Thermal Analysis of Heat Sink Temperature Dissipation

Research Question: Which of 3 designs of heatsink with differing surface area (by number and placement of fins) is able to achieve the highest average rate of change of temperature for CPUs at different power settings.

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Table of Contents:

1.0 Introduction:

In this increasingly more technology based society, computers have become an essential part of our lives, and their performance has become crucial in various fields ranging from business to education to scientific research. As such the development has continued at a rapid pace, however, a significant challenge has been the generation of heat due to the various tightly fitted heat producing components, with the Central Processing Unit (CPU) being one of the most significant heat producers. (*Haywood*) The focus of this lab is an attempt to mitigate the issue of overheating by investigating first the temperature at which modern chips begin to fail and then the various designs of heatsinks to best mitigate this issue.

Research Question:

Which of 3 designs of heatsink with differing surface area (by number and placement of fins) is able to achieve the highest average rate of change of temperature for CPUs at different power settings.

The research questions will be answered in essay with the application of thermal physics theories In the form of a simulation. This includes basic thermal transfer as well as other factors including airflow convections, Newtonian fluidity, kinematic viscosity and fluid viscosity which all describe the behavior of air in a Newtonian environment as the medium for heat transfer. The various equations and theories which are used in the simulation will be explained in the background section of the lab and the specific settings for the simulation will be added in the simulation setup and procedure. More specifically, the background section will explain the main theory behind the various parameters that needs to be changed in the simulation to achieve optimal results. The data collected will be interpreted in both lowest temperature maintained by the heatsink and the speed at which heat is dissipated to provide a holistic view of the heatsinks performance, however, the focus will be on heat dissipation specifically.

Background Information

1.1 Simulation Choice:

In the setting of a highschool student,it is unrealistic to create metallic heat sinks and purchase computer chips, a simulation approach was chosen to accurately represent the experiment. There were various options for potential programs that performed basic simulation with set conditions, and the most used ones include Autocad, Altair, and Simscale. The simulation chosen must be variable, user friendly and cheap.

Table 1

	Variability	Cost	Ease of Use
SimScale	High	Free	Difficult
Autocad	High	300$ USD	Difficult
Altair	Basic	10$ USD	Good

As shown by table 1, the different softwares were compared and SimScale was ultimately chosen as it was free and had a high degree of functionality. This allows the changing of more variables in the simulation which will increase the accuracy to the real world. Although it is difficult to use, it is to be expected from an advanced simulation and information can still be gathered, therefore the difficulty will not hinder the data gathering process. Simscale is an open cloud-based software also used by companies for larger scale simulations (Simscale, Honda) and will be very useful in this simulation.

1.1 Background Theory:

The Central Processing Unit (CPU) can be thought of as the brain in a human as it controls most of the core processing in a computer, which includes running various systems and programs as well as doing the majority of calculations. In older computers, it is also required to process graphics and calculate images. This makes it the highest power consuming component in a computer which subsequently means it produces the most amount of heat, therefore it is important to cool the CPU to prevent performance issues due to overheating. The most common method to cool the CPU is with the use of a heatsink in order to siphon the heat from the CPU and dissipate it into the surrounding air.

The focus of this lab is on the thermal transfer of heatsinks and the CPU with the surrounding air and this can occur as conduction, convection, and radiation, the three modes of heat transfer. All three will happen in this lab under differing circumstances and heat up the ambient air, which will result in a gradient in temperature of the surrounding air. (Figure 1)

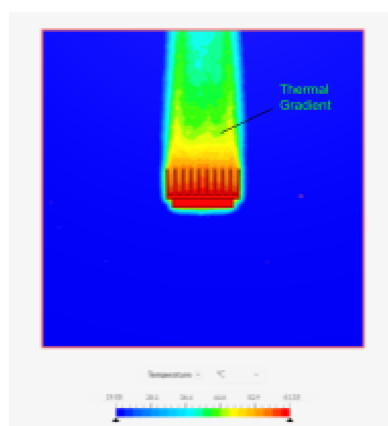


Figure 1
(Author's Own)

This process is most effective with materials with high thermal conductivity, such as metals, hence the common choice of aluminum for the heatsink. In this case, the hotter metal of the heatsink will increase the ambient air which will cause the heated fluid to become less dense. This makes it rise and gets replaced by cooler air. This creates a natural circulation pattern or natural convection (Figure 2) that allows heat to be transferred over longer distances and in a more efficient manner.

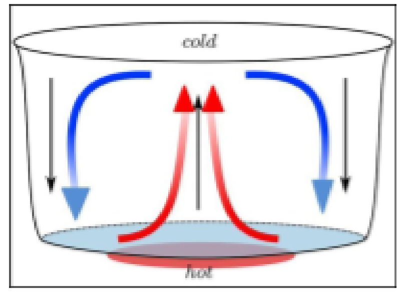


Figure 2
(Quora)

When considering thermal attributes of a material or item, its specific heat capacity is a useful measure to determine the amount of temperature increase the material will undergo when supplied with a certain amount of energy which allows the simulation to vary the temperature of components given the total energy being transferred. It is defined as the amount of thermal energy(Q) absorbed per unit mass (m) when its temperature increases by 1K (T). This can be further represented by the equation.

$$Q=mc\Delta T \qquad \text{Eq1}$$

which allows an accurate prediction of the temperature increase of a certain material given that said material does not change states. In the context of this experiment, the air has a relatively high specific heat capacity which makes it an adequate choice for coolant.

