Enhancing Computer Heat Sink Design with Phase Change Thermal Energy Storage and Thermoelectric Generators

Daniel Kaminski
Advisor: Dr. Crowthers

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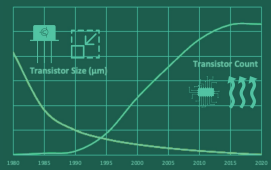
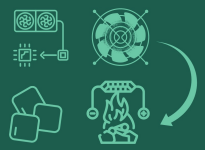
Introduction



CPUs

- Transistor sizes have been shrinking over the past 40 years, with the maximum possible transistor density doubling every two years
- Following the increase in transistor counts, the heat flux of processors has been increasing, and keeping a processor cool is essential
- The capabilites of CPUs reach a limit if cooling performance is not increased



Utilizing Heat

- Common cooling solutions use fans or water loops, but these methods end up releasing the heat into the environment without utilizing it
- Heat can be stored with either thermochemical, phase change, or sensible thermal energy storage, and can then be turned into electricity with a thermoelectric module

Methods

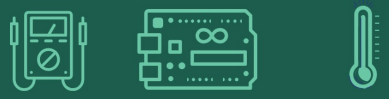
General Design

The device consists of a cubic container for the phase change material, which in this case is paraffin wax. The electrical generation is conducted through the use of thermoelectric generators connected to the container

Design Enchancement

The design can be enhanced in multiple ways, such as though the inclusion of a metal mesh, a thermal interface material for increased conductivity, or the use of heatsinks on the cold plate side of the thermoelectric generators to increase the temperature difference

Testing



The computer will be put under a stress test, and the heatsink will be used as the only cooling method. The temperature of the CPU and the wax will be recorded, as well as the voltage produced by the generators. The CPU temperature data will be collected using the HWiNFO Software, while the voltage and wax temperature will be recorded using an Arduino. A resistor will be connected to a breadboard, so that the voltage & known resistance can be used to calculate the power output of the generators.

Engineering Need

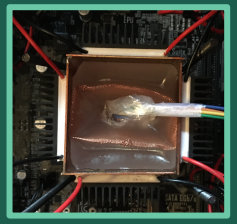
Computer cooling solutions are often insufficient in their cooling abilities and the heat drawn from computer processors is underutilized and discarded into the environment.

Engineering Purpose

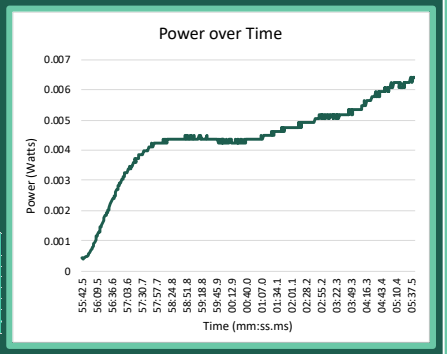
The engineering objective is to design a computer heatsink that can effectively cool a computer central processing unit (CPU) through utilization of a phase change material, and simultaneously generate electricity via a thermoelectric generator.

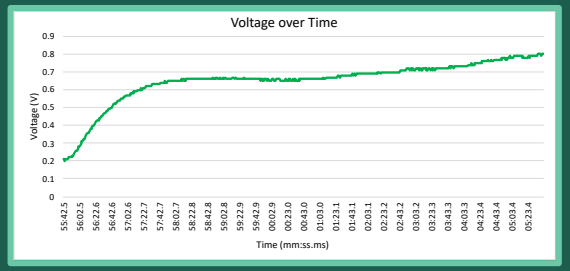
Results

The temperature of the device is kept below the critical threshold when stress tested, and the power increases along with the increase in temperature. However, the power produced is low, below 0.01W, and the temperature of the devices does steadily increase up to almost 90ºC.



