Revised Midterm Report II
Team 2: Cummins Energy Saving

Daniel Baker[#1], Warren Bell[#2], Daniel Carnrike[#3], Kyle Fields[#4], Marvin Fonseca[#5]

[#] *Mechanical Engineering Department, FAMU-FSU College of Engineering*
2525 Pottsdamer Street, Building A, Suite A229
Tallahassee, Florida; United States 32310-6046

[1]dpb11f@my.fsu.edu
[2]wab10@my.fsu.edu
[3]dac10c@my.fsu.edu
[4]krf11b@my.fsu.edu
[5]mgf12g@my.fsu.edu

Dr. Roger England: Project Sponsor
Dr. Michael Hays: Project Mentor/CTC Liaison
Dr. Nikhil Gupta: Project Co-Mentor
Dr. Juan Ordonez: Project Advisor

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Biography

Danny Baker: Dan Baker is a senior in Mechanical Engineering with an aerodynamics focus. Dan worked as a laboratory assistant in the cryogenics laboratory at the National High Magnetic Field Laboratory during his sophomore year. After graduation he will be moving to Ann Arbour, Michigan to start his career while obtaining an MBA.

Warren Bell: Warren Bell is a third year intern at Myco Trailers LLC. He is proficient in Excel, MATLAB, MathCAD, Kubotek Keycreator, and Creo 2.0 (Pro-e) and will be graduating from the Florida State University with a BS in Mechanical Engineering in May 2015.

Daniel Carnrike: Daniel Carnrike will graduate from Florida State University in May 2015. Daniel Carnrike has developed a passion for thermal fluid science and will be specializing in Fluid Mechanics and Heat Transfer upon graduation. During his educational career, Daniel has worked as a Mechanics of Materials and Dynamics teaching assistant.

Kyle Fields: Kyle Fields is a senior Mechanical Engineering student at the Florida State University with a focus in Fluid Mechanics and Heat Transfer. Kyle has previously interned for Cummins as an Application Engineering Intern in the Filtration division located in Cookeville, TN. He is the team leader for the project.

Marvin Fonseca: Marvin Fonseca is a senior Mechanical Engineering student at Florida State University with experience in manufacturing. With this knowledge, he will be able to come up with different ideas to reduce energy consumption. He is in charge of the web design and development and any CAD design.

Abstract

Team 2 has developed the following report to summarize the progress made in developing an energy saving plan to reduce Cummins power consumption at their technical center, in Indiana, by 10%. Team 2 has developed a variety of ideas which are presented throughout the report. Some of the ideas that were developed in order to reduce Cummins Technical Center (CTC) energy consumption are categorized as follows; alternative energy, power generation cycles, increased efficiency and building specifications. Team 2 has created a decision matrix selecting the optimal areas for implementing the proposed energy changes. A cost and energy analysis using MATLAB has been conducted for both solar panels and building insulation changes, in order to rank the most ideal energy savings ideas in terms of cost and efficiency. Through this analysis, the team and sponsor have collectively come to a consensus that future work will focus on designing a system to harness the energy from the exhaust gases emitted from the engines being tested. It is this new criterion that Team 2 will focus their efforts on over the upcoming semester. According to the energy analysis conducted, harnessing these exhaust gases will save Cummins just under 1.15 million kWh of heat energy savings and equates to about $97,519 in annual savings. Through the implementation of the ideas developed, the CTC has a projected $466,401 of annual savings per year.

I. Introduction

Energy efficiency is a major area of concern for many businesses. Whether it is inefficient light bulbs, poor insulation, or heat leaks from piping; wasteful energy practices cost companies hundreds of thousands of dollars each year. Companies have implemented different energy savings techniques that help reduce their energy consumption. Some techniques are replacing out dated light bulbs with more efficient ones, installing motion sensor triggers onto a lighting system and upgrading major energy consumption units to more efficient units. These practices are also known as an energy audit where a company's energy usage is analyzed and energy savings ideas are developed. Cummins has made great strides to become an industry leader in recyclable energy practices that minimize impact on the environment. In 2011, Cummins began to supplement some of its power sources in certain locations with solar panels and rerouting energy developed from their test cell dynamometers back into the grid. Also, Cummins has had an energy audit conducted to help assist their initial energy usage.

Cummins Inc. wanted a further reduction in their energy consumption and has chosen to sponsor a senior design team from Florida State University to reduce their energy consumption by 10%. In order to reduce the CTC energy, team 2 has been assembled to generate the necessary ideas, conduct the required analysis and produce an energy savings plan. Team 2 focused in multiple energy reduction areas for the CTC and created different ideas. Through the use of a decision matrix, the main areas of improvement that team 2 has decided are as followed: installing a solar panel design, installing absorption chillers (AVS), rerouting engine exhaust into a power generation cycle, improving dynamometer efficiency and applying a modern building insulation. These are ideas are analyzed in terms of energy saved per year and total annual dollars saved per year.

There is an important note to make about the report and the progress of the project. After Team 2 visited the CTC in Columbus Indiana in November 14th 2014, the realization that exhaust gases from the testing engines were used for emission testing only; team 2 has converted their focus to utilize the hot temperature of the exhaust gas (~400°F) for power generation. These plans will be further developed and analyzed in the upcoming spring semester.

II. Project Definition

The project definition section consists of background research, need statement for the project, goal statement and objectives and the project constraints. The background research is furthered dissected into background information for an energy audit, solar panels, insulation, engine testing and absorption chillers/ chilled water.

A. Background Research

Since 2011, Cummins has implemented solar cells as an alternative means of power in several of their facilities. Presently, the company has five solar arrays capable of generating up to 230kW. While this is an impressive feat, Cummins is looking to further capitalize on cleaner, more efficient sources of energy. For clarification, many companies and engineers use the notation MMBTU to represent one million BTU (British Thermal Units), and it should be noted that 1 BTU is about 1055 Joules of energy. Cummins has provided the team with the data shown below in Figure 1 to depict the total energy use at the Cummins Technical Center (CTC), which shows that they have already made significant strides in lowering their total energy use, and this value is predicted to be around 60,000 MMBTU for the next four years [1].
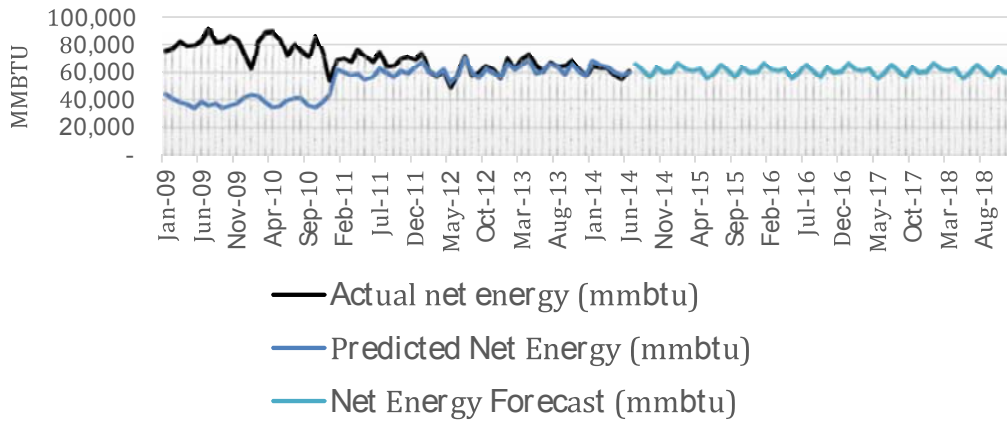
CTC Total Energy Use and Forecast

