, 330 mm (13 in)

PROTECTION SYSTEM
Safety shutoff protection, electrical, ADEM controlled, energized to run

STARTING SYSTEM
Electrical Starting Motor
Dual 24 volt
For above 20 C (68 F), without starting aids)

GENERAL
Paint, Caterpillar yellow
Vibration damper

ADDITIONAL EQUIPMENT INCLUDED:
*Electronic Modular Control Panel II+
*Charging Alternator 24 V, 35 A
*Battery Charger 10 A
*24-Volt Battery set - Dry
*Battery Cables
*Battery Rack
*Fumes Disposal Lines
*Fuel Priming Pump
*Vibration Isolators, Spring Type
*Main Line Circuit Breaker 2500 A, 3 Poles with Auxiliary Switch
*Coolant Level Sensor
*Water Level Switch Gauge
*Flexible Fitting
*Muffler
*Y Adapter
*Flange
*Elbow
*Antifreeze
*Fuel Filter LH
*Primary Fuel Filter
*Fuel Level Switch
*Fuel Cooler
*Oil Filter LH Service
*Jacket Water Heater – Dual
*Low Water Temperature Switch
*Explosion Relief Valve
*Lubricating Oil

TOTAL EQUIPMENT F.O.B. OUR WAREHOUSE; TAXES ARE INCLUDED:	**$ 188,586.00**

WARRANTY : One (1) Year after initial start up.

DELIVERY : 12 to 14 weeks from factory.

VALIDITY : Quotation is valid for 20 days.

We will arrange for initial start-up services at no additional charge. These services include a check of wiring continuity, safety shutoffs and controls; including automatic transfer switches, on and related to the unit that we supply.

Thank you for the opportunity of quoting this project. If additional information or assistance is needed, please feel free to contact us.

Best Regards,

RICARDO DIAZ
Sales Representative
Engine Division

ALONSO & CARUS iron works inc.
ROAD 869, KM. 0.09 BO. PALMAS, P.O. BOX 566, CATAÑO, PUERTO RICO 00963

tel. 250-7111 ext. 2218

TO: Colegio Tecnológico DATE: April 25/2000.
ATT: Mr. Antonio Troncoso PAGE: 1 of 3
FROM: Eng. Francis Rodríguez REF: Fuel Storage Tank Cap. 10,000 gs.

FAX #: 764-2702

QUOTATION

Furnish materials, labor and equipments for the fabrication of one (1) steel tank to be used for fuel storage. The tank will be fabricated in accordance to the following:

A) Capacity: 10,000 gs.
B) Size: 91" Dia. x 30'-0" L.
C) Type: Horizontal - Aboveground tank, single wall type, to be mounted on concrete saddles.
D) Material: Carbon steel, A-36 1/4 in. thickness
E) Code: Underwriters Laboratories U.L. 142
F) Nozzles: One (1) fill conn., 4" NPT

ALONSO & CARUS Iron works inc.
ROAD 869, KM. 0.09 BO. PALMAS, P.O. BOX 566, CATAÑO, PUERTO RICO 00963

tel. 250-7111 ext. 2218

TO: Colegio Tecnológico
ATT: Mr. Antonio Tronecoso
FROM: Eng. Francis Rodríguez

DATE: April 25/2000.

REF: Fuel Storage Tank Cap. 10,000 gs.

FAX #: 764-2702

QUOTATION #

One (1) suction conn., 4" NPT
One (1) drain conn., 2" NPT
One (1) return conn., 2" NPT
One (1) spare conn., 4" NPT
One (1) goose neck vent, 8" dia.
One (1) spare conn., 2" NPT
One (1) Top Manhole, 24" dia.

G) Paint: Exterior - one (1) coat of red oxide primer only.

Interior - Not paint include

Our Price - - - - $8,645.00

Notes: 1- Our price include delivery to Colegio Tecnológico, F.O.B. - Our truck.

