“A BENEFIT AND COST ANALYSIS OF A GROUND TO AIR HEAT TRANSFER SYSTEM (GAHT®)”

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ABSTRACT

A media res BCA report was conducted on a Ground to Air Heat Transfer System (GAHT®) currently being Constructed by Appalachian State University. The GAHT® system was purchased from Ceres Greenhouse Solutions and was found to be identical to Closed Loop Earth to Air Heat Transfer Systems (EAHTS) in the literature. EAHTS utilize the soil's temperature beneath or around a structure to heat or cool an interior space by pumping air in underground tunnels or pipes buried underground. EAHTS were found to have higher installation costs yet lower operational costs than the other heating alternatives. No study has been done to the knowledge of the author that investigated the installation of an EAHTS from a BCA perspective and that here was little information available to prospective consumers about the profitability of an investment in EAHTS technology. This BCA focused solely on the heating ability of the GAHT® system. The study concluded that net benefits of the GAHT are generally positive, but this result is dependent on many variables. When assuming a 0% discount rate, Net Benefits of the GAHT® system are $6,571.20 with a payback period of 12.3 years and when assuming a 7% discount rate Net Benefits were $-1,434.33 with no payback period within the 20 year time horizon of the study. The study also found a wide variation in these calculations based on the assumed inputs, ranging from a payback period of 39.34 to 7.27 years, and a net benefit of $(-)5,138.00 to $18,280.80. The BCA report created information that prospective consumers can use while considering investments in EAHTS technology. Future areas of research include a deeper investigation in the cooling abilities of the GAHT® system.

Introduction

In the past decade awareness of how commercial greenhouse operations negatively affect the environment, such as high energy demand or excess use of water has led to a growth in the utilization of passive solar design elements in commercial greenhouses in efforts to maintain more sustainable practices. (Teitel, 2011) M.I. Santamousis from the University of Athens elaborates on this ideal, claiming there has been a rise in global applications of passive solar greenhouse technology; citing 60,000 passive solar units in Europe alone in the past two decades (Santamouris et. al, 1994). Passive solar design describes how a building has been intentionally designed to harness the radiation from the sun to heat or cool the interior space (Balcomb, 1992). This trend in the rising use of passive solar greenhouses has led to increased research of different passive solar greenhouse designs, but also a rise in investigation of different heating sources for passive solar greenhouses when the sun does not supply enough energy (Pfafferott, 2003).

Passive Solar Greenhouses vary in performance and complexity. For the highly efficient, well insulated passive solar greenhouse, Earth to Air Heat Transfer Systems (EAHTS) have been an alternative method of heating that has grown in use with the growth of passive solar designs (Ozenger, 2011). EAHTS funnel air underground via an underground pipe construction. While underground the air either is cooled or heated by the surrounding soil. The air then escapes into an enclosed space, warming or cooling the space based on the ambient temperature of the air and soil (Bisoniya, 2015). This study performs a Benefit Cost Analysis (BCA) on a closed loop EAHTS called a Ground to Air Heat Transfer System® (GAHT**)** that is produced by Ceres Greenhouse Solutions **.** The objective is to inform possible consumers about the potential economic benefits that come with an EAHTS such as the GAHT®.

Interior Temperature & Relative Humidity

Maintaining a quality interior temperature in any greenhouses is ideal because temperature directly relates to the health and productivity of any crop in question. Specifically, the difference between day time temperatures and night time temperatures (DIF) in greenhouses has been directly correlated to crop development. DIF has direct effects on " internode length, plant height, leaf orientation, shoot orientation, lateral branching and petiole and flower stalk elongation in plants" (Myster et. a, 1993). Temperature obviously has a wide and influential effect on plant development, thus interior temperature control is a key aspect of a passive solar greenhouse's performance in relation to crop yield, and the type of heating system used also impacts results. Due to environmental concern and importance of interior temperature to crop growth, alternative heating sources that do not rely on fossil fuels have been investigated within the literature.

Humidity levels have a large and diverse impact on crop production with greenhouses. Körner and Challa found that relative high levels of humidity affect crops by causing fungal infections, calcium deficiencies and soft and dry leaves, as well as decrease crop growth and inhibit pollination; while low levels lead to plant water stress (2003). Each plant species best grows in a specific humidity level and it is imperative that each growers greenhouse climate operates at an adequate level to support crop production and not hinder it.

Brief History of EAHTS

EAHTS's utilize the soil's temperature beneath or around the structure to heat or cool an interior space by pumping air in underground tunnels or pipes buried underground (Ozenger, 2011). The technology/ingenuity of EAHTS systems is not very complex. Ancient Iranian architects used wind towers and underground tunnels to passively cool indoor spaces (Scott, 1965). This technology was slowly lost through the industrial revolution, but as the world has become more conscious of its energy usage, specifically in agriculture and construction, many researchers have investigated EAHTS as possible heating alternatives.

The logic behind this design is that at a depth of roughly 4 feet, soil temperatures are consistent and can be used to conductively heat or cool air traveling through underground pipes in order to heat or cool an interior space above (Goswami and Dhaliwal, 1985). Specifically, EAHTS function based on the difference between the ambient temperature of the outside air versus the temperature of the soil. In the summer, ambient air temperature is greater than the soil temperature. As the hotter air travels down into the pipes, the cooler soil cools the air before delivering it to the outlet. Vice versa, in the winter months the ambient air temperature is lower than the temperature of the soil, so air is heated up within the pipes before exiting at the outlet (Pereti et. al, 2013). Thus the earth becomes a natural heat sink to be utilized when needed. Typically, fans are used to circulate air into and out of the pipes.

As the growth in studies done on EAHTS occurred, so too did the types of systems. Sanner et. al reported in 2003 that there are two main types of EAHTS widely utilized, classified as open loop systems or closed loop systems (Sanner et. al, 2003). Open loop systems involve an intake location that is outside the construction where ambient air travels through the buried pipes before entering the conditioned space. Figure 1 displays an open loop system based off of Bordoloi (2018) et. al, illustration.