In this experiment, the cooling involved will be passive which means there will be no device actively generating airflow. This means that natural convection will be the main source of cooling. The theoretical amount of thermal energy (Q) transferred can be calculated by the simulation taking into account the contact surface area of the heatsink with the air (A), the difference in temperature (ΔT), and the thermal conductivity of the material(K). (KhanAcademy) This can be represented by the equation

$$KA\Delta T=Q. \qquad \text{Eq2}$$

The value of thermal conductivity differs between materials, and metals such as the aluminum of the heatsink tends to have a higher thermal conductivity due to the delocalised electrons in the metal being able to contact and excite adjacent electrons leading to a high kinetic energy transfer rate.

When discussing natural convection, the behavior of the air must be taken into consideration. Most gasses in our atmosphere follow Newtonian behavior which means it exhibits a constant viscosity under different shear rates, where shear rate is the rate at which fluid layers move past each other when force is applied. (Lab Compare). As exemplified by figure 3, the shear rate(γ) can be denoted by the equation:

$$\gamma = V/x \qquad \text{Eq3 (Figure 3)}$$

The viscosity of a Newtonian fluid is a measure of its resistance to flow, which can be affected by temperature and pressure, but not shear rate. And can be represented by the linear relationship between the shear rate and the shear stress, where the proportionality

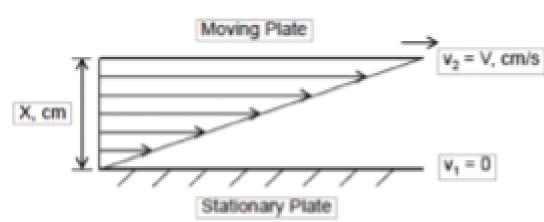


Figure 3
(*Moonay*)

constant is the dynamic viscosity. (Science Direct). This allows the simulation to be accurate in the calculation of the flow rate of air given the temperature and pressure (Rheo). Furthermore, the assumption of Newtonian viscosity allows the simulation to be under considerably less processing stress as Newtonian fluids are more simple to model and measure.

The measure of viscosity can be further elaborated on with a value for kinematic viscosity. The kinematic viscosity is a measure of a fluid's resistance to flow under the influence of gravity that takes into account the density of the fluid. It is defined as the ratio of the dynamic viscosity(μ) to its density(ρ). Mathematically, the kinematic viscosity (v) can be represented by the equation

$$v = \mu / \rho. \qquad \text{Eq4}$$

(EngineeringToolbox) This value represents the fluid's internal friction or resistance to flow due to its own weight and as such is an important parameter to define the movement of the air in this simulation. (MachinaryLubrication). The value of kinematic viscosity allows for a more realistic portrayal of the behavior of the air under an environment with gravity.

Finally, in order to link fluid viscosity of the air with its properties to its thermal diffusion properties, the Prandtl number (Pr) can be used. It is a dimensionless number used in fluid mechanics and heat transfer to characterize the relative importance of viscosity and heat conduction in a fluid. (Sharma).

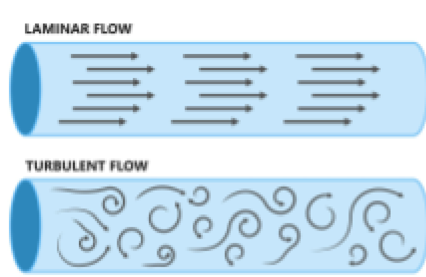


Figure 4
(Murad)

Mathematically, the Prandtl number is defined as the ratio of the kinematic viscosity(v) to the thermal diffusivity of a fluid (α) in the equation

$$Pr = v / \alpha. \qquad \text{Eq5}$$

The thermal diffusivity is simply a ratio of density and specific heat capacity. The value of the Prandtl number is important in determining the characteristics of fluid flow and heat transfer in a variety of applications, including this simulation. However, it is important to note that due to the heatsinks acting as obstacles for natural air flow, the air will be split from a laminar flow originally into a turbulent flow(Figure 4)

1.2 Preliminary Testing:

Preliminary: Is there a correlation between the temperature of a semiconductor used in CPUs and its ability to limit output?

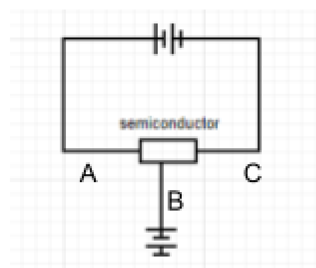


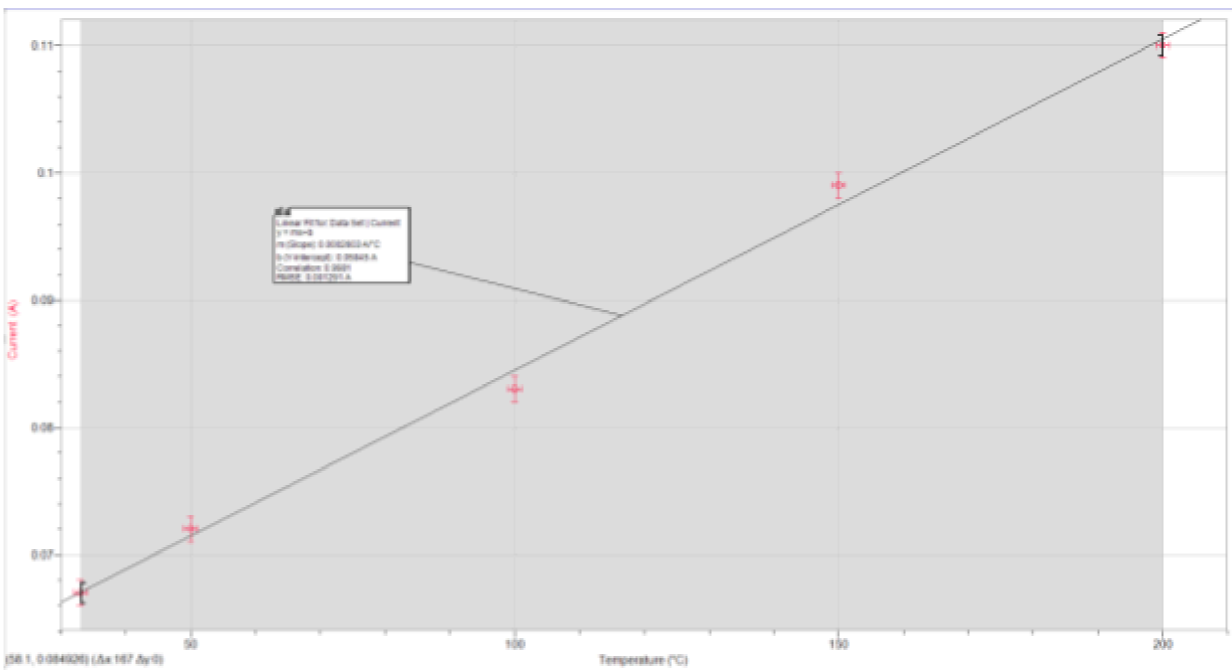
Figure 5
(Author's own)