FIGURE 1: CTC TOTAL ENERGY USAGE AND PREDICATED USAGE (2009-2018)

Team 2 is fortunate to be from Florida State University (FSU) because of the FSU's Off-Grid Zero Emission Building (OGZEB). The OGZEB is a prototype used to test the feasibility of solar power in residential buildings. It consists of several rooms that are powered through solar energy, with the use of hydrogen powered appliances, high efficiency lighting such as sky lights, and recycled material insulation practices. The OGZEB building also has several power and temperature monitoring systems that analyze the conditions inside and outside the building. Though this is a residential application, the theory and techniques can be applied to an industrial setting. By utilizing the OGZEB, Team 2 will have the ability to do the necessary research and have experience with alternative energy power generation methods [2]. These methods proved to be useful in the design of the solar panel design which is presented later in the report.

The next subsections of the background research delve into aspects of energy audits, solar panels, insulation, engine testing, and absorption chillers (AVS).

1) Energy Audit

An energy audit is the practice of surveying a facility in order to identify different opportunities to reduce energy consumption and optimize the efficiency of energy usage [3]. Energy management is critical and consists of organizing financial and technical resources and personnel to maximize energy efficiency. Energy management also consists in keeping and maintaining records of energy usage and the performance of all machinery or appliances. An appropriate record keeping method can help to determine the areas in which the efficiency is under the standards of the facility. Depending on the building, the approaches to improve the efficiency of the energy usage can vary, and are often subject to the areas that consume the most energy. In most cases, the HVAC (heating, ventilating and air conditioning) is the source of major energy consumption in manufacturing facilities mainly due to heat generation from machinery and processes.

2) Solar Panels

A solar panel, or module, is a series of interconnected silicon cells joined together to form a circuit. In large numbers, the amount of power produced by these interconnected cells can be increased and used as an electricity production system [4]. For this project, the main focus will be analyzing the feasibility of implementing photovoltaic cells on the roof of the technical center for energy generation. Photovoltaics cells are designed to supply energy to commercial or residential buildings. The efficiency of these cells can go up to 19% and have a life time of 25 years. These cells need to be in arrays because each cell can only produce a limited amount of energy. Each package of solar panels may include the cell, a DC/AC converter, a solar tracker, and a battery. The theory behind the energy generation of these cells is the photovoltaic effect which consists of converting the energy of the Sun coming to Earth in the form of photons to electrical energy. This is done when the photons interact with the material's surface on the cells and excite the valance electrons, breaking them free and making them jump to the conduction band enabling the use of the electrical energy. The movement of electrons will produce a current and through ohm's law, if the current is supplied across a resistor, a voltage can be developed.

3) Insulation

Thermal insulation refers to the reduction of heat transfer between objects that are in thermal interaction. This can be accomplished by different ways from a specific process to the implementation of a different material. The capacity to insulate a material is measured in thermal conductivity (k). This property is proportional to the heat transfer. In other words the lower the thermal conductivity, the lower the heat transfer will be across the material. Most insulators work by slowing down the heat transfer from the exterior to the building or vice versa. This can be done by increasing the thickness of the insulator, changing the insulator material, or adding reflective barriers to decrease the radiation coming from the outside to the building. The thermal conductivity (k) is measured in watts per meter kelvin. As the thickness of the insulator material increases, the heat transfer decreases because thermal resistance increases. The main application for insulators is present in buildings. In order to maintain an acceptable temperature in a building by heating or cooling, a large portion of the total energy consumption is needed. When a building is well insulated, the owner can see major savings in energy usage. Good insulation helps to provide a more uniform temperature throughout the building reducing the temperature gradient in all directions [5].

4) Engine Testing

To measure the power of the Cummins QSK23 and other tested engines Cummins implements dynamometers. Dynamometers or "dyno's" for short can be categorized into 2 types, inertial dyno's and absorption dyno's. An absorption dyno directly absorbs power from the prime mover (usually driveshaft) and converts it to heat which is generally dissipated into the ambient air [6]. Here is an area where Team 2 plans to improve overall plant efficiency by harnessing this heat or possibly the energy before it is converted to heat and use a DC to AC converter to run this power back into the grid or use the heat if it will be more cost effective. In most dynamometers power is not measured directly and must be calculated from the product of either torque and angular velocity or force and linear velocity. Conversion factors must be implemented to get the result in relatable units.

5) CVS Chillers and Chilled Water

Chillers are used to cool water that is used for air conditioning and cooling machinery. In any industry, chillers are always a major power consumer. In order to reduce energy consumed by the chillers it is recommended that Cummins use absorption chillers. There are three types of absorption chillers: single effect, double effect, and triple effect chillers. In the case of the Technical Center, it will be more prudent to use a single effect chiller as it will be able to use low pressure waste heat to power the chiller efficiently. A double or triple effect chiller will require too much pressure and heat to be a feasible energy saver. Figure 2 depicts a flow chart of a single effect absorption chiller with temperature increasing in the horizontal and pressure increasing in the vertical. The flow of the water begins in the evaporator on the bottom left corner of the figure. Once heated the vapor is sent to the absorber where the hot where the heat is absorbed as the vapor enters the heat exchanger. The vapor runs a turbine attached to a generator to power the chiller. The vapor is sent to the condenser where cooled and returned to the evaporator. Using an absorption chiller as opposed to a mechanical chiller is beneficial because absorption chillers require low maintenance; they have a high reliability, and are relatively quiet and vibration free [7].
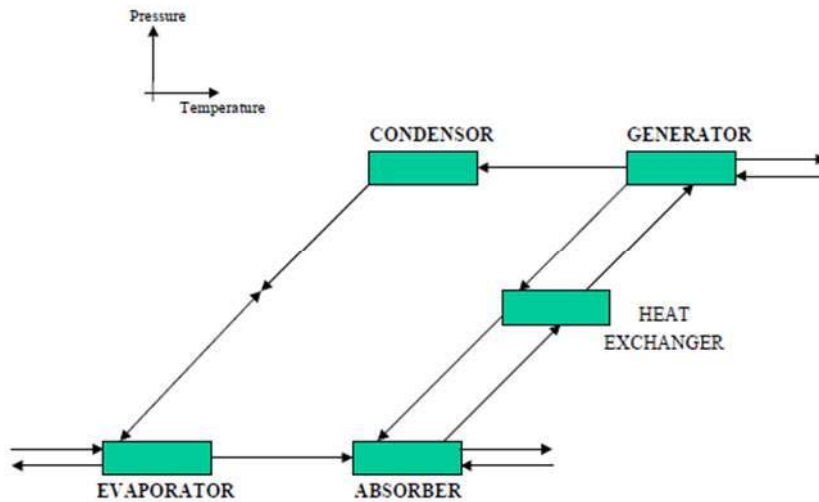
FIGURE 2: ABSORPTION CHILLER CYCLE (CLOSED CYCLE BEGINNING AT HEAT EXCHANGER)

