University of Arkansas, Fayetteville
ScholarWorks@UARK

Mechanical Engineering Undergraduate Honors Theses

Mechanical Engineering

5-2007

A study on the application of thermoelectric heat pumps for heating applications

James Lincicome
University of Arkansas, Fayetteville

Follow this and additional works at: http://scholarworks.uark.edu/meeguht

Recommended Citation

Lincicome, James, "A study on the application of thermoelectric heat pumps for heating applications" (2007). *Mechanical Engineering Undergraduate Honors Theses*. 11.
http://scholarworks.uark.edu/meeguht/11

This Thesis is brought to you for free and open access by the Mechanical Engineering at ScholarWorks@UARK. It has been accepted for inclusion in Mechanical Engineering Undergraduate Honors Theses by an authorized administrator of ScholarWorks@UARK. For more information, please contact scholar@uark.edu, ccmiddle@uark.edu.

A Study on the Application of Thermoelectric Heat Pumps for Heating Applications

An Honors Thesis submitted in partial fulfillment
of the requirement for the Honors Program for the
Degree of Bachelor of Science
In
Mechanical Engineering

By

James Paul Lincicome, Mechanical Engineering

Project Advisor - Dr. Rick J. Couvillion

May 2007
University of Arkansas

Table of Contents

List of Tables

List of Figures

Abstract

Typically, thermoelectric heat pumps are used in cooling applications where space and portability are important, but they can be used efficiently in heating applications under the right conditions. This paper explains the origins of the thermoelectric heat pump, its applications in society, and the technical aspects of the device. The many different appurtenances that the device requires will be discussed along with their drawbacks. The single-stage data for the cells will be compared to the two-stage configuration data, and the data gathered for a specific thermoelectric device will be compared to the manufacturer's published data for the different configurations of the device.

Introduction

While the technology used in thermoelectric heat pumps, also called thermoelectric cells or Peltier cells (TECs), has been around for many years, widespread commercialization did not occur until the early 1960's. At that time, the inefficiencies of thermoelectric heat pumps and their high price tag made them less desirable for use in cooling applications compared to conventional heat pump systems. Recently, the realization of the depleting ozone layer has left scientists and engineers looking for alternatives to the conventional heat pump and the harmful refrigerants that they utilize. These refrigerants contain chlorofluorocarbons that damage the ozone layer irrevocably. A potential alternative, along with environmentally-friendly refrigerants, was thermoelectric heat pumps. Over time, research showed that in small wattage cooling applications, the inefficiencies experienced by thermoelectric heat pumps was not enough to outweigh their advantages. In applications less than a couple of hundred watts, thermoelectric heat pumps were found to be very portable because of their small size, extremely reliable, and quite durable over a large range of cooling temperatures. Because there are no moving parts in a TEC, there is no concern over wear or fatigue, and they are resistant to extremely high shock levels (Buist, 1-2).

As these advantages were being realized, the price to manufacture these TEC's began to decrease making the thermoelectric heat pump a very good alternative to the typical refrigeration system. Many different uses for the devices began to be explored with some experiencing considerable success compared to others. For example, TECs were applied in room air conditioners, dehumidifiers, and full-size refrigerators with poor results (Egli, 34-37), but they began to be widely used in consumer applications such as the portable 12-volt cooler and small portable refrigeration devices that were easily plugged into wall outlets or car cigarette lighters (Buist, 3). They have also played a large part in computer cooling, and as computers continue to become more powerful and heat-producing, cooling will become even more important (Rowe, 143). Within the last ten years, TECs have been used in luxury vehicles as seat heaters and coolers; since a simple reversal of polarity will shift the hot and cold side of the device, they are extremely well suited to this application.

Currently, thermoelectric heat pumps are manufactured primarily for their cooling capabilities, but they are also very efficient in heating applications. This paper will first explore the specific properties of the thermoelectric heat pump and its origins and then research the potential for using the cells in heating applications. Data taken from a Custom Thermoelectric, Inc. device used in heating will be compared to the manufacturer's published data and conclusions will be drawn from the comparison.

Background

In 1821, a German-Estonian physicist, Thomas J. Seebeck, accidentally, discovered that there was a voltage between the two ends of a metal bar when a temperature difference existed in the bar (Wikipedia, 1). In 1923, he proposed that a circuit composed of two dissimilar conductive metals with two different temperatures creates an electromotive force (emf) at the junction between the two metals. This is called the "Seebeck Effect," and it was determined that the emf at each junction was proportional to the temperature difference between the junctions according to:

$$E_{AB} = S_{AB} \cdot \Delta T$$

where:

S_{AB} is the relative Seebeck coefficient between the materials,

E_{AB} is the emf between the two junctions, and

ΔT is the temperature difference between the two metals.

The relative Seebeck coefficient between materials A and B, $S_{AB,}$ is defined as:

$$S_{AB} = S_A - S_B$$

where:

S_A and S_B are the Seebeck coefficients of the two materials.

Eleven years later, Jean C. A. Peltier discovered the exact opposite of the Seebeck Effect; when a circuit composed of two dissimilar conductive metals carries an electric current, heat is produced at one junction and absorbed at the other. This process, the “Peltier Effect,” is fully reversible and is the process by which thermoelectric cells work. The rate at which heat is produced is dependent on the properties of the metals, as in the Seebeck Effect, and the current flowing through the circuit according to the following equation:

$$Q_{AB} = \Pi_{AB} \cdot I$$

where:

Q_{AB} is the rate at which heat is produced on the hot side and absorbed on the cold side,

Π_{AB} is the relative Peltier coefficient, and

I is the current flowing through the circuit.

The relative Peltier coefficient is given by:

$$\Pi_{AB} = \Pi_A - \Pi_B$$

where Π_A and Π_B are the Peltier coefficients of the two metals (Cadoff, 2-5).

The Peltier coefficients represent how much heat current per unit charge is carried through a given material.

Technical Information

Thermoelectric heat pumps, or TECs, are solid-state devices that function as heat pumps. They are typically only a few millimeters thick and only a few centimeters square. The normal TEC will be made up of an array of p- and n-type semiconductor elements that are dissimilar because they can be easily optimized for pumping heat and can control the type of charge carrier. The semiconductors typically used in TECs are composed of bismuth telluride, although many different types of materials have been used in the past. The array is soldered between two ceramic plates, electrically in series and thermally in parallel. When smooth direct current (DC) passes through the p-type to the n-type semiconductor, a temperature drop is experienced at the junction according to the Peltier Effect. This production of a cold side makes the cell absorb heat from the environment. This heat is then passed through the cell by electron transport and released on the opposite hot side. The heating capacity of the cell increases as the amount of p-type and n-type pairs increases (Marlow, 1-2). A diagram of a normal thermoelectric heat pump is shown to the right.

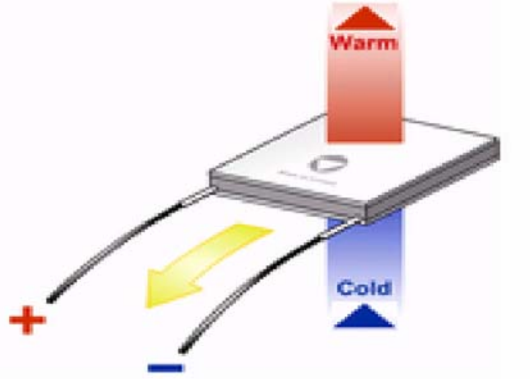

Figure 1: Diagram of thermoelectric module

TECs require smooth DC current so many different sources of power can be used such as batteries, automotive and marine DC systems, AC/DC converters, and linear and switched DC power supplies. The rating on a TEC is the maximum current or voltage allowable to the cell. For example, the cells that were purchased for research for this study were six ampere, 12-volt devices, and above these parameters, the cell would not function properly and likely be destroyed. The cells operate most efficiently at 75% of maximum power. As stated earlier, the Peltier Effect is reversible, so if the power input reversed polarities, the cell's hot side would become the cold side and vice versa (gatewayelex, 1).

One concern in using a TEC is the dispersion or gathering of heat. In typical cooling applications, it is necessary to have a heat sink to disperse heat to the environment on the hot side, and likewise, in heating applications, a heat sink must be used on the cold side to gather heat from the environment. Heat transfer between two surfaces depends on the temperature difference between the surface and the contact area of the surfaces (JC Electronica, 2). One important note is that to effectively have heat transfer from the surface of the cell to the heat sink, the surface area must be maximized to maximize heat transfer. There are microscopic peaks and valley in the surface of the heat sink and the ceramic face of the TEC that reduce the surface area available for heat transfer. To overcome this, thermal interface material (TIM) must be applied between the interface of the heat sink and the TEC surface and also applied between the object to be heated or cooled and the TEC surface. This TIM will maximize the available surface area of the cell and heat sink to allow for maximum heat transfer. The TIM can be made from any number of materials such as silicone-based greases, elastomeric pads, thermally conductive tapes, or thermally conductive adhesives. Any of these will suffice; however, if a grease is used, because the peaks and valleys are microscopic, only a very thin film of heat sink grease should be used or the grease will act as another thermal resistance rather than an aid to heat transfer (peltier-info.com, 4).

The most important factor in the function of a TEC is the dissipation of heat on the hot and cold side, or the heat sink. The efficiency of the heat sink is the most important factor in the achievable temperature difference across the thermoelectric heat pump (gatewyelex.com, 1). The TEC can be mounted to the heat sink in a few ways such as epoxy, soldering, or compression, but some TIM must be included between the interfaces. In most applications, the TEC is used to heat or cool a solid body or the contents of a container, and some consideration must given to how best transfer heat to or from the body. The material that interfaces between the body to be cooled or heated and the TEC must be highly conductive.

Recently, most research involving the optimization of TECs has been exploring multiple heat sinking options. The heat sink can be made of any highly conductive material such as aluminum or copper and even a heat sink extender (HSE) can be used in applicable cases. An HSE can be used to extend the distance between the cold sink plate and the hot sink plate to minimize the heat transfer between the two plates. The area around the HSE should be well insulated, and the HSE must also be a highly conductive material (AIP, 161). The heat sink should be finned and also be air cooled or liquid cooled, and in each case, the fluid should be moving across the highly conductive heat sink to reduce the heat transfer coefficient. Because liquid has a higher coefficient of heat transfer, to maximize the performance of the TEC, a liquid should be moved across the heat sink. While this is the more efficient option, it is much more difficult to use in practice (AIP, 147). When using a liquid with a TEC, there is a concern for moisture reaching the cell. To prevent this, there must be a seal around the TEC area to guard against condensation or any lost liquid in the area (gatewayelex.com, 3). The alternative to using a liquid is moving air across the finned heat sink, and this is the focus of this research.