In order to determine the temperature at which the silicon based semiconductors in a standard CPU begin to fail, preliminary testing was conducted. Semiconductors act as logic gates that allow through voltage when supplied with power, which are essentially switches that represent a value of 1 or 0 which allows the processing of information in binary when there are many semiconductors in a chip. When point B is powered, the circuit is broken and electricity can no longer pass from point A to C which signals the value of 0. (Figure 5). In this experiment. point B will remain powered on and the current of the circuit will be measured.

Results:

Table 2

Temperature (±1℃)	Current (±0.001A)
30	0.067
50	0.072
100	0.083
150	0.099
200	0.11



(Graph 0)

As demonstrated by the graph 0, there is a clear correlation between the temperature and the current of the circuit and the trendline shows a proportional relationship. This means that as the temperature increases, the amount of current let through the circuit by the semiconductor increases which signifies that the semiconductor is beginning to fail more.

2.0 Simulation Setup/Justification

2.1 Errors and Uncertainty:

Due to the nature of a simulation, the values of an experiment are free from any human error and there will be no variation within trials, as such only one trial will be created per increment.

In terms of accuracy, there are various settings in the simulation which can be altered to change the precision of the final simulation in relation to an experiment performed in the real world. This includes:

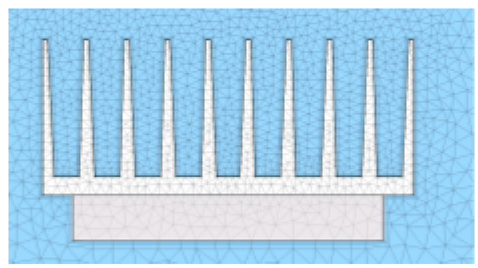


Figure 5
(*SimScale*)

- **Write interval: 5s.** A lower value of write interval means a higher amount of data points will be collected which will increase accuracy. In this case, a data point is being recorded every 5 seconds creating a total of 150 data points. This is similar to taking a temperature reading every 5 seconds in a physical experiment.
- **Mesh Algorithm: Standard (Figure 5)** The mesh determines how elements of the simulation interact and is created around any solid geometry present. It can be imagined as a net that wraps around the geometry which allow the simulation to better calculate the interactions between the object and the surroundings. This is as the net separates a complex shape into small 2d shapes such as triangles or quadrilaterals upon which simple geometry can be applied.

- **Mesh Fitness:**
  - **Small Feature Suppression:** **7.9e-6m.** The minimum edge length below which small features like tiny edges or sliver faces should not be resolved anymore in the mesh. This means that the small 2d shapes will not be further separated into smaller shapes. In this case, faces or edges with length less than 7.9e-6m will not be further resolved into smaller edges.

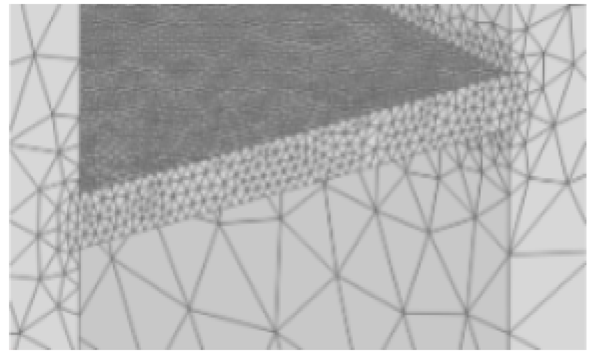


Figure 6:Example of values 4-1 (*SimScale*)

  - **Gap Refinement Factor: 3.** It defines a target number of elements across thin gaps in the mesh. This allows for small gaps, in this case the space between heatsinks, to be accounted for more accurately. A higher value means more accuracy at the cost of more resources.
  - **Global Graduation Rate: 1.22.** This value is the ratio between the size of two adjacent cells. The allowed range is 1.0 - 3.0. 1.0 would produce a uniform mesh with the smallest size everywhere but would cause significantly higher resources. 1.22 allows for some variation in size of the cells.

