Project Proposal

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

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Date: 10/20/21

Project Definition:

Existing computer cooling methods discard the heat generated by computers and are often ineffective in allowing the computer to maintain a stable operating temperature. The engineering goal of this project is to develop a cooling method for computers that stores the heat generated by a computer central processing unit, simultaneously cools the computer, and generates electricity through thermoelectric generators. The method for storing the thermal energy would be phase change materials (PCMs), which experience a phase change during which they store or release energy. The storage of the thermal energy will simultaneously be used to cool the computer central processing unit and as a source of energy. Based on the information available, it is expected that the thermo-electric generators will generate an electric current of a relatively low voltage at lower temperatures as the heat is stored, as the thermoelectric generators will have access to a low temperature gradient (Teffah et al., 2018). Once the heat storage device is saturated and is unable to keep the temperature of itself and the central processing unit constant the thermoelectric generators will increase their electrical output (Teffah et al., 2018).

Background:

Engineering Need:

Computer cooling solutions are often insufficient in their cooling abilities and the heat generated is underutilized and discarded into the environment.

Engineering Objective:

The engineering objective is to develop a computer heatsink design that can effectively cool a computer central processing unit (CPU) through the utilization of paraffin wax as a phase change material which is then cooled by thermo-electric generators that capture some of the heat energy gradually.

General Context of Computers and Cooling:

Computers have become an integral part of our everyday life, and control many of the aspects of our lives, from communication to transportation. However, computers contain integrated circuits which generate heat, and as computers have become more powerful and advanced the heat outputs of computer chips have increased (Chu et al., 2004). With this, there has come a need to increase the cooling potential. Extreme temperatures can result in damage to computer silicon, increased failure rates, higher electrical demand, and a reduction in performance (Wang et al., 2018). The most common cooling systems that are used in computers are air flow forced convection systems and water loop systems (Chu et al. 2004). Additionally, there exist other methods for cooling computers that utilize the expansion of gasses and cold plates, however these are often used in industrial situations and are complicated and expensive (Chu et al., 2004). Cooling solutions most often found in personal desktop computers and laptops today often use either fans and finned heat sinks in the case of desktops, or heat pipes and fans in the case of laptops. Heat pipes work by using water as a working fluid and using a wicker inner surface of a tube that is able to circulate water in an evaporation-condensation cycle that allows for heat transfer, saving space and energy (Wang et al., 2018). However, these common cooling solutions expel heat generated by computers into the environment without reusing it for other purposes. As energy is the basis for many parts of the modern world, this project aims to recapture some of that energy while effectively cooling a computer using a completely energy-demandless solution.

Capturing the heat:

In order to maximally reduce of heat being released into the environment, the energy can be temporarily stored until it can be used elsewhere. The goal is to draw the energy out of the processor and thus cool it by storing that energy. There are three commonly used methods of storing thermal energy: sensible heat storage, thermochemical energy storage, and phase change material energy storage (Energy, 2021). Each of these can be used for the effective cooling of computers. Sensible energy storage is the simplest method and requires heating up some object and then harvesting the heat that is outputted when that object cools down. This can be used to create composite designs for the storage of thermal energy, an example of this being cast steel rods dispersed throughout a cast iron chamber that heat up and then release that energy for use (Rao et al., 2018). In computers, this is what a water cooling loop would do, capturing the heat and storing it for a short while, but then transferring it to an environment through a radiator. It would capture the energy by heating up the water. However, the amount of energy that can be stored per amount of mass is very limited compared to the other two energy storage methods, and it is often unable to cool devices as effectively because as the temperature of the material increases, it warms up its container and thus the CPU.

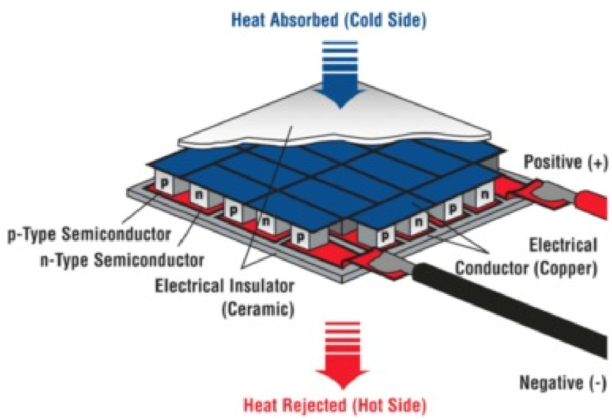
The second method, thermo-chemical energy storage, uses exothermic and endothermic reversible reactions to store thermal energy and then releases the heat when the reaction is reversed. An example of this would be the dehydration of substances to store energy and then the recombination with water in order to release heat (Erlund et al., 2018). This can be used for a broad range of applications. One of the more important applications outside of computer cooling is the utilization of thermo-chemical energy storage for the storage of seasonal energy, which can be used to heat houses in the winter without the need for fuels (Erlund et al., 2018). The reason that it is used for seasonal energy storage is because this type of energy storage is capable of storing energy for an almost indefinite period of time as energy is only released when the chemical recombines, and as long as they do not deteriorate they can simply stay in storage. However, even for simple thermo-chemical energy storage systems that involve water and one other chemical a separate system for hydration and dehydration is needed, as well as a way to replicate specific hydration conditions (Erlund et al., 2018). These difficulties associated with thermo-chemical energy storage result in it not often being used in computers as it is not only costly but also difficult to implement and requires many moving parts.

