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Feasibility of Solar Thermal Water Heating Systems on Case Western's Campus

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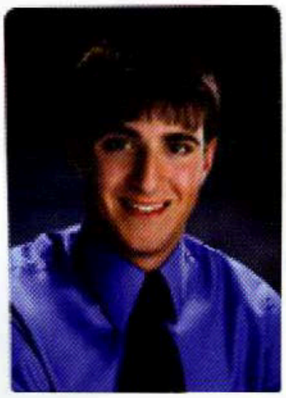
FEASIBILITY OF SOLAR THERMAL WATER HEATING SYSTEMS ON CASE WESTERN'S CAMPUS



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Steve is a fourth year undergraduate at Case majoring in Chemical Engineering and minoring in Environmental Studies. He is a member of the CWRU Cross Country and Track team. He is active in the Student Sustainability Council. He hopes that his research will encourage others to look at renewable energy.

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Matthew Moss is a senior studying Philosophy and Environmental Studies at CWRU. He is active in the Student Sustainability Council and the Case Crew Team. After graduation, he wishes to study environmental science and policy, and start a career managing and constructing policy wherever necessary. In his free time he enjoys the outdoors, particularly rowing on the Cuyahoga river.

ABSTRACT

Solar energy is an abundant and free resource that is available to all who have the space and capital to install the appropriate system to capture and convert the energy into a useable form. Solar thermal water heating systems are one way to use the thermal energy from sunlight to heat domestic water for a variety of uses. Current conventional systems that utilize coal or gas generate significant amounts of pollution that can be offset or even eliminated by this technology. Solar thermal systems can be expensive and complicated to install, and as such, require in depth analysis, significant preparation, and proper planning ensuring effective use of such technology. In order to determine the feasibility and cost-effectiveness of a solar thermal system on Case Western Reserve University's campus, we conducted an investigation into a variety of collectors and a detailed analysis of the potential performance of such systems using simulation software and first-hand accounts of professional installers and manufacturers. In addition, we also questioned companies with functioning solar thermal systems on the efficacy of their installed systems. We found that the technology was feasible for our location (Cleveland, OH), and the effectiveness (and return on investment) of solar thermal depended upon the average daily hot water demand and specific method of water heating in the desired building. Thus, we conclude that this technology is potentially beneficial in the long run pending hot water metering and specific site evaluations conducted by the appropriate professionals.

-Acknowledgments-

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Introduction

There are many ways to obtain this energy in the modern era, from more common resources such as coal and natural gas to less common resources such as the Sun. According to the National Renewable Energy Laboratory (NREL), Ohio receives enough solar energy capable of being harnessed by the appropriate technologies (NREL 2011). This is evidenced by the presence and success of photovoltaic systems currently in place not only on this campus (case Western) but several other locations (including the Great Lakes Science Center), and solar installation companies such as SunRock Solar, ARP Solar and Dovetail Solar, among others. Companies such as these mentioned service homes and businesses in the greater Cleveland area as well as many other parts of Ohio.

Specifically, college campuses use energy to heat water for showers, research labs, cooking, and cleaning. As it pertains to this campus, Case Western Reserve University, this energy comes from coal-fired steam. In an attempt to lessen the demand for coal-fired steam, solar thermal water heaters potentially offer a cost-effective, carbon-neutral way to obtain the energy necessary.

Barbara Snyder, President of Case Western Reserve University, recently signed the American College and University President's Climate Commitment to Sustainability as a part of the Association for the Advancement ofSustainability in Higher Education (AASHE). This made the University's goal to become Carbon Neutral by 2050. Utilizing these solar thermal technologies is one way to achieve our goal of carbon neutrality.

Experimental Background

Solar heating systems

The systems we explored consisted of three different types of panels: Flat plate, compound parabolic trough, and evacuated tubes. Respectively, these are the Heliodyne's GOBI flat plate, Enerworks' HeatSafe flat plate, Solargenix's Winston Series Compound Parabolic Concentrator, and Apricus' evacuated tube collector.