B. Need Statement

The Cummins Technical Center (CTC) in Columbus, Indiana is looking to reduce their power consumption by 10%. While Cummins has already made great strides in reducing power consumption in their company, they believe there is still more work to be done. Cummins has asked Team 2 to develop multiple energy saving ideas and designs that can help contribute to this power reduction. A heavy emphasis was placed on investigation into the feasibility and cost benefit analysis of the proposed designs. "**Cummins needs to reduce their energy usage in order to save money and reduce their environmental impact.**"

C. Goal Statement and Objectives

The goal of the project is to, "Review current Cummins Technical Center (CTC) electrical usage and devise a plan to decrease it by 10%" and deliver it to Roger England by March 14, 2015. The project scope is broken up into an overall goal being the reduction of the facility power consumption and the subsequent objectives that will help the team to accomplish this goal.

1) Analyze feasibility of implementing solar panels for energy generation based on weather, altitude, and longitude conditions
2) Create a Pareto chart to show opportunities to reduce electrical consumption based on capital invested
3) Come up with a variety of creative ideas for potential areas of improvement
4) Investigate the potential application of absorption style chillers and how much energy would be saved with respect to initial and annual costs
5) Determine the insulation practices at the CTC and ways to improve the building insulation
6) Design a way to harness the energy from the engine exhaust emissions before they are released to the outside atmosphere
7) Research the feasibility of increasing the efficiency of the dynamometers used in the actual engine testing
8) Conduct a cost-benefit analysis on the rate of return for each of the suggested ideas

D. Project Constraints

The project must be completed under the following constraints listed below.

1) Any methods applied for reduction in power consumption must be cost effective for capital invested
2) Any power saving ideas (e.g., Solar Panels) should apply to weather conditions for Columbus, IN
3) Solar Panels must be able to fit on the roof of Cummins Technical Center
4) Insulation must meet federal and state regulations
5) Exhaust gases must first be routed through the emissions lab for testing before they can be harnessed
6) Emissions to the atmosphere must comply with environmental regulations

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III. Design and Cost Analysis

Due to the nature of the project, the following design areas are theoretical, and are based off of educated assumptions. Each of these design areas will have subsections of electrical and mechanical components which are subject to revision. This section is broken down into the four different energy saving ideas and their associated design and performance specifications. At the conclusion of this section, a decision matrix will compare the different ideas for implementation based on engineering criteria developed by team 2.

A. Solar Panels

From the average insolation calculated, solar panel dimensions were derived from the constraint of the roof in order to calculate the total area of the solar panels allowed. As shown in Table 1, the dimensions of both roofs and usable area are presented. The amount of useable roof area was found to be   and is sectioned into 3 parts as can be seen in Figure 3 in the design specification section of the report.

TABLE 1
CTC ROOF DIMENSIONS

	Width (m)	Length (m)	Area ( )	% Useable	Useable solar area ( )
Roof 1	35	35	1,225	100	1,225
Roof 2	90	100	9,000	40	3,600

1) Design Specifications

The design specifications for the required solar panels are described in the following section. These design specifications were calculated with the average insolation of   —. A more accurate insolation reading for the CTC can be developed with the implementation of a STR-21G Sun Tracker. The average insolation was calculated by a MATLAB program Team 2 developed, which can be seen in the appendix of this report. The MATLAB code takes into account equations that were derived from Vieira [8] and computes the necessary values used to estimate the average insolation that the CTC is exposed to throughout the year. This code can be seen in the appendix.

In order to transform the solar irradiance into electrical power solar modules were chosen and multiple modules were placed in an array. There will be six different solar arrays, all varying in size depending on the location of the roof which they are placed on. Figure 3 is an image with the three different sections and are labeled as followed: section 1 is the roof for the office building with dimensions of 35m x 35m, section 2 is the 40m x 80m section of the CTC roof and section 3 is a 20m x 20m section of the CTC roof. For section 1, the total area was assumed to be usable for the implementation of solar panels because there are hardly any obstructions. The CTC roof was divided into 2 sections and as stated previously, labeled section 2 and 3. Section 2 and 3 of the roof are the areas with the least amount of obstructions so the maximum number of solar panels can be used. The rest of the CTC roof as displayed, is obstructed and cannot be used for solar panel location.

Section 2 will be split into 4 equally spaced sections. The assumption of evenly spaced arrays made the calculations easier and also presented the maximum area per section. The assumed sections will have dimensions of 40m x 20m. Section 1 and section 3 will have one solar module array. Figure 3 is located on the following page because of the size of the image.
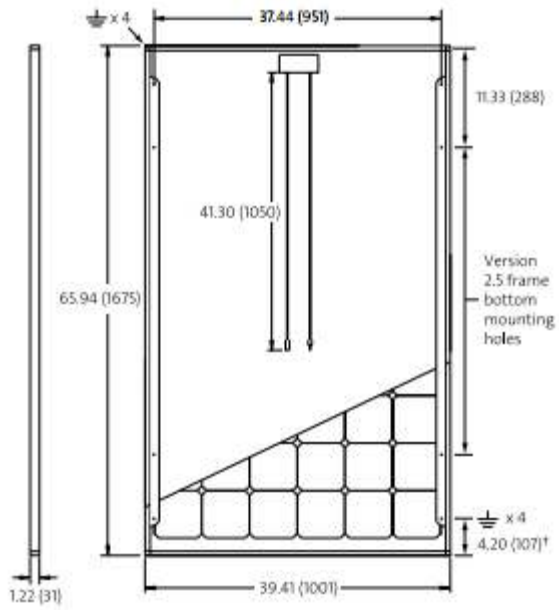
FIGURE 3: SATELLITE IMAGE OF CTC ROOF

FIGURE 4: DIMENSIONS OF SW 265W SUNMODULE

Figure 4 shows the dimensions for the solar cell as 1.675m x 1.001m x 0.031m. From the dimensions of both solar panels and the allowable roof space for each section, there will be a total of 1,415 module cells used for the solar system. Section 1 has 360 solar modules, section 2 has 940 solar modules and section 3 has 115 modules. Table 2 summarizes these sections.

TABLE 2
NUMBER OF PANELS PER SECTION OF ROOF

Section	Dimensions (m)	# of Panels
Office Building (1)	35 x 35	360
CTC Roof (2)	40 x 80	940
CTC Roof (3)	20 x 20	115

2) Performance Specifications

    The performance specifications are limited by the solar modules chosen for this design. The SW 265 W Sunmodule was chosen and the maximum power out voltage and current are 27.6 V and 5.02 A, respectively. The maximum voltage and current were chosen from the maximum power outputted of 138.55 per module [9]. The solar panels will not continuously operate at maximum values because the maximum amount of solar insolation will not reach the CTC 365 days of the year. This was taken into account by taking the average sunshine hours of —. The assumption was made that a solar panel will receive the maximum insolation from the sun for only 4.21 hours of the day. So, the solar panels were assumed to operate at maximum values for only — throughout the entire year [10]. Also, the specifications of the solar panels were rated at — and since the CTC is in a location where the insolation of the sun on average is only —, the current and voltage were adjusted accordingly through a ratio comparison. Each module was joined into an array and depending on the section on the roof, will have different size and power outputs. Table 3 summarizes these performance specifications for the proposed solar arrays in their associated sections.