The final method for thermal energy storage would be phase change material thermal energy storage. This method involves the phase change of a certain material during which energy is either stored or released. Phase change materials (PCM's) melt at a wide range of temperatures and thus can be used for a wide range of applications, primarily for storing thermal energy (Sharma et al., 2009). In some cases, molecular switches have been used to extend the time between the melting and freezing points of PCM's so that the thermal energy storage period can be extended (Chandler, 2017). The reason that PCM's can be used for thermal energy storage is that as the PCM melts, its temperature does not change because the thermal energy is being used to free the molecules of the PCM from each other so that it can melt. Thus, the temperature of PCM's does not increase while they melt, even while they are drawing in thermal energy, so they effectively cool the object while not heating up and simultaneously storing heat. This makes PCMs the ideal choice in this project for both storing thermal energy and cooling. Water can be used as a PCM for applications outside of computer cooling, however it's high boiling point and low melting point result in it being not useful for phase change cooling.

For this project, a phase change material was used to both cool the processor and store the energy. The reason for this is the simplicity of such a system as compared to thermo-chemical energy storage, and the high energy density and ability to cool when compared to sensible energy storage. In terms of cooling, much research is being done in this area. In the past phase change materials have been used for cooling by placing some PCM on computer chips and using it to collect heat (Tan et al., 2004). Additionally, the distribution of heat throughout different heat sources has been changed in order to optimize the cooling, as oftentimes different heat sources produce different amounts of heat (Tan et al., 2004). However, there still remains the question of how thermal energy should be used.

Using the heat:

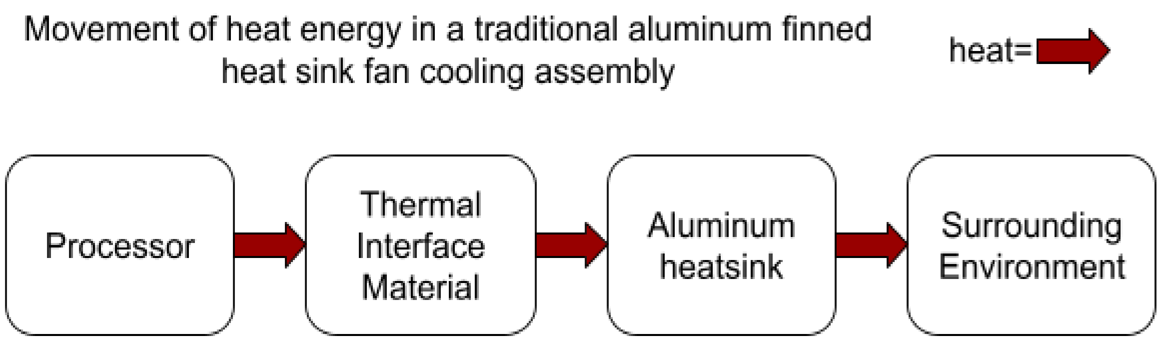
The previous explanation has only dealt with how the thermal energy can be captured and how the CPU can be cooled, but has not explained how the heat will be used in this experiment. For this, the thermoelectric effect will be utilized. The thermoelectric effect occurs when two metals of different levels of conductance are physically connected, and a heat difference is applied to one side (Pourkiaei et al., 2019). The thermoelectric effect, used in thermoelectric modules, also provides the benefit of cooling the PCM after it is all melted and the temperature of it begins to rise, so they may act as a temperature stabilizer. In fact, thermoelectric modules have already actually been used in the past for cooling computers, as when a current is flowed through them the reverse of the generation effect occurs, and a temperature difference is created with one hot side and another cold side (Teffah et al., 2018). Thermoelectric modules have also been used in combination with PCMs to generate electricity using body heat (Lee et al., 2019). However, they have not often been used to create a simple, consumer friendly combination PCM and thermoelectric generator heatsink, and this is the niche this project is going to fill.