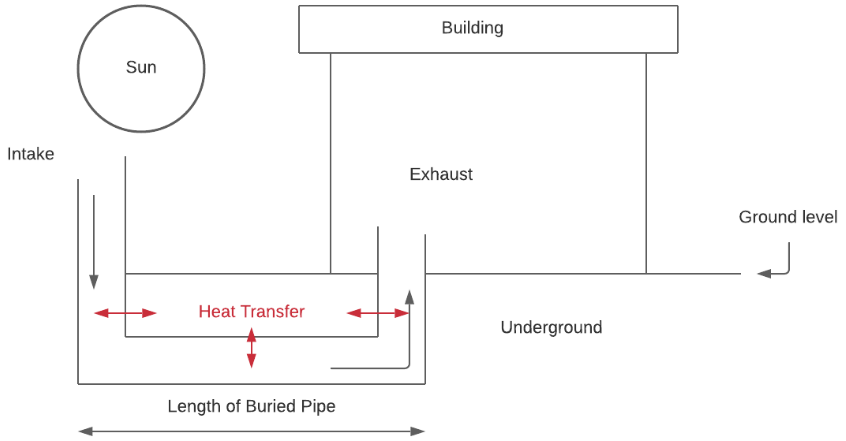

Figure 1. Open Loop EAHTS

Closed loop systems have intakes and outlets within the same interior space. The closed loop system is also called an earth coupled system. Advantages of the closed loop system over an open loop system are that it reduces humidity issues and can lead to a more direct control of interior ambient air temperatures (Bordoloi et. al, 2018). For this study closed loop systems will be investigated.

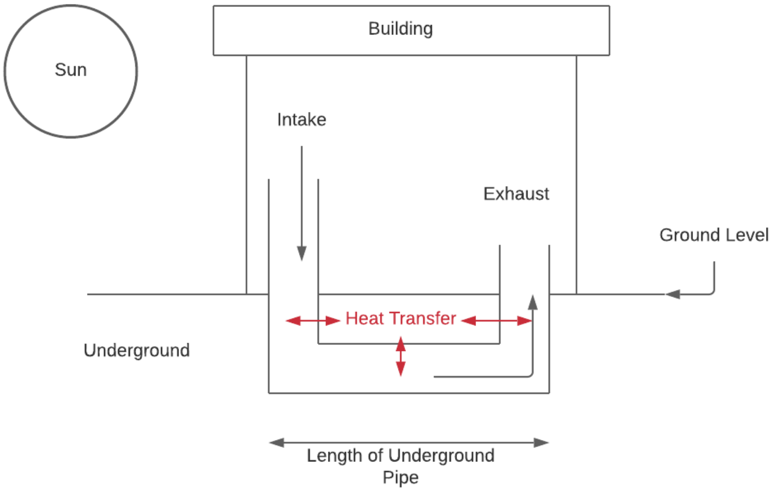

Figure 2. Closed Loop EAHTS

There have been many studies done on evaluating the effectiveness of EAHTS. Santamorius found that closed loop EAHTS performed effectively in heating and cooling spaces, specifically in the reduction of interior temperatures for a greenhouse during summer months and an increase of interior temperatures in winter months by a significant margin (Mihalakakou et. al, 1994). These results are affirmed by Uddin et. al in his study of an EAHTS's performance in ventilated rooms (2016). The system studied was able to bring extreme temperatures of 11 degrees Celsius or 34 degrees Celsius to typical temperatures comfortable for humans (2016). These results are repeated throughout the literature (Yusof et. al, 2018) (Bansal et. al, 2004) (Bansal et. al, 2010).

Additionally, much investigation has been done on how much energy EAHTS can provide. Researchers from Chongqing University in China used a computer modeling software and found that the use of a deeply buried EAHTS can produce up to 3000W of heating or cooling capacity within a single day, providing a maximum difference in heating or cooling by 7 degrees Celsius in comparison to outdoor temperature and interior temperature (Yang et. al, 2016). A group of researchers from Hong Kong Polytechnic University elaborates on these findings, showing how an EAHTS has a daily cooling capacity of 1.8kW and 3.1kW when modeling the performance based on experimental results from a southern China experimental laboratory (Wu et. al, 2007). This thermodynamic performance is heavily affected by its performance parameters, which are local climate conditions, configuration, depth, length and radial width of the pipes used, the type pipe used, the buried depth of the pipes and the thermal physical parameters of the surrounding soil (Mihalakakou et. al, 1996). Thus EAHTS are a viable option for space heating and cooling.

EAHTS are not just effective but economical as well. In a literature review done by Bordolio (et. al) in 2018, it was concluded that EAHTS consume significantly less energy to operate than other conventional heating systems (Bordolio et. al). Ozenger agrees with this point, finding that EAHTS save money by having less operational costs then other heating alternatives (Ozgener et. al, 2011). These energy savings are a huge incentive towards the use of EAHTS. Yet a study done by the Department of Energy Sciences and technology found that EAHTS are 20-40% more expensive in material cost and installation in comparison to ground to air heat pump systems. This is due to the machine and labor costs of installing the underground pipes beneath the structure (Philippacopoulos et. al, 2001). The lower operational cost of EAHTS is from lower energy demand, while the initial cost is larger due to the numerous inputs of materials and labor. Thus initial capital investment of EAHTS is high, but low operational costs allow the owner savings opportunities after the payback period due to savings on utility expenditures.

Need for BCA and Possible Intervention

Although there has been ample research conducted on EAHTS effectiveness and performance, no study has been done to the knowledge of the author that investigated the installation of an EAHTS from a BCA perspective. This means that no study has evaluated the economic benefits of implementing an EAHTS in comparison to the costs of materials, installation, and operation of the system. This study will address this gap in the body of knowledge by conducting a BCA for the GAHT® produced by Ceres Greenhouse Solutions.