Research has been conducted to determine the optimal configuration of an air-cooled heat sink coupled with thermoelectric heat pumps. In heating applications, the heat sink on the cold side must perform well enough that the cold heat sink continues to draw heat from the atmosphere. To maximize the heat transfer coefficient of the air, a fan or blower must be used. Investigations have shown that the better option if the heat sink has very few fins (i.e., fourteen fins over a length of five inches), is a blower (AIP, 147-149). If the heat sink has a higher fin density, a fan is a better option because a blower must overcome a more significant pressure drop to move air from the finned area. As the volumetric flow rate of air increases, the overall heat sink resistance (HSR) decreases, and likewise at a similar volumetric flow rate of air, as the number of fins increases, the HSR also decreases to a certain point. Therefore, to optimize the heat sink for a specific thermoelectric application, the optimal number of fins should be determined by calculation or experimentation (AIP, 147-149).

Performance Calculations

In cooling applications, thermoelectric heat pumps are approximately 75% efficient, but if used in heating applications, TECs can be over 100% efficient. For this reason, it is important to explore the possibility of widely using them in heating applications. To understand the process by which the cell produces more energy than is input several equations must be discussed. The most important concept to understanding thermoelectric heat pumps is the calculation of the coefficient of performance (COP). It is defined simply as the amount of heat output compared the amount of energy input, but mathematically it follows:

$$COP = \frac{Q_h}{Q_h - Q_c}$$

where:

Q_h is the flow of heat out the hot side, and

Q_c is the flow of heat in the cold side.

To find Q_h and Q_c, the properties of the TEC must be known. According to the theory of non-equilibrium thermodynamics for a single-stage thermoelectric heat pump system:

$$Q_h = M\Pi_{AB} I T_h + \frac{I^2 MR}{2} - MK(T_h - T_c)$$

$$Q_c = M\Pi_{AB} I T_h - \frac{I^2 MR}{2} - MK(T_h - T_c)$$

where:

M is the total number of semiconductor pairs,

T_h is the temperature of the hot side of the cell,

T_c is the temperature on the cold side of the cell,

R is the electrical resistance, and

K is the thermal conductance.

These calculations are theoretical and neglect losses that might be experienced during experimentation. For example, for any heat sink, solid body, or finned surface, there will be some heat sink resistance and a small resistance due to the thermal grease applied (Chen, 2).

Over a low temperature difference, the above calculations are valid, but as the temperature difference increases across a thermoelectric cell, the COP decreases. To prevent the loss in performance, multiple thermoelectric cells can be stacked on top of each other to form a multiple-stage heat pump. The stacking of the cell results in a smaller temperature difference across each cell and therefore, the efficiency of the multi-stage configuration remains high. There are a few variations in the possible configurations of multi-stage thermoelectric heat pumps. The cells can simply be stacked on top of each other or they can be designed in a cascade or pyramid style where the bottom cell is the largest in area and the cells get smaller as they progress upward. In the cascade style and the stacked style, the individual cells are all wired in parallel. To find the COP for a multi-stage configuration with two identical thermoelectric cells stacked on top of each other, the temperature between the interfaces of the two cells must be known. The equations that are used to calculate the COP are computed as follows:

$$Q_h = M\Pi_{AB} I T_h + \frac{I^2 MR}{2} - MK(T_h - T_m)$$

$$Q_h = M\Pi_{AB} I T_h - \frac{I^2 MR}{2} - MK(T_h - T_m)$$

$$Q_h = M\Pi_{AB} I T_h + \frac{I^2 MR}{2} - MK(T_m - T_c)$$

$$Q_h = M\Pi_{AB} I T_h - \frac{I^2 MR}{2} - MK(T_m - T_c)$$

where:

T_m is the temperature at the interface between the cells, and

Q_m is the heat flow from the bottom cell to the top cell and vice versa.

The COP is defined the same as in the single-stage configuration. It is important to note that when the temperature difference between the two sides of a thermoelectric heat pump is small, the COPs of a single-stage and two-stage heat pump vary only a small amount, but the two-stage is slightly more efficient. As the temperature difference grows larger, the difference in the COP also grows larger, indicating that a multi-stage heat pump is always more efficient no matter the temperature difference (Chen, 2-4).

Experiment Design

To test the ability of thermoelectric heat pumps to perform in heating applications, the temperature of the solid-state heat sink on the hot side should be easily measurable. Therefore, because the temperature of water is easily measured, it was selected as the substance to be heated. To compare multiple configurations of TECs to one another and determine which configuration would be the most efficient, many identical thermoelectric modules were purchased. The TECs that were purchased were manufactured by Custom Thermoelectric, Inc. The technical specifications are: 127 couples, six ampere, and rated to 110 degrees Celsius. The dimensions of the modules are 40 millimeters (mm) by 40 mm. According to the theoretical performance of the cells, the manufacturer recommended an aluminum heat sink material five inches wide by five and a half inches long to sufficiently draw heat on the cold side of the TEC. A camping tin was used at the container to hold the water and interface with the hot side of the TEC. To ensure good contact, silicone-based heat sink grease was placed between the interface of the hot side and the container and the cold side and the heat sink. The power source used was a DC power source with variable current and voltage ranging up to a maximum of 25 volts and 20 amperes, respectively. The heat sink, TEC, and water container is shown to the right (Figure 2).

Figure 2: Picture of cxperiment configuration.

To compare the single-stage configuration to the two-stage configuration, the tests were run separately with one cell and two cells stacked on one another; in the two-stage configuration, the TECs were wired in parallel. Tests were run with and without a fan to determine the necessity of a fan in the configuration because, according to the background research, a fan aids in the performance. In all cases, the initial water volume was 100 milliliters (ml), and the duration of each test was 20 minutes. Throughout the course of the experiments, the voltage, current, temperature of water, and the temperature of the heat sink were recorded in one minute increments. To determine the energy input to the system, the following equation was used:

$$P = I \cdot V$$

where:

P is the power in watts,

I is the electrical current in amperes read from the power source, and

V is the electrical voltage in volts also read from the power source.

To find the energy output to the water the following equation was used:

$$Q_w = m \cdot C_p \cdot \Delta T$$

where:

Q_w is the energy input to the water in joules,

m is the mass of the water in g,

C_p is the specific heat of water (4.182 J/(g*C)), and

ΔT is the change in temperature of the water.

Using the above calculated values, the COP was computed as energy output divided by energy input according to:

$$COP = \frac{Q_w}{P \cdot \Delta t}$$

where:

Δt is the change in time in seconds.

Data and Results

The data that were compiled compare the single-stage TEC to the two-stage TEC configuration and are included in Appendix A. The plot of the temperature of the water versus time for the one- and two-stage configurations, both with and without a fan is shown below (Figure 3).

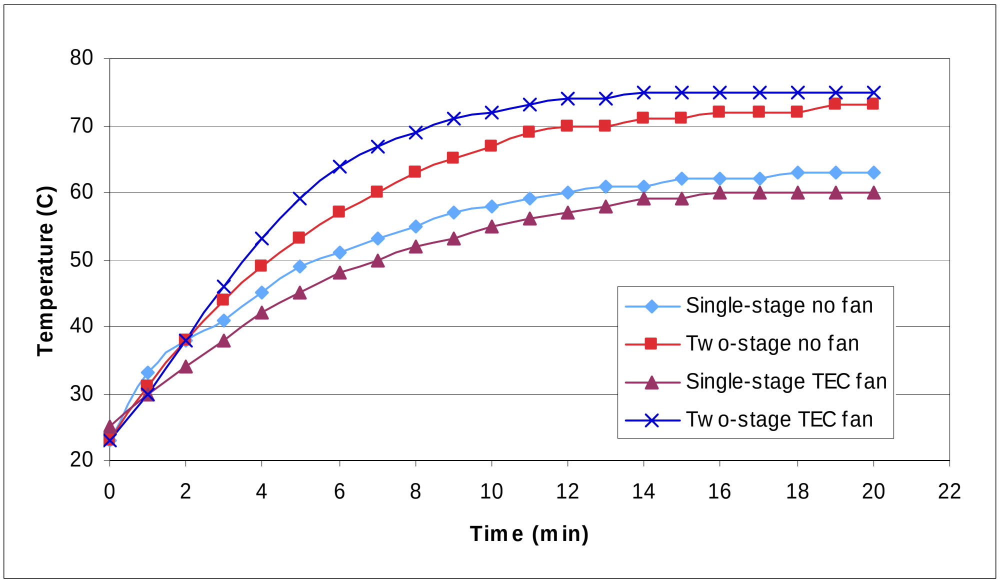

Figure 3: Temperature vs. time all configurations.

As shown by Figure 3, the water reaches a higher temperature using the two-stage configurations compared to the one-stage, but only by about 10 degrees Celsius. It interesting to observe that, inexplicably, one-stage without a fan reaches a higher temperature than the one-stage with a fan, but the two-stage with a fan reaches a higher temperature in the two-stage trials.

The important comparisons to make are that of the COPs of the one-stage versus the two-stage configurations and the COPs with and without a fan. Figure 4 shows the COP versus the temperature difference between the water and the heat sink for the one-stage and two-stage configurations without a fan, and Figure 5 shows the same plot for the configurations with a fan.

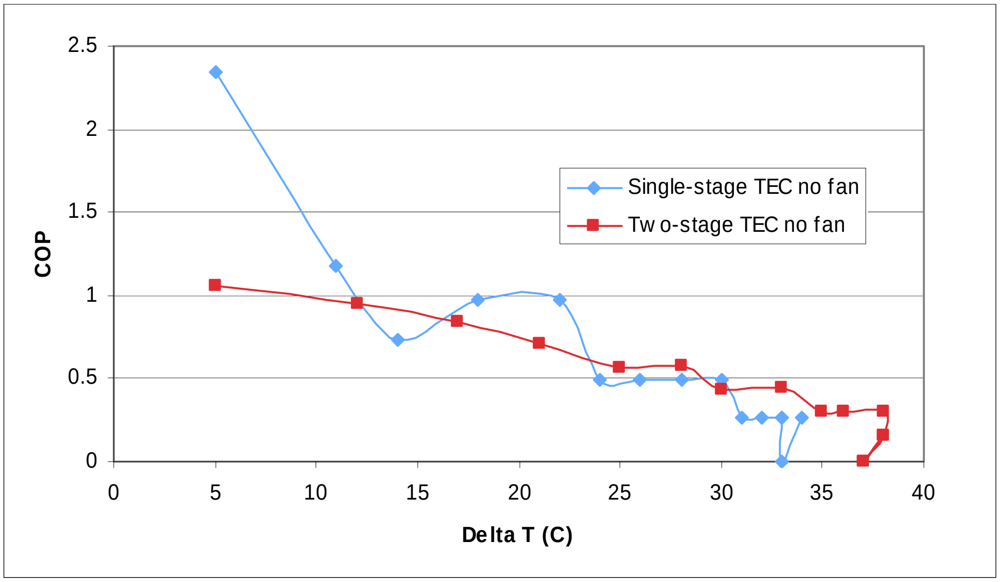

Figure 4: No fan, stage COP comparison.