2.2 Simulation Settings:

There are various settings which have been altered in the simulation to ensure an accurate representation of real life. They are listed below

- **Model (Earth and STP):**
  - **Gravity**: g_y:-9.81(ms^{-2})
  - **Global Pressure:** 101000(Pa) (NationalGeography)
- **Materials:**
  - **Air**
    - Viscosity model: Newtonian
    - Kinematic viscosity: 1.53e-5 (m^2s^{-1})
    - Density:1.20 (kgm^{-2})
    - Thermal Expansion Coefficient: 3.43e-3(K^{-1})
    - Laminar Prandtl number: 0.713
    - Turbulent Prandtl number: 0.850
    - Specific heat: 1004 ($J\ kg^{-1}K^{-1}$)
  - **Aluminum (Heatsink)**
    - Conductivity type: Isotropic
    - Thermal conductivity: 235 ($Wm^{-1}K^{-1}$)
    - Specific heat:897 ($Jkg^{-1}K^{-1}$)
    - Density:2700 (kgm^{-2})
  - **Silicon (CPU)**

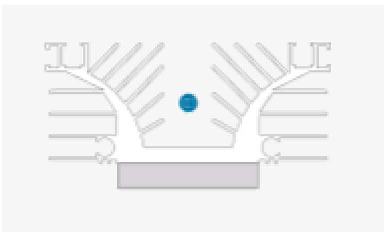
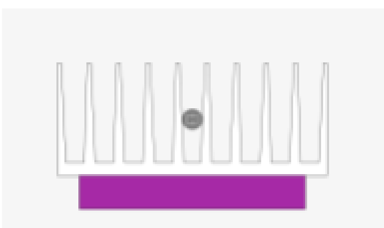
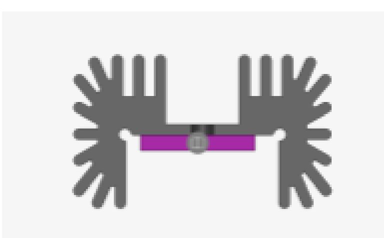
        - Conductivity type: Isotropic
        - Thermal conductivity: 148($Wm^{-1}K^{-1}$)
        - Specific heat:705 ($Jkg^{-1}K^{-1}$)
        - Density:2330 (kgm^{-2})

- **Initial Conditions**
    - **Initial Velocity of Air around Heatsink:**V_y:0.1(ms^{-1}) to simulate natural convection
    - **Initial Temperature of Heatsink and CPU**: 50(℃) to simulate a running CPU under load
- **Solver Type:** Preconditioned Bi-conjugate Gradient Solver (PBiCG). A solver making use of the conjugate gradient method, which is the most common algorithm used to solve for a large number of linear equations in a short amount of time such as those that will be appearing in the simulation. The limitation of this solver is that it can only be used for positive and definite matrices, but that is the only matrix that appears in this simulation. (Shewchuk, 2)
- **Power Settings:** The absolute power of the CPU is set to 5 intervals of power (3W, 5W, 7W, 9W, 11W)

2.3 Procedure:

Using the models, create the simulation under incompressible heat transfer. Double check that the models imported are of the right dimensions as some programs may be incompatible. Then, input all the settings and start the simulation, this may take some time. Once done, analyze the results using both the data collected and a thermal map you can create in the post simulation tab. This will allow a visualization of the simulation. For the data collected, find the lowest temperature maintained by finding the point at which the slope is zero and find the rate of change by taking a tangent of the downward slope.

2.4 Test Objects:

HeatSink Stats	Surface Area (m^2)	Number of Fins	Volume (m^3)
 **HeatSink A** Volume:1.605e-4 (m^3) Surface Area:9.536e-2 (m^2)	0.954	26	1.61e-4
 **HeatSink B** Volume:1.596e-4 (m^3) Surface Area: 5.002e-2 (m^2)	0.500	10	1.60e-4
 **HeatSink C** Volume:1.661e-4 (m^3) Surface Area:4.293e-2 (m^2)	0.429	22	1.66e-4

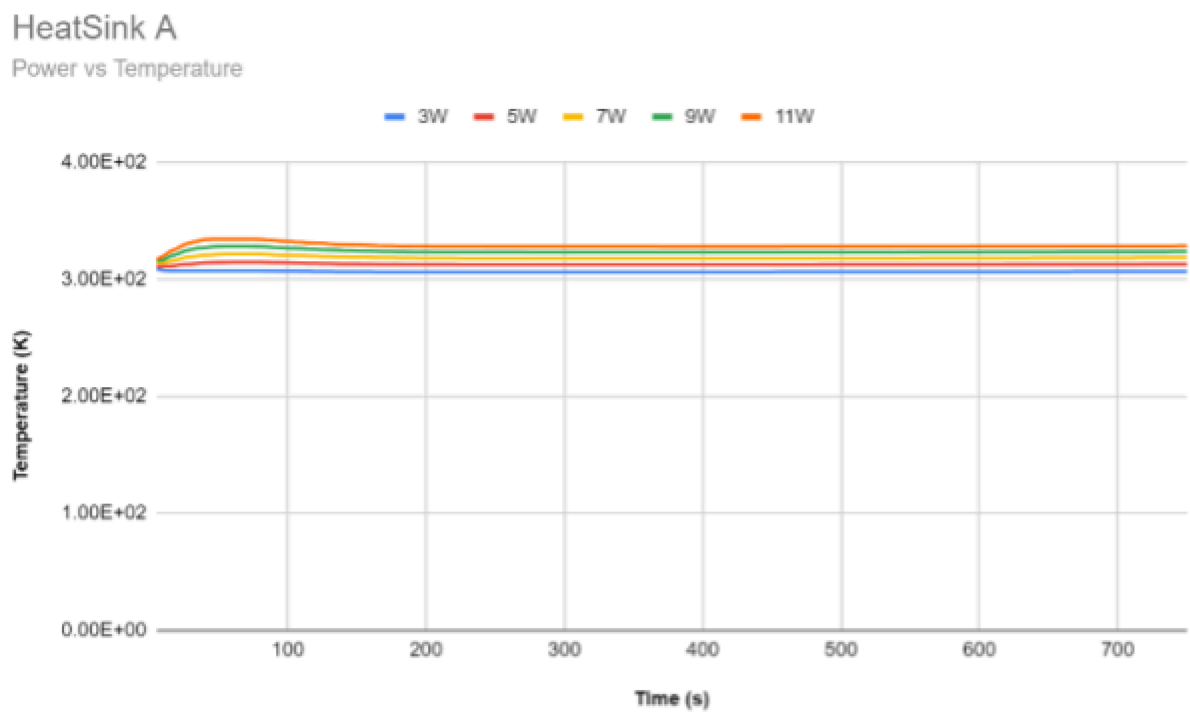
As discussed in the background theory, the rate of heat transfer is proportional to the area of contact between the two medians. Therefore, a higher surface area by the placement and size of fins will theoretically lead to a higher rate of heat transfer.