ALONSO & CARUS iron works inc.
ROAD 869, KM. 0.09 BO. PALMAS, P.O. BOX 566, CATAÑO, PUERTO RICO 00963

tel. 250-7111 ext. 2218

TO: Colegio Tecnológico
ATT: Mr. Antonio Tirelcaso
FROM: Eng. Francis Rodríguez

DATE: April 25/2000.
PAGE: 3 of 3
REF: Fuel Storage Tank Cap. 10,000 gls.

FAX #: 764-2702

QUOTATION #

Unloading and installation by others.
2- We are not including any type of equipments like drain / refill, foot valve, level alarms, etc.
3- We can include a level indicator system, aluminum board type with an additional cost of $1,400.00
4- We can include an exterior finish paint (final color to be selected by customer) with an additional cost of $825.00

Price Good Until: 30 days
Delivery Time: 3 @ 4 weeks
Terms: Net 30 days

Francis C. Rodríguez
Sales Engineer

TANKS • STEEL STRUCTURES • PIPELINES • WELDING • COMPLETE PLATE SHOP • ENGINEERING SERVICES
PHONE (787) 788-1065 / FAX 788-0350

M&C Electric, Inc.
1121 Américo Miranda
San Juan, Puerto Rico 00921-2214
Tel.: 774-8320 • Fax. 783-3105
WWW.GUIAPR.COM/MANDCELECTRIC

COTIZACION
ACUERDO DE COMPRAVENTA DE EQUIPO

27 de Abril de 2000
Vía Telecopiadora

TO:
Sr Antonio Troncoso
Colegio Técnologico de San Juan
Ave José Oliver No 180
Urb Industrial Tres Monjitas
Hato Rey, PR. 00918

PROJECT:
COLEGIO TECNOLOGICO DE SAN JUAN
URB INDUSTRIAL TRES MONJITAS
HATO REY PR
OFIC 250-7111 EXT 2218

A. DESCRIPTION OF THE GENERATOR SET DPS 800 (TRIF):

Generator set consisting of engine and alternator mounted on a fabricated steel profile base, painted with a phosphate coating and top coat.

The alternator is directly coupled to the engine flywheel housing to SAE standards. The rotor is fixed to the flywheel using steel discs for flexibilty. Perfect alignment and the absence of vibration are thus guaranteed.

The unit is fixed to the baseframe using anti-vibration pads.

The set is suppplied with a SOUNDPROOFED METAL CANOPY in all versions. This canopy is covered on the inside with soundproofing material which added to the silencer gives a noise level of 68 db(A) at 7mts.

ENGINE

4-stroke diesel engine with direct injection.

Manufacturer	PERKINS
Model	3012 TAG 3A
No. of cylinders	12 60º V
Engine capacity	26 110 cc
Bore	135 mm
Stroke	152 mm
Compression ratio	14.5:1
Aspiration	Turbocharged with intercooler
Cooling system	Water
Engine speed 60 Hz	1800 rpm
Prime power 1500 rpm	674 kW
Fuel consumption 100% load 1500 rpm	170.9 ltr/h
Noise level 1800 rpm	108 dB(A) at 1 metre

POWER RATING	1800 rpm/60 Hz
Prime	800 kVA, 640 kW
Standby	880 kVA, 704 kW

Cooling system

Closed circuit water cooled with expander tank included in the radiator. Tropical radiator and pusher fan with guard. Equipped to work at ambient temperature of up to 56º C.

Cooling air flow from fan 1800 rpm 1049 m3/min
Cooling system capacity... 122.7 litres

Lubrication system

Forced lubrication using gear driven pump. Oil filter

Oil sump capacity.. 73.8 litres
Oil consumption .... 0.5 / 1% of fuel consumption

Air intake system

Turbocharged intake via dry air filter and intermediate air cooling of combustion air.