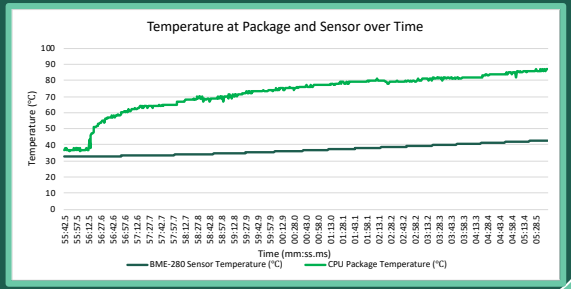
Design Criteria (+ is better, - is worse, 0 is equal)	Fan and Alluminum Heatsink (Control)	Water Cooling	Prototype #1
Temperature Kept Below Maximum	0	+	-
Energy Stored	0	0	+
No Electrical Input Needed	0	-	+
Resistance To Failure	0	0	+
Cost of Production	0	-	s
Noise Level	0	0	+
Totals:	0	-1	3





The voltage increases quickly once the stress test begins, but then plateaus with only a small increase for the rest of the test

The temperature at the sensor follows a voltage-like trend, going up quickly and then plateauing. The temperature recorded by the in-wax sensor does not appear to accurately show the wax melting



Analysis

- The results indicate that the power produced depends highly on small differences in voltage, as going from around 0.65-0.7V results in the power produced changing from 0.004W-0.006W.
- There is no consistent temperature plateau for the CPU package temperature, and this likely due to the wax not melting quick enough to absorb all the heat produced by the CPU
- The total power produced is low, with only 0.006W being produced with four thermoelectric generators
- The sensor is unable to track the moment when the wax melts, likely due to the sensor being placed in the middle of the wax block which does not melt by the end of the test
- The temperature increase at both the BME280 sensor and the CPU package sensor is almost completely linear after the test is begun
- Overall, the higher temperatures result in higher voltage and thus higher power, supporting the idea that thermoelectric devices produce more power at higher temperatures

Conclusion

- As a result of the low power production, it is important for there to be improvements in thermoelectric technology before devices such as these are implemented
- Other PCMs with higher energy densities may be able to better control the temperature of the CPU over a longer period of time
- Even though the power produced is low, the cooling aspect of this product is effective at low CPU utilization, and is even capable of keeping the CPU below maximum operatable temperature for short 100% utilization bursts
- This device is useful in areas where CPUs do not have a high TDP, and the amount of power needed to be recycled is low, such as for long term sensor data collection systems
- Devices such as this one may be better suited to applications where CPUs do not reach 100% of TDP
- If a Bi-Te based thermoelectric generator (TEG) was used it would likely result in a higher output voltage
- In the field of computer cooling this proves that for short term bursts of 100% utilization and consistent below 50% utilization applications, PCMs can be used to store the energy produced by CPUs
- In the field of power production this shows that PCMs can be effectively used with TEGs to generate power from heat, however the technology is not yet at a level that would allow for an above 10% conversion rate, and thus traditional methods such as steam turbines may still be the better option for large scale energy production
- Overall, the creation of this device is one of the first combinations of an all-in-one thermal energy storage and utilization system

Engineering Need:

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Engineering Goal:

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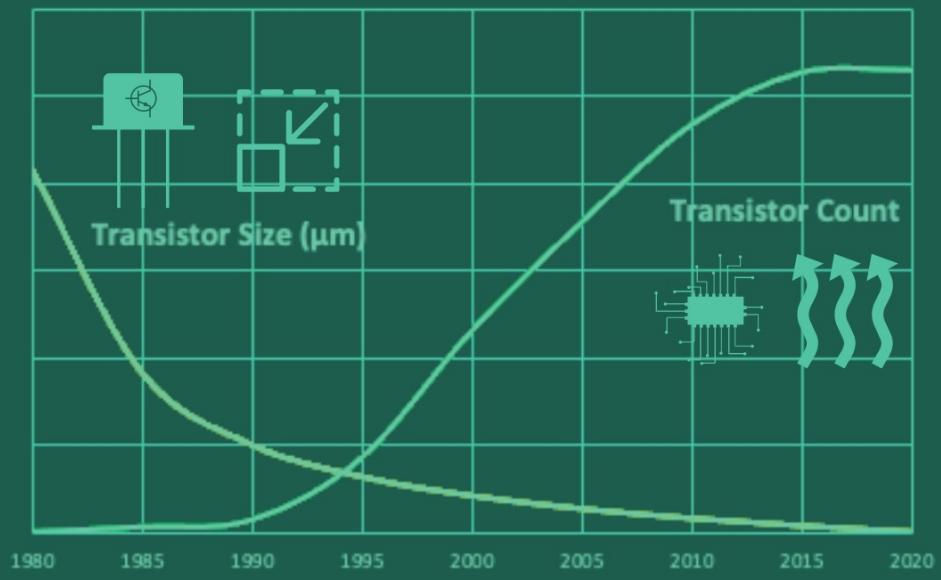
Introduction



