Senior Design Project

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Bachelor of Science

in

Mechanical Engineering

Solar Absorption Chiller

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Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of JUAN ARISTIZABAL, ANDRIAN GONZALEZ, ROBERT MARTIN and MIKAIL WILLIAMS and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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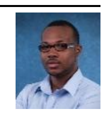

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III. Nomenclature

Symbol	Definition
P	**Pressure**
V	**Volume**
n	**Number of moles**
R	**Gas Law Constant**
m	**Mass**
T	**Temperature**
V_E	**Expansion Momental Volume**
V_C	**Compression Momental Volume**
V_{SE}	**Volume of Power Piston**
-dx	**Phase Angle**
V_R	**Regenerator Space Volume**
t	**Temperature Ratio**
v	**Swept Volume Ratio**
X	**Dead Volume Ratio**
P_0	**Power Output**
B_n	**Beale Number**
f	**Frequency**
V_{RA}	**Volume Ratio**
L_{CH}	**Displacer Chamber Length**
d_{CH}	**Internal Displacer Diameter**

Symbol	Definition

Table 1 – Nomenclature Table

IV. Abstract

Industry standard for commercial and residential cooling requires the use of vapor compression and electrical compressors in chillers. The proposed design is of a solar heat absorption chiller. The absorption chiller provides a low COP, due to the lack of power input. Minimal power is required to use water and solution pumps. The ultimate goal is to design a net-zero energy system that uses renewable energy to supply the necessary energy to operate this system. Due to the energy efficiency and reduction in consumption, the absorption chiller is an appropriate system to build on. Renewable energy and their sources are being researched and invested in to allow for a sustainable future. This includes solar energy, and the utilization of waste heat to recycle this energy instead of rejecting it. The solar and waste heat provide enough heat energy to drive a simple, mobile packaged absorption chiller and provide cooling in temporary locations or places that lack electrical power.

1. Introduction

A. Problem Statement

By today’s standards, non-renewable energy sources are depleted constantly, and the environment loses a battle every day to humans. Harmful emissions from fossil fuels and chlorine-based refrigerants have led to economic and more severely, environmental hardships. The world has been working to reduce hazardous emissions while developing renewable energy sources and technology. Leading the industry of renewable energy is solar power. By collecting and storing solar heat, and transferring this energy to power an absorption chiller, energy efficiency can improve, eradicating usually necessary electricity. Considering electrical power prices increasing, systems are developed to reduce electrical consumption and improve efficiency.

Heat is a widely under-developed and under-utilized form of energy that can provide the necessary power for a net-zero energy efficient packaged air conditioning system. Worldwide organizations and military units provide health and support services, often in countries that have no electrical power. Some may have insufficient electricity to power a system to cool or dehumidify a space. These sites provide shelter and basic needs, but often lack comfortable conditions. An air conditioning system can greatly increase and improve living and health conditions. The implementation of a net-zero packaged air conditioning system allows it to run itself, and be moved between locations with minimal extra set-up. This design utilizes otherwise wasted and often overlooked sources of energy, that leads to future designs and improvements.

B. Motivation

Hazardous emissions from fossil fuels and chlorine-based refrigerants are released into the atmosphere when people drive automobiles, fossil fuels are burnt, and refrigerants are released. In addition to deteriorating the ozone and air quality, the expansion of cities and globalization has overtaken entire ecosystems and depleted natural resources. This exemplifies the importance of new and more efficient systems. The development of such systems, using available renewable energy to reduce carbon and green gas emissions has increased tremendously. The world has been working to reduce hazardous emissions while developing renewable energy sources and technology. The most abundantly available energy source proves to be the most useful – the sun. Government agencies and private companies have funded and researched projects and products to harness and utilize this commonly overlooked source. The sun's radiation heat provides a renewable, but not constant energy source. This has led to the production of devices to store this energy when it may not be available at a certain time.

In order to take advantage of this widely desired energy, this project utilizes solar collectors to heat water. Thermal storage tanks can hold this high temperature water, similar to a domestic hot water tank, until needed by the system. This provides necessary heat during off-peak hours at night. The solar heated water provides the driving energy of a water-fired absorption chiller. This unit eliminates the need of a mechanical, electrical compressor. Instead the process is driven by heat and science. The heat rejected into another water circuit by the condenser can be recycled into the system. Instead of losing this other available heat source to an unobjectionable place, the thermal energy of this hot water can add to the solar heated water.

Renewable energy and their sources are being researched and invested in to allow for a sustainable future. This includes solar energy, and the utilization of waste heat to recycle this energy instead of rejecting it. The solar and waste heat provide enough heat energy to drive a simple, mobile packaged absorption chiller and provide cooling in temporary locations or places that lack electrical power. The heat and solar energy can drive pumps, using a heat Sterling engine, and exclude electrical components completely.