Combustion air flow 1800 rpm.. 53.9 m3/min

Injection system

Direct injection with BARBER COLEMAN electronic speed governor.

Electrical system

24 V electric starting system. Axial starter motor. 2 x 240 A.h. battery. 32 Amp battery charging alternator. Oil pressure and engine temperature sensors.

Protection system

Automatic engine shutdown for low oil pressure, low fuel level, high temperature and battery charge defect.

Exhaust system

Consists of silencer with 10 db(A) noise reduction, flexible exhaust pipe and brackets. Residential silencer optional.

Exhaust gas flow 1500 rpm... 126.7 m3/min.

ALTERNATOR

Synchronous, three phase and brushless. Self regulation via automatic voltage regulator maintaining voltage within +/- 1.5%. Class "H" insulation. All windings are impregnated with ployester resin varnish, making them resistant to acids and oil. IP 22 protection. Electrical characteristics to BS 5000, VDE 0530, UTE 5100, NEMA MG 1-22, CMA IEC 34, CSA 22,2 and AS 1359. Harmonic distortion below 3,5%. Radio interference suppression to BS-800.

Manufacturer.. Stamford
Model... HC 634 G
Power rating .... 925 kVA at 1800rpm
Voltage (*) .... 480/277 V three phase
Frequency .... 60 Hz
Speed.. 1800 rpm
Regulation .... Electronic
Nominal current.. 1 216 A

(*) 12 wire output permitting reconnection to any existing voltage.

AUTOMATIC
The automatic version generator set is supplied on a skidbase with an automatic start/stop panel for mains failure.

Control panel
Mounted in a metal cabinet with IP 54 protection and supplied loose for wall mounting.Includes control, measuring and transfer system.

Monitoring and control system
Automatically monitors the mains, and, if the mains fails (in one or all three phases) connects the consumers to the generator set via mechanically and electrically interlocking contactors. When the mains is restored, the load is reconnected to the mains, the set idles and then stops. Equipped with:

- Push button controls, indicator lamp and protection fuses.
- No. of start up attempts: 3
- Three phase voltage monitor with adjustable values.

Measuring equipment
Consists of the following items:

- 3 Ammeters
- 1 Voltmeter
- 1 mains-generator set voltmeter selector switch.
- 1 Frequency meter
- 1 Battery voltmeter.
- Selector switch for Disconnect, Automatic Service, Manual Service and Test
- Off button.
- Start-up selector switch.
- Heater indicator lamp.
- Battery maintenance system.
- Audible alarm for faults
- Visual alarm system for low oil pressure, high temperature and/or overload.
- Mushroom type emergency stop pushbutton.

The set may be selected to run manually or automatically: When running manually a pushbutton is used for shutdown and a selector switch is used for start-up and changeover.

Heater
In this version, the set incorporates a heater which aids diesel engine start-up and response. It consists of a tank connected to the engine cooling system and a heating element with an adjustable thermostat.

Dimensions and weight
Length: 3700 mm
Width: 1400 mm
Height: 1954 mm
Weight: 4600 kg

Price of The Generator .... $ 127,500.00

B. DESCRIPTION OF THE INSTALLATION:
1. Transportation toward their destination
2. Electric installation and mechanics of their generator in the floor up to 40 feet of distance in pipe of the meter to the machine.
3. This project will be supervised and certified by a Certified Electrical Expert.
4. Installation in pipe that exceeds the 40 feet you will get paid at $ 15.00 for additional foot
5. Installation of the Automatic Transfer.
6. Installation of the tank for diesel
7. It includes service of Crane
8. Guarantee: 2 years
9. *Optional: Contract of Preventive Maintenance for Generator*
10. *Optional: Service of Delivery of Diesel*

Price of The Installation... $ 45,000.00

C. SALE OF TRANSFER SWITCH AUTOMATIC:

1. Sale of Transfer Switch Automatic 1,250 amp.

Price of The Transfer Switch Automatic................................ $ 14,700.00

D. SALE OF BASE TANK FOR DIESEL:

1. Sale of Base Tank (Double Wall) for diesel 2000 gals.
   - ***Production of Dike***

Price of The Base and Tank Diesel.. $ 9,000.00

TOTAL OF PROJECT...$ 196,200.00

- ---- TERM AND CONDITIONS -----

1. The Buyer accepts to have read and to agree with the price and terms of this rate.

2. The terms, price and specifications contained in this contract will have validity for a term of thirty (30) days, starting from the date of their preparation.