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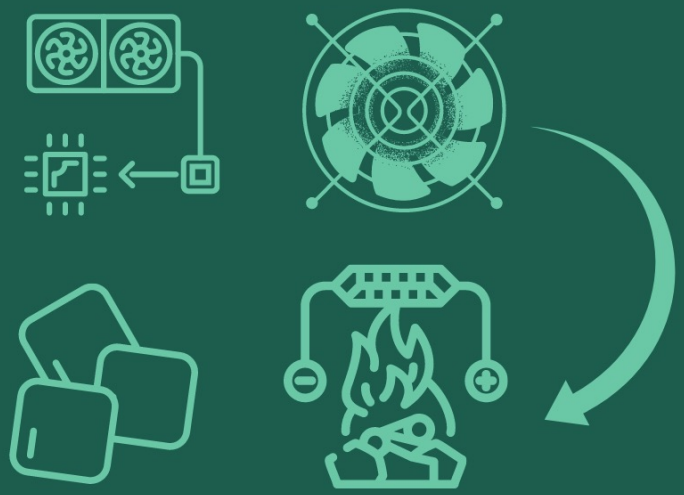

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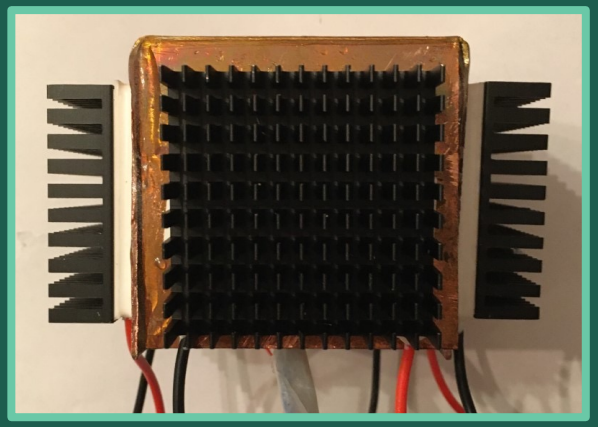
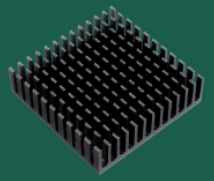


Design Enchancement



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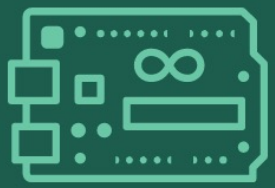