In designing and completing this project, the new application of existing technologies will reduce the need of fossil fuel generated power, and therefore, decrease the impact of energy consumption and the use of harmful materials and depleting energy sources. Due to the energy efficiency and reduction in consumption, the absorption chiller is an appropriate system to build on.

C. Literature Survey

The proposed design is of a solar heat absorption chiller. The misconception of the absorption chiller is a low COP. This is not due to a lack of power input, but rather a lack of power input. The ultimate goal is to design a net-zero energy system. Due to the energy efficiency and reduction in consumption, the absorption chiller is an appropriate system to build on. Centrifugal chillers have the decreased their power requirement, and efficiency is improving. However, the design is proposed intended to require no electrical power and improve system efficiency compared to the industry standard mechanical vapor compression system. The single, double, or triple-effect types use the internal heat to generate energy that can be applied to a motor. The heat-driven concentration and pressure difference, with improved heat transfer devices will allow for the addition of Sterling engine technology.

The purpose of using the Sterling engine is to generate mechanical energy using heat rejected and wasted by an HVAC system. The heat rejected by the water and refrigeration system can be collected and converted into mechanical energy, to power or reduce the consumption of standard pumps. The heat input required for this heat engine is large in comparison to the converted mechanical work it outputs. Considering warm climate regions along with the discharge temperatures of the refrigeration system of well over 100 ℉, the collection and usage of heat is of ultimate concern. The absorption chiller boils water at a low temperature by reducing its pressure, and generating steam. The latent heat of vaporization can be absorbed from the water, which produces 970 BTU. Instead of rejecting heat to the atmosphere, the assortment of heat sources can be utilized. To increase the heat content and useful work for the system, the largest existing heat source, the sun, can significantly improve the efficiency of this system.

The use of solar energy has gained popularity with manufacturers and the Department of Energy supports this renewable energy. The obvious downside is the limited sun exposure in a day and can be direction dependent. However, the cooling demand decreases as the sun goes down. The use of thermal heat collection and the addition of the waste heat recovered from the system will allow the energy obtained to satisfy the energy required to operate. The ultimate goal is to design a system that requires less or no electrical power, and utilizes the several available heat sources. This design is proposed to run a net-zero energy efficient HVAC system, and improve on or replace the current existing technology, and promise a sustainable future.

1. Absorption Chiller

Absorption cycles have been used in air conditioning systems for over 50 years. This specific system was successfully chosen because of lower operating costs and better system performance than other system types. Other systems began to use gas to provide a power source, such as natural gas, propane or ammonia. However, due to economic hardships, and demand, natural gas prices began to skyrocket. This led to the improvement of electric motors, and coupled with the drop in prices for electrical power, these electrically powered systems became more widespread. This reduction in gas availability greatly diminished the use of gas systems. As with any cycle and as power companies understood supply and demand, electric costs also began to increase. There are some cities around the country that still use natural gas, as their demand dropped off, so did their prices. Due to the high electric prices, people look to cut costs anywhere they can. Companies looked to utilize any energy source available. The typical HVAC system uses electric power, while the standard absorption chiller uses heat. The source of heat energy is provided by gas, in direct-fired or indirect-fired systems, and hot water or steam, in water-fired systems. While most HVAC systems use a refrigerant to supply efficient heat transfer, the absorption chiller uses water as the “refrigerant”. The refrigerants today contain the chemical chlorine, which is the leading cause in their ozone depleting capabilities. This fact has led many users and environmentalists to question their necessity. The development of refrigerants without chlorine has reduced this global impact, but their handling and usage still requires training and certification.

The advantage of the absorption chiller versus a standard centrifugal chiller is based on its driving power. The absorption cycle uses heat to drive the system. Heat transfer basics, relying on temperature differences to move heat forces the refrigerant and solutions to move through the system. The addition of heat to the generator causes the solution inside to boil. The pressure inside the generator allows the water refrigerant to begin to boil. By decreasing the pressure below atmospheric, the water boils at a temperature below 212 ℉. It can be seen in Table 2 how lowering the pressure inside this system, would allow for less heat to drive the generator, by boiling the water at a much lower temperature.

Pressure (mm-Hg)	Boiling Point (℉)
760 (1 atm)	212 ℉
76 (0.1 atm)	115 ℉
25.6 (0.34 atm)	80 ℉
7.6 (0.01 atm)	45 ℉

Table 2 – Boiling Temperatures for Water

Similar to the vapor-compression refrigeration system, the absorption cycle is separated into two pressure sides. The generator and condenser are considered the "high side" of the system, and the evaporator and absorber are considered the "low side" of the system. If the generator was supplied with direct fired heat sources, the pressure inside the vessel reaches several hundred psi. In order to reduce this heat load requirement, and allow for adequate operation, the system uses a water-fired heat source between 100-300 ℉. The lower pressure vessel of the generator allows the refrigerant solution to boil the water at these lower temperatures and pressures. The purpose of this generator is to distribute this water refrigerant vapor to the rest of the absorption system. By boiling the refrigerant water vapor, the lithium-bromide or ammonia and water solution are separated. In the water-fired system, the coil tubes are placed in or around the generator. The hot water or steam are pumped through this coil, as the absorbent solution absorbs the temperature from this heat source. When the temperature of this solution is increased to the mentioned temperatures at given pressures, the water boils out, concentrating the solution of more absorbent. This concentrated solution flows through piping back to the absorber, as the boiled refrigerant water vapor migrates up and out of the generator to the condenser.