Heliodyne's GOBI flat plate collector (fig. 1) is a panel consisting of a surface with an absorptive coating attached to copper piping that runs through several channels along the underside of the surface. The panel is also carefully insulated to prevent heat loss to the environment. These panels perform fairly well in cold weather because the surface radiates enough heat to melt snow and ice, leaving the surface clear year round. All around, this is a versatile and efficient collector for most systems in most locations.

Figure 1: https://www.altestore.com/store/i/multimedia/images/Heliodyne_no_tank.jpg/x180/y210

Enerworks' HeatSafe (fig. 2) flat plate collector is very similar to the Heliodyne. It differs in coating type and a few safety measures, including a vent for hot air to prevent pressure build up. The Enerworks panel is slightly smaller than Heliodyne's largest panel (the 410), with roughly 32 square feet as opposed to roughly 40.

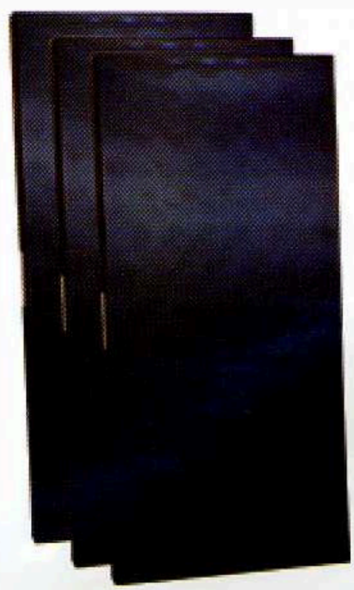

Figure2:http://www.enerworks.com/images/HeatSafeCollectors.png

Solargenix's Winston series compound parabolic concentrator (fig. 3) is similar to the GOBI in that ultimately it is a flat plate, however the internals are much different. The surface is a glass panel covering rows of parabolic mirrors that serve to reflect and concentrate light onto copper piping that carries the heat transfer fluid. As opposed to a flat black-body surface, these panels are generally more efficient at collecting light from a larger variety of angles than flat plate collectors.

Figure 3:http://www.solarconsultants.com/images/Solar-Genix_Winston_coll.jpg

Apricus makes an evacuated tube solar collector (fig. 4). These consist of a series of glass tubes that are evacuated to form a partial vacuum between the glass and a copper pipe that carries the heat transfer fluid. When pitched at an angle, the colder fluid pools at the bottom while warmer fluid rises up the pipe, setting up a convection current. These collectors are very efficient in that they emit very little heat to the environment, yet this can pose problems in cold climates due to the buildup of snow and ice. Another problem in inclement weather is that these tubes tend to be more fragile, resulting in damage from falling ice or hail. This can result in increased maintenance costs over the lifetime of the collector.

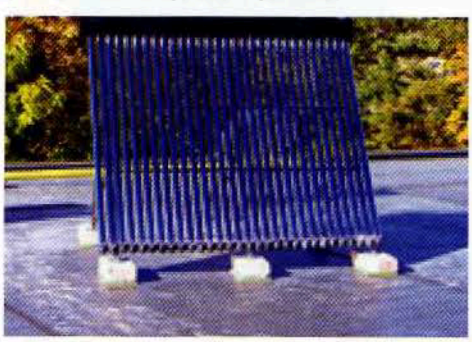

Figure 4: http://ecosolarct.com/images/gallery/Zanes-Cycle-Apricus-solar-h.jpg

Conventional heating system

The most common method of heating water in campus buildings is to use steam purchased and piped over from the Medical Center Company (MCCo). To understand how this works and to know the Btu potential and cost of a unit of steam (usually pounds and thousands of pounds, respectively), we questioned several professionals involved in the company, including the president Mike Heise. Our initial estimates showed a pound of steam carries 6.7 British thermal units (Btus). After acquiring more accurate data from the MCCo, it turns out that a pound of steam carries roughly 1,414 Btus. At 13 dollars for 1,000 pounds (1.3 cents a pound), the offsets of conventional heating costs from a solar system are minimal when compared to the costs of steam. This result is discussed more below and in our conclusion.