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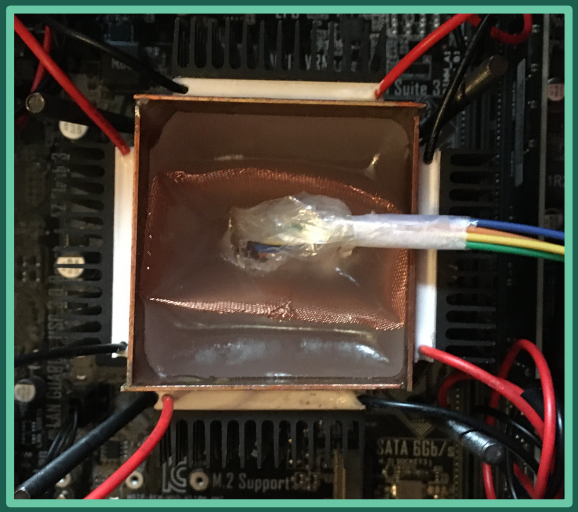
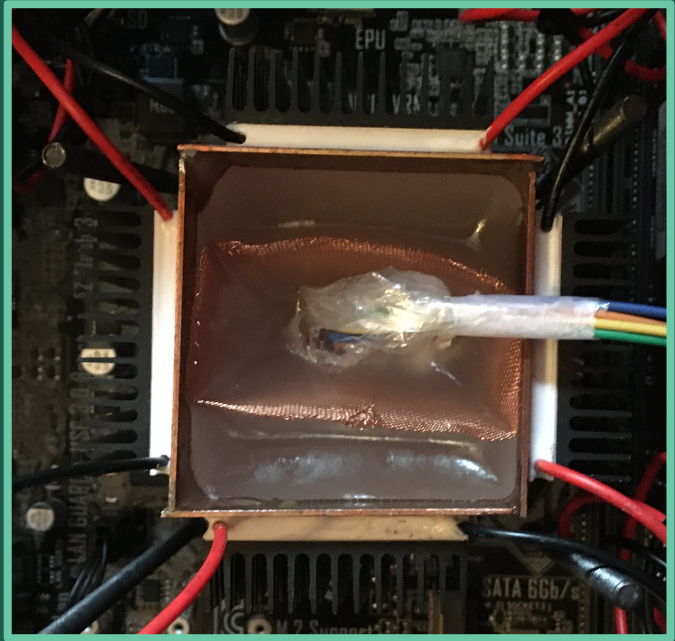
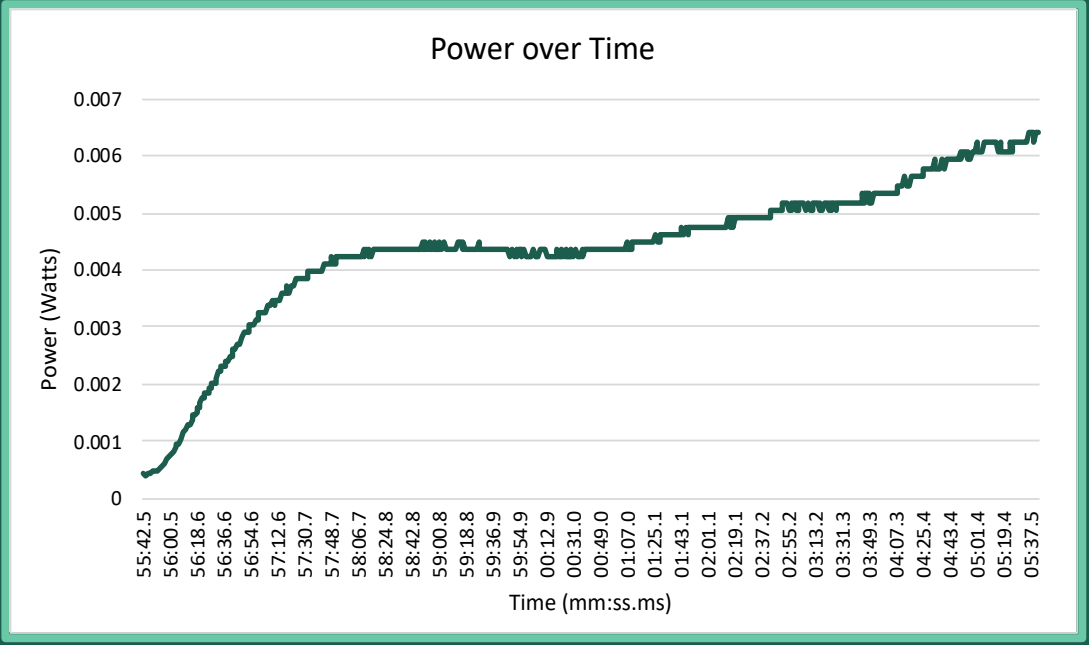
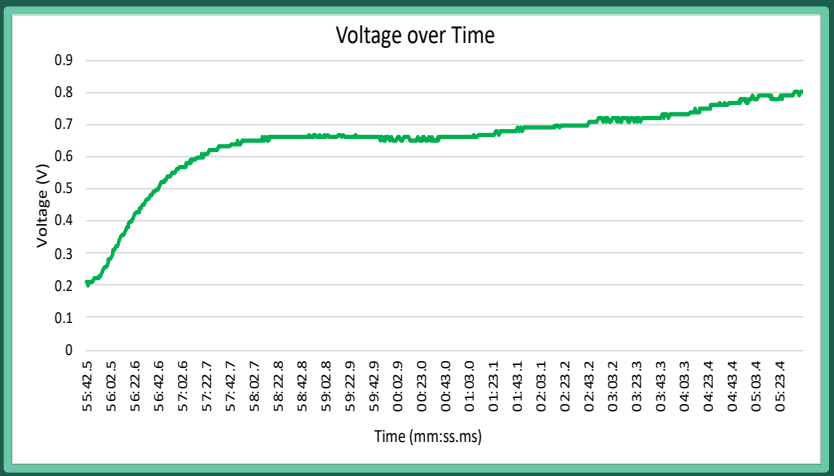
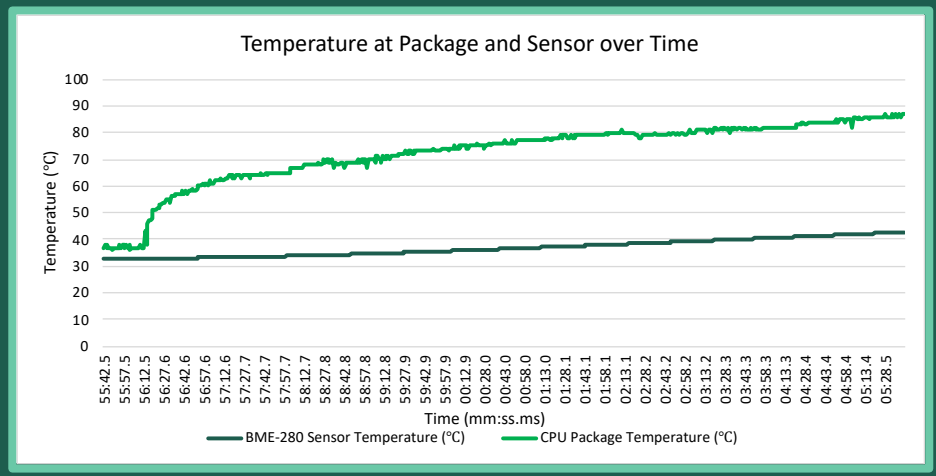