The heatsinks used in this experiment were made with the intention of testing this theory and they were made in Tinkercad by forming a rectangular 3D shape and carving out all the fins with the “split” tool. Design A was my design attempt to maximize the surface area of the heatsink with the same volume (with a negligible variation). In order to do this, I made use of a high number of thin fins and arranged them diagonally. Design B is a basic design most commonly used in modern day applications which makes it important to test in this experiment. Design C is based off the common design of heatsinks for chips in Random Access Memory Sticks (RAM) as well as Solid State Drives (SSD) as they are commonly in a long rectangular shape. Therefore it is common for the chip to be surrounded on all sides by the heatsink. Design C follows a design that is usually smaller in size but I scaled it to match the other designs.

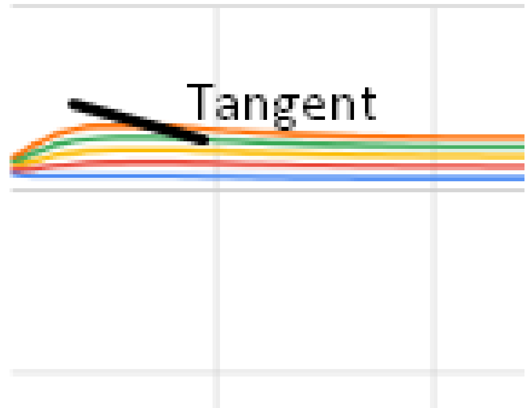
According to the surface areas of the three heatsinks, Heatsink A is predicted to be the most efficient at dissipating heat due to its surface area being about twice that of the other heatsinks. However, the different designs of the heatsinks may cause different problems with their performance. For HeatSink A, the curved shape of the blades and the small amount of space between each blade may cause issues with airflow and slow down the rate of heat transfer. Heatsink C may have a similar problem due to the lack of space between the fins, but the more major problem is the smaller amount of surface area compared to the other two heatsinks.

3.0 Data Analysis

3.1 Raw Data Graphs:



(Graph 1)



3.2 Processed Data Tables:

1. Rate of Decrease in Temperature (Found by taking a tangent of curve):

	ΔT/Δt (K/s)		
Power	Heatsink A	Heatsink B	Heatsink C
3	-0.010	-0.038	-0.012
5	-0.021	-0.062	-0.031
7	-0.034	-0.087	-0.049
9	-0.046	-0.114	-0.069
11	-0.057	-0.152	-0.087

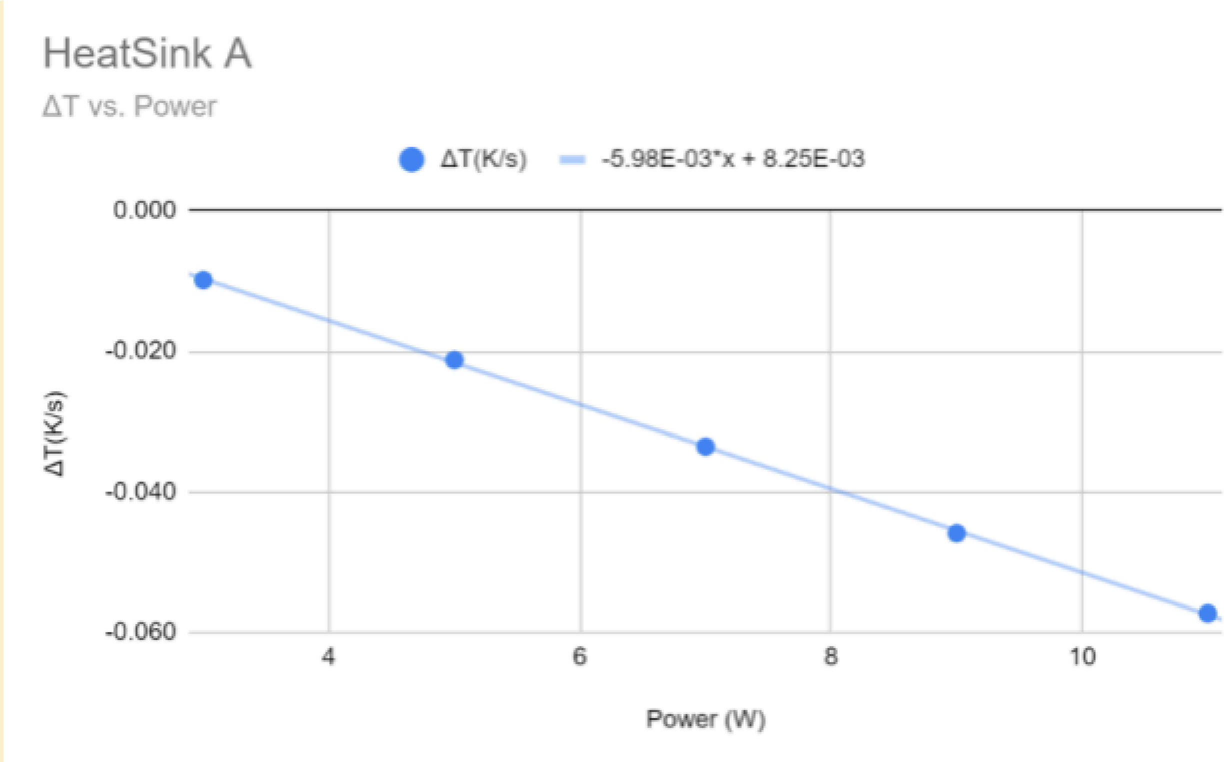
Average ΔT/Δt(K/s)	
HeatSink A	-0.034
HeatSink B	-0.091
HeatSink C	-0.050