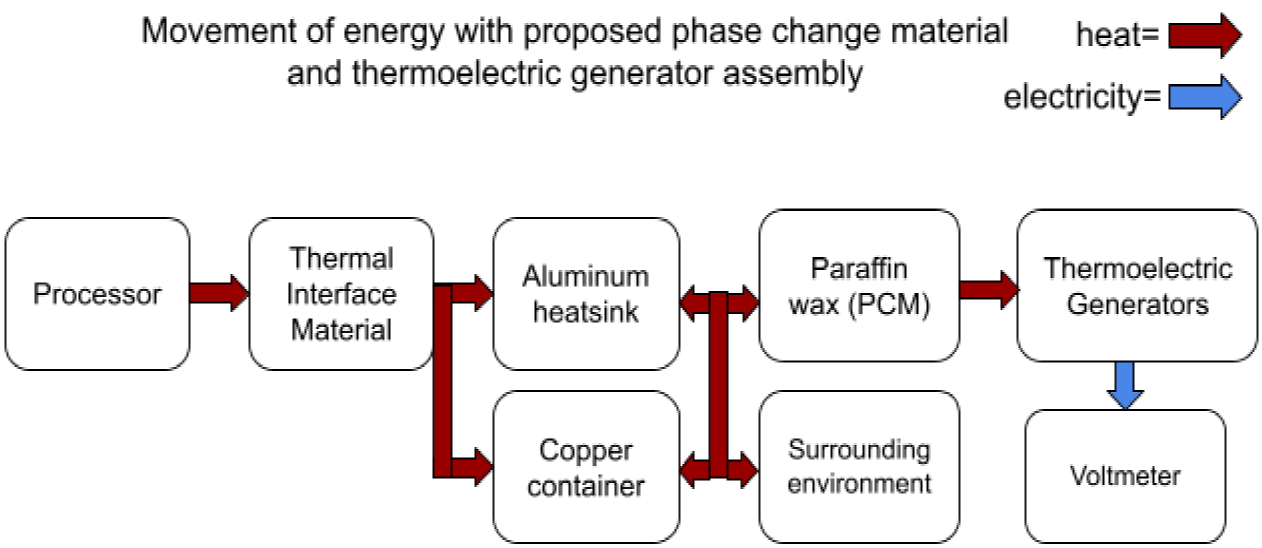


This is a figure detailing the structure of a thermoelectric generator
Pourkiaei, S. M., Ahmadi, M. H., Sadeghzadeh, M., Moosavi, S., Pourfayaz, F., Chen, L., Pour Yazdi, M. A., & Kumar, R. (2019). Thermoelectric cooler and thermoelectric generator devices: A review of present and potential applications, modeling and materials. Energy (Oxford), 186, 115849–. https://doi.org/10.1016/j.energy.2019.07.179.

Purpose and specifics:

Following all of the previous explanations, this project is looking to fill a gap in consumer cooling solutions that are simple and cheap that utilize simple materials to cool a computer and also recuperate some of the energy. This will not only allow for a certain recycling of energy but will also allow for a computer to perform optimally. The thermoelectric modules will act as temperature regulators for the PCM for if it melts the rise in its temperature will result in an increase in the electrical production of the thermoelectric modules, and thus a conversion of heat into electricity. So, in order to fill this gap, a simple heat sink will be designed that includes a PCM that melts to store, heat, and cool the CPU, and thermoelectric modules to turn that heat into electricity and to enable the CPU cooling. When the temperature of the heatsink increases, the thermoelectric generators will convert more heat into electricity, and will thus regulate the temperature of the heatsink and thus the CPU. For a control the aluminum heatsink and fan design that is included with most desktop computers will be used.