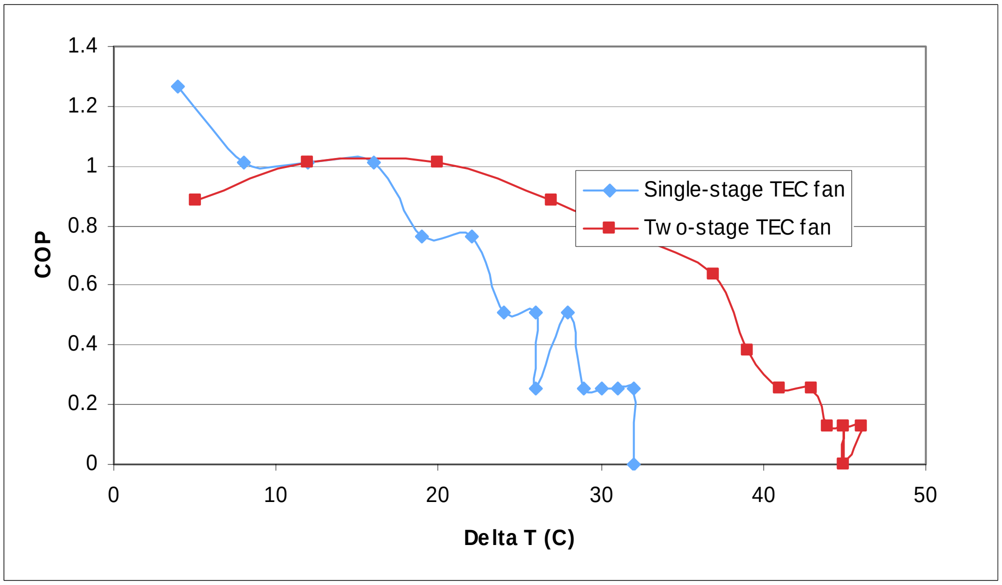

Figure 5: Fan, stage COP comparison.

In these and all the COP comparisons, only the first 15 minutes of the test are shown on the chart because little temperature change was observed during the final 5 minutes. The most apparent observation from Figures 4 and 5 is that the two-stage configurations' COPs are much steadier over a wider range of temperature differences. While the one-stage configuration starts at a higher COP, it quickly drops, but the two-stage remains in an efficient mode for a longer period of time (over a wider change in temperature).

Figures 6 and 7 show the comparisons between the COP performance with a fan blowing over the heat sink and without it in like configurations of TECs. As in the previous figures, the temperature difference shown is between the water and the heat sink.

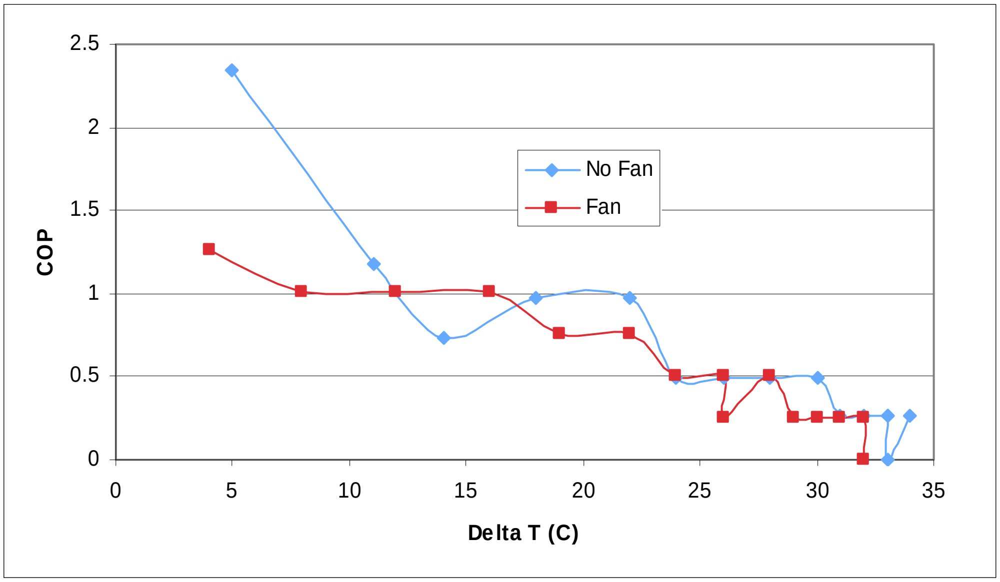

Figure 6: Single-stage fan COP comparison.

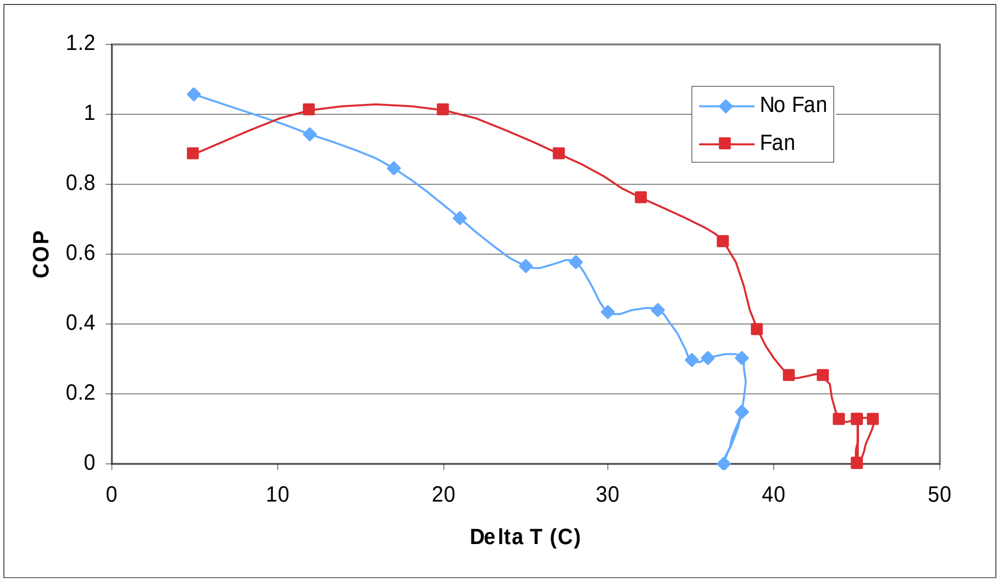

Figure 7: Two-stage fan COP comparison.

Comparing the two figures, it is observed that the COPs of the configurations with the addition of a fan are steadier over a larger temperature difference. While the COP is not necessarily greater, the data show that a fan will sustain a greater and steadier COP to a given temperature difference at which point, the COP begins to drop rapidly. The table below shows the four configurations with their maximum water temperature and the overall COP for the full 20 minutes tabulated.

Table 1: Overall performance of configurations.

		Water	Heat Sink	
		Maximum Temp. Diff. (C)	Maximum Temp. Diff. (C)	Overall COP
No Fan	Single-Stage	40	2	0.504
	Two-Stage	50	9	0.363
Fan	Single-Stage	35	2	0.444
	Two-Stage	52	5	0.328

Conclusions

From the results of the experimentation it can be concluded that, from the standpoint of overall performance, the best configuration is the two-stage with a fan blowing over the heat sink because the COP remains steady over a larger temperature difference. However, from the standpoint of overall COP, the single-stage configuration without a fan has the best performance over the full twenty minute test. It would be consistent with the background research for the two-stage configuration with the fan blowing over the heat sink to perform the best, but examination of COP data tabulated in Table 1 does not show this to be true. According to the manufacturer’s data, these TECs will reach a surface temperature of 110 degrees Celsius, and could boil water if that was the purpose. It was immediately apparent upon the first test of these devices, that some factor in the process was impeding the TECs ability to perform according to the manufacturer’s technical data. According to the manufacturer’s data, the six ampere devices purchased for this experiment operate most efficiently over the three to four ampere range, but after many different attempts with multiple power sources, such as 12-volt batteries, these cells would not carry more than two and a half amperes each. At 12 volts and two and a half amperes, the results are consistent with the manufacturer’s data (Appendix B), showing poor performance (COP less than 0.7) at high voltages and low amperages. After conferring with the manufacturer regarding changes that could be made to the configuration to improve the results, a few changes to the system were implemented. For example, a glass beaker was replaced with a more conductive camping tin and alligator clips connecting wire leads and the TECs removed, but the results were the same.

Many hypotheses could be formulated as to what the sources of error in this experiment were, but without more research, they cannot be conclusively determined. Potential sources of error or poor performance that have been considered are:

- The power source could have some source of internal resistance causing the data output to be skewed. This was disproved by using a 12-volt car battery to power the cells, and the maximum current achieved was no higher than with the power source.
- The heat sink material and fan did not appear to be the source of error because the data was very similar with and without a fan in both configurations.
- It is also possible that the thermal grease applied on the faces of the cell to interface the heat sink and the container of water was too thick, but this would most likely only lead to minimal losses.
- The most plausible explanation is perhaps that because the specific heat capacity of water is so high compared to other substances (highest among liquids except ammonia), the heat was not able to be dissipated quickly enough from the face of the thermoelectric cell to the container and into the water. The container could have also been dissipating heat very quickly to the environment because the specific heat capacity of air is less than that of water.

Recommendations

Originally for this project, thermoelectric heat pumps were explored as an option to rapidly boil water in a situation with minimal power, but as the research continued, it was obvious that thermoelectric heat pumps would not outperform a simple electric resistance heater. To use TECs, a fan would have had to be used to cool the heat sink, and that would require additional energy. This additional energy requirement for the fan would cancel out the advantage gained from the COP of the TECs if they were to perform correctly. It was determined that to boil a small amount of water in a short time, an electric immersion heater would perform better than TECs because the heat would not have to be transferred through a medium to the water. In the future, TECs should be purchased from more than one manufacturer to be able to consult with, and receive advice from a broader range of technical experts. With input from different experts, it is possible that the flaw in the design could be determined, and the TECs would perform in conformance with the manufacturer’s data. It is obvious that TECs have been used more widely in cooling applications than heating application because there are many simple alternatives to small scale heating applications. On the other hand, TECs are the one of the only small scale cooling devices on the market today. The alternative is a conventional heat pump system with a compressor and other moving parts which is big, bulky, and not portable. In the near future, the multiple accessories that thermoelectric heat pumps require will prevent them from being widely applied in heating applications due to the simplicity of many electric heaters.