TABLE 3
PERFORMANCE SPECIFICATIONS FOR SOLAR PANEL ARRAYS

Section	Voltage	Current	Power	Energy $\frac{\quad\quad}{!"}$#
Office Building (1)	437.8	119.6	52.38	80,483
CTC Roof (2)	501.2	67.62	142.7	208,330
CTC Roof (3)	247.4	67.62	16.73	25,708

The values for current, voltage, power and energy were calculated with the developed MATLAB and knowledge mentioned in the introduction about the behavior of solar panels depending on orientation; the MATLAB code can be found in the appendix. The total energy generated from the proposed solar panel system is an addition of the three different sections and equals $ $\frac{\%}{\&}$.

3) Cost Analysis

    The follow section will describe the initial cost to install the solar panels onto the CTC roof. The SW 265 Sunmodule from solar world are listed at $270.00 a piece [9]. These solar panels were found to be the best on the market with the maximum power output and size. The cost to purchase 1,415 SW 265 Sunmodule's is ' $. The average cost of labor for a solar technician is $\frac{'()}{}$*+ and an estimated 400 hours of labor was used to calculate the labor cost of ' ,   . Other cost assumptions were used and can be seen in the following Table 4.

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TABLE 4
ASSUMPTIONS MADE FOR SOLAR PANEL COST

Item	Cost
SW 265 Sunmodule	$382,050
Labor	$7,812
Battery System	$15,000

The battery system is the system needed to store the voltage that the solar panels create. This storage system will be to store any voltage generated from the solar panels that were not converted to power. The battery system costs include; cables needed, batteries, a DC/AC convertor, installation costs, and a monitoring system. These cost estimates are all relative to the contractor chosen to perform the installation, but, the total cost is ' for the proposed solar panel design. Once solar panels are installed there will be a payback period of 18 years.

B. Insulation

The following section is an analysis done for replacing the insulation at the CTC and this section consists of design specifications, performance specifications and cost analysis.

1) Design Specifications

Table 5 lists several alternative insulation options for Cummins. Table 5 shows the thermal resistance, what type of insulation, how 'Green' each material is, and whether or not it is fire resistant. These categories were all characteristics used to describe modern day insulation.

TABLE 5
INSULATION DESIGN SPECIFICATIONS

Material	Thermal Resistance	Types	Green	Fire Resistant
Fiber Glass	2.2 to 2.7	High, Medium, Low Density	20% to 30% Recycled	Yes
Mineral Wool	3.7	Blanket and loose fill	75% post-industrial recycled	Yes
Cellulose	3.2 to 3.8	loose fill or spray	82% to 85% recycled	No
Plastic Fiber	3.8 to 4.3	High, Low Density	----	Yes
Closed Cell Foam	5.6 to 8	Spray, Foam board	-----	No
Closed Cell Foam modified	9	Foil	----	Yes

2) Performance Specifications

The reason for updating insulation is based mainly on the thermal resistance of the current insulation installed at the facility. A higher thermal resistance means a greater savings in heat because less is transferred to the outside. The different types of insulation listed gives one an idea of how feasible it will be to install in the facility. This is based on work involved as well as cost of each material. A "green" material may result in tax reductions due to the environmentally friendly nature of the material. This could be done through the 'green point' system or following government standards for green initiatives. The next area of design consideration is engine testing.

3) Cost Analysis

The total cost of implementing insulation is given by a fixed installation cost of $50,000. It will take Cummins about two and a half years to make a return. This was calculated by calculating the heat flux of each insulation

material. To calculate the heat flux the difference between the outside and the inside temperature of the building was calculated and then divided by the thermal resistance values of the material given in Table 5. Multiplying the heat flux by the average energy cost for industrial facilities for each material will provide the savings generated by each material. The total savings will be equal to the difference between loss in the insulating material Cummins is currently using (asphalt) and the new materials shown in Table 6.

TABLE 6
COST ANAYLSIS FOR INSULATION

Material	Cost (per ft^2)	Total Cost for the roof	Total Saving per year
Fiber Glass	0.42	$59,606.66	$18,331.76
Mineral Wool	0.625	$64,295.62	$18,352.97
Cellulose	1.25	$78,591.25	$18,448.09
Plastic Fiber	1.5	$84,309.50	$18,596.58
Closed Cell Foam	2.2	$100,320.60	$18,955.43
Closed Cell Foam modified	2.3	$102,607.90	$19,068.17

C. Engine Testing
   The CTC currently has 88 main test cells with an additional 8 auxiliary cells. The CTC is currently testing the Cummins ISX and ISB engines. For ease of calculations, the assumption was made that all test cells contain the ISX15 600 due to the fact that specifications for this engine are readily available. This assumption has been preapproved by Dr. Hays. These engine specs are listed below and from this data performance specifications were made for both the mechanical energy generated by the dynamometers and the heat captured from exhaust gasses.

1) Design Specifications
   The design specifications are limited to constraints of the engines shown in Table 7.

TABLE 7
ENGINE SPECIFICATIONS

Engine Type	In-line, 6-cylinder
Advertised Horsepower	447 kW
Peak Torque	2,779 Nm
Governor Speed	2,000 rpm
Certification Level	EPA 2013
T_out	400°C
Test Cell Temperature Range	(-20 – 150) degrees C

With these engine specifications, performance specifications are generated to harness this available energy. With ninety-six engines, each generating up to 447 kW of power there is a huge amount of energy available for capture. Also all ninety-six engines are emitting exhaust gasses at upwards of 400 degrees Celsius.

2) Performance Specifications – Dynamometers
   As stated earlier, the CTC currently has 88 main test cells with an additional 8 auxiliary cells, each hypothetically containing an ISX engine. The ISX has an average test speed of 1200 rpm generating 268.2 kW per engine or test cell. At the CTC Cummins has implemented absorption dynamometers. A dynamometer efficiency was assumed to be 85% and the power is being added directly back to the grid. An assumption was made that the usage ratio was 10% because assuming all test cells are on all the time would cause unnecessary error. This leads to an annual power generated from dynamometers of 7,878,643 kWh and annual savings of $569,232 as seen in Table 8. One area that can save Cummins energy is to approve this efficiency. At the current efficiency over 1 million

kilowatt hours are lost annually. If the dynamometer efficiency was increased, another 7% an additional $50,000 in energy would be converted back to the grid.