Procedure

In order to determine the feasibility of implementing a solar thermal system on Case's campus, we had to examine and compare several factors: location, system type, water use (daily average), operation temperatures, conventional fuel (steam in our case), and financial costs. The most important variable pertaining to the efficacy of a solar thermal water heating system is the daily average hot water use (the details of which will be addressed in the results section). It is challenging to organize and analyze all these factors and variables by hand, so to aid us in our investigation we made use of simulation software. RETScreen is a simulation program that enabled us to do this concisely. This program (originally developed mainly by the Canadian government, http://www.retscreen.net/ang/home.php) was developed to display the current costs of producing power or heating water for a particular location and demand and predict the energy output of a renewable energy system that could be implemented. In order to accurately predict a system's output, we had to input the correct user defined variables (those mentioned in the beginning of this paragraph).

Location itself is a very general term especially as it applies to this study. Pertaining to this case, location includes position on the planet, position relative to the sun, and the specific building. The location for our case was Cleveland, Ohio. Giving the location of the system allowed RETScreen to tap into its database for solar output data on different areas. Solar output data for such locations was aggregated with the aid of organizations such as NASA. Even within Cleveland, OH, there is variation in solar output. Various installers suggest a pitch angle of the present latitude + 5 degrees. The specific building we tested was Emerson gym, a part of the Veale Athletic Center. We chose this location because it is one of the most demanding buildings with regards to hot water is used extensively by students. We also decided to examine Kelvin Smith Library because it has an electric water heater, not a steam converter.

RETScreen also comes equipped with a database of various solar thermal panels, allowing for a diverse selection; specifically it provided all the necessary data in regards to the particular collectors we are investigating. Data for the specific panels is acquired from the manufacturers, who acquire it from independently certified installers of their panels. However, performance data does vary from location to location (and specific installation to installation), so there is potential room for error (this risk can be reduced by an on site evaluation from a specific installer).

For our daily hot water usage, we estimated the amount in gallons per day based on the occupancy rate and time of year. For example, during the summer, there are few sports teams that shower in the Veale Athletic Center regularly, but during the school year, there are teams that shower almost everyday. During winter break in December and January, the campus is closed, so there is negligible water demand. However, it is impossible to know precisely how much water is being consumed without a meter on the line. In order to obtain accurate data, water meters are essential. Without this crucial measurement, our best prediction is formed from discussion with facilities services staff whose experience with the current systems provided the best perspective on actual hot water use in Emerson. The value suggested was a maximum turnover of 3 times for the 1300-gallon tank, resulting in at most 3,900 gallons a day. To make the calculations easier (and understanding this educated guess), we decided to use 3,500 gallons as our daily average use. This is because on weekends during the summer and various campus holidays, Veale/Emerson is closed, and the daily hot water used is approximately zero.

Another variable that we inputted into RETScreen was the operating temperatures of the water. During the winter months, the inlet water comes in at around 40 degrees, while in the summer the water can come in as high as 70 degrees. These varying operating temperatures will affect the system because it will change the seasonal demand and therefore the British Thermal Units (Btus) necessary to reach the desired temperature.

The next step was to appropriately identify the conventional fuel source that is currently used to heat water in most places on campus. Specifically, we needed to know the cost and the Btu load of a unit of fuel, in this case steam. To acquire these numbers, we requested the average amount of thermal energy contained within a pound of coal from the MCCo, as well as how many pounds of steam this produces (~13,600 Btus and 9.18-9.93 lbs, respectively). RETScreen allows us to input our own type of fuel source, but it requires an accurate unit – Btus per lb of steam. With help from the MCCo, we calculated this to be about 1,414. This data is used to determine how much conventional fuel might be offset by the solar thermal system, and thus how much money could be saved.