Works Cited

1. "A Little Information on Peltier Junctions." Gateway Electronics. 18 Apr. 2007 <http://www.gatewayelex.com/peltier.htm>.
2. Buist, Richard J. Short Course on Thermoelectrics. International Thermoelectric Society. Yokohama, Japan: The International Thermoelectric Society, 1993. 1-8. 18 Apr. 2007.
3. Cadoff, Irving B., and Edward Miller. Thermoelectric Devices and Data. New York: Reinold Corporation. 1-8.
4. Egli, Paul H. Thermoelectricity. USA: John Wiley & Sons, Inc., 1960. 35-40.
5. "Frequently Asked Questions." Marlow Industries, Inc. 18 Apr. 2007 <http://www.marlow.com/TechnicalInfo/frequently_asked_questions_faqs>.
6. Lai, Hongkai, Yuzhuo Pan, and Jincan Chen. "Optimum Design of the Performance Parameters of a Two-Stage Combined Semiconductor Thermoelectric Heat Pump." Semiconductor Science Technology 19 (2004): 17-22. 18 Apr. 2007.
7. Mathiprakasam, B., and Patrick Heenan. AIP Conferece Proceedings 316. USA: AIP P, 1995. 135-165.
8. "Peltier Device Information Directory." Thermoelectric Design LLC. 18 Apr. 2007 <http://www.peltier-info.com/info.html>.
9. Rowe, D. M. CRC Handook of Thermoelectrics. 10th ed. New York: CRC P, 1995. 143-155.
10. "Thermoelectric Cooling with Peltier Cells." JC Electronica. 18 Apr. 2007 <http://www.jcelectronica.com/articles/peltier.htm>.

Appendix A

Table A-1: One-stage no fan

one cell dc power supply								
100 ml								
no fan								
t (min)	Volts (V)	Current (A)	Watts	T water C	T heat sink C	ΔT	Energy Output	COP
0	11	2.8	30.8	23	29	-6		
1	11	2.7	29.7	33	28	5	4182	2.346801347
2	11	2.7	29.7	38	27	11	2091	1.173400673
3	11	2.6	28.6	41	27	14	1254.6	0.731118881
4	11	2.6	28.6	45	27	18	1672.8	0.974825175
5	11	2.6	28.6	49	27	22	1672.8	0.974825175
6	11	2.6	28.6	51	27	24	836.4	0.487412587
7	11	2.6	28.6	53	27	26	836.4	0.487412587
8	11	2.6	28.6	55	27	28	836.4	0.487412587
9	11	2.6	28.6	57	27	30	836.4	0.487412587
10	11	2.4	26.4	58	27	31	418.2	0.264015152
11	11	2.4	26.4	59	27	32	418.2	0.264015152
12	11	2.4	26.4	60	27	33	418.2	0.264015152
13	11	2.4	26.4	61	28	33	418.2	0.264015152
14	11	2.4	26.4	61	28	33	0	0
15	11	2.4	26.4	62	28	34	418.2	0.264015152
16	11	2.4	26.4	62	28	34	0	0
17	11	2.4	26.4	62	28	34	0	0
18	11	2.4	26.4	63	28	35	418.2	0.264015152
19	11	2.4	26.4	63	28	35	0	0
20	11	2.4	26.4	63	29	34	0	0
	Average Watts	Delta T	Energy Input	Energy Output	COP			
	27.65714286	40	33188.57143	16728	0.504028926			

Table A-2: Two-stage no fan

two cell dc power supply								
100 ml								
no fan								
t (min)	Volts (V)	Current (A)	Watts	T water C	T heat sink C	ΔT	Energy Output	COP
0	11	5	55	23	26	-3		
1	11	4.8	52.8	31	26	5	3345.6	1.056060606
2	11	4.7	51.7	38	26	12	2927.4	0.943713733
3	11	4.5	49.5	44	27	17	2509.2	0.844848485
4	11	4.5	49.5	49	28	21	2091	0.704040404
5	11	4.5	49.5	53	28	25	1672.8	0.563232323
6	11	4.4	48.4	57	29	28	1672.8	0.576033058
7	11	4.4	48.4	60	30	30	1254.6	0.432024793
8	11	4.3	47.3	63	30	33	1254.6	0.442071882
9	11	4.3	47.3	65	30	35	836.4	0.294714588
10	11	4.2	46.2	67	31	36	836.4	0.301731602
11	11	4.2	46.2	69	31	38	836.4	0.301731602
12	11	4.2	46.2	70	32	38	418.2	0.150865801
13	11	4.2	46.2	70	33	37	0	0
14	11	4.2	46.2	71	33	38	418.2	0.150865801
15	11	4.2	46.2	71	34	37	0	0
16	11	4.2	46.2	72	34	38	418.2	0.150865801
17	11	4.2	46.2	72	35	37	0	0
18	11	4.2	46.2	72	35	37	0	0
19	11	4.2	46.2	73	35	38	418.2	0.150865801
20	11	4.2	46.2	73	35	38	0	0
	Average Watts	Delta T	Energy Input	Energy Output	COP			
	47.98095238	50	57577.14286	20910	0.363164946			

Table A-3: One-stage fan

one cell dc power supply								
100 ml								
fan								
t (min)	Volts (V)	Current (A)	Watts	T water C	T heat sink C	ΔT	Energy Output	COP
0	11	2.5	27.5	25	26	-1		
1	11	2.5	27.5	30	26	4	2091	1.267272727
2	11	2.5	27.5	34	26	8	1672.8	1.013818182
3	11	2.5	27.5	38	26	12	1672.8	1.013818182
4	11	2.5	27.5	42	26	16	1672.8	1.013818182
5	11	2.5	27.5	45	26	19	1254.6	0.760363636
6	11	2.5	27.5	48	26	22	1254.6	0.760363636
7	11	2.5	27.5	50	26	24	836.4	0.506909091
8	11	2.5	27.5	52	26	26	836.4	0.506909091
9	11	2.5	27.5	53	27	26	418.2	0.253454545
10	11	2.5	27.5	55	27	28	836.4	0.506909091
11	11	2.5	27.5	56	27	29	418.2	0.253454545
12	11	2.5	27.5	57	27	30	418.2	0.253454545
13	11	2.5	27.5	58	27	31	418.2	0.253454545
14	11	2.5	27.5	59	27	32	418.2	0.253454545
15	11	2.5	27.5	59	27	32	0	0
16	11	2.5	27.5	60	28	32	418.2	0.253454545
17	11	2.5	27.5	60	28	32	0	0
18	11	2.5	27.5	60	28	32	0	0
19	11	2.5	27.5	60	28	32	0	0
20	11	2.5	27.5	60	28	32	0	0
	Average Watts	Delta T	Energy Input	Energy Output	COP			
	27.5	35	33000	14637	0.443545455			

Table A-4: Two-stage fan

two cell dc power supply								
100 ml								
no fan								
t (min)	Volts (V)	Current (A)	Watts	T water C	T heat sink C	ΔT	Energy Output	COP
0	11	5.5	60.5	23	25	-2		
1	11	5	55	30	25	5	2927.4	0.887
2	11	5	55	38	26	12	3345.6	1.014
3	11	5	55	46	26	20	3345.6	1.014
4	11	5	55	53	26	27	2927.4	0.887
5	11	5	55	59	27	32	2509.2	0.760
6	11	5	55	64	27	37	2091	0.634
7	11	5	55	67	28	39	1254.6	0.380
8	11	5	55	69	28	41	836.4	0.253
9	11	5	55	71	28	43	836.4	0.253
10	11	5	55	72	28	44	418.2	0.127
11	11	5	55	73	28	45	418.2	0.127
12	11	5	55	74	28	46	418.2	0.127
13	11	5	55	74	29	45	0	0.000
14	11	5	55	75	30	45	418.2	0.127
15	11	5	55	75	30	45	0	0.000
16	11	5	55	75	30	45	0	0.000
17	11	5	55	75	30	45	0	0.000
18	11	5	55	75	30	45	0	0.000
19	11	5	55	75	30	45	0	0.000
20	11	5	55	75	30	45	0	0.000
	Average Watts	Delta T	Energy Input	Energy Output	COP			
	55.26190476	52	66314.28571	21746.4	0.327929341			