2. Lowest Temperature Maintained:

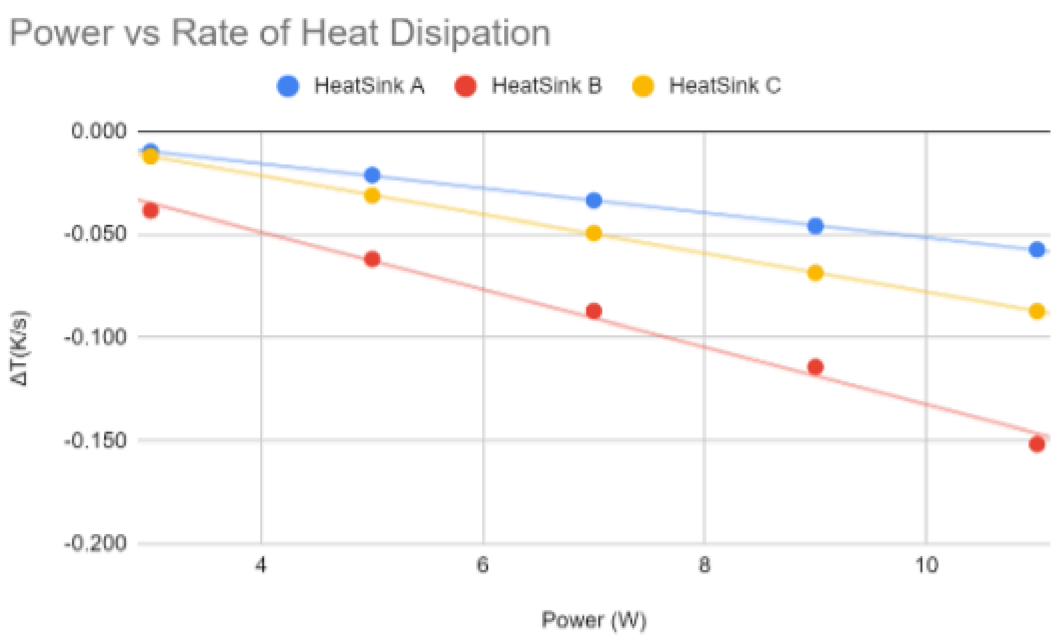
	Lowest Temperature Maintained				
	3W	5W	7W	9W	11W
HeatSink A	307	313	319	324	329
HeatSink B	308	314	320	326	334
HeatSink C	317	328	339	349	358

3.3 Processed Graphs:

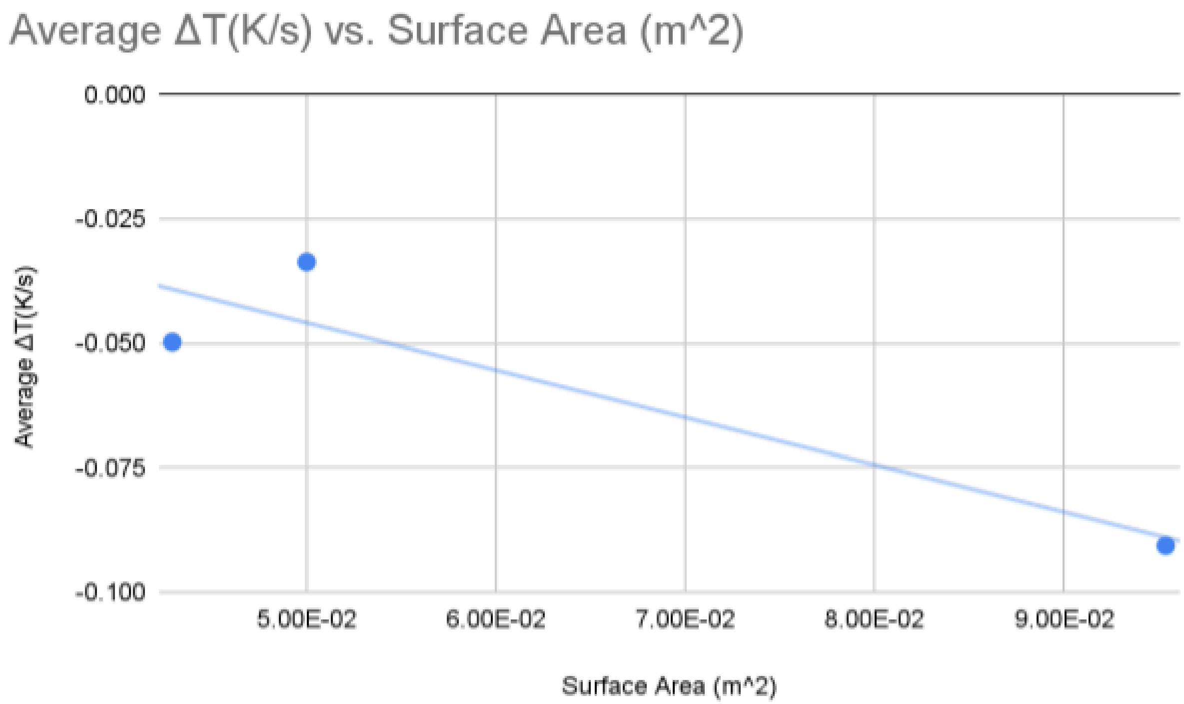
1. Rate of Heat Dissipation:



(Graph 2)

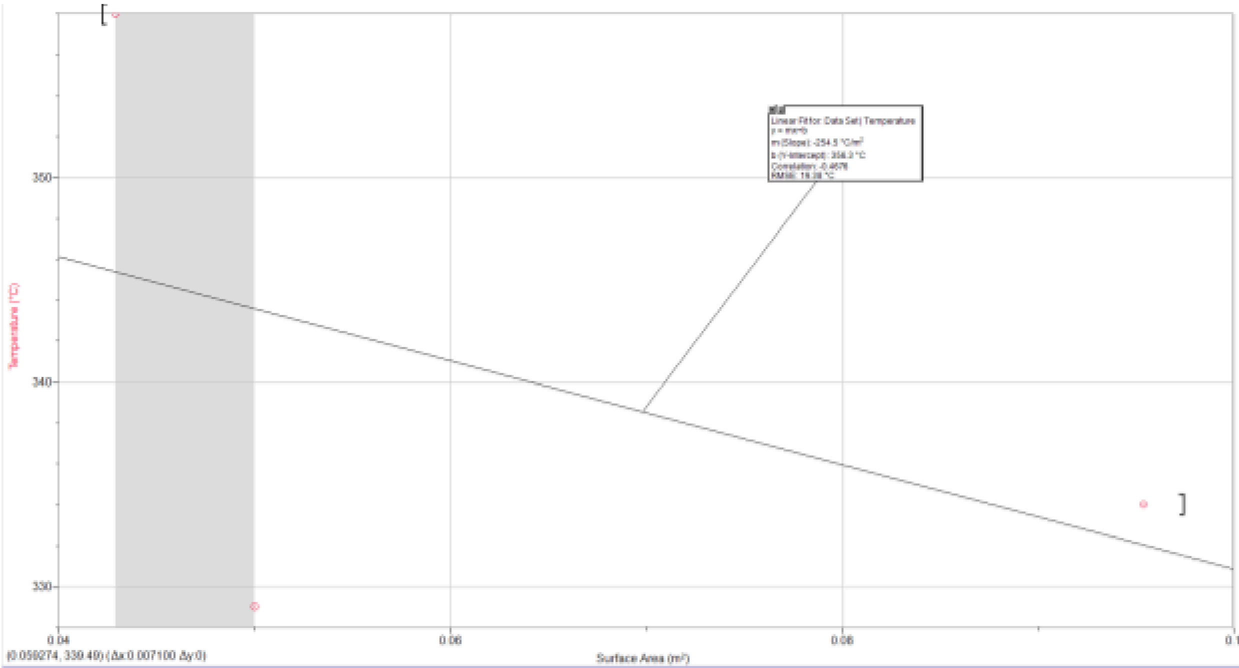


(Graph 3)
Lower Value Means Faster Rate


Average ΔT(K/s) vs. Surface Area (m^2)
0.000
-0.025
-0.050
-0.075
-0.100
Average ΔT(K/s)
5.00E-02
6.00E-02
7.00E-02
8.00E-02
9.00E-02
Surface Area (m^2)

(Graph 4)

Surface Area vs Temperature Maintained :