TABLE 8
ENGINE TESTING PERFORMANCE SPECIFICATIONS

Variable	Value
Test Power	268.2 kW
Power Generation	7,878,643 kWh
Power Lost	1,390,348 kWh
Annual Savings	$569,232
Annual Savings Lost (inefficiency)	$100,453

3) Performance Specifications – Exhaust Gases

The performance specifications for exhaust gases is a theoretical assumption and the process is explained for values determined. The CTC currently does not use exhaust gases exiting the engines. One reason is the engine exhaust gases must be analyzed prior to any type of recirculation. Cummins suggested to take into account an efficiency loss of 10-15% in this process which will reduce the total mass flow rate exiting from the emissions lab. The Next step team 2 took was to calculate the amount of energy available through exhaust gas heat. Team 2 started with the conservative assumption that fuel consumption of the ISX15 600 is 6 m/G. This consumption is at a highway velocity of 70 m/h, leading to fuel Consumption of 11.67 G/h. According to emissions data from a study conducted by Cummins and the American Transportation Research Institute during, one ISX engine running for one hour, would produce 1174 kg of CO_2, 1.167 g Particulate Matter, and have 130 g of Methane Hydrocarbons. These pollutants are well under the EPA regulations and would be found analyzed and reduced before recirculating into the exhaust gas heat converter. Team 2 assumed an ambient temperature of 25^OC and use the earlier stated outlet temperature of 400^OF in order to calculate the temperature gradient with the system. Team 2 used a Diesel fuel density of 832 kg/m^3 and air density of 1.225 kg/m^3. Next Volumetric flow rate of fuel in is converted to $ - ·+ G/s and then $ - ·* m^3/s and used to find mass flow rate of fuel in of 10.21 g/s. Cummins also supplied us a volumetric flow rate of air into the engines of 18.3 ft^3/min which is converted to $ - ·+ m^3/s and used to find mass flow rate in of air at 10.58 g/s. Flow rates are then balanced and using conservation of mass along with the ideal gas law to find mass flow rate refuel of 1.021 g/s and mass flow rate exhaust of 19.77 g/s. Then, with assumed Specific Heat values for fuel equal to 0.43 BTU/lb.*F found for Petroleum Diesel, which is then converted to 1.832 kJ / kg*K for our equation. With these values; Newton's Law of Cooling was applied to find Heat Energy.

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Q is the amount of heat generated from the exhaust gases, which is usable energy. Cv is the constant specific heat at constant volume which is an assumption that was made and Ta is the ambient temperature that was established. Tout is the exhaust gas temperature of 400°F. The heat energy of 345 kW generated was found through Eq. (1). An assumed heat lost in combustion was 10% and is reflected within the calculations, resulting in 319 kw heat energy available to convert. The results of these assumptions are found in Table 9 which can be found on the proceeding page.

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TABLE 9
ENGINE TESTING PERFORMANCE SPECIFICATIONS

Variable	Value
Fuel Consumption	11.67 Gallons / Hour
Mass Flow Fuel In	10.21 g/s
Mass Flow In Air	10.58 g/s
Mass Flow In Total	20.79 g/s
Mass Flow Refuel	1.021 g/s
Mass Flow Exhaust	19.77 g/s
Specific Heat Fuel	1.832 kJ / kg*K
Heat Generated	354.1 kW
Heat Available to Convert	318.7 kW
Heat Available	1,147,294 kWh

The next step is what to do with the million kWh of heat energy available from the engine exhaust. Because heat is a degraded form of energy, which is not easily transferrable, the exhaust gas heat will be rerouted through a power generation cycle. The ideal power generation cycle would be an organic Rankine cycle and performance specifications for the different power generation cycles are presented in Table 10.

TABLE 10
POWER GENERATION CYCLE SPECIFICATIONS

Transfer Method	Theoretical eff.	Actual eff.	Initial cost	Annual maintenance cost
Thermionic Generator	40%	10%	low	low
Generation Thermocoupler	10%	(5% - 8%)	low	low
Rankine Cycle	42%	40%	med	med
Single Reheat Rankine	46%	44%	med-high	med-high
Double Reheat Rankine	48%	46%	high	high
Regeneration Rankine (open)	45%	43%	high	med-high
Regen. Rankine (closed)	47%	44%	high	high
Steam Turbine Cogeneration	100%	80%	high	high
Verdicorp Converter	80%	N/A	med-high	med-low

In the next section of this course Team 2 will generate more quantitative data for the conversion of this exhausted heat energy. For now, the potential methods are rated low, medium-low, medium, medium-high and high. Once the team researches this topic further in the next semester, these values will be given accurate numerical values. This section is the basis for the next semester.

D. Absorption Chillers

Average absorption and compression chiller components and power consumptions were obtained from the department of mechanical engineering at Anna University [11]. The components are listed in Table 11 and the power consumptions are listed in Table 12. Both compression (VCRS) and absorption (VARS) refrigeration systems were compared to show the potential savings of the absorption chillers.

1) Design Specifications

The components listed in Table 11 are the major power consuming parts for absorption and compression systems. The absorption system uses several pumps to run hot water, cold water, and refrigerant through the heat exchanger. The compression system uses a compressor to cool water as well as cold water pumps. These different components have a major impact on the power consumption of each design as shown in the performance specifications.

TABLE 11
LIST OF COMPONENTS OF VARS AND VCRS

Components	VARS	VCRS
Refrigerant Pump	X	
Solution Pump	X	
Compressor		X
Chilled Water Pump	X	X
Cooling Tower Fan	X	X
LT Hot Water Pump	X	
HT Hot Water Pump	X	
Cooling Water Pump	X	X

2) Performance Specifications

Table 12 lists the annual power consumption of VARS and VCRS components in kWh/yr. The bottom row shows the cumulative cost and it is apparent that the absorption system uses significantly less power than the compression system, about 74% less power. This is due mostly due to the removal of the compressor from the system as it used 81% of the compression systems power.

TABLE 12
ANNUAL POWER CONUMSPTION OF VARS AND VCRS

Components	VARS	VCRS
Refrigerant Pump	13,140	N/A
Solution Pump	61,320	N/A
Compressor Power	N/A	2,938,980
Chilled Water Pump	324,120	324,120
Cooling Tower Fan	131,400	87,600
LT Hot Water Pump	43,800	N/A
HT Hot Water Pump	43,800	N/A
Cooling Water Pump	324,120	262,800
Total Annual Power Consumption	**941,700**	**3,613,500**

3) Cost Analysis

Table 13 shows the average initial cost of the VARS and VCRS. The absorption systems tend to be more expensive because of their machining cost and the extra pumps. However the annual operating costs shown in Table 14 shows the absorption is less expensive than the compression system.

TABLE 13
INITIAL COST OF VARS AND VCRS

	VARS	VCRS
Machine Cost	$278,478	$112,041
Cooling Tower	$22,826	$19,565
Cooling Water Pump	$5,435	$4,348
Chilled Water Pump	$3,913	$3,913
LT Hot Water Pump	$1,848	N/A
HT Hot Water Pump	$1,848	N/A
Total Initial Cost	**$314,348**	**$139,868**

TABLE 14
ANNUAL OPERATING COST OF VARS AND VCRS

	VARS	VCRS
Refrigerant Pump	$1,097.19	N/A
Solution Pump	$5,120.22	N/A
Compressor Power	N/A	$245,404.83
Chilled Water Pump	$27,064.02	$27,064.02
Cooling Tower Fan	$10,971.90	$7,314.60
LT Hot Water Pump	$3,657.30	N/A
HT Hot Water Pump	$3,657.30	N/A
Cooling Water Pump	$27,064.02	$21,943.80
Total	**$78,631.95**	**$301,727.25**

Figure 5 shows the total cost of both an absorption and a compression system. Figure 5 also shows that an absorption system will have the initial cost of the system paid back in less than a year compared to the compression system. Figure 5 can be found on the preceding page.