Appendix B: Manufacturer’s Data

```
*     *     *     *     *     *     *     *     *     *     *     *     *     *

             SINGLE STAGE MODULE HEATING PERFORMANCE - QH vs TC

NUMBER OF COUPLES IN MODULE.......> 127
OPTIMUM CURRENT IN AMPERES........> 12
HOT SIDE TEMPERATURE IN DEGREES C.> 25
  Note:  DT=Tc-Th and Tc>Th


  Tc          QH        DT        Iin       Vin        Pin         QC
DEG. C      WATTS     DEG.C      AMPS     VOLTS      WATTS      WATTS      COPH
------      ------    -----     -----     -----     ------     ------    ------
  25.0       31.01       0.0       2.0      2.28       4.57      26.44     6.786
  27.0       29.20       2.0       2.0      2.39       4.79      24.42     6.102
  29.0       27.39       4.0       2.0      2.50       5.00      22.38     5.474
  31.0       25.56       6.0       2.0      2.61       5.22      20.34     4.895
  33.0       23.71       8.0       2.0      2.72       5.44      18.27     4.360
  35.0       21.86      10.0       2.0      2.83       5.66      16.20     3.863
  37.0       19.99      12.0       2.0      2.94       5.88      14.11     3.400
  39.0       18.10      14.0       2.0      3.05       6.10      12.00     2.968
  41.0       16.19      16.0       2.0      3.16       6.32       9.88     2.563
  43.0       14.27      18.0       2.0      3.27       6.54       7.73     2.182
  45.0       12.33      20.0       2.0      3.38       6.76       5.57     1.824
  47.0       10.37      22.0       2.0      3.49       6.98       3.39     1.485
  49.0        8.39      24.0       2.0      3.60       7.21       1.19     1.165
  51.0        6.39      26.0       2.0      3.72       7.43      -1.04     0.861
  53.0        4.37      28.0       2.0      3.83       7.65      -3.28     0.571
  55.0        2.33      30.0       2.0      3.94       7.88      -5.55     0.295
  57.0        0.26      32.0       2.0      4.05       8.10      -7.84     0.032
  59.0       -1.84      34.0       2.0      4.16       8.33     -10.16    -0.221
  61.0       -3.96      36.0       2.0      4.28       8.55     -12.51    -0.463
  63.0       -6.10      38.0       2.0      4.39       8.78     -14.88    -0.695
  65.0       -8.27      40.0       2.0      4.50       9.00     -17.28    -0.919
  67.0      -10.48      42.0       2.0      4.61       9.23     -19.70    -1.136
  69.0      -12.71      44.0       2.0      4.73       9.45     -22.16    -1.344
  71.0      -14.97      46.0       2.0      4.84       9.68     -24.64    -1.547
  73.0      -17.26      48.0       2.0      4.95       9.90     -27.16    -1.743
  75.0      -19.58      50.0       2.0      5.06      10.13     -29.71    -1.933
  77.0      -21.94      52.0       2.0      5.18      10.35     -32.29    -2.119
  79.0      -24.33      54.0       2.0      5.29      10.58     -34.91    -2.300
  81.0      -26.75      56.0       2.0      5.40      10.80     -37.55    -2.476
  83.0      -29.21      58.0       2.0      5.51      11.03     -40.24    -2.648
  85.0      -31.70      60.0       2.0      5.63      11.25     -42.96    -2.817
  87.0      -34.23      62.0       2.0      5.74      11.48     -45.71    -2.982
  89.0      -36.80      64.0       2.0      5.85      11.70     -48.51    -3.144
  91.0      -39.41      66.0       2.0      5.96      11.93     -51.34    -3.304
  93.0      -42.06      68.0       2.0      6.08      12.15     -54.21    -3.461
  95.0      -44.74      70.0       2.0      6.19      12.38     -57.12    -3.615
  97.0      -47.47      72.0       2.0      6.30      12.60     -60.07    -3.767
  99.0      -50.24      74.0       2.0      6.41      12.82     -63.06    -3.918
 101.0      -53.05      76.0       2.0      6.52      13.05     -66.10    -4.067
 103.0      -55.91      78.0       2.0      6.63      13.27     -69.18    -4.214
 105.0      -58.81      80.0       2.0      6.74      13.49     -72.29    -4.359
 107.0      -61.75      82.0       2.0      6.85      13.71     -75.46    -4.504
 109.0      -64.74      84.0       2.0      6.97      13.93     -78.67    -4.647

  Tc          QH        DT        Iin       Vin        Pin         QC
DEG. C      WATTS     DEG.C      AMPS     VOLTS      WATTS      WATTS      COPH
------      ------    -----     -----     -----     ------     ------    ------
  25.0       66.59       0.0       4.0      4.57      18.28      48.31     3.643
  27.0       65.06       2.0       4.0      4.69      18.76      46.30     3.468
  29.0       63.52       4.0       4.0      4.81      19.24      44.28     3.301
```

```
  31.0       61.96       6.0       4.0      4.93      19.72      42.24     3.142
  33.0       60.40       8.0       4.0      5.05      20.21      40.19     2.989
  35.0       58.81      10.0       4.0      5.17      20.69      38.12     2.842
  37.0       57.22      12.0       4.0      5.29      21.18      36.04     2.702
  39.0       55.60      14.0       4.0      5.42      21.67      33.94     2.566
  41.0       53.97      16.0       4.0      5.54      22.16      31.82     2.436
  43.0       52.33      18.0       4.0      5.66      22.65      29.68     2.310
  45.0       50.66      20.0       4.0      5.78      23.14      27.52     2.189
  47.0       48.97      22.0       4.0      5.91      23.63      25.34     2.072
  49.0       47.26      24.0       4.0      6.03      24.13      23.14     1.959
  51.0       45.53      26.0       4.0      6.15      24.62      20.91     1.849
  53.0       43.78      28.0       4.0      6.28      25.11      18.67     1.743
  55.0       42.00      30.0       4.0      6.40      25.61      16.39     1.640
  57.0       40.20      32.0       4.0      6.53      26.11      14.10     1.540
  59.0       38.38      34.0       4.0      6.65      26.60      11.77     1.443
  61.0       36.52      36.0       4.0      6.78      27.10       9.42     1.348
  63.0       34.64      38.0       4.0      6.90      27.60       7.04     1.255
  65.0       32.73      40.0       4.0      7.02      28.10       4.64     1.165
  67.0       30.79      42.0       4.0      7.15      28.60       2.20     1.077
  69.0       28.82      44.0       4.0      7.27      29.09      -0.27     0.991
  71.0       26.82      46.0       4.0      7.40      29.59      -2.77     0.906
  73.0       24.79      48.0       4.0      7.52      30.09      -5.30     0.824
  75.0       22.73      50.0       4.0      7.65      30.59      -7.86     0.743
  77.0       20.63      52.0       4.0      7.77      31.09     -10.46     0.664
  79.0       18.49      54.0       4.0      7.90      31.59     -13.10     0.585
  81.0       16.32      56.0       4.0      8.02      32.09     -15.76     0.509
  83.0       14.12      58.0       4.0      8.15      32.58     -18.47     0.433
  85.0       11.87      60.0       4.0      8.27      33.08     -21.21     0.359
  87.0        9.59      62.0       4.0      8.39      33.58     -23.99     0.286
  89.0        7.27      64.0       4.0      8.52      34.07     -26.81     0.213
  91.0        4.90      66.0       4.0      8.64      34.57     -29.67     0.142
  93.0        2.50      68.0       4.0      8.77      35.07     -32.57     0.071
  95.0        0.06      70.0       4.0      8.89      35.56     -35.50     0.002
  97.0       -2.43      72.0       4.0      9.01      36.05     -38.49    -0.068
  99.0       -4.97      74.0       4.0      9.14      36.54     -41.51    -0.136
 101.0       -7.54      76.0       4.0      9.26      37.03     -44.58    -0.204
 103.0      -10.17      78.0       4.0      9.38      37.52     -47.69    -0.271
 105.0      -12.83      80.0       4.0      9.50      38.01     -50.85    -0.338
 107.0      -15.55      82.0       4.0      9.62      38.50     -54.05    -0.404
 109.0      -18.31      84.0       4.0      9.75      38.98     -57.29    -0.470

  Tc          QH        DT        Iin       Vin        Pin         QC
DEG. C      WATTS     DEG.C      AMPS     VOLTS      WATTS      WATTS      COPH
------      ------    -----     -----     -----     ------     ------    ------
  25.0      106.73       0.0       6.0      6.85      41.12      65.61     2.595
  27.0      105.50       2.0       6.0      6.99      41.91      63.59     2.517
  29.0      104.26       4.0       6.0      7.12      42.71      61.55     2.441
  31.0      103.01       6.0       6.0      7.25      43.50      59.50     2.368
  33.0      101.74       8.0       6.0      7.38      44.30      57.44     2.297
  35.0      100.46      10.0       6.0      7.52      45.10      55.36     2.227
  37.0       99.16      12.0       6.0      7.65      45.90      53.26     2.160
  39.0       97.85      14.0       6.0      7.78      46.71      51.14     2.095
  41.0       96.51      16.0       6.0      7.92      47.51      49.00     2.031
  43.0       95.16      18.0       6.0      8.05      48.32      46.84     1.969
  45.0       93.79      20.0       6.0      8.19      49.13      44.66     1.909
  47.0       92.40      22.0       6.0      8.32      49.94      42.46     1.850
  49.0       90.99      24.0       6.0      8.46      50.75      40.23     1.793
  51.0       89.55      26.0       6.0      8.59      51.57      37.98     1.737
  53.0       88.09      28.0       6.0      8.73      52.38      35.71     1.682
  55.0       86.61      30.0       6.0      8.87      53.20      33.41     1.628
  57.0       85.10      32.0       6.0      9.00      54.01      31.09     1.575
  59.0       83.56      34.0       6.0      9.14      54.83      28.73     1.524
  61.0       82.00      36.0       6.0      9.27      55.65      26.35     1.474
  63.0       80.41      38.0       6.0      9.41      56.47      23.94     1.424
```

```
   65.0      78.79      40.0       6.0      9.55     57.29     21.50    1.375
   67.0      77.13      42.0       6.0      9.68     58.11     19.03    1.327
   69.0      75.45      44.0       6.0      9.82     58.93     16.52    1.280
   71.0      73.74      46.0       6.0      9.96     59.75     13.99    1.234
   73.0      71.99      48.0       6.0     10.09     60.57     11.42    1.189
   75.0      70.20      50.0       6.0     10.23     61.39      8.82    1.144
   77.0      68.38      52.0       6.0     10.37     62.21      6.18    1.099
   79.0      66.53      54.0       6.0     10.50     63.03      3.50    1.056
   81.0      64.63      56.0       6.0     10.64     63.84      0.79    1.012
   83.0      62.70      58.0       6.0     10.78     64.66     -1.96    0.970
   85.0      60.73      60.0       6.0     10.91     65.48     -4.75    0.927
   87.0      58.72      62.0       6.0     11.05     66.30     -7.57    0.886
   89.0      56.67      64.0       6.0     11.19     67.11    -10.44    0.844
   91.0      54.57      66.0       6.0     11.32     67.92    -13.35    0.803
   93.0      52.44      68.0       6.0     11.46     68.74    -16.30    0.763
   95.0      50.26      70.0       6.0     11.59     69.55    -19.29    0.723
   97.0      48.03      72.0       6.0     11.73     70.36    -22.33    0.683
   99.0      45.76      74.0       6.0     11.86     71.16    -25.41    0.643
  101.0      43.44      76.0       6.0     11.99     71.97    -28.53    0.604
  103.0      41.07      78.0       6.0     12.13     72.77    -31.70    0.564
  105.0      38.66      80.0       6.0     12.26     73.57    -34.91    0.525
  107.0      36.19      82.0       6.0     12.39     74.37    -38.18    0.487
  109.0      33.68      84.0       6.0     12.53     75.16    -41.48    0.448

   Tc         QH        DT       Iin      Vin      Pin       QC
 DEG. C     WATTS     DEG.C     AMPS     VOLTS    WATTS     WATTS     COPH
 ------     ------    -----     -----    -----    ------    ------   ------
   25.0     151.45       0.0       8.0      9.14     73.11     78.34    2.072
   27.0     150.54       2.0       8.0      9.28     74.26     76.28    2.027
   29.0     149.63       4.0       8.0      9.43     75.41     74.22    1.984
   31.0     148.70       6.0       8.0      9.57     76.57     72.13    1.942
   33.0     147.75       8.0       8.0      9.72     77.72     70.03    1.901
   35.0     146.79      10.0       8.0      9.86     78.89     67.90    1.861
   37.0     145.82      12.0       8.0     10.01     80.05     65.76    1.822
   39.0     144.82      14.0       8.0     10.15     81.22     63.60    1.783
   41.0     143.81      16.0       8.0     10.30     82.39     61.42    1.746
   43.0     142.78      18.0       8.0     10.45     83.56     59.22    1.709
   45.0     141.73      20.0       8.0     10.59     84.74     56.99    1.673
   47.0     140.66      22.0       8.0     10.74     85.91     54.75    1.637
   49.0     139.57      24.0       8.0     10.89     87.09     52.47    1.602
   51.0     138.45      26.0       8.0     11.03     88.27     50.18    1.568
   53.0     137.31      28.0       8.0     11.18     89.46     47.85    1.535
   55.0     136.14      30.0       8.0     11.33     90.64     45.50    1.502
   57.0     134.95      32.0       8.0     11.48     91.82     43.12    1.470
   59.0     133.73      34.0       8.0     11.63     93.01     40.72    1.438
   61.0     132.48      36.0       8.0     11.77     94.20     38.28    1.406
   63.0     131.20      38.0       8.0     11.92     95.39     35.81    1.375
   65.0     129.89      40.0       8.0     12.07     96.57     33.32    1.345
   67.0     128.55      42.0       8.0     12.22     97.76     30.79    1.315
   69.0     127.17      44.0       8.0     12.37     98.95     28.22    1.285
   71.0     125.77      46.0       8.0     12.52    100.14     25.63    1.256
   73.0     124.32      48.0       8.0     12.67    101.33     22.99    1.227
   75.0     122.85      50.0       8.0     12.81    102.52     20.33    1.198
   77.0     121.33      52.0       8.0     12.96    103.71     17.62    1.170
   79.0     119.78      54.0       8.0     13.11    104.89     14.88    1.142
   81.0     118.18      56.0       8.0     13.26    106.08     12.10    1.114
   83.0     116.55      58.0       8.0     13.41    107.26      9.29    1.087
   85.0     114.88      60.0       8.0     13.56    108.45      6.43    1.059
   87.0     113.16      62.0       8.0     13.70    109.63      3.53    1.032
   89.0     111.40      64.0       8.0     13.85    110.81      0.59    1.005
   91.0     109.60      66.0       8.0     14.00    111.99     -2.39    0.979
   93.0     107.75      68.0       8.0     14.15    113.17     -5.41    0.952
   95.0     105.86      70.0       8.0     14.29    114.34     -8.48    0.926
   97.0     103.92      72.0       8.0     14.44    115.51    -11.59    0.900
```

```
   99.0     101.93      74.0       8.0     14.58    116.68    -14.75    0.874
  101.0      99.89      76.0       8.0     14.73    117.84    -17.95    0.848
  103.0      97.80      78.0       8.0     14.88    119.00    -21.20    0.822
  105.0      95.66      80.0       8.0     15.02    120.16    -24.50    0.796
  107.0      93.47      82.0       8.0     15.16    121.32    -27.84    0.770
  109.0      91.23      84.0       8.0     15.31    122.47    -31.24    0.745

   Tc         QH        DT       Iin      Vin      Pin       QC
 DEG. C     WATTS     DEG.C     AMPS     VOLTS    WATTS     WATTS     COPH
 ------     ------    -----     -----    -----    ------    ------   ------
   25.0     200.73       0.0      10.0     11.42    114.23     86.50    1.757
   27.0     200.17       2.0      10.0     11.58    115.79     84.39    1.729
   29.0     199.61       4.0      10.0     11.73    117.35     82.26    1.701
   31.0     199.02       6.0      10.0     11.89    118.91     80.11    1.674
   33.0     198.42       8.0      10.0     12.05    120.48     77.95    1.647
   35.0     197.81      10.0      10.0     12.20    122.05     75.76    1.621
   37.0     197.18      12.0      10.0     12.36    123.62     73.56    1.595
   39.0     196.53      14.0      10.0     12.52    125.20     71.33    1.570
   41.0     195.87      16.0      10.0     12.68    126.78     69.09    1.545
   43.0     195.18      18.0      10.0     12.84    128.37     66.81    1.520
   45.0     194.48      20.0      10.0     13.00    129.96     64.52    1.496
   47.0     193.75      22.0      10.0     13.15    131.55     62.20    1.473
   49.0     193.00      24.0      10.0     13.31    133.14     59.86    1.450
   51.0     192.23      26.0      10.0     13.47    134.74     57.49    1.427
   53.0     191.43      28.0      10.0     13.63    136.34     55.09    1.404
   55.0     190.60      30.0      10.0     13.79    137.94     52.66    1.382
   57.0     189.75      32.0      10.0     13.95    139.54     50.21    1.360
   59.0     188.87      34.0      10.0     14.11    141.14     47.73    1.338
   61.0     187.95      36.0      10.0     14.27    142.74     45.21    1.317
   63.0     187.01      38.0      10.0     14.43    144.35     42.66    1.296
   65.0     186.04      40.0      10.0     14.60    145.96     40.08    1.275
   67.0     185.03      42.0      10.0     14.76    147.56     37.47    1.254
   69.0     183.99      44.0      10.0     14.92    149.17     34.82    1.233
   71.0     182.92      46.0      10.0     15.08    150.77     32.14    1.213
   73.0     181.80      48.0      10.0     15.24    152.38     29.43    1.193
   75.0     180.66      50.0      10.0     15.40    153.98     26.67    1.173
   77.0     179.47      52.0      10.0     15.56    155.59     23.88    1.153
   79.0     178.24      54.0      10.0     15.72    157.19     21.05    1.134
   81.0     176.97      56.0      10.0     15.88    158.79     18.18    1.114
   83.0     175.66      58.0      10.0     16.04    160.39     15.27    1.095
   85.0     174.31      60.0      10.0     16.20    161.99     12.32    1.076
   87.0     172.91      62.0      10.0     16.36    163.58      9.33    1.057
   89.0     171.47      64.0      10.0     16.52    165.18      6.29    1.038
   91.0     169.98      66.0      10.0     16.68    166.77      3.22    1.019
   93.0     168.45      68.0      10.0     16.84    168.35      0.09    1.001
   95.0     166.87      70.0      10.0     16.99    169.94     -3.07    0.982
   97.0     165.23      72.0      10.0     17.15    171.52     -6.28    0.963
   99.0     163.55      74.0      10.0     17.31    173.09     -9.54    0.945
  101.0     161.82      76.0      10.0     17.47    174.66    -12.85    0.926
  103.0     160.03      78.0      10.0     17.62    176.23    -16.20    0.908
  105.0     158.19      80.0      10.0     17.78    177.79    -19.60    0.890
  107.0     156.29      82.0      10.0     17.93    179.35    -23.05    0.871
  109.0     154.34      84.0      10.0     18.09    180.90    -26.55    0.853

   Tc         QH        DT       Iin      Vin      Pin       QC
 DEG. C     WATTS     DEG.C     AMPS     VOLTS    WATTS     WATTS     COPH
 ------     ------    -----     -----    -----    ------    ------   ------
   25.0     254.59       0.0      12.0     13.71    164.50     90.09    1.548
   27.0     254.40       2.0      12.0     13.88    166.50     87.90    1.528
   29.0     254.20       4.0      12.0     14.04    168.51     85.69    1.508
   31.0     253.99       6.0      12.0     14.21    170.53     83.46    1.489
   33.0     253.76       8.0      12.0     14.38    172.56     81.21    1.471
   35.0     253.52      10.0      12.0     14.55    174.58     78.94    1.452
   37.0     253.26      12.0      12.0     14.72    176.62     76.64    1.434
```