Results



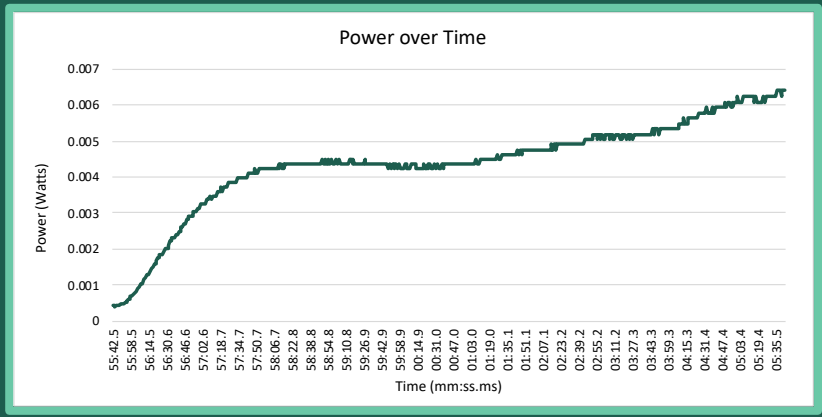

Power over Time
Power (Watts)
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
55:42.5
56:00.5
56:18.6
56:36.6
56:54.6
57:12.6
57:30.7
57:48.7
58:06.7
58:24.8
58:42.8
59:00.8
59:18.8
59:36.9
59:54.9
00:12.9
00:31.0
00:49.0
01:07.0
01:25.1
01:43.1
02:01.1
02:19.1
02:37.2
02:55.2
03:13.2
03:31.3
03:49.3
04:07.3
04:25.4
04:43.4
05:01.4
05:19.4
05:37.5
Time (mm:ss.ms)

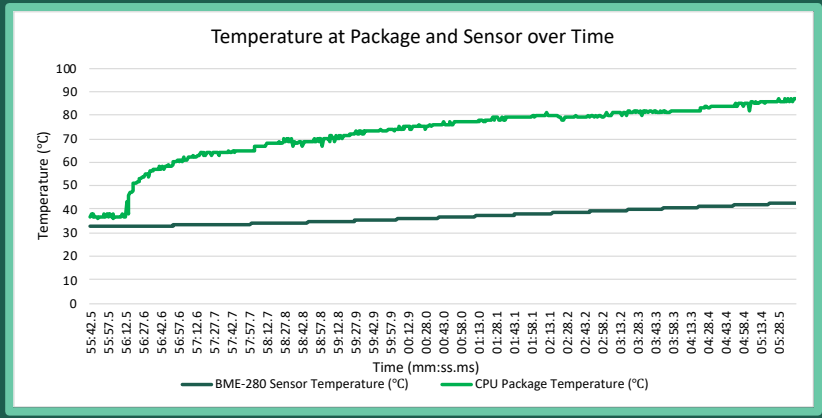

Voltage over Time
Voltage (V)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
55:42.5
56:02.5
56:22.6
56:42.6
57:02.6
57:22.7
57:42.7
58:02.7
58:22.8
58:42.8
59:02.8
59:22.9
59:42.9
00:02.9
00:23.0
00:43.0
01:03.0
01:23.1
01:43.1
02:03.1
02:23.2
02:43.2
03:03.2
03:23.3
03:43.3
04:03.3
04:23.4
04:43.4
05:03.4
05:23.4
Time (mm:ss.ms)