****FINISH COMPONENTS AND CYCLE*****

****MENTION DIFFERENT TYPES OF CYCLES AND OPERATION*****

York and Trane have been leaders in research and development of triple-effect and hybrid absorption chillers. They intend to improve cooling efficiency by 30-50%.

Equipment Type & Size	Standard Efficiency		High Efficiency	
	COP	kW/ton	COP	kW/ton
Electric Screw, <150 tons	3.8	0.93	4.45	0.79
Electric Screw, =>150 to 300	4.2	0.84	4.90	0.72
Electric Centrifugal, >300	5.2	0.68	6.01	0.58
Single Effect Absorption			0.60	5.86
Double Effect Absorption			1.00	3.51

Reference: ASHRAE 90.1R "Minimum Efficiency" and "Efficiency as of Jan, 2000"

Figure 1 - Cooling Equipment Efficiencies [#]

2. Solar Energy

Photovoltaic energy referrers to the generation of electricity by converting light energy into electrical energy, and this process is normally done with the use of a solar cells (or solar panels). Sunlight hits the surface of the solar panel, which is made of out silicon in most cases, and makes the electrons that bond the silicon excited and therefore generate an electric current. This current generated power that can be immediately used or store for later use.

******INTRODUCE MORE ABOUT SOLAR ENERGY*************

- <u>Equation for Power</u>

$$\boldsymbol{P = V * I} \qquad \text{(Eq. 2-1)}$$

Unfortunately photovoltaic systems are not very efficient. With the current technology it can only convert up to 22 to 23 percent of the energy obtained into electricity. In order to have a more efficient design, it is very important that losses are minimized by using materials that generate resistance to the current. This would decrease the power losses. These losses can be estimated using Eq. 2-2.

- Equation for Power Losses

$$\boldsymbol{P_L = I * R} \qquad \text{(Eq. 2-2)}$$

*****TALK MORE ABOUT EFFICIENCY OF SOLAR-COMPARE SYSTEMS*****

Depending on the sun position and weather, solar panels are capable of generating certain amount of electricity. This is referred as the solar spectrum which measures the amount of power per meter square that can be produced in accordance with the conditions.

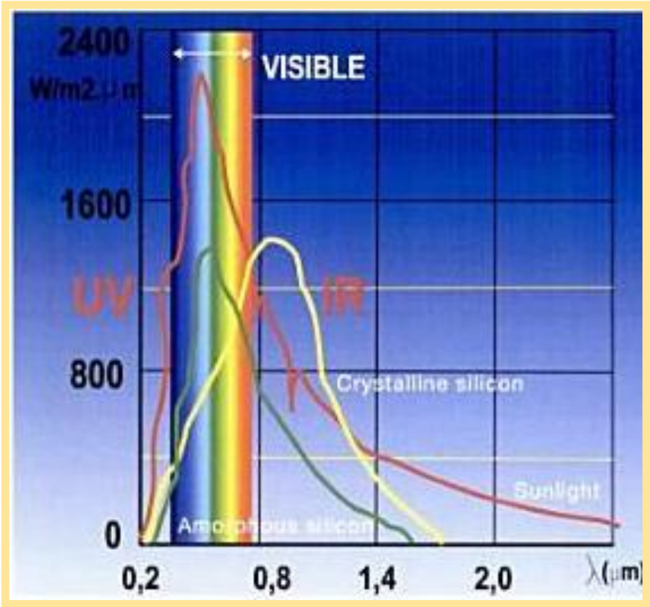

Figure 2 - Solar Spectrum Relative to PV Silicon Type [#]

(Source: Designing with Solar Power, page 204).

a. <u>*Solar Heating*</u>

The power for the Sterling engines is heat. The solar heat is harnessed using solar collectors. This heat is applied to water and with the heated water, the temperature difference applied to the Sterling engine, and the hot water pumped to the generator, drives the solar absorption chiller.

