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Feasibility of Peltier Chips as Thermoelectric Generators on Heatsinks

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Abstract

As the demand of computer processing grows, the burden placed on CPUs will increase as well. Computing systems produce heat, which is attracted to a metal heatsink where it is dissipated out of the system by a fan. Liquid cooling can be more effective, but is more expensive and increases the risk of damaging leaks. Peltier chips, electronic components which transfer heat into electricity, can be used in an effort to reclaim and reuse some of this waste heat. This experiment tested twelve heatsinks of various designs to maximize the effect of the Peltier chip. Variations in designs of the heatsinks allowed for inspection of designs which are not commonly seen in computer heatsinks to evaluate previously untested heatsink designs for use with Peltier chips. Coupled with collected data, this allowed for inspection of both quantitative and qualitative factors which govern the magnitude of the output voltage from the Peltier chip. In addition, five configurations of the heatsink, Peltier chip, and fan were tested, searching for arrangements that yield higher voltages at the lowest possible temperatures. Data showed that while voltages can be increased by various methods, the same methods have costs which render their widespread use unrealistic. Heatsinks should be redesigned to accommodate Peltier chips and avoid wasted energy. Improvements in heatsink designs were proposed which may help increase the output voltage.

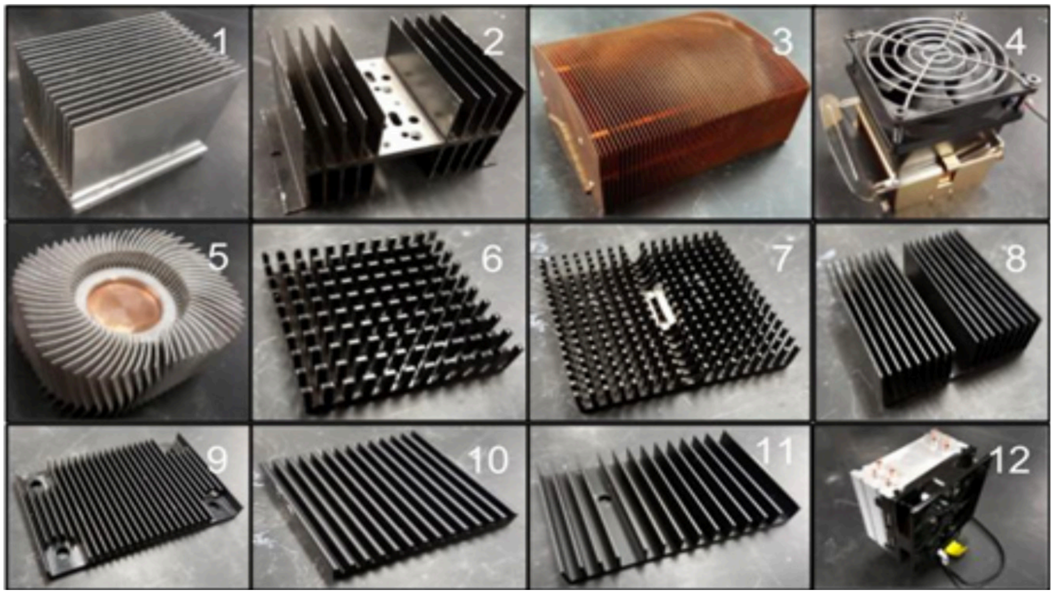
Introduction

In computers, processing units create heat, which is dangerous when it builds up. To eliminate this heat, computers have heatsinks—pieces of metal which attract heat. A fan then pushes the hot air out of the computer. Heat is a form of energy, and currently this energy is being wasted. Peltier chips are electronic components which consist of two different semiconductors encased in a ceramic coating. The semiconductors, by nature, conduct electricity only when certain temperature and chemical composition criteria are met. When heat flows through each semiconductor and meets at a junction, a potential difference is produced by the Seebeck effect.1 The process can also run in reverse, where a voltage through the Peltier chip will cause one side to heat up and the other to cool. This is called the Peltier effect.1,2 Peltier chips designed for room temperature use are typically manufactured with bismuth and tellurium as the two semiconductors. Previous experiments have shown Peltier chips to have limited efficiency and therefore limited effectiveness.3 Research by Sajid et al. suggests cooling the cold side of the chip is not as effective,4 and as such this experiment primarily focused on heating the hot side and locating heat buildup on the heatsink. If Peltier chips can be used to generate additional electricity, it could be used to recharge a laptop battery, or slowly charge a backup battery in a process called trickle charging.