The GAHT® is the exact same as the Closed Loop EAHTS cited above. It involves an air intake pipe located at a high elevation within the heated space, a fan blowing the air down into an array of underground pipes, and an outlet pipe which is lower in elevation within the interior space than the inlet pipe. Ceres Greenhouse Solutions offers many different GAHT® packages for a homeowner/business to install or have installed with professional help. These GAHT® packages include all piping, pipe connections, blue prints/description of installation, and fans used to circulate the air. The GAHT® system is advertised as a year-round climate battery that creates an energy efficient space by heating the space via heat transfer from the soil to the air passing through the pipes with very little electricity demand other than that used by the fan (Ceres, n.d.). This heat transfer is maximized due to the specified Ceres design, leading to much less dependency on fossil fuel-based heating for a Ceres greenhouse compared to a standard commercial greenhouse. The GAHT® system has been proven to be effective in both heating and cooling the space to which it is connected (Ceres, n.d.). This finding aligns with the literature cited above. The GAHT® system comes as an optional addition to any Ceres Greenhouse construction. An image of the GAHT® system seen below is from the Ceres Greenhouse website (Ceres, n.d.).

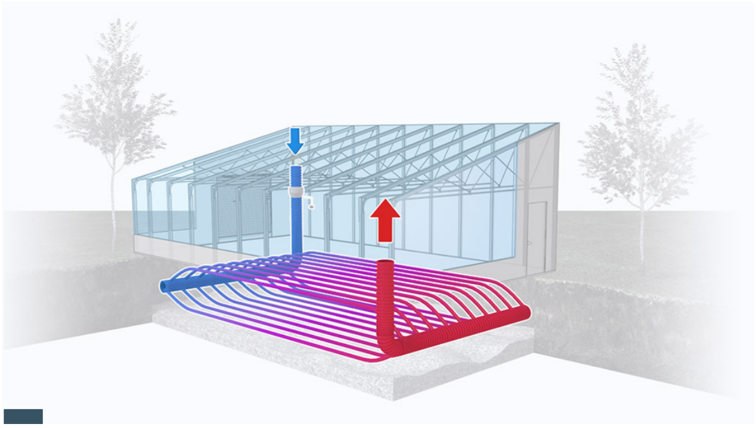

Figure 3. GAHT® rendering, https://ceresgs.com/environmental-controls/gaht/, April 16th, 2021

The goal of this media res BCA is to identify the possible economic benefits for EAHTS technology like the GAHT® system and compare them to costs. The research will be beneficial as it can be used by Ceres and other private companies who deal with EAHTS technology to analyze if this product truly performs as they may expect/advertise. Additionally, the results of this BCA can be used by prospective consumers of EAHTS or specifically the GAHT® system for informational purposes in evaluating whether or not to invest in the technology.

Baseline and Proposed Intervention

Qualitative Description of the Baseline Scenario

The Ceres Greenhouse that will be studied for this research is currently under construction at Appalachian State University's Sustainable Development and Research Farm in Ashe County, NC. The University plans to use this greenhouse for educational and research purposes. The Greenhouse itself is 1,475 sq ft with an average height of 12.86ft. Thus the total volume of the greenhouse is 18,979 cubic feet. For this BCA report the baseline is that the Greenhouse will not have a GAHT® system installed, and instead will rely solely on a natural gas interior space heating system. This natural gas heater will be installed in both the baseline and proposed intervention scenarios, but for the latter it will only act as a supplement for the GAHT system when necessary.

Qualitative Description of the Proposed Intervention

The proposed intervention will be to install a GAHT® system during the construction of the Ceres Greenhouse that Appalachian State University is currently building. The GAHT®

system will be installed after the creation of the structure's foundation walls. The GAHT® system will be at roughly two, three, and four feet below the ground level of the structure and will actually contain two separate closed loop systems, meaning there will be two intakes and two outputs that penetrate the floor assembly of the greenhouse, four penetrations total. The GAHT® will be made up of 18” and 4” HDPE pipe. The 18” pipe will be used for the intake and exhaust as well as the intake and exhaust manifolds for each GAHT® system, while the 4” pipe will connect each intake and output manifold. The manifolds are 18’ 9” long. The connecting 4” pipes will be roughly 24’ 6” long. Each system has a total of 12 connecting pipes, meaning there will be 12 pipes connected to both the intake and output manifolds per system. These connecting tubes are spaced 18 inches apart horizontally and broken into three vertical layers that are 12 inches apart. This spacing is to ensure the amount of conducted heat that moves from the air in the pipes to the soil or vice versa is not affected by the heat transfer from another pipe, thus maximizing the heating or cooling abilities of the GAHT® system. In order to circulate the air through the underground piping, two FanTech Model KD 18 fans will be connected to the intake pipes (FanTech, n.d.). Figure 4 illustrates the configuration of the two GAHT® systems underneath the floor assembly of the Greenhouse and shows the locations of the intake and output pipes.

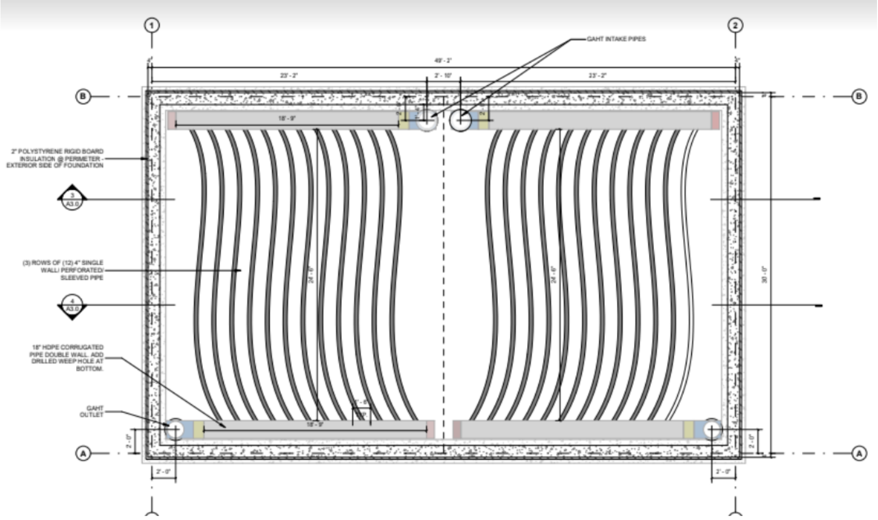

Figure 4. Architectural rendering of Ceres GAHT® systems. (J. Ferrell, Personal Communication, February 21st, 2020)

BCA Standing and Time Period

Determining who has standing in a BCA simply means determining whose benefits and costs should be accounted for. Appalachian State University will have standing as in theory they are the “consumer” of the Ceres Greenhouse and the investors in the GAHT® system. Thus the BCA report will be informative to other potential consumers as it will analyze whether the decision to install the GAHT® is economically justifiable. As Appalachian State University’s

Ceres Greenhouse will be utilized for educational purposes both Appalachian State faculty and students are populations that will interact with the GAHT® system as they both have the opportunity to learn more about energy efficient space heating via the GAHT® system in the future.