3. The price of this rate includes the sale, mechanical and electric installation and guarante in pieces and services according to the terms of the guaranteed for (1) year starting from the date of the initial outburst (start up) or of the delivery, wath comes frist. **M & C Electric, Inc.** reserved the option to repair or to replace the equipment or any part of this. The guarantee of the equipment doesn't cover overload uses to which has been dedicated the same one that the equipment has not been made by **M & C Electric, Inc**. and it will be sudject to the rates for hour that are in vigor in that moment. The sought-after price or the guarantee don't include the fuel.

4. All equipment order requires an equivalent deposit to 60% of the total price indicated in this rate. The remainder of the agreed price will before the initial outburst (start up) of the equipment. Automatically they will notice interest rate to 1.5% monthly the first of every month for all quantity that has not been paid before the initial outburst (start up). Order some won't be processed until the payment of the deposit. All order cancellation will bear an equivalent overcharge to 30% of the total price indicated in this rate that will be automatically discounted of the deposit. The remainder will be returned in a term of thirty (30) days. The buyer commits to reimburse M & C Electric, Inc. for the reclamation costs, expenses and lawyer's costs, including the damages, of any due and not paid quantity inside the terms here provided.

5. The team to order is cared of Europe. Although we will make all the adminstrations within our reach to give it in less than twelve (12) weeks starting from the required deposit, we cannot quarantee the date of receipt of the team. Delays in the team won't authorize the buyer to demend the cancellation of their order.

6. The validity of the guarantee of this team requires that M & C Electric, Inc. be who takes to end the initial outburst of the equipment. The buyer recognizes that he has been explained and he understands wath bears the initial outburst.

I CERTIFY: That I have read and understood the before expressed, and constancy of my acceptance, I authorize to the present contract with their signature in the place and date.

In ____________________, Puerto Rico, the day ____________________, 2000.

M & C Electric, Inc Representation by: Felix Monserrate	Colegio Técnologico de Puerto Rico

M&C Electric, Inc.

1121 Américo Miranda
San Juan, Puerto Rico 00921-2214
Tel.: 774-8320 • Fax. 783-3105
WWW.GUIAPR.COM/MANDCELECTRIC

COTIZACION
ACUERDO DE COMPRAVENTA DE EQUIPO

27 de Abril de 2000
Vía Telecopiadora

TO:
Sr Antonio Troncoso
Colegio Técnologico de San Juan
Ave José Oliver No 180
Urb Industrial Tres Monjitas
Hato Rey, PR. 00918

PROJECT:
COLEGIO TECNOLOGICO DE SAN JUAN
URB INDUSTRIAL TRES MONJITAS
HATO REY PR
OFIC 250-7111 EXT 2218

A. DESCRIPTION OF THE GENERATOR SET DPS 1100 (TRIF):

Generator set consisting of engine and alternator mounted on a fabricated steel profile base, painted with a phosphate coating and top coat.

The alternator is directly coupled to the engine flywheel housing to SAE standards. The rotor is fixed to the flywheel using steel discs for flexibilty. Perfect alignment and the absence of vibration are thus guaranteed.

The unit is fixed to the baseframe using anti-vibration pads.

The set is suppplied with a SOUNDPROOFED METAL CANOPY in all versions. This canopy is covered on the inside with soundproofing material which added to the silencer gives a noise level of 68 db(A) at 7mts.