******DISCUSS SOLAR WATER HEATING BASICS************

~~The solar heater composed of an array of evacuated tubes that will collect the energy from the sunlight and transmit this energy to a fluid, in this case water, which will run inside the tubes. This water will be capable of reaching temperatures of around 400 °F with a pressure of 145 psi (1MPa). This heated water will then go into a coil that surrounds the hot cylinder of the sterling engine. All the remaining heat will be stored in a hot reservoir, and it will be available for use during night time.~~

**********INTRODUCE AND DISCUSS WAYS TO COLLECT SOLAR HEAT****

Evacuated tubes

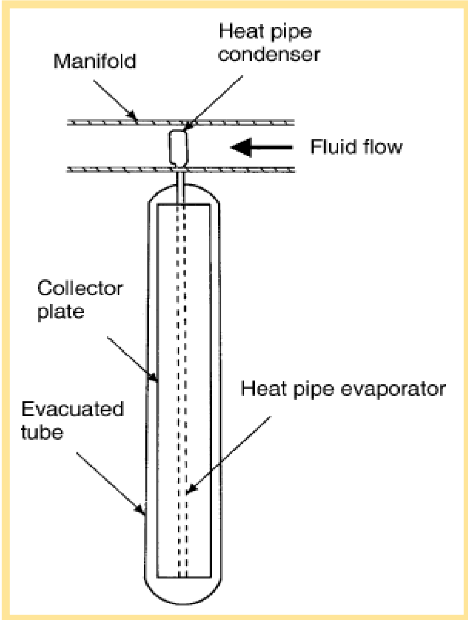

Figure 3 - Schematic Diagram of an Evacuated Tube Collector [#]

(Source: Progress in Energy and Combustion Science, page 246).

They are responsible for absorbing the energy generated by the sunlight, and they convert this energy into usable heat for different cycles. They are made out of two strong glass tubes that are joined together at the top and bottom. The space between the tubes is then evacuated to create a vacuum. This vacuum warranties that there is a minimum amount of heat lost though air and other fluids. Finally, inside the glass tubes goes the piping that carries the water of fluid that is intended to be heated. Since their invention in the 1980s, these tubes have demonstrated great efficiency and very lost maintenance cost.

Evacuated tubes are normally installed on the south side of a building where the greatest amount of heat can be absorbed. The heat generated by the evacuated tubes is directly related to its area and the proportionality factor q_p which varies with the position on Earth. ****GO MORE INTO DETAIL ON COLLECTING SOLAR HEAT – POSITION, AREA, AND FACTORS: CONVERSION, TRANSMISSION********

- Equation for Heat Generated by Evacuated Tubes

$$\boldsymbol{Q}^{*} = \boldsymbol{q_p} * \boldsymbol{A_t} \qquad \text{(Eq. 2-3)}$$

****THERE IS A TABLE AND FIGURES THAT SHOW EARTH/SUN POSITION AND COLLECTING SOLAR ENERGY****

Of the various forms to capture and harness the heat from the sun, there are pros and cons to each system. The solar heater collects the heat and applies it to a medium, such as water, air, or a metal. The PV (Photovoltaic) system collects the solar energy and converts it into electricity. In comparing these two systems, Table 3 outlines their similarities and differences.

Photovoltaic	**Solar Heater**
Reduce carbon foot print	Reduce carbon foot print
Takes around 3 years to recover carbon cost	Takes around 2 years to recover carbon cost
Projects are big and complex	They are simple and efficient
High-end have efficiency of 24%	Converts between 60 and 70% of sunlight to heat
Excess electricity can be store for later use	Waste occurs in heat lost due to cooling in storage
Cost between 15K and 25K for a house	They are cheaper to install

Table 3 – Comparison of PV and Solar Heater Systems

3. The Stirling Engine

The purpose of the stirling engine will be to generate mechanical energy to pump fluid throughout the system for cooling. The stirling engine is a device which converts heat energy into mechanical energy. Stirling engines can seem to be rather complex and tricky to understand but the key points will be discussed.

Firstly, all stirling engines have a sealed cylinder with one section hot and the other cold. The engine has a working gas within it, which is often air, helium or hydrogen, which is moved by a mechanism, from the hot side to the cold side. The air expands in the hot end, pushing the hot end piston inward while the cold end stays relatively in place. Next the cool piston draws in air from the hot end allowing the hot piston to move outward. The cool piston then compresses the gas as the cooling device removes heat from the air. Lastly the air is pushed/drawn into the hot end where it begins its cycle all over again.

The Stirling Cycle was derived from Gay-Lussac gas law, seen in Eq. 3-1:

$$\frac{(p_1V_1)}{T_1} = \frac{(p_2V_2)}{T_2} = nR \qquad \text{(Eq. 3-1)}$$

According to what is known as the Schmidt Theory, the performance of a stirling engine can be calculated by a P-V diagram. The volume of an engine can be easily calculated with use of its internal geometry. Once the volume, mass (of the working gas) and the temperature are determined, the pressure can be further determined using the following ideal gas law equation in Eq. 3-2.

$$pV = mRT \qquad \text{(Eq. 3-2)}$$

There are various types and configurations of the stirling engine but for this project, the displacer type stirling engine will be implemented. The space below the displacer piston is continuously heated by a heat source of hot water ranging in temperatures of 200 °F – 250 °F, while the space above the displacer piston is continuously cooled. The displacer piston moves the air from the hot side to the cold side. The following diagram, Fig. #4, illustrates the displacer type stirling engine.