Once this is complete, the next step is to recognize all of the costs (potential and actual) of a solar thermal system and how they compare to the operating costs of the current heating system. Included are initial installation costs (panel, mounting, piping, contractor fees), continual maintenance costs, and even opportunity costs. Fortunately, installers have a feel for this data, and their advice in combination with the calculations done by RETScreen makes acquiring this data fairly easy to do. For example, the cost of a ten panel Heliodyne system has been quoted at around sixty-eighty thousand dollars, excluding maintenance costs. The cost of the conventional system over time is calculated from the quantity of steam consumed multiplied by the cost, with maintenance costs already being known.

Once the desired manufacturer, type, and specifications of the solar thermal system is inputted into the program, RETScreen calculates the estimated number of panels the will be necessary. From our discussions with installers and solar thermal experts (more on that below), having a range of 50-80% of annual hot water demand coming from solar thermal is the optimal range in terms of payback. The payback period, otherwise known as a Return On Investment (ROI), is how long it takes for the savings from the system (the costs offset from the conventional heating system) to break even with the cost of the system. This is the most important factor to determine the economic feasibility. The shorter the payback period is the more appealing the project will be to University administrators.

Expert Opinions

In order to make sure our understanding of a solar thermal system and the accuracy of our estimations, so we scheduled meetings with professionals in the field of energy management, specifically solar thermal installation. Professionals included administrators of the MCCo, workers at installers/manufacturers and town/city hall officials. Through discussions and interviews, we were able to grasp a better understanding of the benefits of having first hand experience in designing a optimally sized system. The evident conclusion from many sources was that site analysis is imperative to determine the design considerations of a solar thermal system. Our research and analysis on buildings of Case Western Reserve University's campus were so site specific that a building's end result would vary from not receiving any short-term payback to receiving under a year payback. This led us to recognize how important having a site evaluation from a certified installer is to providing the maximum amount of solar thermal energy with the lowest ROI.

Results

Before going into the results of our research, it is important to note the key variable in determining the size of a system, and thus the costs and ROI is the average daily hot water use. This value is, in other words, the amount of water (in U.S. gallons) consumed a day averaged over the course of a year (365 days). This number reflects the demand on a system on any given day, on average. In order to ensure that a system is appropriately sized (neither too small or too large), this value should be known as accurately as possible. A system that is too small will not provide enough energy to supplement the load on a conventional heater enough to warrant the initial costs. A system that is too large is basically wasting dollars on installation that could be utilized elsewhere. The executive director of the Northeast Ohio Advanced Energy District, Athan Barkoukis, provided us with information on a city fire station project. With only a month of meter data, a system was installed that anticipated at least 50% of the demand. After six months, the system was found to only supply 20% of the demand. Taking into account sinks, showers, and laundry machines, a lack of meter data warrants a safe, educated overestimate to determine the capability of a system on Emerson gym.

The best way to measure this variable is to install a meter in the hot water line and record the data over the course of a year. Currently Case lacks flow meters on many if not all of the hot water lines in individual buildings on campus, especially in our target building, Emerson. It would be foolish to attempt to install a system based on rough estimates, because again one would have to guess the size. An investment of around 2,500 dollars in a water meter can provide valuable information pertaining to a system's capability. However, a lack of data in this area does not preclude a system or an investigation into the overall feasibility of a system on campus.

Before deciding whether a system should be installed on campus, a professional should be consulted and brought in to examine the site. The benefits of this are the experienced opinion afforded by the professional and a clearer understanding/assessment of the cost of installing a system such as piping, heat exchanger placement and solar capacity. The following tables (page 9) show the results of an attempt to overestimate the demand in Emerson to see if, even at a level that is likely to be higher than the average daily use, a system is cost effective or at least feasible given the available roof space and quoted installation costs.