ENGINE

4-stroke diesel engine with direct injection.

Manufacturer	PERKINS
Model	4008 TAG 1
No. of cylinders	8
Engine capacity	30.561 cc
Bore	160 mm
Stroke	190 mm
Compression ratio	6:1
Aspiration	Turbocharged with intercooler
Cooling system	Water
Engine speed 60 Hz	1800 rpm
Prime power 1500 rpm	1100 Kwiso 3046
Fuel consumption 100% load 1500 rpm	198 ltr/h
Noise level 1800 rpm	108 dB(A) at 1 metre

POWER RATING	1800 rpm/60 Hz
Prime	**1000 kVA, 1000 kW**
Standby	**1100 kVA, 1100 kW**

Cooling system

Closed circuit water cooled with expander tank included in the radiator. Tropical radiator and pusher fan with guard. Equipped to work at ambient temperature of up to 56º C.

Cooling air flow from fan 1800 rpm 1049 m3/min
Cooling system capacity.. 122.7 litres

Lubrication system

Forced lubrication using gear driven pump. Oil filter

Oil sump capacity... 73.8 litres
Oil consumption .... 0.5 / 1% of fuel consumption

Air intake system

Turbocharged intake via dry air filter and intermediate air cooling of combustion air.

Combustion air flow 1800 rpm... 49.8 m3/min

Injection system

Direct injection with BARBER COLEMAN electronic speed governor.

Electrical system

24 V electric starting system. Axial starter motor. 2 x 240 A.h. battery. 32 Amp battery charging alternator. Oil pressure and engine temperature sensors.

Protection system

Automatic engine shutdown for low oil pressure, low fuel level, high temperature and battery charge defect.

Exhaust system

Consists of silencer with 10 db(A) noise reduction, flexible exhaust pipe and brackets. Residential silencer optional.

Exhaust gas flow 1800 rpm... 176 m3/min.

ALTERNATOR

Synchronous, three phase and brushless. Self regulation via automatic voltage regulator maintaining voltage within +/- 1.5%. Class "H" insulation. All windings are impregnated with ployester resin varnish, making them resistant to acids and oil. IP 22 protection. Electrical characteristics to BS 5000, VDE 0530, UTE 5100, NEMA MG 1-22, CMA IEC 34, CSA 22,2 and AS 1359. Harmonic distortion below 3,5%. Radio interference suppression to BS-800.

Manufacturer.. Stamford
Model... HC 634 J
Power rating .... 1100 KW at 1800rpm
Voltage (*) .... 480/277 V three phase
Frequency .... 60 Hz
Speed... 1800 rpm
Regulation .... Electronic
Nominal current.. 1658 A

(*) 12 wire output permitting reconnection to any existing voltage.

AUTOMATIC

The automatic version generator set is supplied on a skidbase with an automatic start/stop panel for mains failure.

Control panel

Mounted in a metal cabinet with IP 54 protection and supplied loose for wall mounting.Includes control, measuring and transfer system.

Monitoring and control system

Automatically monitors the mains, and, if the mains fails (in one or all three phases) connects the consumers to the generator set via mechanically and electrically interlocking contactors. When the mains is restored, the load is reconnected to the mains, the set idles and then stops. Equipped with:

- Push button controls, indicator lamp and protection fuses.
- No. of start up attempts: 3
- Three phase voltage monitor with adjustable values.

Measuring equipment

Consists of the following items:

- 3 Ammeters
- 1 Voltmeter
- 1 mains-generator set voltmeter selector switch.
- 1 Frequency meter
- 1 Battery voltmeter.
- Selector switch for Disconnect, Automatic Service, Manual Service and Test
- Off button.
- Start-up selector switch.
- Heater indicator lamp.
- Battery maintenance system.
- Audible alarm for faults
- Visual alarm system for low oil pressure, high temperature and/or overload.
- Mushroom type emergency stop pushbutton.