A key assumption of this report is that there will be a dynamic timeline over a 20-year period. This 20-year time horizon is based on the assumption that the FanTech Model KD 18 fans can operate for up to 20 years. This assumption is due to the researcher's best professional judgement. The other parts of the GAHT® system require very little maintenance, and can last for a very long time underground because of the durability of the HDPE piping.

Costs

In identifying all costs associated with the GAHT® system, there can be a separation between installation costs and operational costs incurred by the University.

Installation Costs

Regarding installation costs, first the costs of all materials were calculated. All pipes needed were bought from Cranberry Wood Works, a construction supply store in Fleetwood, NC. As listed in Table 1, the materials bought included 120 20ft 18" wide pipe sections used for the manifolds, 4 18" 90 degree couplings, 4 18" plastic caps, 8 18" plastic bands, and 17 4" wide 100ft long sections of sock piping. The total costs for all piping material was S3068.88. With an additional sales tax of $214.83 the total cost for the piping material was $3,283.70. The other material used was the two FanTech Model KD 18 fans. Each GAHT system has one fan, so two fans were bought for the project. Each fan retailed at $1,822 (FanTech, n.d.) for a combined investment of $3,644.00. Total cost of materials with sales tax was $6927.70.

Table 1. Installation Material Costs

Qty	Description	Cost Per Unit ($)	Itemized Cost($)
120	18" x 20' HDPE - Double Wall	8.50	1,020.00
4	18" - 90 Degree HDPE	123.76	495.04
4	18" Plastic cap.	45.00	180.00
8	18" Plastic Band	18.73	149.84
17	4" x 100 ft SOCK PIPE	72.00	1,224.00
2	FanTech Model KD 18 Fans	1,822.00	3,644.00
		Total Cost	6,927.70

In addition to material costs are the costs of installing the system at the construction site. The University had to first rent two different pieces of heavy machinery from the Jefferson Rent All in Jefferson, NC. These two pieces of equipment were an IHI CL35 Tracked Loader and a 303.5E2 CR Mini Excavator. These two pieces of equipment were used to dig the hole needed within the foundation, move the dirt to a storing area, and then put the dirt back on top of the fully constructed GAHT® system and level the interior area back to grade. Each piece of equipment was rented for two days. The tracked loader's total rental cost was $540.00 and the Mini Excavators total cost was $550.00. The fuel to run each piece of equipment was also incurred by the University. On the first day the total fuel cost was $84.60 and the second day was $69.30. The total cost for the rented machinery was $1,352.90 (K. Cook personal communication, March 23rd, 2019).

The University also had to pay the workers who operated these machines for a total of 16 hours of labor each. Both of these workers were employees at the University's physical plant. The total amount of money paid to these employees to operate the machinery was $860.00.

For the lower-skilled labor involved, such as building the GAHT® system by connecting the HDPE pipes and moving any excess dirt the machinists missed was done by Appalachian State University faculty and students. This labor came at no direct cost to the University itself as all were there volunteering to help with the installation. The author would like to note this could be an indirect cost, however, because there is an opportunity cost associated with university-employed faculty committing time to the installation of the GAHT® system. However, because this study is meant to be informative to Ceres Greenhouse Solutions as a private company and consumers interested in adopting EAHTS technology such as a GAHT® system; this cost which was not directly applicable to the University was still quantified and monetized to make the total cost estimates more applicable to the private sector. The cost of 11.70 per hour was assumed based on ZipRecruiters estimation of entry level excavation and grading workers' wages in western NC (Ziprecruiter, n.d.). There were roughly seven combined students and faculty working on the GAHT® installation from 8am-4pm for two days, implying a total number of 16 labor hours per person. The cost of labor is thus $1,310.40 and was calculated using the equation below. All labor, equipment, rentals, and material costs associated with the installation of the GAHT system are summarized in Table 2.

$$Equation\ 1\text{: } \$11.70\ per\ hour \times \#\ of\ \ workers\ \times \#\ of\ hours\ per\ day\ \times\ 2\text{days}$$

Table 2. Summary of Installation Costs (Present Value, 2020$, USD)	
Installation Costs	Policy Intervention
Equipment Rental	1,352.90
Equipment Operators Labor	860.00

Installation Material Cost	6,927.70
Excavation and Grading Labor	1,310.40
Total Costs	10,451.00

Operational Costs

The only operational cost of the GAHT® system is the electricity consumption of the two fans. This operational cost was calculated using Climate Battery Version 2.0, a Climate Battery calculator created by Eco Systems Design Inc. Climate Battery Version 2.0 is an Excel spreadsheet that focuses on thermodynamics of EAHTS and is offered for free to the public by Eco Systems Design Inc (Eco, n.d.). First the regional price of electricity was determined by contacting the local power company as $0.103 per kwh (Blue Ridge Energy, personal communication Feb. 19th, 2021). This was then combined with the known electrical specs (FanTech, n.d.) of the FanTech Model KD 18 fans and the assumed Daily Hours of operation of 6 to get an annual operating cost of $319.82 for both fans.

$$Equation\ 2: 115V \times 12.5A = 1,437.5W$$

$$Equation\ 3: 1,437.5W \times 6\text{hr per day} \times 2\text{ fans} = 17.25\text{ kWh per day}$$

$$Equation\ 4: 17.25kWh \times 180\ days \times \$0.103\ per = 319.82$$

Table 3. Summary of Annual Costs (2020$, USD)	
Operational Costs	
Annual Electricity Demand of Fans	319.82
Total Operational Costs	319.82

Benefits

The primary purpose of the GAHT® system is to use less fossil fuel-based energy sources to heat the interior space of the Greenhouse. Thus, the main benefit monetized in this report was propane heating costs avoided due to the GAHT® system. Propane based interior air heating is the only other option for interior space heating for the specific Ceres Greenhouse studied in this report.