Temperature at Package and Sensor over Time
Temperature (°C)
100
90
80
70
60
50
40
30
20
10
0
55:42.5
55:57.5
56:12.5
56:27.6
56:42.6
56:57.6
57:12.6
57:27.7
57:42.7
57:57.7
58:12.7
58:27.8
58:42.8
58:57.8
59:12.8
59:27.9
59:42.9
59:57.9
00:12.9
00:28.0
00:43.0
00:58.0
01:13.0
01:28.1
01:43.1
01:58.1
02:13.1
02:28.2
02:43.2
02:58.2
03:13.2
03:28.3
03:43.3
03:58.3
04:13.3
04:28.4
04:43.4
04:58.4
05:13.4
05:28.5
Time (mm:ss.ms)
BME-280 Sensor Temperature (°C)
CPU Package Temperature (°C)

Analysis

- Power produced depends heavily on voltage because $P = v^2/r$
- The total power produced is low
- The sensor appears to be unable to track the moment when the wax melts
- There is a long plateau in voltage
- There is a slow increase in temperature, but the CPU remains below critical temp





Design Criteria (+ is better, - is worse, 0 is equal)	Fan and Alluminum Heatsink (Control)	Water Cooling	Prototype #1
Temperature Kept Below Maximum	0	+	-
Energy Stored	0	0	+
No Electrical Input Needed	0	-	+
Resistance To Failure	0	0	+
Cost of Production	0	-	s
Noise Level	0	0	+
Totals:	0	-1	+3

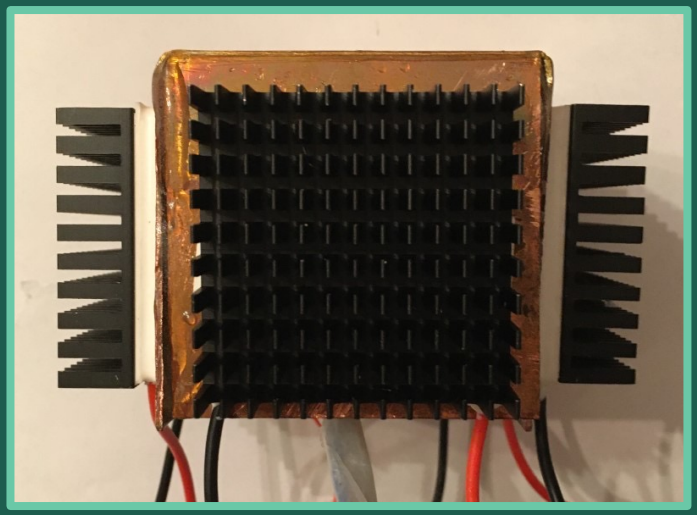
Potential Contributions to Fields

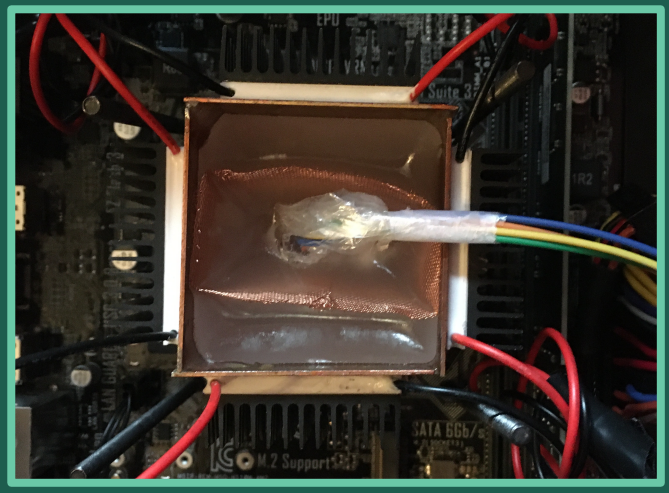
- Alternative power generation method that would reduce the amount of energy needed by computers
- If with modifications becomes capable of cooling computers at 100% utilization for longer periods, could be used as an alternative cooling solution and could have a wide range of benefits
- The heat from the PCM could be used directly, such as for heating a home, or water, etc.