The set may be selected to run manually or automatically: When running manually a pushbutton is used for shutdown and a selector switch is used for start-up and changeover.

Heater

In this version, the set incorporates a heater which aids diesel engine start-up and response. It consists of a tank connected to the engine cooling system and a heating element with an adjustable thermostat.

Dimensions and weight

Length: 3700 mm
Width: 1400 mm
Height: 1954 mm
Weight: 4600 kg

Price of The Generator .... $ 281,000.00

B. DESCRIPTION OF THE INSTALLATION:

1. Transportation toward their destination
2. Electric installation and mechanics of their generator in the floor up to 40 feet of distance in pipe of the meter to the machine.
3. This project will be supervised and certified by a Certified Electrical Expert.
4. Installation in pipe that exceeds the 40 feet you will get paid at $ 15.00 for additional foot
5. Installation of the Automatic Transfer.
6. Installation of the tank for diesel
7. It includes service of Crane
8. Guarantee: 2 years
9. *Optional: Contract of Preventive Maintenance for Generator*
10. *Optional: Service of Delivery of Diesel*

Price of The Installation.. $ 50,000.00

C. SALE OF TRANSFER SWITCH AUTOMATIC:

1. Sale of Transfer Switch Automatic 1,600 amp.
   - *480\277 Volt.*

Price of The Transfer Switch Automatic................................ $ 25,000.00

D. SALE OF BASE TANK FOR DIESEL:

1. Sale of Base Tank (Double Wall) for diesel 2500 gals.
   - ***Production of Dike***

Price of The Base and Tank Diesel.. $ 9,000.00

TOTAL OF PROJECT...$ 365,000.00

- ---- TERM AND CONDITIONS -----

1. The Buyer accepts to have read and to agree with the price and terms of this rate.

2. The terms, price and specifications contained in this contract will have validity for a term of thirty (30) days, starting from the date of their preparation.

3. The price of this rate includes the sale, mechanical and electric installation and guarante in pieces and services according to the terms of the guaranteed for (1) year starting from the date of the initial outburst (start up) or of the delivery, wath comes frist. **M & C Electric, Inc.** reserved the option to repair or to replace the equipment or any part of this. The guarantee of the equipment doesn't cover overload uses to which has been dedicated the same one that the equipment has not been made by **M & C Electric, Inc**. and it will be sudject to the rates for hour that are in vigor in that moment. The sought-after price or the guarantee don't include the fuel.

4. All equipment order requires an equivalent deposit to 60% of the total price indicated in this rate. The remainder of the agreed price will before the initial outburst (start up) of the equipment. Automatically they will notice interest rate to 1.5% monthly the first of every month for all quantity that has not been paid before the initial outburst (start up). Order some won't be processed until the payment of the deposit. All order cancellation will bear an equivalent overcharge to 30% of the total price indicated in this rate that will be automatically discounted of the deposit. The remainder will be returned in a term of thirty (30) days. The buyer commits to reimburse M & C Electric, Inc. for the reclamation costs, expenses and lawyer's costs, including the damages, of any due and not paid quantity inside the terms here provided.

5. The team to order is cared of Europe. Although we will make all the adminstrations within our reach to give it in less than twelve (12) weeks starting from the required deposit, we cannot quarantee the date of receipt of the team. Delays in the team won't authorize the buyer to demend the cancellation of their order.

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I CERTIFY: That I have read and understood the before expressed, and constancy of my acceptance, I authorize to the present contract with their signature in the place and date.

In ______________________, Puerto Rico, the day ______________________, 2000.

M & C Electric, Inc Representation by: Felix Monserrate	Colegio Técnologico de Puerto Rico

M&C Electric, Inc.

1121 Américo Miranda
San Juan, Puerto Rico 00921-2214
Tel.: 774-8320 • Fax. 783-3105
WWW.GUIAPR.COM/MANDCELECTRIC

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