This avoided propane cost was quantified using the Climate Battery Version 2.0. First the local cost of a Therm (100,000 BTUs) was identified as $1.47 (Thompson Gas personal communication, Jan. 20th, 2021). Then the volume of soil underneath the floor assembly of the greenhouse within the foundation walls was identified.

$$Equation\ 5:\ 4ft\ depth\ \times\ 1,475.1\ sq\ ft\ =\ 5,900.4\ Cft$$

It was the Climate Battery 2.0 assumption that each Cft of soil could hold 75 Btus of heat when the soil increased 1 degree fahrenheit in temperature as there is 75lbs per cubic foot of soil.

$$Equation\ 6:\ 5,900.4CFt\ \times\ 75Btu\ =\ 442,530\ Btu\ stored$$

442,530 Btus represents the total amount of heat the soil would store if it was raised 1 degree fahrenheit. This value was converted into therms to make 4.42 therms as 1 therm = 100,000Btus.

$$Equation\ 7: 4.42\ Therms\ \times\ \$1.47\ per\ Therm\ =\ \$6.51$$

$6.51 represents the total amount of money needed per day to heat the soil with propane underneath the Greenhouse so that its temperature would increase by one degree Fahrenheit. Thus it also represents the amount of money saved when the soil increases in temperature naturally by 1 degree Fahreniheit. The logic behind this is that all the heat stored in the soil would transfer via conduction to the air moving in the underground pipes and would be released back into the Ceres Greenhouse, thus providing natural heating for the space. Due to the local climate of the construction site it was estimated that there would be 180 days in which the soil would increase by 1 degree in temperature. So, $6.51 times 180 equals $1,170.93 of propane costs avoided annually.

Ancillary Environmental Benefits

The propane that is not used yields another benefit to society more broadly. Propane is a fossil fuel which upon combustion emits Greenhouse Gases, which contribute to the global crisis of Climate Change. Using the GAHT® system means that roughly 4.42 therms of propane would be saved as the GAHT® system provided the heat, instead of the installed propane heater. This amounts to 4.8 gallons of propane saved each year. As each gallon of propane when combusted emits 12.7 pounds of carbon dioxide (EIA) there is 61.34 pounds of carbon dioxide emissions avoided annually. When this result is extrapolated over the 20-year time horizon of this analysis, a total of 1,226.8 pounds of CO2 emissions is avoided. That is 0.6134 of a ton. The Environmental Defense Fund (2020) estimated the social cost of carbon to be $50/ton. This estimated social cost includes marginal reductions in mortality and morbidity risks, and environmental and property damage. This leads to a social benefit of $1.53 per year, or $30.67 for the assumed 20-year life span of the GAHT® system. Although this benefit is small, this ancillary benefit could become substantial when accounting for the cumulative effect over all EAHTS systems that are or will be implemented.

Non-Monetized Benefits

Of the non-monetized benefits in this study there are two that will be addressed. The first is the benefits of being seen as Environmentally friendly firm. As the issues of climate change becomes more prevalent, more consumers wish to spend their money with firms that are more conscious of their environmental impact. When adopting the GAHT® system, the University as an institution becomes more environmentally friendly in the eyes of the public. This aligns with the Universities sustainability goal to be carbon neutral by 2050 (Appalachian, n.d.). This would have the same impact on any public or private firm that wished to adopt an EAHTS such as the Ceres GAHT® and could lead to greater demand for products and better public relations.

The second major benefit for implementing the GAHT® system is the cooling abilities it offers the consumer as a way to cool an interior space without using a significant amount of energy when temperatures are very high for crops. The maximum benefit is seen when there is no need for more heat added to the space, but rather ventilation. As the GAHT® system is providing cooler air from the exhaust pipe, this acts in the same way as ventilation does. Dr. Jeremy Ferrell from Appalachian State University has investigated the cooling abilities of the Ceres GAHT® system. Given different temperature inputs and outputs of a GAHT® system that is currently operational within a Ceres Greenhouse in Boulder, Colorado, as well as the ambient interior temperature, Ferrell was able to illustrate the effects of the GAHT® system in the line graph below. This data stretched from March 14th, 2019 to March 18th, 2019. The data was measured using temperature sensors at the intake and output pipes and a sensor for the ambient exterior space. As seen in the illustration, the outlet pipe shows a dramatically decreased air temperature, averaging a roughly 10 degree difference during the warmest times of the day. The greatest benefit for consumers here is that the GAHT system provides a cost effective way to cool the interior space, and this added cooling amongst high interior temperatures could lead to a greater crop yield and avoidance of wilting crops (J. Ferrell personal communication, March 20th 2021).

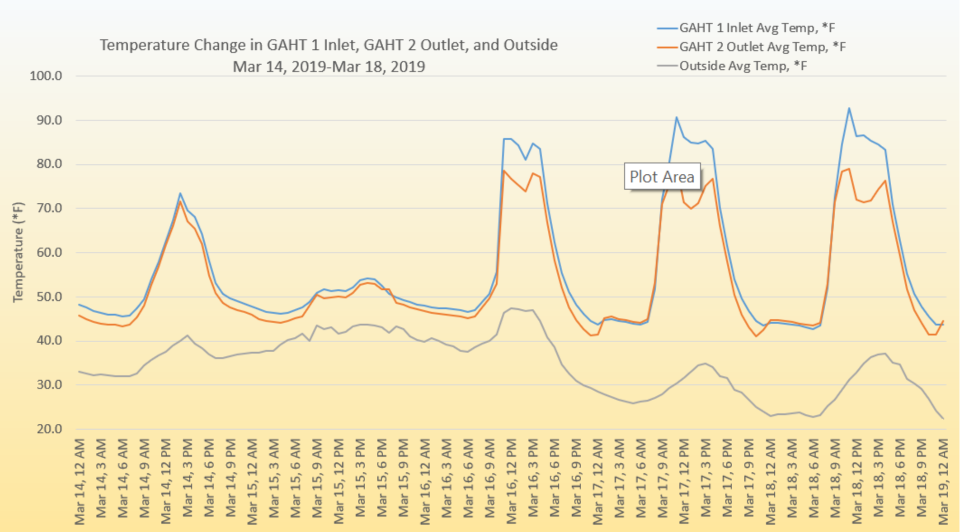

Figure 5. Boulder Colorado Ceres GAHT® Temperatures

Table 4. Summary of Annual Benefits (2020$, USD)	
Benefits	Policy Intervention
Monetized Benefits	
Avoided Propane Heating Costs	1,170.93
Non-Monetized Benefits	
Environmentally Friendly PR	Not Estimated
GAHT® Cooling Greenhouse	Not Estimated
Total Benefits	1,170.93+B*

* B denotes all Non-monetized Benefits.