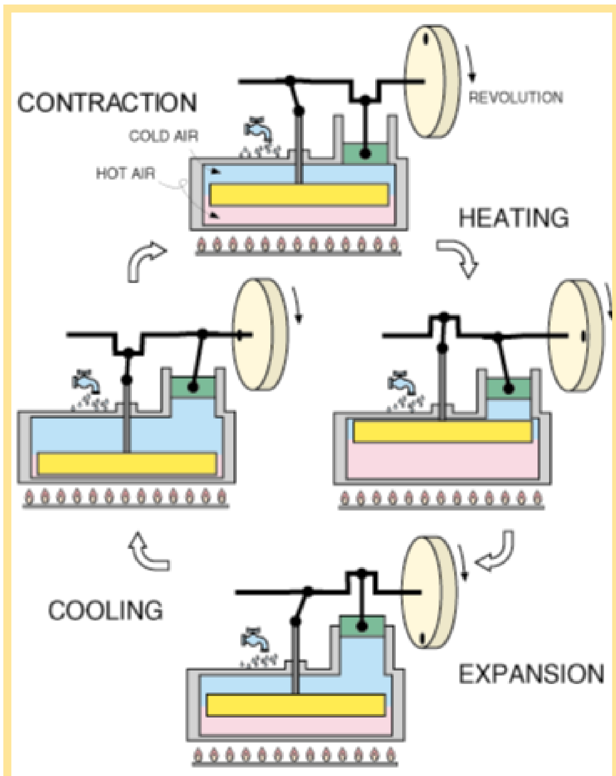

Figure 4 - Stirling Engine Displace Cycle

Engine pressure is changed by the movement of the displacer, where there is a temperature difference between upper displacer space and lower displacer space. Pressure increases when the displacer is at the upper end of the cylinder, i.e. most of the air is on the hot lower side, and vice-versa. Note that the displacer only moves the air back and forth from the hot side to the cold side, therefore the connecting rod to the displacer could be a string in this engine and it would still work. When the engine pressure reaches its peak due to the motion of the displacer, a power piston is pushed by the expanding gas adding energy to the crankshaft. This power piston should ideally be around 90 degrees out of phase with the displacer piston. This is commonly known as the 'phase angle'.

As aforementioned, there are different types of stirling engines, which all fall under either; Alpha, Beta or Gamma type configurations. The displacer type stirling engine falls under the Gamma type category. All stirling engines follow the same basic concept and their equations vary by few minor factors. Below illustrates a calculation model of a Gamma type stirling engine, in Fig #5.

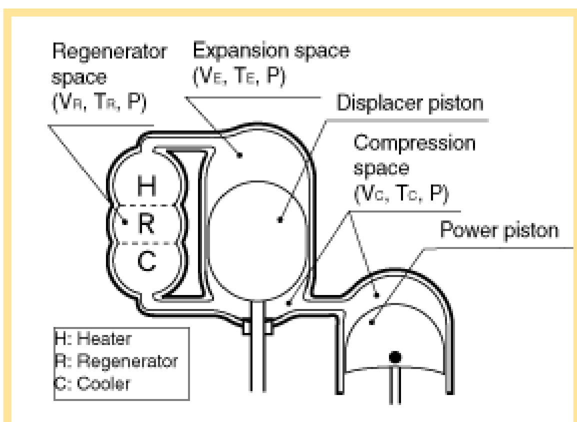

Figure 5 - Calculation Model of Gamma Type Sterling Engine

The necessary equations for determining pressure, as well as various other parameters including; the expansion momental volume (V_E), the compression momental volume (V_C), the swept volume of the displacer piston (V_{SE}), the swept volume of a power piston (V_{SE}) and the phase angle -dx, are as follows:

$$V_E = \frac{V_{SE}}{2}(1 - cosx) + V_{DE} \qquad \text{(Eq. 3-3)}$$

$$V_C = \frac{V_{SE}}{2}(1 - cosx) + \frac{V_{SC}}{2}\{1 - \cos(x - dx)\} + V_{DC} \qquad \text{(Eq. 3-4)}$$

Total Momental Volume: $\boldsymbol{V = V_E + V_R + V_C}$ (Eq. 3-5)

The engine pressure (P), based upon the mean pressure P_{mean}, the minimum pressure P_{min} and the maximum pressure P_{max}, are found in the equations as follows:

$$\boldsymbol{P = \frac{P_{mean}\sqrt{1-c^2}}{1-c*\cos(x-a)} = \frac{P_{min}(1+c)}{1-c*\cos(x-a)} = \frac{P_{max}(1-c)}{1-c*\cos(x-a)}} \qquad \text{(Eq. 3-6)}$$