For our system, RETScreen provided us with an estimate of the amount of Btus from the systems that we potentially would install, as well as crucial financial data. On the next page is a table listing the important data from our simulations. Factored into the ROI is a grant from Green Energy Ohio solar thermal rebate program of a maximum of 2,400 dollars. As a school, Case is eligible for this rebate. Solar fraction is the fraction of the water demand carried by the solar system, and outputs and costs are over the course of a year (note: assuming a daily average use of 3500 gallons. Again these are rough estimates).

As the data shows, the ROI exceeds a system lifespan of 25 years. At 1.3 cents a pound of steam (first mentioned earlier) and thus 1.3 cents for 1,414 Btus, the cost per Btu of solar greatly exceeds the cost of the current steam heating system. The MCCo has told us that the cost of steam has the potential to rise 20% in 5 years, and perhaps even higher in subsequent years. This could mean that solar thermal is more cost-effective as the price if steam rivals the cost of the technology.

Emerson	Solargenix	EnerWorks	Heliodyne	Apricus
# Of Collectors	175	70	60	90
Area (ft²)	4,220	2,164.4	2,421.8	2,796
Btu Output	324.1 million	281.5 million	334.5 million	274.3 million
Solar Fraction	58%	50%	60%	50%
Total weight	21,936.25 lbs	9,240 lbs	9,783	16,816.2
Weight/ft²	5.2 lbs	4.27 lbs	4.04 lbs	4.5 lbs
Cost ($)	350,000	450,000	500,000	700,000
Steam Savings ($ per year)	3,725	3,235	3,844	3,152
ROI (years)	93.9	140.5	131.3	223.5

Results for Emerson Gym Analysis

Steam, however, is not the only heat source for water on this campus. Some buildings use electric water heaters because they are not hooked up to the campus steam system, or their demand is too low to require it. Kelvin Smith Library is one such example. To see how the technologies compare, we decided to run some simulations on KSL as well.

We were able to calculate an offset from electric heating because the carbon production of electric power is more easily obtained. As the data shows, the payback periods for systems supplementing an electric water heater are much more reasonable. This is because we pay more per unit of energy for electricity than we do for steam.

KSL	Solargenix	EnerWorks	Heliodyne	Apricus
# Of Collectors	8	4	3	5
Area (ft²)	192.8	123.8	120.9	155.3
Btu Output	15.4 million	14.9 million	16 million	14.6 million
Solar Fraction	59%	62%	66%	60%
Total weight	1,002.8 lbs	528 lbs	489.15 lbs	934.2
Weight/ft²	5.2 lbs	4.26 lbs	4.05 lbs	6.02 lbs
Cost ($)	8,000	8,000	8,000	8,000
MWh savings ($ per year)	486	460	499	454
ROI (years)	11.5	11.6	11.2	12.3
CO_2 offset (tons)	1.1	1.2	1.15	1

Table 2: Results for Kelvin Smith Library Analysis

Conclusion

Considering the range of data results in the table above, we would recommend that the university install meters as soon as possible to start obtaining accurate data on daily hot water usage for high demand buildings. In addition to metering, a site evaluation should be conducted by professional installers that are certified by the Solar Rating and Certification Corporation (SRCC), the North American Board of Certified Energy Practitioners (NABCEP), or the Interstate Renewable Energy Council (IREC) which are the certifications that we found to be correlated with the highest quality installations. As far as our simulated estimates are concerned, it appears to be the case that solar thermal is not a cost-effective way to ultimately save money on conventional heating costs and to reduce the carbon footprint of our University as a whole given how cheap steam is for us. However, the cost of steam is expected to rise; at the same time, the cost of solar thermal technology could potentially decrease in the same amount of time. Furthermore, not all buildings heat their domestic water with steam. In buildings that use gas or electric heaters, solar thermal could still be a cost-effective replacement or supplement. With more data, consultation, and further scrutiny, a system may be beneficial on buildings that use electricity or gas to heat water.

REFERENCES

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