Table 5. Summary of Annual Ancillary Benefits (2020$, USD)	
Benefits	Policy Intervention
Avoided Co2 Emissions	1.53
Total Ancillary Benefits	1.53

Net Benefits

For this report, Net Benefits were measured annually for each year the GAHT® will operate. The annual benefits per year of operation is estimated to be $1,170.93. The annual cost per year of operation was $319.82. Using the equation below the estimated operational net benefit per year is $851.11.

If this annual operational net benefit is extrapolated over the 20-year time period of the study, then the operational net benefit over time would be $23,418.60. If the initial installation costs and then operating cost per year are subtracted from this figure then the Net Benefit of the GAHT® system is $6,571.20.

$$Equation\ 8: Net\ benefit\ =\ Total\ Benefits\ -\ Total\ Costs$$

As with the nature of many types of sustainable technology systems initial costs are large and benefits are strung out over a period of time. This time period where benefits build up until they finally outweigh initial costs is called the payback period. The payback period was identified for this GAHT® system using Equation 9 was found to be 12.24 years after beginning the operation of the GAHT® system assuming a 0% discount rate.

$$Equation\ 9: Installation\ cost\ /\ Annual\ Net\ Benefits$$

Discounting

As the report is using a dynamic 20-year timeline, the net benefits were discounted using a rate of 0% (seen below), and 7% (seen below). The 7% discount rate was applied to the annual Net Benefit of $851.11 over the projected 20-year time horizon. Rationale for applying a 7% discount rate aligned with the Office of Management and Budget's suggestion of the upper bound discount rate in 2003 (Office). This 7% rate is based on the average before tax rate of return on capital investments in the United States. NB_1 is equal to $851.11. The resulting net benefits are displayed in the table below as well as the total present value (PV) of the net benefits of the GAHT® at $-1434.33. The payback period of the discounted results was 30 years.

$$Eq.\ 10: Discounted\ Total\ Net\ Benefits = 851.11/(1+.07)t$$

Table 6. Net Benefits Per Year of GAHT® System					
Years	Annual Costs	Annual Benefits	PV Net Benefits (0%)	Discounted Annual NB (7%)	PV Net Benefits (7%)
t=0	10,451.00	0	-10,451.00		-10,451.00
t=1	319.82	1,170.93	-9,599.89	795.43	-9,655.57
t=2	319.82	1,170.93	-8,748.78	743.40	-8,912.18
t=3	319.82	1,170.93	-7,897.67	694.76	-8,217.42
t=4	319.82	1,170.93	-7,046.56	649.30	-7,568.11
t=5	319.82	1,170.93	-6,195.45	606.83	-6,961.28
t=6	319.82	1,170.93	-5,344.34	567.13	-6,394.15
t=7	319.82	1,170.93	-4,493.23	530.03	-5,864.12
t=8	319.82	1,170.93	-3,642.12	495.35	-5,368.77
t=9	319.82	1,170.93	-2,791.01	462.95	-4,905.82

t=10	319.82	1,170.93	-1,939.9	432.66	-4,473.16
t=11	319.82	1,170.93	-1,088.79	404.36	-4,068.80
t=12	319.82	1,170.93	-237.68	377.90	-3,690.90
t=13	319.82	1,170.93	613.43	353.18	-3,337.72
t=14	319.82	1,170.93	1,464.54	330.08	-3,007.64
t=15	319.82	1,170.93	2,315.65	308.48	-2,699.16
t=16	319.82	1,170.93	3,166.76	288.300	-2,410.86
t=17	319.82	1,170.93	4,017.87	269.44	-2,141.42
t=18	319.82	1,170.93	4,868.98	251.81	-1,889.61
t=19	319.82	1,170.93	5,720.09	235.34	-1,654.27
t=20	319.82	1,170.93	6,571.20	219.94	-1,434.33
Total	**-16,847.4**	**23,418.60**	**6,571.20**	**9,016.67**	**-1,434.33**

Table 7. Summary of Net Present Value (2020$, USD)	
Monetized Benefits	23,419.00
Monetized Costs	16,847.00
NPV of Monetized Impacts (0%)	6,571.20
NPV of Monetized Impacts (7%)	-1,434.33
Final Net Present Value (0%)	**6571.20 + B**
Final Net Present Value (7%)	**-1434.33 + B**

* B denotes all Non-monetized Benefits.

Sensitivity Analysis

This study’s results were founded upon the use of the Climate Battery 2.0 thermodynamic model cited above. Within this model there were many input values that were specific to the study that may vary in applications. Therefore multiple sensitivity analyses were implemented where one variable was altered by multiplying the study's original input value by percentages ranging from 50% to 150%, increasing at 10% increments, while all other variables were held constant. This variation of inputs affected the payback period and net benefit calculations as discussed below. A 0% discount rate is assumed for all the payback periods and NPV presented below.

The variables that were analyzed were the (1) electricity cost (measured in kWh), (2) cost of a therm of propane, (3) daily hours of fan operation, (4) # of days expecting a 1 degree Fahrenheit rise in soil temperature annually, and (5) Total Costs, broken down into (5A) equipment costs.