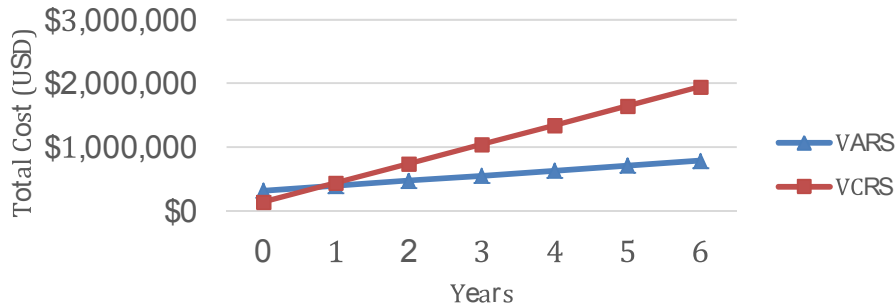# Total Cost of VARS v. VCRS Over 7 Year Period

FIGURE 5: TOTAL COSTS OF VARS VS VCRS

E. Decision Matrix

A decision matrix was developed for the analysis of the different ideas generated in order to reduce the CTC's energy consumption. The chart is sectioned into different categories with different associated weights that Team 2 deemed necessary for the analysis. Also, the ranking scale is 1,3 and 9 where 1 is the lowest and 9 is the highest value that can be received. Table 15 summarizes the previous ideas and includes other ideas that were generated by Team 2.

TABLE 15
DECISION MATRIX OF ENERGY SAVING IDEAS

Importance	30%	25%	25%	20%	
	Power Saving Potential	Feasibility	Cost	Maintenance Required	Decision Score
Absorption Chillers	9	9	1	9	7.8
Solar Panels	1	9	9	3	4.8
Wind Turbine	1	1	3	1	1.3
Rerouting Exhaust Gases	9	3	3	3	5.7
Insulation	1	9	9	9	5.4
Heat Treat Components	1	3	3	9	2.7
HVAC	1	9	3	3	3.9
Power Generation Cycle	9	3	1	1	5.2
Increase Dyno Eff. 15%	3	1	3	3	2.4

From Table 15, the ideas that are highlighted showed the greatest potential. The categories that are seen are; power saving potential, feasibility for installation, cost of the system and maintenance required for the system. Some ideas that were not analyzed because of the low score that they received. Heat treat components was a technique done at other facilities and by heat treating materials, the material becomes stronger and has a higher life cycle. Heat treating all the components at the CTC would not be feasible. The power generation cycle is associated with rerouting the exhaust gases because once the exhaust gases were captured, a power generation cycle is needed in order to convert heat into useable energy. The power generation cycle currently is being selected and analyzed before the completion of the next semester. The highlighted ideas were presented previously in the report.

14

F. Pareto Chart

The Pareto Chart in Figure 6 shows the savings of each energy saving option. The bar chart represents each individual idea and their potential savings listed on the left vertical axis. The line graph represents the cumulative percentages of each idea. The percentage is shown on the right vertical axis. Both graphs superimposed show how much each individual idea affects the total savings. Since all of the ideas cannot be implemented at one time the Pareto Chart gives a clear visual of which option will be most effective.
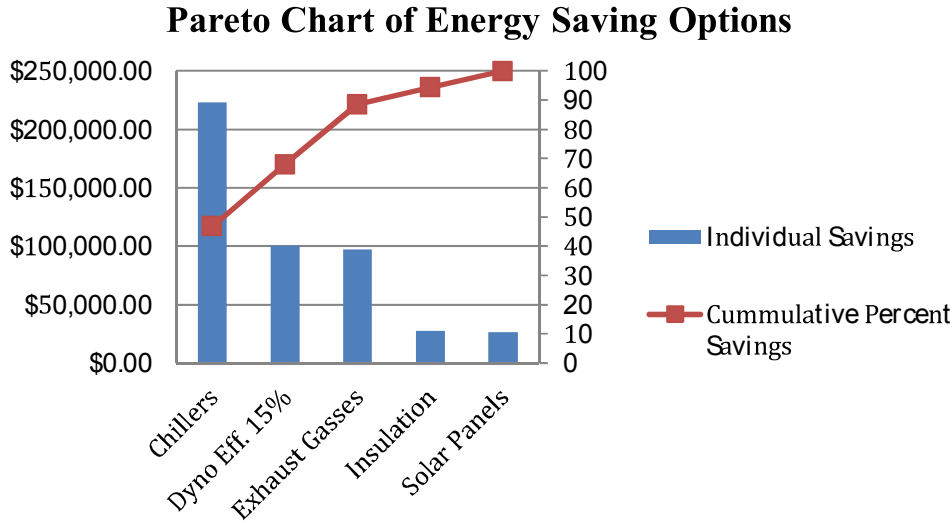

FIGURE 6: PARETO CHART OF ENERGY SAVING OPTIONS

IV. Communications

The communication between team members, sponsor, and advisors is a critical component of the project. In the beginning, most communication was conducted online and text messaging to group members, and emailing the project sponsor and project adviser. Through a trial and error process, the team found that the best method for contact was directly calling the person of interest over the phone. Oftentimes, the person of interest the team was attempting to reach out to via email would never respond, likely due to the sheer amount of other emails they receive. Therefore, calling the person of interest to discuss everything cleared up a lot of issues. However, the best form of communication was meeting in person. The team learned the majority of what the sponsor wanted by meeting with Dr. Roger England at the beginning of the semester. Likewise, meeting with Dr. Nikhil Gupta helped alleviate many of the funding issues for the team's travel arrangements to Columbus, Indiana. Additionally, having the opportunity to meet with Dr. Michael Hays at the Cummins Technical Center enabled the team to work out many of the kinks that had been plaguing the project since the beginning of the semester. Thanks to his input, the team is now able to refocus their efforts from a large and vaguely open ended design project with no real direction into a concrete idea with a specific purpose and design.

V. Environmental and Safety Issues

There are associated health concerns when harnessing and rerouting exhaust gasses. Some molecules that need to be regulated include carbon dioxide, particulate matter, and methane hydrocarbons. Carbon dioxide and methane hydrocarbons are hazardous because they destroy the Ozone layer, which protects us from harmful UV rays. Particulate matter on the other hand is harmful because it can kill you if entered into the body through normal respiration. Because of these concerns Team 2 will calculate the emissions of these harmful by-products. Team 2 calculated the highway speed the Cummins ISX15 600 consumes fuel at a rate of 11.67 G/h. According to emissions data from a study conducted by Cummins and the American Transportation Research Institute during this hour running all 96 ISX engines would produce 1,174 kg of carbon dioxide, 1.167 g Particulate Matter, and 130 g of

Methane Hydrocarbons. These pollutants are well under the EPA regulations and would be found, analyzed, and disposed before recirculating into the exhaust gas heat converter. When asked of these emissions Dr. Hays said, "The air coming out is cleaner then the air going in. Besides the fact it's poisonous."