Methodology

A fitted copper sheet was placed on a hot plate, with various heatsinks set on top in turn. A Peltier chip was attached to each heatsink using Sywon thermal tape with 2 centimeter width. Multiple strips were used to fully cover and secure the chip. Arctic MX-4 thermal compound was also used for increased adhesion and heat transfer where a flat surface on the heatsink was available. The copper sheet was used to keep the hot plate clean of thermal tape and thermal compound and simultaneously transfer heat from the hot plate to the heatsink on top. Computer fans were connected to power supplies to mimic the forced convection a heatsink experiences in a computer. For each of the heatsinks, a control trial was performed to determine its normal heating and cooling cycle with a fan. Vernier stainless steel and wire temperature probes measured the temperature at different points on the heatsink. The points were at equal height on the heatsink so the temperature can be assumed to be nearly equal to the surface beneath the Peltier chip. Two types of probes were used because the wire probe provided flexibility, but it became less accurate at high temperatures. A steel probe was also placed on the cold side of the Peltier chip. A Vernier differential voltage probe measured the voltage output from the Peltier chip. The graphical results were obtained using the Vernier software LoggerPro. Pictures of the tested heatsinks are shown in Figure 1, and descriptions in Table 1.

Figure 1 - Composite image of the twelve heatsinks tested



A 12 centimeter by 12 centimeter 12 Volt fan was used in the setups for Heatsinks 1, 2, 3 and 5. A smaller fan, 8 centimeter by 8 centimeter, but also 12 Volts was used with Heatsinks 6-11. Heatsinks 4 and 12 were tested with the fans they were manufactured with. This allowed for testing of each heatsink in a manner most similar to its intended purpose based on its size. Larger heatsinks are used in larger electronics which produce more heat and consequently have larger fans, and therefore the fans were changed so the setup would be as realistic as possible. In every case, each individual heatsink was tested with the same fan throughout all of its trials to maintain consistency.

Twelve different heatsinks of various designs were tested, and their maximum temperatures with and without the Peltier chip attached were recorded. To improve efficiency, several different configurations of the above-mentioned materials were tested. These tests were only conducted on Heatsink 1, because it has a design typical of a heatsink found in computers, and produced voltages substantial enough to easily measure any variation resulting from changing the setup. The tested configurations included;

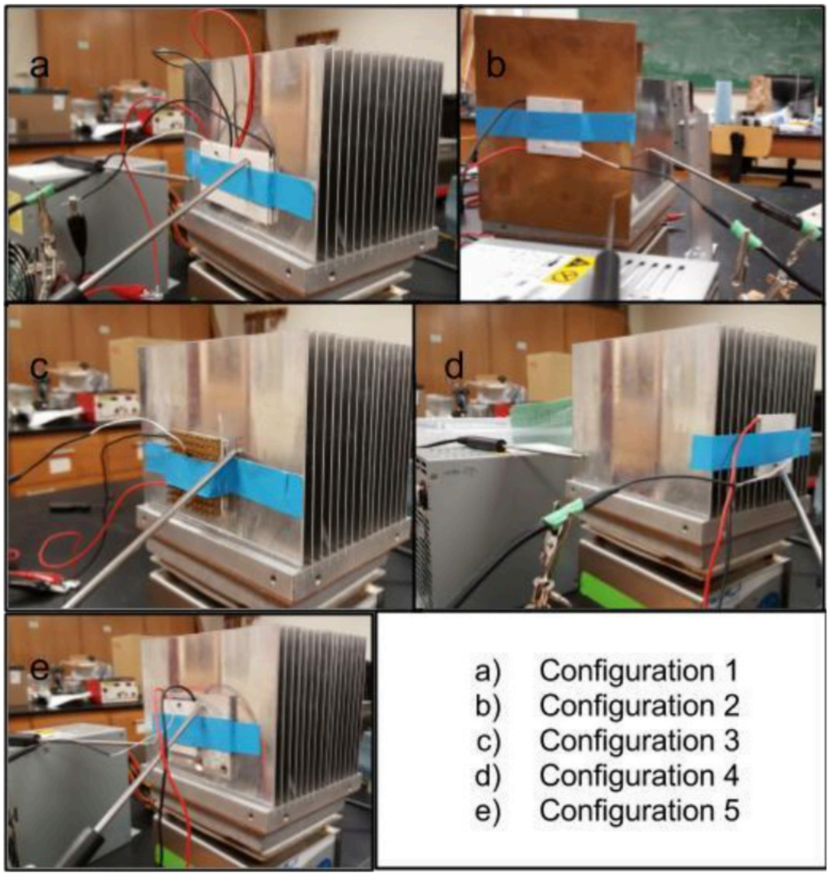
1) Using two Peltier chips on the same heatsink,
2) Placing a copper sheet at the back of the heatsink and placing the Peltier chip on the reverse,
3) Placing a second, smaller heatsink on the cold side of the Peltier chip,
4) Placing the Peltier chip between the fan and the heatsink in effort to cool the cold side, and
5) Placing the Peltier chip in a hole milled in a piece of aluminum, in an effort to encompass the hot side of the Peltier chip.