<u>Experimental Design/Research Plan Goals:</u>

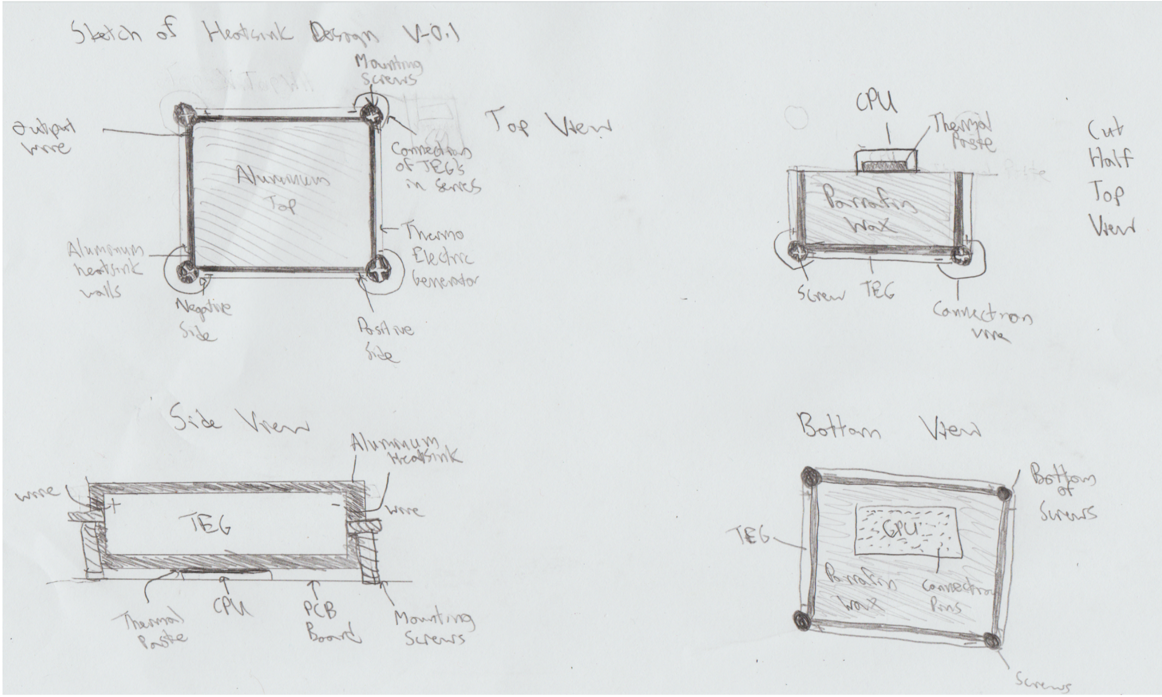
IDV: The amount of paraffin wax used/the design used
DV: The temperature of the computer chip and the voltage of produced
Standardized variable/controls:

- Workload of the central processing unit
- Temperature of the air
- The amount of thermo-electric generators
- The computer used
- The type of phase change material used

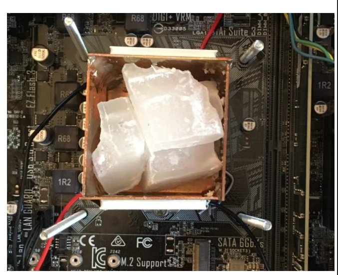
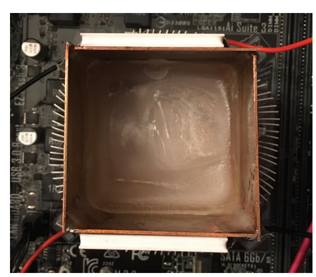
Control group: The heatsink-fan assembly included with the computer with a finned aluminum heat sink and a fan
Iterations:

1. The first iteration would consist of an aluminum cavity with four peltier modules attached to the sides of it in series via screws. The cavity is filled with paraffin wax and is covered. Then the heat sink assembly is attached to a central processing unit in a computer, the thermo-electric generators are connected to a voltmeter, and the computer is stress

tested. Sketch:



2. The second iteration and the one pictured below are similar but the connections are not created through screws but through epoxy and already existing metal connections. Additionally, the heatsink board attachment screws will come up through the bottom of the cooler mounting socket upwards through the cover, and will be covered with plastic rivets for electrical protection and bolts at the top to seal the device.
3. The goal of the third iteration was to change the apparatus by introducing a different design and seeing which one would achieve a performance level closer to that that could be sustainable for the computer. For this the temperature of three setups was tested in the BIOS after five minutes, and this was recorded to see whether or not a design that included the aluminum heatsink below the design would be more viable. The collected data showed that Design #2 was more optimal than Design #1.

Description:	Control Design: Heatsink and fan	Design #1: PCM only	Design #2: PCM with aluminum heatsink
Image:			
CPU temp in BIOS after 5 minutes	33℃	46℃	43℃
Temp difference from control	0℃	13℃	**10℃**

Materials List:

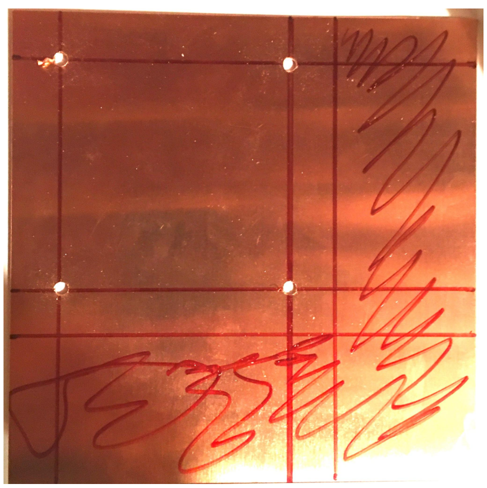
1. A desktop computer with an Intel Pentium G4400
2. Thermal paste kit with 2g of paste and included plastic paste spreader
3. Two 6”x6” 18 guage copper sheets
4. 1 lb. of unscented paraffin wax
5. 5 40mmx40mm 12V 50W thermo-electric generators
6. CPU stress testing software
7. 1 File
8. One sheet of sandpaper
9. Cordless electric drill
10. Isopropyl Alcohol
11. Roll of paper towels
12. Q-tips
13. Extra Strong Gorilla Glue brand epoxy
14. Small hex-saw
15. Dremel diamond cutting attachment
16. 5/32” screw bit
17. Sharpies (any color, regular thickness)
18. Safety goggles
19. Cutting gloves
20. Latex gloves
21. Included aluminum heatsink and fan
22. Electrical tape
23. Scissors
24. 4 #8-32 x 3in zinc round head screws
25. 4 #8-32 zinc bolts
26. 17/32” plastic flat washers
27. PC power cable
28. Monitor (any resolution above 480p)
29. PC to monitor cable
30. Monitor power cable

All images in the following procedure were taken by Daniel Kaminski.

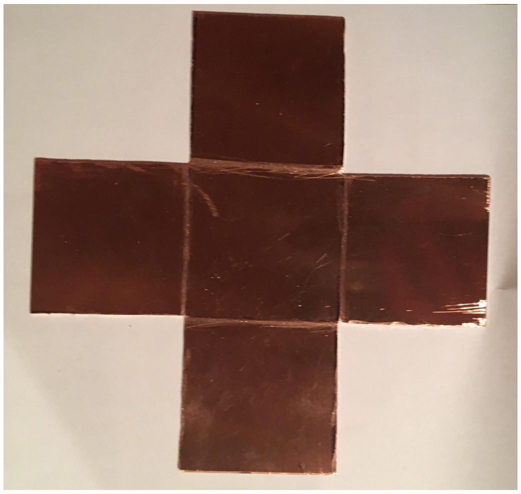
Procedure:

1. Make sure the computer is turned off and unplugged
2. Remove the side cover for the computer (this depends on the case)
3. Unscrew the old CPU fan cooler screws, and remove the CPU fan and put it to the side (if it is unplugged, the computer may not start)
4. Clean the thermal paste off of the CPU by dipping q-tips in isopropyl alcohol and gently rubbing it over the top of the CPU until clean

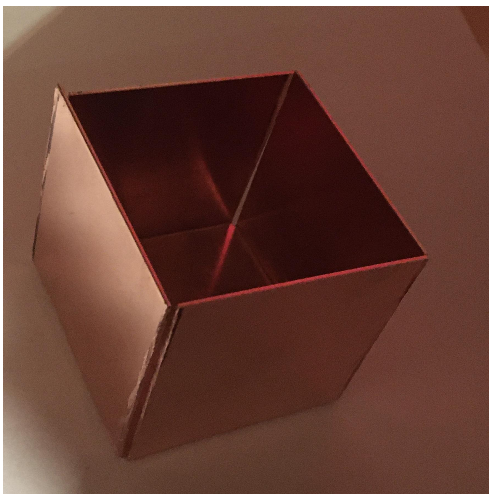
5. Mark off one of the copper plates with lines horizontally and vertically every two inches with a sharpie, until a 9 square grid is created of 2” by 2” squares
6. Mark another copper plate with a 105 by 105 mm square, with dots places at 15mm in both directions from the corners of the square



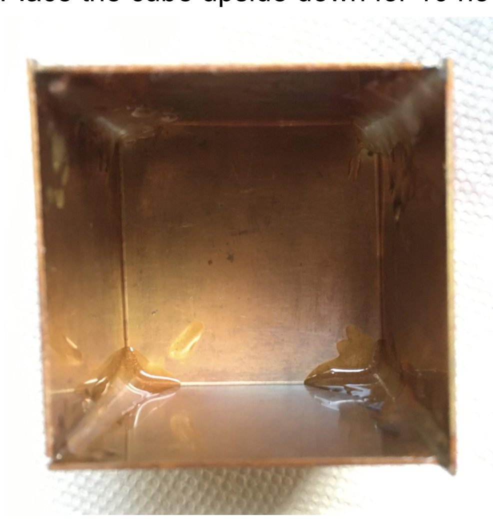
7. Take the electric drill and attach the cutting attachment
8. Put on the safety goggles and cutting gloves
9. Begin to pre-score along the lines of the 9 square grid, but only scoring deeply along the outside corner lines, and not the inner lines, so that the four corners can be cut off
10. Take the hex-saw and begin cutting away at the four corners, so that eight cuts will be made in total
11. Once the corners are cut away take the other scored lines and begin bending each of the ‘outside” copper squares inwards by using a right angle surface like a table or a block of wood