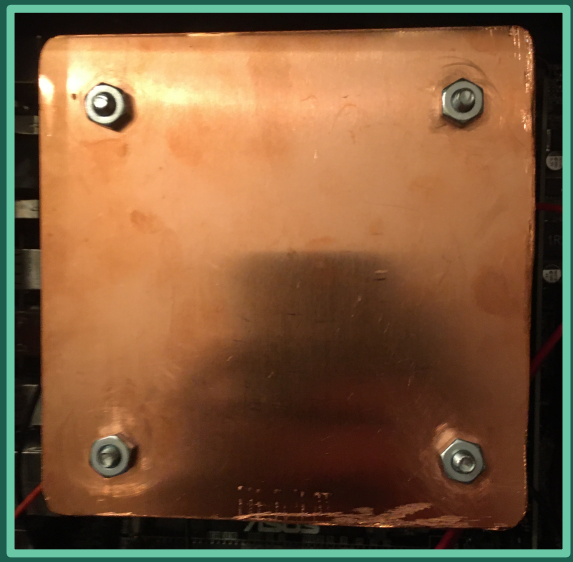
Conclusion

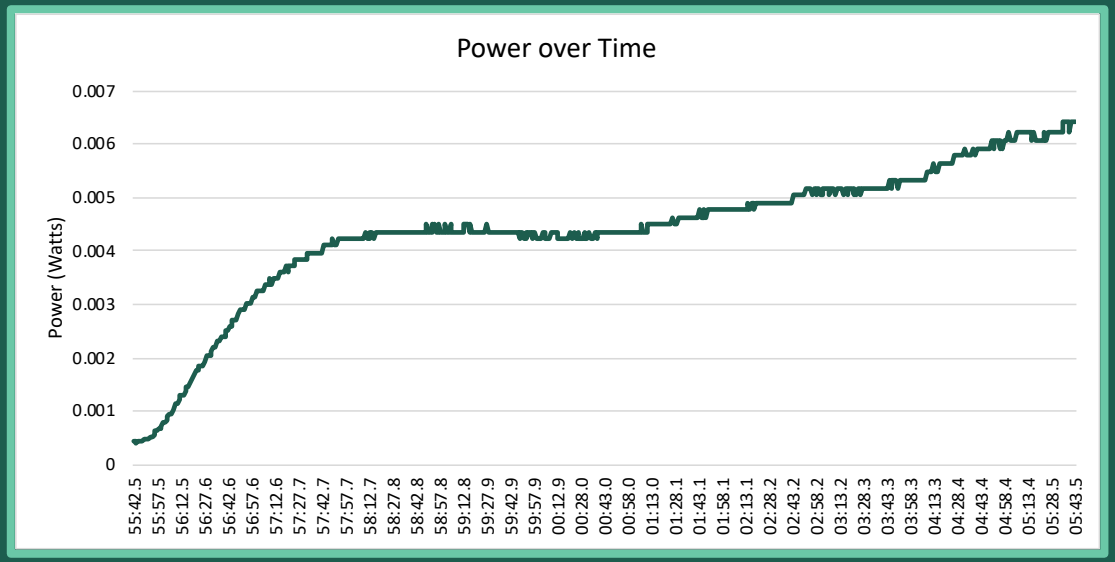
- Low power, so better TEGs may be needed
- Other PCMs with higher energy densities may be able to better control temperature
- Useful in areas where CPUs do not have a high TDP and are not at 100% load
- For short term bursts of 100% utilization and consistent below 50% utilization applications, PCMs can be used to store the energy produced by CPUs
-PCMs can be effectively used with TEGs to generate power

Thank you for listening to my presentation! Any questions?









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Lee, G., Kim, C. S., Kim, S., Kim, Y. J., Choi, H., & Cho, B. J. (2019). Flexible heatsink based on a phase-change material for a wearable thermoelectric generator. *Energy (Oxford)*, *179*, 12–18. https://doi.org/10.1016/j.energy.2019.05.018.