39.0	252.98	14.0	12.0	14.89	178.65	74.33	1.416
41.0	252.69	16.0	12.0	15.06	180.70	71.99	1.398
43.0	252.37	18.0	12.0	15.23	182.74	69.63	1.381
45.0	252.03	20.0	12.0	15.40	184.79	67.24	1.364
47.0	251.67	22.0	12.0	15.57	186.85	64.83	1.347
49.0	251.29	24.0	12.0	15.74	188.90	62.39	1.330
51.0	250.88	26.0	12.0	15.91	190.96	59.92	1.314
53.0	250.45	28.0	12.0	16.09	193.02	57.42	1.297
55.0	249.99	30.0	12.0	16.26	195.09	54.90	1.281
57.0	249.50	32.0	12.0	16.43	197.15	52.34	1.265
59.0	248.98	34.0	12.0	16.60	199.22	49.76	1.250
61.0	248.43	36.0	12.0	16.77	201.29	47.14	1.234
63.0	247.85	38.0	12.0	16.95	203.36	44.49	1.219
65.0	247.24	40.0	12.0	17.12	205.43	41.80	1.203
67.0	246.59	42.0	12.0	17.29	207.50	39.09	1.188
69.0	245.91	44.0	12.0	17.46	209.57	36.33	1.173
71.0	245.19	46.0	12.0	17.64	211.64	33.54	1.158
73.0	244.43	48.0	12.0	17.81	213.71	30.71	1.144
75.0	243.63	50.0	12.0	17.98	215.78	27.85	1.129
77.0	242.80	52.0	12.0	18.15	217.85	24.95	1.115
79.0	241.92	54.0	12.0	18.33	219.92	22.00	1.100
81.0	241.00	56.0	12.0	18.50	221.98	19.02	1.086
83.0	240.03	58.0	12.0	18.67	224.04	15.99	1.071
85.0	239.03	60.0	12.0	18.84	226.10	12.93	1.057
87.0	237.97	62.0	12.0	19.01	228.16	9.82	1.043
89.0	236.87	64.0	12.0	19.18	230.21	6.66	1.029
91.0	235.72	66.0	12.0	19.35	232.26	3.47	1.015
93.0	234.52	68.0	12.0	19.53	234.30	0.22	1.001
95.0	233.28	70.0	12.0	19.70	236.34	-3.06	0.987
97.0	231.97	72.0	12.0	19.86	238.37	-6.40	0.973
99.0	230.62	74.0	12.0	20.03	240.40	-9.78	0.959
101.0	229.21	76.0	12.0	20.20	242.43	-13.21	0.945
103.0	227.75	78.0	12.0	20.37	244.44	-16.69	0.932
105.0	226.23	80.0	12.0	20.54	246.45	-20.22	0.918
107.0	224.65	82.0	12.0	20.70	248.45	-23.80	0.904
109.0	223.02	84.0	12.0	20.87	250.45	-27.43	0.890

```
*     *     *     *     *     *     *     *     *     *     *     *     *     *

             SINGLE STAGE MODULE HEATING PERFORMANCE - QH vs TC

NUMBER OF COUPLES IN MODULE.......> 127
OPTIMUM CURRENT IN AMPERES........> 6
HOT SIDE TEMPERATURE IN DEGREES C.> 25
  Note:  DT=Tc-Th and Tc>Th


  Tc          QH         DT         Iin        Vin        Pin          QC
DEG. C      WATTS      DEG.C      AMPS       VOLTS      WATTS       WATTS        COPH
------      ------     -----      -----      -----      ------      ------      ------
  25.0       15.50        0.0        1.0       2.28       2.28       13.22       6.786
  27.0       14.60        2.0        1.0       2.39       2.39       12.21       6.102
  29.0       13.69        4.0        1.0       2.50       2.50       11.19       5.474
  31.0       12.78        6.0        1.0       2.61       2.61       10.17       4.895
  33.0       11.86        8.0        1.0       2.72       2.72        9.14       4.360
  35.0       10.93       10.0        1.0       2.83       2.83        8.10       3.863
  37.0        9.99       12.0        1.0       2.94       2.94        7.05       3.400
  39.0        9.05       14.0        1.0       3.05       3.05        6.00       2.968
  41.0        8.10       16.0        1.0       3.16       3.16        4.94       2.563
  43.0        7.14       18.0        1.0       3.27       3.27        3.87       2.182
  45.0        6.17       20.0        1.0       3.38       3.38        2.79       1.824
  47.0        5.19       22.0        1.0       3.49       3.49        1.69       1.485
  49.0        4.20       24.0        1.0       3.60       3.60        0.59       1.165
  51.0        3.20       26.0        1.0       3.72       3.72       -0.52       0.861
  53.0        2.19       28.0        1.0       3.83       3.83       -1.64       0.571
  55.0        1.16       30.0        1.0       3.94       3.94       -2.78       0.295
  57.0        0.13       32.0        1.0       4.05       4.05       -3.92       0.032
  59.0       -0.92       34.0        1.0       4.16       4.16       -5.08      -0.221
  61.0       -1.98       36.0        1.0       4.28       4.28       -6.25      -0.463
  63.0       -3.05       38.0        1.0       4.39       4.39       -7.44      -0.695
  65.0       -4.14       40.0        1.0       4.50       4.50       -8.64      -0.919
  67.0       -5.24       42.0        1.0       4.61       4.61       -9.85      -1.136
  69.0       -6.35       44.0        1.0       4.73       4.73      -11.08      -1.344
  71.0       -7.48       46.0        1.0       4.84       4.84      -12.32      -1.547
  73.0       -8.63       48.0        1.0       4.95       4.95      -13.58      -1.743
  75.0       -9.79       50.0        1.0       5.06       5.06      -14.85      -1.933
  77.0      -10.97       52.0        1.0       5.18       5.18      -16.15      -2.119
  79.0      -12.16       54.0        1.0       5.29       5.29      -17.45      -2.300
  81.0      -13.37       56.0        1.0       5.40       5.40      -18.78      -2.476
  83.0      -14.60       58.0        1.0       5.51       5.51      -20.12      -2.648
  85.0      -15.85       60.0        1.0       5.63       5.63      -21.48      -2.817
  87.0      -17.12       62.0        1.0       5.74       5.74      -22.86      -2.982
  89.0      -18.40       64.0        1.0       5.85       5.85      -24.25      -3.144
  91.0      -19.71       66.0        1.0       5.96       5.96      -25.67      -3.304
  93.0      -21.03       68.0        1.0       6.08       6.08      -27.11      -3.461
  95.0      -22.37       70.0        1.0       6.19       6.19      -28.56      -3.615
  97.0      -23.74       72.0        1.0       6.30       6.30      -30.04      -3.767
  99.0      -25.12       74.0        1.0       6.41       6.41      -31.53      -3.918
 101.0      -26.53       76.0        1.0       6.52       6.52      -33.05      -4.067
 103.0      -27.95       78.0        1.0       6.63       6.63      -34.59      -4.214
 105.0      -29.40       80.0        1.0       6.74       6.74      -36.15      -4.359
 107.0      -30.87       82.0        1.0       6.85       6.85      -37.73      -4.504
 109.0      -32.37       84.0        1.0       6.97       6.97      -39.33      -4.647

  Tc          QH         DT         Iin        Vin        Pin          QC
DEG. C      WATTS      DEG.C      AMPS       VOLTS      WATTS       WATTS        COPH
------      ------     -----      -----      -----      ------      ------      ------
  25.0       33.29        0.0        2.0       4.57       9.14       24.15       3.643
  27.0       32.53        2.0        2.0       4.69       9.38       23.15       3.468
  29.0       31.76        4.0        2.0       4.81       9.62       22.14       3.301
  31.0       30.98        6.0        2.0       4.93       9.86       21.12       3.142
  33.0       30.20        8.0        2.0       5.05      10.10       20.09       2.989
  35.0       29.41       10.0        2.0       5.17      10.35       19.06       2.842
  37.0       28.61       12.0        2.0       5.29      10.59       18.02       2.702
  39.0       27.80       14.0        2.0       5.42      10.83       16.97       2.566
  41.0       26.99       16.0        2.0       5.54      11.08       15.91       2.436
  43.0       26.16       18.0        2.0       5.66      11.32       14.84       2.310
  45.0       25.33       20.0        2.0       5.78      11.57       13.76       2.189
  47.0       24.49       22.0        2.0       5.91      11.82       12.67       2.072
  49.0       23.63       24.0        2.0       6.03      12.06       11.57       1.959
  51.0       22.77       26.0        2.0       6.15      12.31       10.46       1.849
  53.0       21.89       28.0        2.0       6.28      12.56        9.33       1.743
  55.0       21.00       30.0        2.0       6.40      12.81        8.20       1.640
  57.0       20.10       32.0        2.0       6.53      13.05        7.05       1.540
  59.0       19.19       34.0        2.0       6.65      13.30        5.89       1.443
  61.0       18.26       36.0        2.0       6.78      13.55        4.71       1.348
  63.0       17.32       38.0        2.0       6.90      13.80        3.52       1.255
  65.0       16.37       40.0        2.0       7.02      14.05        2.32       1.165
  67.0       15.40       42.0        2.0       7.15      14.30        1.10       1.077
  69.0       14.41       44.0        2.0       7.27      14.55       -0.13       0.991
  71.0       13.41       46.0        2.0       7.40      14.80       -1.38       0.906
  73.0       12.40       48.0        2.0       7.52      15.05       -2.65       0.824
  75.0       11.36       50.0        2.0       7.65      15.30       -3.93       0.743
  77.0       10.31       52.0        2.0       7.77      15.54       -5.23       0.664
  79.0        9.25       54.0        2.0       7.90      15.79       -6.55       0.585
  81.0        8.16       56.0        2.0       8.02      16.04       -7.88       0.509
  83.0        7.06       58.0        2.0       8.15      16.29       -9.23       0.433
  85.0        5.94       60.0        2.0       8.27      16.54      -10.60       0.359
  87.0        4.79       62.0        2.0       8.39      16.79      -11.99       0.286
  89.0        3.63       64.0        2.0       8.52      17.04      -13.40       0.213
  91.0        2.45       66.0        2.0       8.64      17.29      -14.83       0.142
  93.0        1.25       68.0        2.0       8.77      17.53      -16.28       0.071
  95.0        0.03       70.0        2.0       8.89      17.78      -17.75       0.002
  97.0       -1.22       72.0        2.0       9.01      18.03      -19.24      -0.068
  99.0       -2.48       74.0        2.0       9.14      18.27      -20.76      -0.136
 101.0       -3.77       76.0        2.0       9.26      18.52      -22.29      -0.204
 103.0       -5.08       78.0        2.0       9.38      18.76      -23.84      -0.271
 105.0       -6.42       80.0        2.0       9.50      19.01      -25.42      -0.338
 107.0       -7.77       82.0        2.0       9.62      19.25      -27.02      -0.404
 109.0       -9.15       84.0        2.0       9.75      19.49      -28.65      -0.470

  Tc          QH         DT         Iin        Vin        Pin          QC
DEG. C      WATTS      DEG.C      AMPS       VOLTS      WATTS       WATTS        COPH
------      ------     -----      -----      -----      ------      ------      ------
  25.0       53.37        0.0        3.0       6.85      20.56       32.80       2.595
  27.0       52.75        2.0        3.0       6.99      20.96       31.79       2.517
  29.0       52.13        4.0        3.0       7.12      21.35       30.78       2.441
  31.0       51.50        6.0        3.0       7.25      21.75       29.75       2.368
  33.0       50.87        8.0        3.0       7.38      22.15       28.72       2.297
  35.0       50.23       10.0        3.0       7.52      22.55       27.68       2.227
  37.0       49.58       12.0        3.0       7.65      22.95       26.63       2.160
  39.0       48.92       14.0        3.0       7.78      23.35       25.57       2.095
  41.0       48.26       16.0        3.0       7.92      23.76       24.50       2.031