These modifications can be seen in Figure 2.

Table 1 - List of materials and dimensions of the twelve tested heatsinks

Heatsink Number	Primary Material	Dimensions (cm)	Description
1	Aluminum	15.2 x 12 x 12.2	Bonded fin, 16 fins
2	Aluminum	12.2 x 7.7 x 6.3	Looks like a radio antenna, symmetrical, five fins on each side
3	Copper	8.3 x 6.9 x 3.8	55 fins, domed in the middle
4	Copper	8.3 x 6.9 x 3.8	Similar to Heatsink 3 but has a custom fan and case.
5	Aluminum with copper core	8.2 x 6.9 x 3.6	Rounded rectangle, 66 aluminum fins, 3 cm diameter copper cylinder through middle
6	Aluminum	3.8 x 3.8 x .9	120 0.2 x 0.1 pins
7	Aluminum	4 x 4 x 1	272 0.05 * .1 cm pins separated in two sections by a . 4 cm split for a removed z-mount
8	Aluminum	4.5 x 4.5 x 1.9	18 fins split in two sections by a 0.6 cm gap.
9	Aluminum	5.8 x 3.7 x .6	26 fins, some lengths adjusted to allow for four holes on the corners.
10	Aluminum	4.5 x 4.5 x .7	14 fins, thick
11	Aluminum	7.3 x 4.9 x 1.1	14 fins, two wide gaps to allow for mounting holes
12	Aluminum with copper heat pipes	11.5 x 5.0 x 15.5	57 fins, 4 heat pipes which lie on the processor

Figure 2 – Composite image of the five tested Configurations



For Configuration 1, it was expected that the voltage output would be slightly more than doubled. This is because the Peltier chips are assumed to be equally effective, and the increased area of the heatsink they cover will lead to a greater heat build-up, increasing the temperature on the hot side. Configuration 2 was tested on the hypothesis that the fan blows hot air out through the fins, so the copper sheet would serve to absorb that heat. The Peltier chip works by heat transfer, so cooling the cold side was thought to serve as potentially useful. In Configuration 3, the second heatsink was proposed to pull heat from the cold side. Configuration 4 was predicted to work by similar logic. The cold side is predicted to stay cooler, but there will be much less contact area on the heatsink. Configuration 5 would ideally help trap heat around all four edges of the chip in addition to the hot side and shelter it from the cold air pushed by the fan. Since this setup had a separate piece of metal attached to the heatsink, a control trial was performed with the milled piece flipped over and the Peltier chip fixed to the flat side of the aluminum.

All five Configurations were predicted to either cool the cold side of the chip or heat the hot side, but the effects of turbulent air flow and how much of an improvement it is over attaching a Peltier chip on the side of the heatsink remain unknown and may hinder their practicality.

Results

The recorded results for the twelve tested heatsinks can be seen in Table 2. The similar data for the five various configurations follow in Tables 3-9.