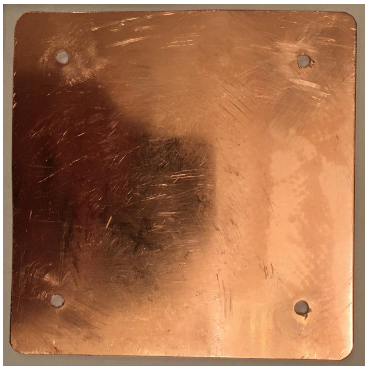
12. Keep being them until they are at right angles with the centerpiece and they form a cube without a top



13. Put on the latex gloves
14. Then take the epoxy and open it, squeezing some of it into a container of choice
15. Being to mix it to start the reaction
16. Carefully take some epoxy on a toothpick and put it on the inside of the metal cube where the sides conjoin together, as they will likely not be perfect but must be made to not leak
17. Place the cube upside down for 10 hours to cure (picture of it when cured)



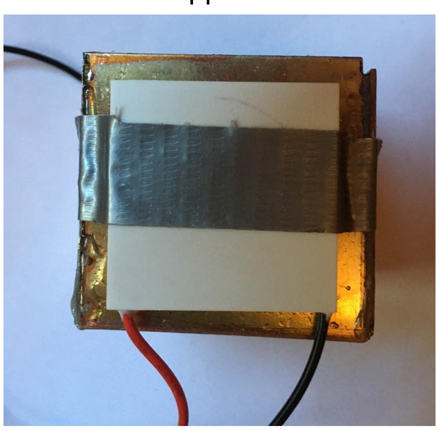
18. Begin to cut the other piece by drilling using the 5/32” drillbit where the dots were placed
19. Then begin to cut along the border lines for the 105mm by 105mm square
20. Using sandpaper and a file smooth out the corners and edges



21. Take the positive lead of one thermoelectric generator and the negative lead of another and using scissors slows cut into part of the wire covering, then remove it
22. Twist the wires together and then tape the end with electrical tape

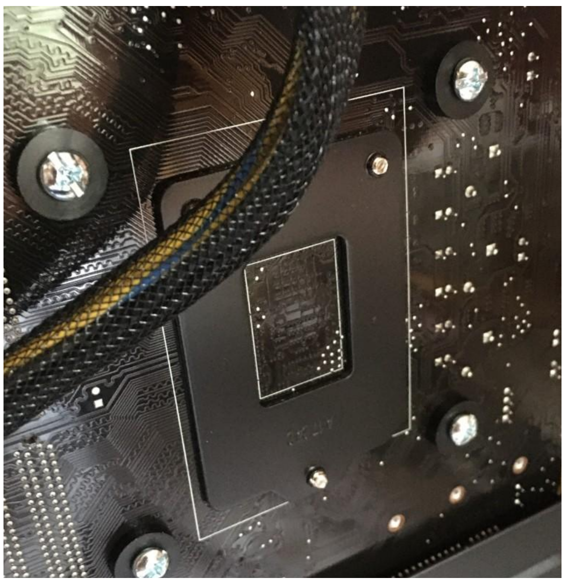
 

23. Take the two thermoelectric generators and tape them to two opposite vertical sides of the copper cube



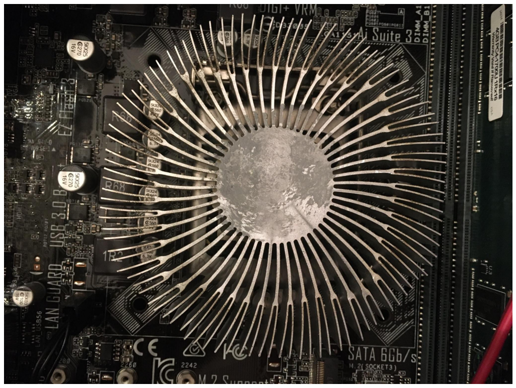
24. Place some thermal paste on the CPU and spread it out using the included thermal paste spreader (a small piece of flat plastic)

25. Remove the back of the computer case (case dependent)
26. Place the plastic washers on four of the zinc screws, and put them through the fan screw holes so that they are pointing outwards