  43.0       47.58       18.0        3.0       8.05      24.16       23.42       1.969
  45.0       46.90       20.0        3.0       8.19      24.57       22.33       1.909
  47.0       46.20       22.0        3.0       8.32      24.97       21.23       1.850
  49.0       45.49       24.0        3.0       8.46      25.38       20.12       1.793
  51.0       44.78       26.0        3.0       8.59      25.78       18.99       1.737
  53.0       44.05       28.0        3.0       8.73      26.19       17.86       1.682
  55.0       43.30       30.0        3.0       8.87      26.60       16.71       1.628
  57.0       42.55       32.0        3.0       9.00      27.01       15.54       1.575
  59.0       41.78       34.0        3.0       9.14      27.42       14.37       1.524
  61.0       41.00       36.0        3.0       9.27      27.82       13.18       1.474
  63.0       40.20       38.0        3.0       9.41      28.23       11.97       1.424
```

```
  65.0      39.39      40.0       3.0      9.55      28.64      10.75     1.375
  67.0      38.57      42.0       3.0      9.68      29.05       9.51     1.327
  69.0      37.73      44.0       3.0      9.82      29.46       8.26     1.280
  71.0      36.87      46.0       3.0      9.96      29.87       6.99     1.234
  73.0      35.99      48.0       3.0     10.09      30.28       5.71     1.189
  75.0      35.10      50.0       3.0     10.23      30.69       4.41     1.144
  77.0      34.19      52.0       3.0     10.37      31.10       3.09     1.099
  79.0      33.26      54.0       3.0     10.50      31.51       1.75     1.056
  81.0      32.32      56.0       3.0     10.64      31.92       0.40     1.012
  83.0      31.35      58.0       3.0     10.78      32.33      -0.98     0.970
  85.0      30.37      60.0       3.0     10.91      32.74      -2.37     0.927
  87.0      29.36      62.0       3.0     11.05      33.15      -3.79     0.886
  89.0      28.33      64.0       3.0     11.19      33.56      -5.22     0.844
  91.0      27.29      66.0       3.0     11.32      33.96      -6.67     0.803
  93.0      26.22      68.0       3.0     11.46      34.37      -8.15     0.763
  95.0      25.13      70.0       3.0     11.59      34.77      -9.65     0.723
  97.0      24.01      72.0       3.0     11.73      35.18     -11.16     0.683
  99.0      22.88      74.0       3.0     11.86      35.58     -12.70     0.643
 101.0      21.72      76.0       3.0     11.99      35.98     -14.26     0.604
 103.0      20.54      78.0       3.0     12.13      36.39     -15.85     0.564
 105.0      19.33      80.0       3.0     12.26      36.79     -17.46     0.525
 107.0      18.10      82.0       3.0     12.39      37.18     -19.09     0.487
 109.0      16.84      84.0       3.0     12.53      37.58     -20.74     0.448

   Tc         QH        DT        Iin       Vin        Pin         QC
 DEG. C     WATTS     DEG.C      AMPS      VOLTS      WATTS      WATTS      COPH
 ------     ------    -----      -----     -----      ------     ------    ------
  25.0      75.72       0.0       4.0      9.14      36.55      39.17     2.072
  27.0      75.27       2.0       4.0      9.28      37.13      38.14     2.027
  29.0      74.81       4.0       4.0      9.43      37.71      37.11     1.984
  31.0      74.35       6.0       4.0      9.57      38.28      36.06     1.942
  33.0      73.88       8.0       4.0      9.72      38.86      35.01     1.901
  35.0      73.40      10.0       4.0      9.86      39.44      33.95     1.861
  37.0      72.91      12.0       4.0     10.01      40.03      32.88     1.822
  39.0      72.41      14.0       4.0     10.15      40.61      31.80     1.783
  41.0      71.91      16.0       4.0     10.30      41.19      30.71     1.746
  43.0      71.39      18.0       4.0     10.45      41.78      29.61     1.709
  45.0      70.87      20.0       4.0     10.59      42.37      28.50     1.673
  47.0      70.33      22.0       4.0     10.74      42.96      27.37     1.637
  49.0      69.78      24.0       4.0     10.89      43.55      26.24     1.602
  51.0      69.22      26.0       4.0     11.03      44.14      25.09     1.568
  53.0      68.65      28.0       4.0     11.18      44.73      23.93     1.535
  55.0      68.07      30.0       4.0     11.33      45.32      22.75     1.502
  57.0      67.47      32.0       4.0     11.48      45.91      21.56     1.470
  59.0      66.86      34.0       4.0     11.63      46.51      20.36     1.438
  61.0      66.24      36.0       4.0     11.77      47.10      19.14     1.406
  63.0      65.60      38.0       4.0     11.92      47.69      17.91     1.375
  65.0      64.94      40.0       4.0     12.07      48.29      16.66     1.345
  67.0      64.27      42.0       4.0     12.22      48.88      15.39     1.315
  69.0      63.59      44.0       4.0     12.37      49.48      14.11     1.285
  71.0      62.88      46.0       4.0     12.52      50.07      12.81     1.256
  73.0      62.16      48.0       4.0     12.67      50.66      11.50     1.227
  75.0      61.42      50.0       4.0     12.81      51.26      10.16     1.198
  77.0      60.67      52.0       4.0     12.96      51.85       8.81     1.170
  79.0      59.89      54.0       4.0     13.11      52.45       7.44     1.142
  81.0      59.09      56.0       4.0     13.26      53.04       6.05     1.114
  83.0      58.28      58.0       4.0     13.41      53.63       4.64     1.087
  85.0      57.44      60.0       4.0     13.56      54.22       3.21     1.059
  87.0      56.58      62.0       4.0     13.70      54.82       1.77     1.032
  89.0      55.70      64.0       4.0     13.85      55.41       0.30     1.005
  91.0      54.80      66.0       4.0     14.00      55.99      -1.19     0.979
  93.0      53.88      68.0       4.0     14.15      56.58      -2.71     0.952
  95.0      52.93      70.0       4.0     14.29      57.17      -4.24     0.926
  97.0      51.96      72.0       4.0     14.44      57.76      -5.80     0.900
  99.0      50.96      74.0       4.0     14.58      58.34      -7.37     0.874
 101.0      49.95      76.0       4.0     14.73      58.92      -8.98     0.848
 103.0      48.90      78.0       4.0     14.88      59.50     -10.60     0.822
 105.0      47.83      80.0       4.0     15.02      60.08     -12.25     0.796
 107.0      46.74      82.0       4.0     15.16      60.66     -13.92     0.770
 109.0      45.62      84.0       4.0     15.31      61.23     -15.62     0.745

   Tc         QH        DT        Iin       Vin        Pin         QC
 DEG. C     WATTS     DEG.C      AMPS      VOLTS      WATTS      WATTS      COPH
 ------     ------    -----      -----     -----      ------     ------    ------
  25.0     100.37       0.0       5.0     11.42      57.12      43.25     1.757
  27.0     100.09       2.0       5.0     11.58      57.89      42.19     1.729
  29.0      99.80       4.0       5.0     11.73      58.67      41.13     1.701
  31.0      99.51       6.0       5.0     11.89      59.45      40.06     1.674
  33.0      99.21       8.0       5.0     12.05      60.24      38.97     1.647
  35.0      98.91      10.0       5.0     12.20      61.02      37.88     1.621
  37.0      98.59      12.0       5.0     12.36      61.81      36.78     1.595
  39.0      98.27      14.0       5.0     12.52      62.60      35.67     1.570
  41.0      97.93      16.0       5.0     12.68      63.39      34.54     1.545
  43.0      97.59      18.0       5.0     12.84      64.18      33.41     1.520
  45.0      97.24      20.0       5.0     13.00      64.98      32.26     1.496
  47.0      96.88      22.0       5.0     13.15      65.77      31.10     1.473
  49.0      96.50      24.0       5.0     13.31      66.57      29.93     1.450
  51.0      96.11      26.0       5.0     13.47      67.37      28.74     1.427
  53.0      95.71      28.0       5.0     13.63      68.17      27.54     1.404
  55.0      95.30      30.0       5.0     13.79      68.97      26.33     1.382
  57.0      94.87      32.0       5.0     13.95      69.77      25.10     1.360
  59.0      94.43      34.0       5.0     14.11      70.57      23.86     1.338
  61.0      93.98      36.0       5.0     14.27      71.37      22.60     1.317
  63.0      93.51      38.0       5.0     14.43      72.17      21.33     1.296
  65.0      93.02      40.0       5.0     14.60      72.98      20.04     1.275
  67.0      92.52      42.0       5.0     14.76      73.78      18.74     1.254
  69.0      92.00      44.0       5.0     14.92      74.58      17.41     1.233
  71.0      91.46      46.0       5.0     15.08      75.39      16.07     1.213
  73.0      90.90      48.0       5.0     15.24      76.19      14.71     1.193
  75.0      90.33      50.0       5.0     15.40      76.99      13.34     1.173
  77.0      89.73      52.0       5.0     15.56      77.79      11.94     1.153
  79.0      89.12      54.0       5.0     15.72      78.60      10.52     1.134
  81.0      88.49      56.0       5.0     15.88      79.40       9.09     1.114
  83.0      87.83      58.0       5.0     16.04      80.20       7.64     1.095
  85.0      87.15      60.0       5.0     16.20      80.99       6.16     1.076
  87.0      86.46      62.0       5.0     16.36      81.79       4.66     1.057
  89.0      85.74      64.0       5.0     16.52      82.59       3.15     1.038
  91.0      84.99      66.0       5.0     16.68      83.38       1.61     1.019
  93.0      84.22      68.0       5.0     16.84      84.18       0.05     1.001
  95.0      83.43      70.0       5.0     16.99      84.97      -1.54     0.982
  97.0      82.62      72.0       5.0     17.15      85.76      -3.14     0.963
  99.0      81.77      74.0       5.0     17.31      86.55      -4.77     0.945
 101.0      80.91      76.0       5.0     17.47      87.33      -6.42     0.926
 103.0      80.01      78.0       5.0     17.62      88.11      -8.10     0.908
 105.0      79.09      80.0       5.0     17.78      88.89      -9.80     0.890
 107.0      78.15      82.0       5.0     17.93      89.67     -11.53     0.871
 109.0      77.17      84.0       5.0     18.09      90.45     -13.28     0.853

   Tc         QH        DT        Iin       Vin        Pin         QC
 DEG. C     WATTS     DEG.C      AMPS      VOLTS      WATTS      WATTS      COPH
 ------     ------    -----      -----     -----      ------     ------    ------
  25.0     127.29       0.0       6.0     13.71      82.25      45.05     1.548
  27.0     127.20       2.0       6.0     13.88      83.25      43.95     1.528
  29.0     127.10       4.0       6.0     14.04      84.26      42.84     1.508
  31.0     126.99       6.0       6.0     14.21      85.27      41.73     1.489
  33.0     126.88       8.0       6.0     14.38      86.28      40.60     1.471
  35.0     126.76      10.0       6.0     14.55      87.29      39.47     1.452
  37.0     126.63      12.0       6.0     14.72      88.31      38.32     1.434
```