Where;

$t = \frac{T_C}{T_E}$ (Eq. 3-7) , $v = \frac{V_{SC}}{V_{SE}}$ (Eq. 3-8)

$X_{DE} = \frac{V_{DE}}{V_{SE}}$ (Eq. 3-9) , $X_{DC} = \frac{V_{DC}}{V_{SE}}$ (Eq. 3-10) , $X_R = \frac{V_R}{V_{SE}}$ (Eq. 3-11)

$$a = \tan^{-1}\frac{vsindx}{t+cosdx+1} \qquad \text{(Eq. 3-12)}$$

$$S = t + 2tX_{DE} + \frac{4tV_R}{1+t} = v + 2X_{DC} + 1 \qquad \text{(Eq. 3-13)}$$

$$B = \sqrt{t^2 + 2(t-1)vcosdx + v^2 - 2t + 1} \qquad \text{(Eq. 3-14)}$$

$$c = \frac{B}{S} \qquad \text{(Eq. 3-15)}$$

The power or performance capabilities are often define by what is termed as the "Beale number", which is an empirically derived number named after Williams Beale (inventor of the free-piston stirling engine). He illustrated that the performance of many stirling engines tend to abide to a common equation:

$$P_0 = B_n \, P \, f \, V_E \tag{Eq. 3-16}$$

The figure below illustrates a graph plotted by measuring data from various stirling engines. The solid middle line is the norm path for most stirling engines, while both the upper and lower lines denote high and low performing engines, respectively. The engine to be implemented for this project is estimated to lie somewhere between the lower line and the middle line, hence giving a Beale Number somewhere between 0.001-0.003.

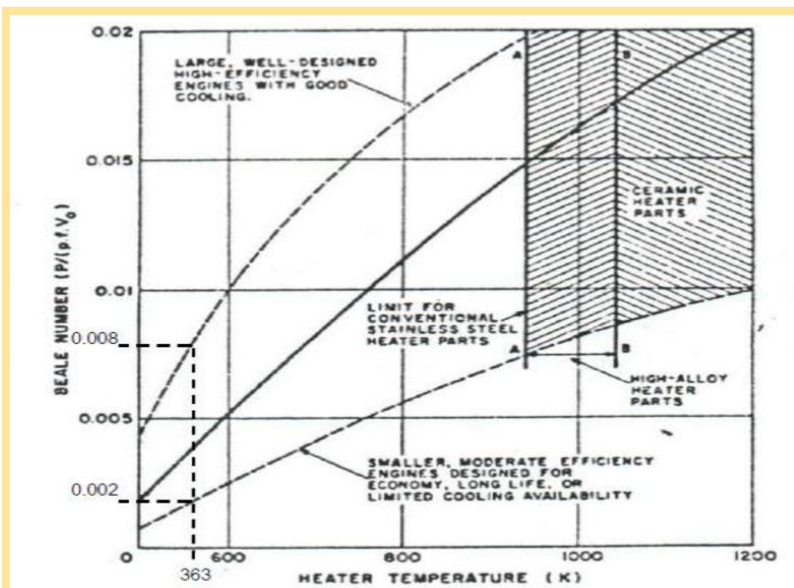

Figure 6 - Various Engines using Beale Number and Heater Temperature

Using what is known as the Volume Ratio or VR, can be further found to also determine the volume of the displacer chamber V_{CH}. The Volume Ratio can be found using the following equation:

$$V_{RA} = (1 + \frac{\triangleq T}{1100}) \qquad \text{(Eq. 3-17)}$$

Hence; $\boldsymbol{V_{CH}} = \frac{\boldsymbol{V_E}}{\boldsymbol{V_{RA} - 1}}$ (Eq. 3-18)

Also, in interest of an efficient design for the lowest temperature differential operating limits, the required displacer chamber length can be determined using the following equation:

$$L_{CH} = \frac{3V_{CH}}{\pi(\frac{d_{CH}}{2})^2} \qquad \text{(Eq. 3-19)}$$

where d_{CH} is the internal displacer chamber diameter.

2. Design

A. Conceptual Design

******LIST AND EXPLAIN ALL POSSIBLE DESIGNS OF PARTS**********

B. Proposed Design

Considering extensive research and including various parameters and limitations, the proposed design is listed below. The prototype may achieve the same goals, and require simpler applications. The portable, packaged, solar powered absorption chiller consists of