VII. Methodology

To complete this project within the deadline, Team 2's first priority will be to continue gathering pertinent information. First and foremost, Team 2 will continue doing research on the Technical Center through the Cummins sponsor Roger England and plant liaison Michael Hays in the spring semester. It will be important to understand the priorities of Cummins and ensuring that the company gets exactly what it needs. After gathering information from the OGZEB, as well as meetings with Dr. Ordonez, Dr. Hays, and Dr. England, Team 2 conducted several brainstorming sessions thinking of any and all possible energy savings ideas. These ideas will be updated throughout the year but originally 10 ideas were listed as shown previously in the decision matrix. From these ideas, Team 2 created a decision matrix and separated each idea into 5 aspects that were ranked according to criteria developed by Team 2. From this decision matrix, the top 4 major areas of interest were selected. Team 2 then split up these 4 main foci between the 5 team members as stated below in the resource allocation.

Every two weeks, Team 2 plans to talk with its advisor, Dr. Ordonez, to provide updates and gather insight on how to move forward. Each step forward will be documented weekly on the website by Marvin Fonseca, the webmaster. Once Team 2 obtains information about the process to capture exhaust gases, they will create a draft of the overall energy saving plan and design a prototype to capture exhaust gases and generate energy.

1) Gantt Chart

Figure 7 shows a Gantt chart for team 2. Figure 7 describes how the team has divided time from October 13th, 2014 to December 4th, 2014.

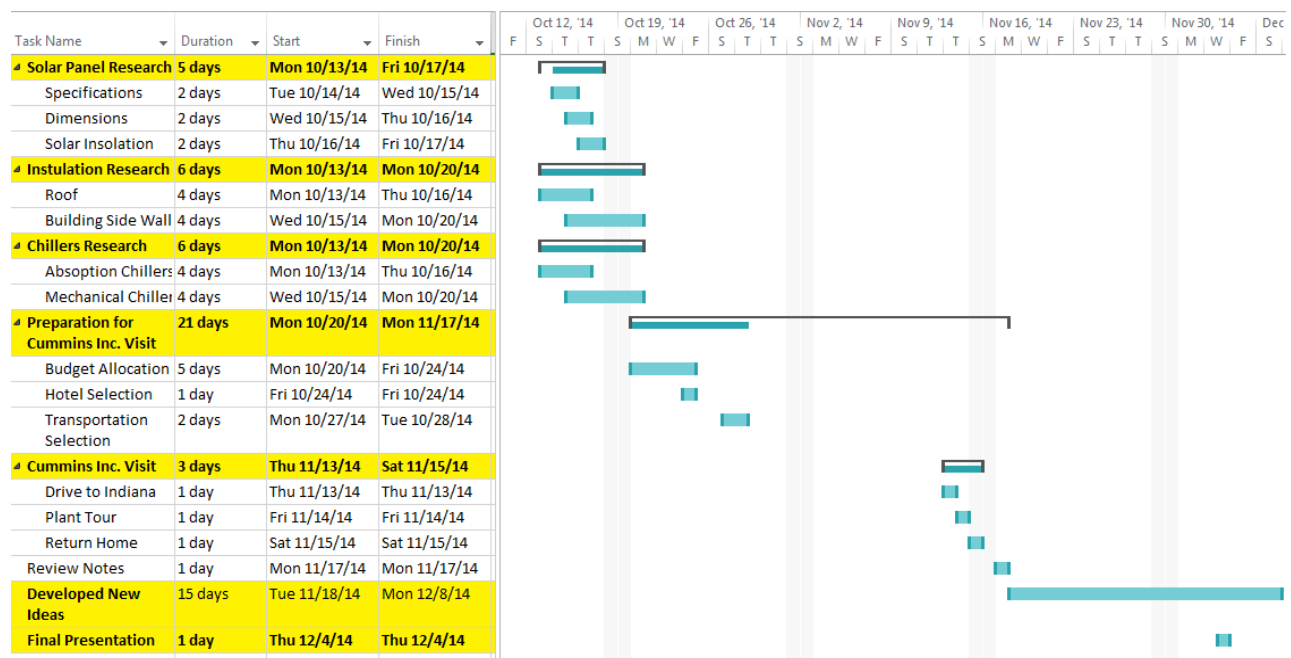FIGURE 7: TEAM 2 GANTT CHART

Figure 7 is a description of Team 2's work schedule from October 13th to December 14th 2014. This time section was the most important since the trip to the CTC was within this time frame. For a more detailed Gantt chart from the beginning of the semester please refer to previous reports or Team 2's website (http://eng.fsu.edu/me/senior_design/2015/team02/index.html).

2) Resource Allocation
   This section is broken into task, owners and status. The task is the required task that is needed to be completed for the completion of project. Owners are the people or person responsible for the allocated task, while the status describes if the task is completed or not.

TABLE 16
RESOURCE ALLOCATION

Task	Owners	Status
Energy Audit Research	All	Completed
Energy Saving Concept Generation	All	Completed
Choosing Final Concepts	All	Completed
Chillers Background Research	Dan Baker	Completed
Chillers Cost Comparison	Dan Baker	Completed
Dynamometer and Exhaust Research	Warren Bell & Kyle Fields	Completed
Engine Thermal Energy Output Computational Analysis	Warren Bell & Kyle Fields	In Process
Solar Panel Research	Daniel Carnrike	Completed
Solar Panel Energy and Cost Computational Analysis	Daniel Carnrike & Warren Bell	Completed
Insulation Research	Marvin Fonseca & Kyle Fields	Completed
Initial Web Page Design	Marvin Fonseca	Completed
Future Work Selection	All	20 days

VIII. Conclusion

Following the completion of the Midterm I report, Team 2 has made significant strides in narrowing down implementation suggestions for the energy savings options that Cummins requested, and has come to the conclusion that designing a method to capture and utilize the energy from the exhaust gases will be the primary focus moving forward with the project. The cost effectiveness of the solar panels has been estimated based on calculations made using prior knowledge in MATLAB code as well as Excel in order to find the feasibility and cost savings, respectively. Additionally, the cost effectiveness of replacing the building insulation has also been estimated in the same manner. Likewise, cost analysis for the absorption chillers has been based on an ideal Vapor Absorption Refrigeration System (VARS) study. On the administrative side of the project, Team 2 has come up with a Gantt Chart and resource allocation for each team member that will help the project stay on schedule. The team has met at the OGZEB house and learned that the design of the prototype grid monitoring system would be too overly complicated and ultimately unhelpful to this design project. Team 2 visited the CTC in Columbus, Indiana November 13th-15th and met with Dr. Michael Hays, the plant liaison, and John Lashbrook, the facilities manager. From the visit, the team learned several key facts. First and foremost is that the facility is not currently recapturing the exhaust gases being emitted to the atmosphere. From this, the team and the sponsor have agreed that this is an area of immediate impact, and that future work should focus primarily on this area. Additionally, the facility has been reinsulated with the Closed Cell Foam Insulation mentioned previously in this report, closing off this avenue for potential energy savings. Finally, Cummins has informed Team 2 that they are currently researching the benefits of installing VARS chillers, and would like the team to continue researching this area if enough time is available. Team 2 also plans to continue meeting with the advisor Dr. Ordonez for support in the design of the solar panels and general guidance in the other design suggestions. Additionally, Team 2 will have staff meetings to ensure that the work being done is productive and will help ensure that deliverables are completed in a timely and satisfactory manner. Further work will be required to finalize the actual cost of implementing these designs. Problems may arise in the ability to implement these designs due to feasibility, innovation, and funding. The team is also tasked with coming up with as many design suggestions as possible, however, this is now a secondary assignment to the main focus of capturing the engine exhaust gas energy. In the future for the spring semester, possible work may include researching the feasibility of installing wind turbines or improving the HVAC system of the facility for further energy savings opportunities.