Table 8. Summary of Sensitivity Analysis

	50%	100%	150%	Range in Payback Period(Years)	Range in Net Present Value Calc. ($)
Electricity Cost ($)	0.0515	0.103	0.1545	10.34-15.12	9,769.60 - 3,373.20
Cost of Propane ($)	0.735	1.47	2.205	39.34-7.27	(-)5,138.00 - 18,280.80
Daily Fan Hours (Hr)	3	6	9	10.34-15.12	9,769.60 - 3,373.20
#Days w/1 deg F rise in soil	90	180	270	24.56-8.19	(-)1,939.80-15,082.60
Total Costs	5,255.50	10,451.00	15,676.50	6.14-18.42	11,797.20 – 1,345.70

(1) Electricity cost for the local area of Watauga County is $0.103 per kWh (Blue Ridge Energy, personal communication Feb. 19th, 2021). This variable was analyzed as electricity costs vary per region/state. The $0.103 value was multiplied by percentages listed above, creating a variable range of $0.0515 per kWh and $0.1545 per kWh. This variation resulted in a payback period range of 10.34 to 15.12 years.The sensitivity of the electricity cost variable slope was recorded at .47. The range of NPV produced due to the variation in the electricity cost was $9,769.60 - $3,373.20.

(2) Cost of a Therm of propane, or roughly a gallon of propane was $1.47. Propane prices, like electricity costs, vary per region/state. The $1.47 value was multiplied by percentages listed above, creating a variable range of $0.735 to $2.205 cost per

Therm. This variation resulted in a payback period range of 39.34 to 7.27 years. The sensitivity for the cost per therm variable was a slope of -2.66, showing a negative correlation between therm cost and the payback period. The range of NPV produced due the variation in the cost per therm of propane was \$(-)5,138.00 - \$18,280.80. This was by far the most sensitive variable in the Climate Battery Version 2.0 thermodynamic model.

(3) Daily Hours of Fan operation was estimated to be 6 hours per day for both fans in the two GAHT® systems. This value was multiplied by percentages listed above, creating a variable range of 3 hours per day to 9 hours per day. This variation resulted in a payback period range of 10.35 to 15.12 years. The slope sensitivity for Daily Hours of Fan operation was .47 years. The range of NPV produced due to the variation in the daily hours of fan operation was \$9,769.60 - \$3,373.20. These results were identical to the sensitivity analysis conducted of Electricity costs. This shows that variation in electricity costs and daily fan hours of operation have the exact same impact on the payback period of the GAHT® system.

(4) Number of days expecting a 1-degree Fahrenheit rise in temperature was estimated to be 180. This value was multiplied by percentages listed above, creating a variable range of 90 to 270 days a year. This variation resulted in a payback period range of 24.56 to 8.19 years. The range of NPV produced due to the variation in the # of days was \$(-)1,939.80 - \$15,082.60. The slope sensitivity for this variable was -1.53 in relation to the payback period, showing a negative correlation between the number of days expecting a 1-degree Fahrenheit rise in temperature and the payback period.

(5) Total Cost was estimated at \$10,451.00. This value was analyzed as it is dependent upon many different materials, labor and equipment costs that can vary given individual firms, location of construction site, etc. and it is a major variable for determining the payback period of the GAHT® system. \$10,451.00 was multiplied by percentages listed above, creating a variable range of \$5,225.50 to \$15,676.5. This variation resulted in a payback period range of 6.14 to 18.42 years. The projected range in NPV is \$11,797.20 – \$1,345.70. The sensitivity for the total cost produced a slope of 1,2276.

(5A) Total equipment costs were also analyzed. Different firms could already have the equipment needed to excavate/grade soil for GAHT® installation. The University had to spend money on equipment as it did not have any available. The total cost of equipment was \$1,352.90. Equation 5 represents the process taken to apply the varied equipment costs to the total cost to find a new total cost of the GAHT®.

$$Equation\ 11: New\ Total\ Cost\ =\ (1,352.90\ \times\ variation\ \%)\ +\ (Total\ cost\ -\ 1,352.90)$$

This equation resulted in a new range in total cost from $9,774.55 to $11,127.45. This new range created a payback period of 11.48 to 13.07 years. The slope of this sensitivity was .159 per 100% increase in Total Equipment Costs. The new range in NPV was estimated to be $9,774.55 - $11,127.45.

Figure 2 represents the New PayBack Period ranges per variable displayed for each 10% interval increase of the original input value starting at 50% and ending at 150%. Most variables show a linear relationship between their input values and the new payback period of the entire GAHT® system. The cost per therm is the most sensitive variable and displayed an exponential relationship between the input value and the payback period. This relationship also aligns with the NPV of the cost of therms/propane. Thus when implementing a EAHTS consumers of the technology should be aware of the price of propane for their location as it significantly affects the payback period of their investment.

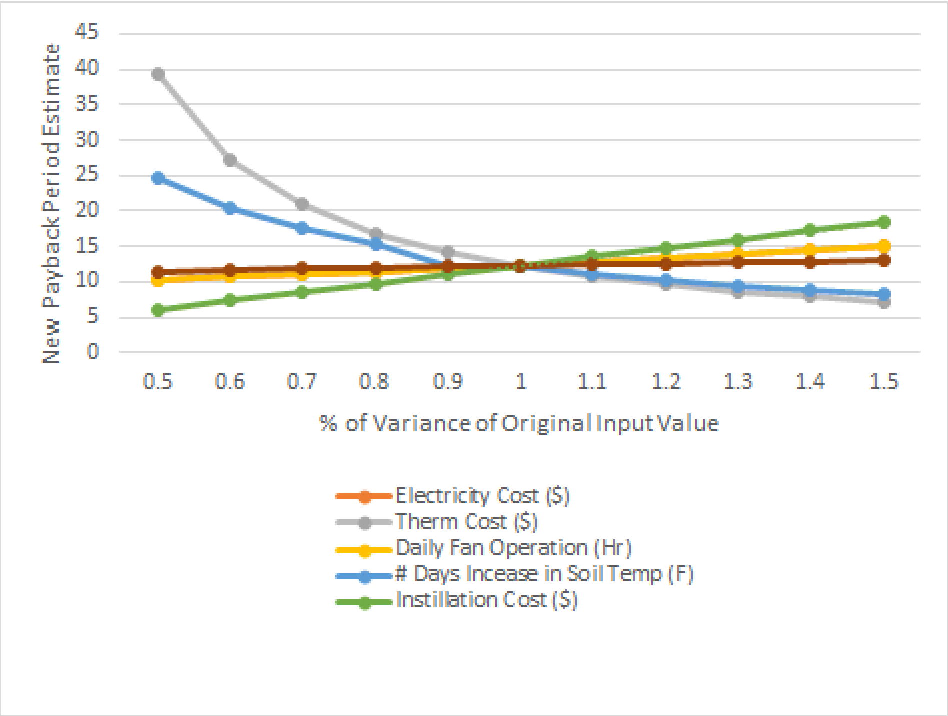

Figure 6. Sensitivity Analysis of all main variables

Examination of the present value of the net benefit calculations from the sensitivity analysis suggest that the GAHT® system's NPV will be positive for most consumers as only two variables tested reveal a negative NPV. The NPV is dependent upon many parameters and can be negative depending on the value of key inputs like Cost of Propane and the number of Days with a 1 degree Fahrenheit rise in soil. Cost of propane produced a NPV range of (-)1,939.80 to