- Water-fired absorption chiller
    - Hot water is heat source to drive generator (200-250 ℉)
    - Lower pressure system – allows water to boil at lower pressures and temperatures
    - Single-effect – requires less temperature and components than double, triple effect or hybrid
    - Waste heat recovery to recirculate heat rejected to condenser water
    - Low temperature and pressure evap/absorber supplies 45 ℉ to chill water and send to space coils
- Evacuated Tube Solar Collectors
    - Heats water up to 250 ℉
    - Hot water storage in thermal storage tank
    - Hot water pump to send heat to generator and Sterling engine
    - Chosen to heat water most efficiently, instead of micro-troughs which produce or use steam
- Stirling Engine
    - Requires significant temperature difference to power (not controllable)
    - Have to modulate amount of water, NOT temperature
    - Powered continuously – uses cooler condenser water or cooling water to provide temperature difference.
- PV Panels
    - Can be used as supplementary/complimentary
    - Used to power controls for system
    - Can power motors and pumps if necessary
    - Provides DC voltage – no inverter needed, easy to use, control

3. Cost Analysis

A. System Cost Analysis

The installation costs of the absorption chiller has been the leading economic factor to restricting consumers to applying such a system. The additional requirement of a significant heat source tends to limit the application of a heat driven absorption chiller to process plants using turbines or furnaces. The lack of natural gas supplied to buildings and residences equivalent to electricity, hinders the use of direct-fired absorption cooling systems in these locations. The desire of government agencies and privately funded projects to expand the renewable energy market has increased the integration and implementation of solar energy. The loss of oil and fossil fuel consumption would lead to many countries and private sectors contending and rejecting the globalization of this technology. In order to consider and analyze the total cost of utilizing such a system, the long-term period of eventual payback and cost savings display the advantages of using this net-zero energy absorption chiller. Typical, average costs of employing this system are included in Table 4:

Component	Cost
Absorption Chiller (20 Ton)	$60,000
Evacuated Tube Solar Collectors (100)	$10,000
Thermal Storage Tanks (1000 gal)	$4,000
Solar Pumps (2)	$1,000
Sterling Engines (2)	$2,000
PV Panels (2 kW)	$2,000
Misc – Controls, Piping	$5,000
TOTAL	**$84,000**

Table 4 – Cost Analysis of Typical System

B. Prototype Budget

To build a prototype that explains and portrays the solar absorption cycle, it is necessary to use manufactured and off-the-shelf components. The absorption cycle does not require further engineering or designing. The primary goal of applying solar power and waste heat to drive this system can be completed using solar water heating, photovoltaic panels, thermal storage, and heat driven or solar powered pumps. In communicating with industry companies, and comparing product cost, efficiency, and capability, the combination of multiple components requires ultimate care, design, and understanding. To build a possible prototype, the unit is modeled on a much smaller scale than the industry-used actual system. The small capacity absorption chiller units are uncommon, considering their design. The typical absorption chiller is used in large applications with huge turbines, rather than small, economic, residential or light commercial applications. The availability then proves difficult in locating such a manufacturer with a unit of the required size, let alone for sale. In speaking with companies, the best choice includes a unit from a company named, Robur. They provided specifications and higher-education consideration to allow for a financially capable unit. In being the most expensive component, it becomes difficult to afford, but even more important in the build. The unit used is a 5-ton, direct-fired, single-stage absorption chiller. The cost was reduced from $9,800 to $7,000 for being a higher-education institution. The presented obstacles in obtaining funding and sources. Many companies were contacted to present ideas and inquire about products, specifications and pricing. Organizations and people offered invaluable advice and information to designing such a system. To build the prototype successfully, the absorption chiller needed to operate correctly, and the combination of the solar water heating system and Sterling engine technology needed to cooperate. In figuring the necessary heating and cooling loads, flow rates and energy quantities, the sizing of the solar water heating system could be made more exact. The absolute finalization could only come after testing and balancing the system, and operating. In order to plan for the possible solar heating system required, an over estimation can be applied to ensure quantity and quality necessary. The estimates of the prototype budget can be seen in Table 5.

Component	**Cost**
Robur Absorption Chiller (5 Ton)	$7,000
Solar Evacuated Tubes (10)	$2,000
Thermal Storage Tank and Piping	-
Sterling Engines	$1,000
PV Panels	$500
Solar Pumps	$500
CHW Fan Coil	$100
Misc – Piping/Controls/Parts	$1,400
TOTAL	**$12,500**

Table 5 – Prototype Budget

The solar water heating system contains the evacuated tube solar collectors, storage tank, solar heat piping, and the necessary pump. This system can be self-built using basic parts and components. The tank, tubes, and piping can be higher quality if purchased through a manufacturer. But the cost of building this solar water heating system can be cut in half by building it personally. There are directions and diagrams of users who have built and use this system successfully.

In addition, the typical HVAC components and parts can be considered in quantifying a budget, but changes when more exact parts and manufacturers are figured. The advantage of working in this industry, affords two of this team's members the ability to receive discounts and information more freely than average students. In this case, some of the necessary components may not have to be purchased, but in considering a budget, the cost of these components are calculated to estimate what is necessary.