Table 2 - Maximum voltages and corresponding temperatures for the twelve tested heatsinks

Heatsink	Maximum Temperature Without Peltier Chip (°C)	Maximum Temperature with Peltier Chip (°C)	Temperature Differential (°C)	Maximum Voltage (V)
1	45.53	44.23	1.30	0.3604
2	69.60	49.60	20.00	0.2518
3	40.59	46.09	-5.50	0.1297
4	40.08	38.02	2.06	0.0550
5	52.75	42.68	10.07	0.1816
6	35.92	41.13	-5.21	0.1694
7	43.89	61.39	-17.50	0.2976
8	32.78	49.36	-16.58	0.2396
9	31.06	41.77	-10.71	0.4380
10	43.58	49.10	-5.52	0.3434
11	46.20	63.14	-16.94	0.3953
12	25.76	36.53	-10.77	0.0351

Table 3 - Collected data for the standard configuration

Standard Configuration	Maximum Voltage (V)	Heatsink Temperature (Wire Probe) (°C)	Heatsink Temperature (Steel Probe) (°C)	Temperature Average (°C)	Peltier Chip Temperature (°C)
Trial 1	0.2030	32.0	28.1	30.1	40.9
Trial 2	0.2213	32.5	28.9	30.7	39.6
Trial 3	0.2213	32.1	28.9	30.5	39.1
Averages	0.2152	32.2	28.6	30.4	39.9

Table 4 - Collected data for Configuration 1

Configuration 1	Maximum Voltage (V)	Temperature of Heatsink (°C)	Peltier Chip Temperature (°C)
Trial 1	0.3434	34.2	33.7
Trial 2	0.3464	33.9	32.5
Trial 3	0.2854	42.6	36.1
Averages	0.3251	36.9	34.1

Table 5 - Collected data for Configuration 2

Configuration 2	Maximum Voltage (V)	Temperature of Copper Plate (°C)	Temperature of Heatsink (°C)	Peltier Chip Temperature (°C)
Trial 1	0.2030	28.6	37.3	29.8
Trial 2	0.1522	26.8	31.5	26.7
Trial 3	0.1938	27.6	32.0	28.3
Averages	0.1830	27.7	33.6	28.3

Table 6 - Collected data for Configuration 3

Configuration 3	Maximum Voltage (V)	Temperature of Heatsink 1 (°C)	Temperature of Heatsink 6 (°C)
Trial 1	0.1725	33.4	38.2
Trial 2	0.1908	29.8	37.8
Trial 3	0.2122	40.3	32.6
Averages	0.01918	34.5	36.2

Table 7 - Collected data for Configuration 4

Configuration 4	Maximum Voltage (V)	Heatsink Temperature (Wire Probe) (°C)	Heatsink Temperature (Steel Probe) (°C)	Average Heatsink Temperature (°C)	Peltier Chip Temperature (°C)
Trial 1	0.1999	31.0	32.1	31.6	26.3
Trial 2	0.319	40.5	41.7	41.1	26.9
Trial 3	0.3098	39.7	41.2	40.5	26.6
Averages	0.2762	37.1	38.3	37.7	26.6

Table 8 - Collected data for Configuration 5

Configuration 5	Maximum Voltage (V)	Peltier Chip Temperature (°C)	Aluminum Temperature (°C)	Heatsink Temperature (°C)
Trial 1	0.1938	38.0	34.4	42.9
Trial 2	0.1175	33.8	27.9	30.6
Trial 3	0.1541	32.0	31.3	39.4
Averages	0.1551	34.6	31.2	37.6

Table 9 - Collected data for the control of Configuration 5

Configuration 5 Control	Maximum Voltage (V)	Peltier Chip Temperature (°C)	Aluminum Temperature (°C)	Heatsink Temperature (°C)
Trial 1	0.1999	34.2	31.6	42.7
Trial 2	0.1480	30.0	29.6	41.0
Trial 3	0.1419	30.3	29.4	40.1
Averages	0.1633	31.5	30.2	41.3

Analysis

An expected result was that when the Peltier chip was applied, the temperature of the heatsink would increase. This was due to the Peltier chip covering up part of the heatsink surface, which limits its capacity to attract heat. Heatsinks 6 through 11 did see a decrease, and that may be due to the fact that the Peltier chip is the same size or slightly smaller than those heatsinks. As for heatsinks 1 through 5 and 12, which were larger, the absence of a temperature drop may be explained by a few reasons. First, heatsinks 1 and 4 saw very small increases, which may not be consistent given additional trials. Second, the designs of heatsinks 2 and 5 differ greatly from most computer heatsinks - 2 resembles a radio antenna and may have been used for mounting, and 5 has an unusual shape suggesting it was made for a specific purpose, and has no flat surface for the Peltier chip to be attached to. Heatsink 12 is highly efficient at dissipating heat, and did not allow for any significant thermal energy buildup.