39.0	126.49	14.0	6.0	14.89	89.33	37.16	1.416
41.0	126.34	16.0	6.0	15.06	90.35	35.99	1.398
43.0	126.19	18.0	6.0	15.23	91.37	34.81	1.381
45.0	126.02	20.0	6.0	15.40	92.40	33.62	1.364
47.0	125.84	22.0	6.0	15.57	93.42	32.41	1.347
49.0	125.64	24.0	6.0	15.74	94.45	31.19	1.330
51.0	125.44	26.0	6.0	15.91	95.48	29.96	1.314
53.0	125.22	28.0	6.0	16.09	96.51	28.71	1.297
55.0	124.99	30.0	6.0	16.26	97.54	27.45	1.281
57.0	124.75	32.0	6.0	16.43	98.58	26.17	1.265
59.0	124.49	34.0	6.0	16.60	99.61	24.88	1.250
61.0	124.22	36.0	6.0	16.77	100.65	23.57	1.234
63.0	123.92	38.0	6.0	16.95	101.68	22.24	1.219
65.0	123.62	40.0	6.0	17.12	102.72	20.90	1.203
67.0	123.29	42.0	6.0	17.29	103.75	19.54	1.188
69.0	122.95	44.0	6.0	17.46	104.79	18.17	1.173
71.0	122.59	46.0	6.0	17.64	105.82	16.77	1.158
73.0	122.21	48.0	6.0	17.81	106.86	15.36	1.144
75.0	121.82	50.0	6.0	17.98	107.89	13.92	1.129
77.0	121.40	52.0	6.0	18.15	108.93	12.47	1.115
79.0	120.96	54.0	6.0	18.33	109.96	11.00	1.100
81.0	120.50	56.0	6.0	18.50	110.99	9.51	1.086
83.0	120.02	58.0	6.0	18.67	112.02	8.00	1.071
85.0	119.51	60.0	6.0	18.84	113.05	6.46	1.057
87.0	118.99	62.0	6.0	19.01	114.08	4.91	1.043
89.0	118.44	64.0	6.0	19.18	115.10	3.33	1.029
91.0	117.86	66.0	6.0	19.35	116.13	1.73	1.015
93.0	117.26	68.0	6.0	19.53	117.15	0.11	1.001
95.0	116.64	70.0	6.0	19.70	118.17	-1.53	0.987
97.0	115.99	72.0	6.0	19.86	119.19	-3.20	0.973
99.0	115.31	74.0	6.0	20.03	120.20	-4.89	0.959
101.0	114.61	76.0	6.0	20.20	121.21	-6.61	0.945
103.0	113.87	78.0	6.0	20.37	122.22	-8.35	0.932
105.0	113.12	80.0	6.0	20.54	123.23	-10.11	0.918
107.0	112.33	82.0	6.0	20.70	124.23	-11.90	0.904
109.0	111.51	84.0	6.0	20.87	125.22	-13.71	0.890