IX. Future Plans for Prototype

Team 2 will continue on the development of ideas for the spring 2015 semester. The ideas will try to save the remaining energy required to reach our goal. These ideas will be focused around, but not limited to, the rerouting of exhaust gases. A piping system will be developed in order to transport these gases into a power generation cycle. Team 2 will also analysis the different power generation cycle ideas in order to decide on which cycle will be better suited for the CTC. Another idea that Team 2 will dive into, will be the replacement of their chillers. Team 2 wants to replace the mechanical chillers that are currently in use with absorption chillers. The feasibility of replacing this unit will be looked at in more detail with the heat source coming from the exhaust gases. More ideas will be developed in the alternate energy field such as wind energy and geothermal energy analysis. Also, Team 2 will create a go green plan that will highlight tax reductions from the solar panels and from making their building more environmentally friendly. There are multiple areas for improvement which Team 2 plans on addressing with their advisor.

XI. References

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XII. Appendix

<u>A1 - MATLAB Code for Insolation Calculations</u>

```
%Team 2
%Senior Design  Solar Estimates

clc
a = 0.14;
h = .192; % km above sea level
AM = 1.5; % Air Mass Index [100 units]
I_o = 1365; % Outside Atmosphere W/m^2
ALPHA = zeros(1,100);
time_day = zeros(1,100);
zenith = zeros(1,100);
azimuth = zeros(1,100);
Insolation = zeros(1,100);
azimuth_y = zeros(1,100);
azimuth_x = zeros(1,100);
ratio = zeros(1,100);

%%% Building Dimensions %%%
Length1 = 100;
Width1 = 120;
Length2 = 40;
Width2 = 40;
Area_Building1 = Length1*Width1; %% meter squared
Area_Building2 = Length2*Width2; %% meter squared
Total_Area = Area_Building1*.1 + Area_Building2;



%%% Solar Time throughout the day %%%
day =   input('What day of the year is it = ');
sunrise = input('What is sunrise solar time = ');%solar
sunset =  input('What is sunset solar time = ');
zeta = 180; % directions that the solar panels face



%%% Coordinates for Indiana %%%
lamda = Coordinate_Time(39,12,4.49298); % lattitude
W = Coordinate_Time(85,54,13.0428); % Lonigtude
elevation = lamda;
cloud = .70; %%% Cloudyness factor

%%% Average Insolation Equation %%%
I_local = I_o.*((1-a.*h).*(0.7.^(((AM).^0.678))) + (a.*h))


declination = 23.44.*sind(360*((day-80)/365.25));


for i=1:100

    time_day(i) = sunrise + ((sunset-sunrise)/99)*(i-1);
    ALPHA(i) = 15.*(time_day(i) - 12);
    zenith(i) = acosd(sind(declination).*sind(lamda) + ...
```

```matlab
        cosd(declination).*cosd(lamda).*cosd(ALPHA(i)));
    azimuth_y(i) = sind(ALPHA(i));
    azimuth_x(i) = (sind(lamda).*cosd(ALPHA(i)) - ...
        cosd(lamda).*tand(declination));
    ratio(i) = azimuth_y(i) ./ azimuth_x(i);
    azimuth(i) = atan2d(azimuth_y(i), azimuth_x(i));

    if ALPHA(i) > 0 &&  ratio(i) > 0
        azimuth(i) = 180 + azimuth(i);
    elseif ALPHA(i) > 0 && ratio(i) < 0
        azimuth(i) = 360 + azimuth(i)  ;
end

    Insolation(i) = cloud.*(I_local.*(cosd(elevation).*cosd(zenith(i)) + ...
        sind(elevation).*sind(zenith(i)).*cosd(azimuth(i) - zeta)));

end

Sun = mean(Insolation) %% Calculationg the Mean Insolation

%%% Plots
plot(time_day,Insolation)
xlabel('Time (Hr)')
ylabel('Insolation')
title('Insolation in Day')
    grid on
```

A

A-2 – MATLAB Code for System Dimensions

```
% Solar Panel Number Calculations 60x20 section
clc
%Solar Panel Dimensions
Length = 1.675; %m
Width = 1.001; %m
Edge_Spacing = 0.5; % Spacing From the Edge (m)
Spacing = Edge_Spacing; % Spacing between Panels (m)
Roof_Sections = 1; % Sections for solar panels
AverageSunshine = 4.21;


Total_Length = 35;% Total Length of Section (m)
Total_Width = 35; % Total Width of Section (m)


N_Long = (Total_Length - (2*Edge_Spacing) + Spacing)./...
    (Length + Spacing);
N_Wide = (Total_Width - (2*Edge_Spacing) + Spacing)./...
    (Width + Spacing);
Panels_Section = N_Long * N_Wide;


Total_Number_Panels = Roof_Sections * Panels_Section


%Solar Panel Specifications
V_max = 27.6; %% Adjusted for 600 Insolation
I_max = 5.205; %% Adjusted for 600 Insolation
P_max = V_max * I_max;


Voltage_Row = V_max * N_Long  % Volts
Current_Wide = I_max * N_Wide % Amps
Power_Section = Voltage_Row * Current_Wide


Power_System = Power_Section * Roof_Sections
Power_System_kWhr_day = (Power_System * AverageSunshine) / 1000;
Power_System_kWhr_year = (Power_System_kWhr_day * 365)


%%% Cost of Panels
Cost_Of_Electricity = .08; %Cents/kWhr
One_Panel_Dollars = 270;
Cost_Of_Panels = One_Panel_Dollars * ...
        Total_Number_Panels
%%% LCOE
Average_Hour_Worker = 19.53;
Worktime = 400;
KI = Cost_Of_Panels;
KMaintenance = Average_Hour_Worker * Worktime;
Kfuel = 0;
E_annual = Power_System_kWhr_year;
Interest_Rate = .1; %% 10 percent interest rate
n = 20;             % Number of years to pay back investment.


CRF = ((Interest_Rate)*(1+Interest_Rate)^n) / (((1+Interest_Rate)^n) - 1);


LCOE = (CRF * KI + KMaintenance) / E_annual; % Cents per kWhr
```