4. Timeline

A. Project Planner Timeline

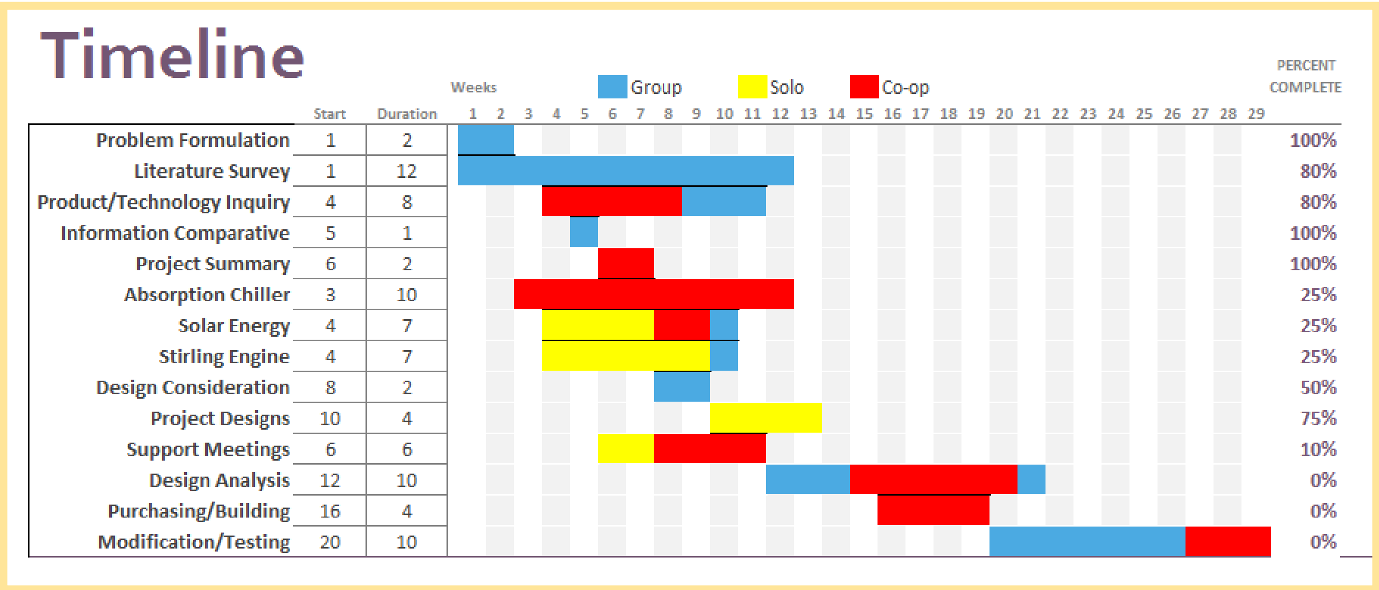

Figure 7 - Project Planner Timeline

B. Responsibility Distribution

The cooperation and combination of team members in any group function is critical in the success of their goals. In order to evenly distribute the necessary tasks, and complete goals in allotted times, group communication and cooperation is necessary. To utilize the knowledge and experience of each group member, their tasks were chosen accordingly. The literature review, research and designing is accomplished by all group members to allow for representation and consideration of all possible ideas. The compiling and combining of research and information is task specific, and achieved eventually by a sole group member to ensure consistency and fluidity in technical report writing. The total group contributed information and feedback to this process to allow for complete agreement. Communicating with companies can be promising in achieving and securing funding or valuable information to assist in the design and research process. The more companies contacted, the more possibilities to succeed, but not all group members could convey this information. In designing however, simulations and modelling needed input and time from every group member to theoretically analyze and represent the proposed design. The success of any group requires the addition of equal parts, and the delicate balance of what is necessary and what you want to do. The breakdown list of group member contributions is listed in Table 6.

Task	Juan A.	Adrian G.	Robert M.	Mikail W.
Research				
Absorption Chiller				
Solar Water Heating				
Stirling Engine				
Modelling				
Design				
Calculations				
Prototype				
Cost				
Report				

Table 6 – Participation Table

Color				
% Participation	**25%**	**50%**	**75%**	**100%**

5. Conclusion

A. Recommendations for Further Research

6. Appendix

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Appendix C: Equations and Calculations	
Appendix D: Data – Result Tables and Graphs	

Appendix A

References

Deo Prasad & Mark Snow; Designing with Solar Power: A Source book for Building Integrated Photovoltaics; Images Publishing (2005)

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Zeiler M, Sustainable Energy Supply Of An Austrian Winery based On Solar And Biomass Driven Micro CHCP, Austria's Institute of Energy Research, (Article) Published; Apr 2009.

*****NEED TO COMBINE ALL SOURCES TO ADD REFERENCES/FOOTNOTES TO BODY OF REPORT AND FIGURES*******************

Appendix B

Boundary Conditions and Assumptions

Appendix C

Equations and Calculations

Appendix D

Results – Tables and Graphs