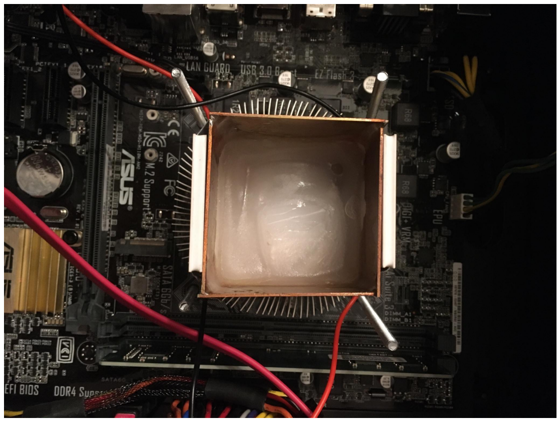


27. Cut off 2” of wax from the bar and place it into the copper container

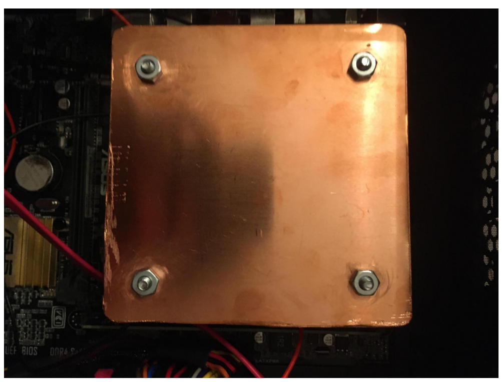
28. Spread thermal paste onto the top of the center part of the aluminum heatsink
29. Place the aluminum heatsink centered onto the CPU

a. 

30. Place the PCM heat sink centered onto the aluminum heatsink

a. 

31. Attach the top plate of the heatsink and screw on the bolts

a. 

32. Finally, attach the red thermo-electric generator wire to the red voltmeter lead and the black wire to the black lead, and turn the voltmeter on to measure DC voltage

33. Plug in the computer to the monitor, and plug both the PC and the monitor into a wall socket (monitor dependent)
34. Log into the computer and launch HWMonitor and Prime95
35. Run Prime95 on the smallest setting, and benign recording the CPU temp with HWMonitor

Risk/Safety Concerns:

In this project the phase change material (PCM) used will be a non-scented paraffin wax, which is a non-toxic petroleum based product, and this will pose no threat. However, there will be the danger of electrocution, but this will be minimized with careful insulation. Additionally, high temperatures can be expected of up to 80 degrees Celsius, but this will be minimized through the use of gloves and necessary protective equipment. During the fabrication of the apparatus tools such as saws may be used, and safety glasses and gloves will be used.

Data Analysis:

In order to validate that the software used is showing an accurate temperature reading I will place a thermocouple near the central processing unit and the temperature form this will be recorded to ensure that the increases in temperature in the CPU correspond to the correct increases from the application data. Additionally, graphs will be made that relate the time since beginning of operation, to the production of electricity and to the temperature of the central processing unit. This will allow for the performance of the cooling system to be visually represented.

Potential Roadblocks:

1. The heat sink design may not cool the central processing unit enough for it to not overheat
    - I could research different phase change materials and try those as well
    - I could adjust the amount of the PCM used or the design of the cavity
    - I could adjust the thermal paste used
2. The peltier modules may not generate higher amounts of electricity at higher temperatures
    - I could improve the airflow inside of the computer case
    - The thermal connection of the peltiers to the heatsink could be improved
    - The peltiers used could be changed
3. Although unlikely the amount of phase change material may not affect the temperature of the computer processor
    - If this is the case then it is likely that the phase change materials are not cooling the processor so to see if this is the case the design could be tested without any phase change materials
    - If this is the case the design would have to be reworked
    - If this is not the case then troubleshooting could be done by changing the amount of paraffin wax
4. The performance of the design may be lower than the performance of a regular heatsink fan assembly
    - In this case a different PCM may be used
    - The thermal connections can be improved upon through the use of a different thermal interface material
    - A combination of two systems could be used

References:

Chandler, D. L. (2017, November 16). A new way to store thermal energy. MIT News | Massachusetts Institute of Technology. https://news.mit.edu/2017/new-way-store-thermal-energy-1117.

Chu, R., Simons, R., Ellsworth, M., Schmidt, R., & Cozzolino, V. (2004). Review of cooling technologies for computer products. IEEE Transactions on Device and Materials Reliability, 4(4), 568–585. https://doi.org/10.1109/TDMR.2004.840855.

Erlund, R., & Zevenhoven, R. (2018). Hydration of magnesium carbonate in a thermal energy storage process and its HEATING application design. Energies, 11(1), 170. https://doi.org/10.3390/en11010170.