15,082.60 and the number of Days with a 1 degree Fahrenheit rise in soil produced a larger NPV range of $(-)5,138.00 to $18,280.80. The sensitivity analysis reveals that the GAHT® is mainly profitable to consumers given a wide range of possible inputs within the 20 year timeline.

Examination of the payback period from the sensitivity analysis suggests that the payback of the system varies largely with different levels of inputs. Although the majority of the payback period calculations are within the 20 year timeline of the study, the variation of Cost of Propane and the number of Days with a 1 degree Fahrenheit rise in soil lead to maximum payback periods of 39.34 and 29.56 years respectively. Minimum payback periods were also produced from the variation of Cost of Propane and the number of Days with a 1 degree Fahrenheit in soil of 7.27 and 8.19 years. Examination of the sensitivity analysis highlights the significant effect that values for the variables of the Cost of Propane and and the number of Days with a 1 degree Fahrenheit have on both NPV and payback period. Consumers of the GAHT® need to be aware of the values they will have for both variables and investigate how significant these effects are on the profitability of their investment.

Discussion & Conclusion

Considering a time horizon of 20 years, this report concludes that net benefits are generally positive, but this is context specific and depends on various assumptions. In the main case, and assuming a 0% discount rate, we find positive net benefits of the GAHT® system of $6,571.20 with a payback period of 12.3 years. The study also found a wide variation in these calculations based on the assumed inputs, ranging from a payback period of 39.34 to 7.27 years, and a net benefit of $(-)5,138.00 to $18,280.80. When a 7% discount rate is applied the net benefits are negative at $-1,434.33 and present no payback period within the 20 year time horizon of the study. The payback period is 30 years with a 7% discount rate. The largest drivers of the uncertainty in NPV and the payback period was the Cost of Propane and number of Days with a 1 degree Fahrenheit in soil and the level of discount rate. The goal of this conclusion would be to further inform consumers, either individuals or companies who are thinking of adopting EAHTS technology. With this conclusion consumers can see that EAHTS are profitable given a certain amount of time of operation that will produce a payback period. The payback period of the system was found to be dependent on many different input variables.

To control for the possible variation in input variables, the author conducted a sensitivity analysis on electricity cost (measured in kWh), which produced a variable range from $0.0515 per kWh and $0.1545 per kWh, an estimated payback period ranging from 10.34 to 15.12 years and a range of NPV estimates of $9,769.60 - $3,373.20. When the sensitivity analysis was conducted on the daily fan hours the results were identical to that of the electricity cost variation. Cost of a therm of propane produced a variable range from $0.735 to $2.205 cost per Therm, an estimated payback period ranging from 39.34 to 7.27 years and a range of NPV estimates of $(-)5,138.00 - $18,280.80. Number of days expecting a 1 degree Fahrenheit rise in soil temperature annually produced a variable range from 90 to 270 days, an estimated payback period ranging from 24.56 to 8.19 years and a range of NPV estimates of $(-)1,939.80 -

$15,082.60. Total Cost produced a variable range from $5,225.50 to $15,676.50, an estimated payback period ranging from 6.14 to 18.42 years and a NPV range of $11,797.20 – $1,345.70. Total equipment costs produced a variable range from $9,774.55 to $11,127.45, an estimated payback period ranging from years 11.48 to 13.07 and a NPV range of $9,774.55 - $11,127.45.

Limitations of the BCA report include the limitations of the Climate Battery Model 2.0 used. Specifically, the methodology within the model of using the estimated number of days where the soil received a 1 degree Fahrenheit rise in temperature. This variable was not very well defined, and could not be calculated due to the lack of specification of the variable from the model. Researchers had to make an educated assumption for the input value of this variable. Additional limitations include the lack of quantitative data available to base the estimation of the daily hours of fan time for the GAHT® system within the Ceres Greenhouse construction overall.

The total amount of Carbon Dioxide avoided per year was 61.34 pounds, giving a total amount of abated emissions to be 1,226.8 pounds or 0.6134 of a ton of CO2. Given the $50/ton estimate of a social cost of carbon (EDF ACT), the social benefits of avoided emissions were $1.53 per year and $30.67 per the entire life span of the GAHT® system. These are not benefits to the private firm but this avoided pollution does offer altruistic motivations for the firm to produce EAHTS as they can be seen as an environmentally friendly company with environmentally conscious products. These benefits are relatively small, but if EAHTS are adopted at a large scale by many firms then the social benefits would become non-negligible.

Other benefits to mention would be the non-monetized benefits such as Environmentally Friendly PR that Appalachian State University receives as the consumer of the GAHT® system. The University would be able to further advertise its mission and actions taken to operate in an environmentally friendly way.

Areas for Further Research

The GAHT® system has the proven ability to cool the Ceres Greenhouse when needed, especially in sunny but colder temperatures. This ability is not figured into the BCA report as this BCA focused solely on the GAHT's® ability to heat the interior space of the Greenhouse. The cooling of the interior space could reduce exterior exhaust fan run time of the greenhouse and/or increase the GAHT fans daily operation hours, which would significantly affect payback period. A lower interior temperature would significantly affect the relative humidity of interior space potentially increasing crop yield. Further research could be done on the benefits of these cooling effects on crop yield versus the potential increased expenses on the GAHT® fan electricity demand.

The BCA report was successful in achieving its goal of creating information that prospective consumers of EAHTS could use to make a better informed decision as to whether they should invest in EAHTS technology.

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