A trend seen in the data is that higher voltages were obtained when testing smaller heatsinks at higher temperatures (usually in the 40 to 50 degree Celsius range). In the way they were tested, the Peltier chip was placed on top of the fins or pins, so it was parallel to the base. This configuration would not restrict airflow with a fan blowing air parallel to the heatsink base.

While two of the tested Configurations produced voltages greater than the standard setup, they were not without effects which compromise their performance. Configuration 1 yielded voltages greater than the standard configuration at lower temperatures, however that was predicted due to the presence of two Peltier chips. The result is that it prevents the heatsink from gathering and dissipating heat effectively.

Configuration 2 gave somewhat lower voltages at approximately the same temperatures. The copper sheet at the back did not absorb enough energy from the hot air pushed back from the fan to be efficient. More heat could be absorbed by the sheet by placing angled metal on top of the heatsink to deflect hot air back towards it, but this would greatly impact the heatsinks ability to dissipate heat.

Configuration 3 had no noticeable increase in voltage. However, there are concerns about what may happen when the system reaches equilibrium and the Peltier chip may begin transferring heat back into the cold side of the Peltier chip.

Configuration 4 produced an increase in voltage at lower temperatures, but the Peltier chip between the fan and the heatsink does block air and likely creates turbulence behind the Peltier chip.

Configuration 5, with the milled piece of aluminum, yielded much lower voltages than the standard configuration. It is important to note, however, that the milled piece was attached to the heatsink with thermal tape, and therefore would not have the same temperature as the heatsink unless the connection was airtight. A further test would be recommended where a hole is milled directly into the heatsink. This was not possible on the heatsink used in this experiment since the thin fins would likely be warped by the force of the mill. Even when comparing the data to its control, however, there is a decrease in voltage output. One possible explanation is that the milled piece was exposed to a large amount of air moved by the fan. This would have a large effect even with a small air gap between the milled piece and the heatsink, since most heat from the heatsink would be blown away by the fan before it reached the milled piece of aluminum.

Conclusions

Several outcomes of this experiment are listed as follows;

1. Using Peltier chips as thermoelectric generators on heatsinks is currently not a reasonable modification.
2. The reasoning for the previous statement is because effective heatsinks don’t store enough thermal energy to generate a practical voltage.
3. Peltier chips could be used in this application if there are improvements in Peltier chip materials or heatsink design.

It was expected that the addition of a Peltier chip would increase the temperature of the heatsink, and this was confirmed. On all the smaller heatsinks, (6-11) temperature increases of at least 5 degrees Celsius were observed. The larger heatsinks experienced smaller increases in temperature, but this may still be unfavorable. A temperature increase in the heatsink signals a concurring decrease in efficiency of the heatsink. Over a long period of time, this will contribute to a thermal energy buildup in the computer if it is running for several hours.

To adapt Peltier chip technology to heatsinks, there will have to be a design change in either heatsinks or Peltier chips. On the latter, a recent development is using organic, polymer-based conductors in the chips5. Thus far, the method has had limited success, but remains promising as more about the conductive nature of the polymers becomes known. As for redesigning heatsinks, this experiment showed that cooling the cold side is effective, but not practical for air flow. Instead, future designs should focus on heating the opposite side. One possibility, as mentioned above, is to test a heatsink with a milled hole to fit a Peltier chip directly into one of the outside fins. This would have more heat flowing directly into the Peltier chip than what was tested in this experiment. Another possibility is to have the hot side of the Peltier chip on the top of the base, and the bottom of the fins arched slightly to allow room for the Peltier chip. This may cause turbulence, but the resulting airflow could potentially cool the cold side of the Peltier chip.

The authors of this paper see the current state of this applied technology is not efficient for practical usage without improvements. With a small increase in voltage output, perhaps to the 0.5 Volt range, trickle charging may be an efficient option to charge computers and other electronics as their batteries are being used. For comparison, a typical computer fan has a maximum input of 12 Volts, so a self-cooling setup requires more efficient technology.

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