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.

Pourkiaei, S. M., Ahmadi, M. H., Sadeghzadeh, M., Moosavi, S., Pourfayaz, F., Chen, L., Pour Yazdi, M. A., & Kumar, R. (2019). Thermoelectric cooler and thermoelectric generator devices: A review of present and potential applications, modeling and materials. Energy (Oxford), 186, 115849–. https://doi.org/10.1016/j.energy.2019.07.179.

Rao, C. R. C., Niyas, H., & Muthukumar, P. (2018). Performance tests on lab–scale sensible heat storage prototypes. Applied Thermal Engineering, 129, 953–967. https://doi.org/10.1016/j.applthermaleng.2017.10.085.

Sharma, A., Tyagi, V. V., Chen, C. R., & Buddhi, D. (2009). Review on thermal energy storage with phase change materials and applications. Renewable and Sustainable Energy Reviews, 13(2), 318–345. https://doi.org/10.1016/j.rser.2007.10.005.

Tan, F. L., & Tso, C. P. (2004). Cooling of mobile electronic devices using phase change materials. Applied Thermal Engineering, 24(2-3), 159–169. https://doi.org/10.1016/j.applthermaleng.2003.09.005.

Teffah, K., Zhang, Y., & Mou, X.-long. (2018). Modeling and experimentation of new thermoelectric cooler–thermoelectric generator module. Energies, 11(3), 576. https://doi.org/10.3390/en11030576.

Wang, Y., B., Zhu, K., Li, H., He, W., & Liu, S. (2018). Energy saving potential of using heat pipes for CPU cooling. Applied Thermal Engineering, 143, 630–638. https://doi.org/10.1016/j.applthermaleng.2018.07.132

Energy Tech Review. (2021, September 3). *3 types of thermal storage system*. Energy Tech Review. Retrieved October 25, 2021, from https://www.energytechreview.com/news/3-types-of-thermal-storage-system--nwid-567.html.

Timeline:

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Phase 1: Brainstorming
1. Decide on three areas fields on which to focus
2. Being finalizing ideas with visual brainstorming methods such as pie charts, fishbone diagrams, etc.
3. Specify three main needs
4. Being to focus in one one main idea and start to find articles and information that could help me learn more about the topic

Total Time Frame: Sept. 2nd

Phase 2: Research and Patent Search
1. Find tentative researchable question (1 week along with other tasks)
2. Find knowledge gaps that need to be filled and begin researching them (5-10 hours)
3. Find 10 articles and two patents (30 hours)
4. Research what kinds of chemicals will be needed and what kind of machinery will be needed for heatsink production (2-3 hours)
5. Device on method of energy storage based on benefits and drawbacks (back of head thinking, perhaps 1/2 hour?)
6. Begin to learn the basics of some CAD software if needed (2-3 hours)
7. Learn where materials needed could be acquired (1-2 hour)
8. Identify what computer will be used (10 minutes)
9. Begin coming up with preliminary designs and sketching or modeling them (2-3 hours)
10. Work on project proposal (2-5 hours)

Total Time Frame: Oct. 18th

Phase 3: Designing and Prototyping Project
1. Model design in CAD or sketching that is ready to be produced (3-5 hours)
2. Begin to purchase and source chemicals and materials needed (1 hours)
3. Create model whether this is an assembly from manufactured parts or an assembly from raw materials myself (1-10 hours)
4. Test project as a proof of concept with computer, perhaps take preliminary data (-1 hour)
5. Submit paperwork for fair (-2 hours)
6. Work on finalizing proposal and having it submitted (-2 hours)

Total Time Frame: Nov. 8th (Tentative)

Phase 4: Data Collection and Analysis
1. Finalize device if not ready for preliminary data (-30 mins)
2. Work on collecting preliminary data (-5 hours, tentative)
3. Making adjustments to the apparatus if necessary (-1 hour)
4. Begin another round of testing (-5 hours)
5. Gather all data up and make it presentable (-2 hours)
6. Analyze data and make graphs, etc. (-3-5 hours)

Total Time Frame: Jan. 10th

Phase 5: Analyze Data & Wrap-up
1. Make any final adjustments to the project design, for example change heatsink, fix small leaks, etc., if needed collect a bit more data (1-3 hours)
2. Gather all data in a presentable way and begin analysis (1-5 hours?)
3. Start writing final paper and conclusion (2-5 hours?)
4. Finish working on paper and conclusion (-2 hours?)

Final Due Date: 1/28/21

5. Work on Project board and finalizing design as well as making the whole project presentable (-10 hours?

Final Due Date: 2/4/21