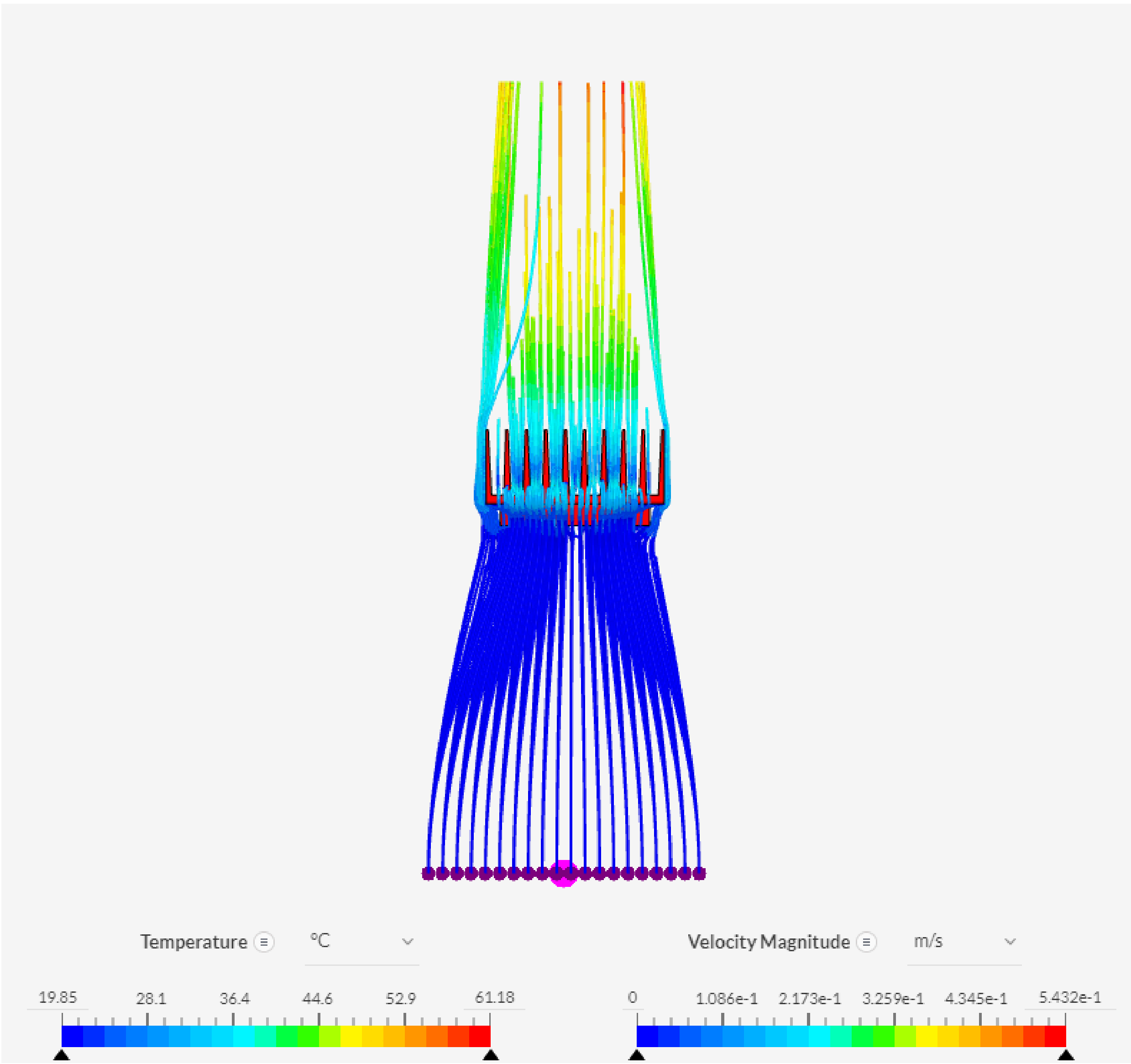


(Graph 5)

3.4 Visual Representations:

***Representations are of the 11W increment to best show heat movement**

1. Flow of Air Surrounding the Heatsinks



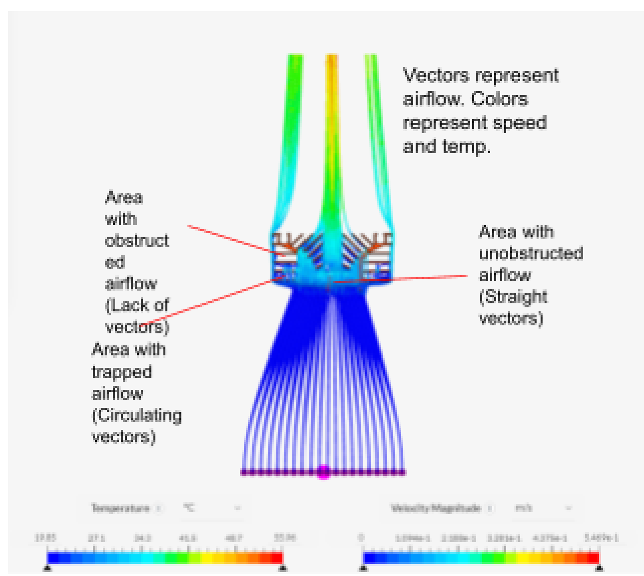
4.0 Evaluation and Conclusion

4.1 Analysis:

By analyzing the results gathered from the experiment, a number of observations can be made regarding each individual heatsink. This will allow the data to be put into context based on the different characteristics of the heatsink and help draw a conclusion to explore the relationship between surface area and the rate of heat transfer.

Heat Sink A:

This heatsink was the one with the largest surface area of $0.095m^2$.This was achieved with the diagonal placement of the fins and overall thinner fins which is a very unconventional design. In terms of performance, this heatsink was able to maintain the overall lowest average temperature of the CPU in all the power setting increments, and it achieved the temperature range of 307-329K (Table 2), which was lower than both heat sinks B and C. However, in terms of rate of thermal dissipation, it performed the worst among the 3 heatsinks as it maintained an average of

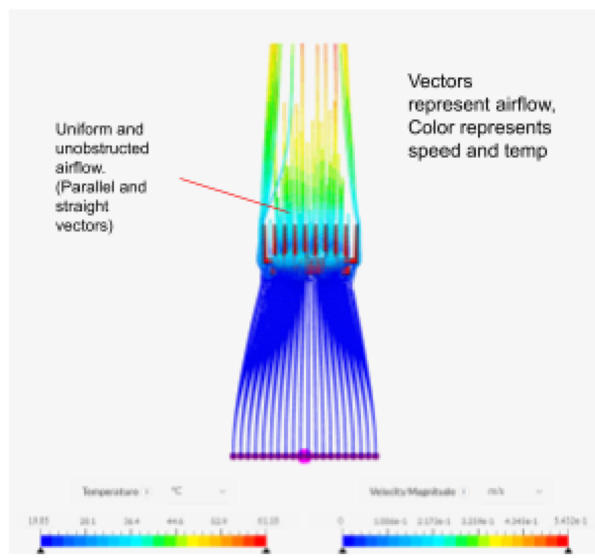


Vector Map of Heatsink A
Diagram 1
(*Simscale*)

0.034K/s (Table 1). This is correlated with the ability of the heatsink to facilitate airflow as convection is the most significant method of heat transfer present. As shown in Diagram 1, there are various areas where the air is trapped which limits convection which slows down the rate of heat dissipation. Finally, it is important to note that Heatsink A specifically performed much better than the other two at a high power setting for the CPU in lowest temperature maintained as it had an absolute temperature difference of 5K (Table 2). This indicates that some property of this design allowed it to maintain a better performance on a higher load, this will be further explored in the next section.

Heat Sink B:

This heatsink was the one with a middle amount of surface area of 0.050m^2 and follows a very traditional and common design. In terms of performance, this heatsink maintained the second lowest temperature with a range of 308-334K (Table 2) across all the power increments. It is worth mentioning that this was very close to the temperature of Heatsink A, which means the temperature difference will be unlikely to be noticed in a real world setting. In terms of the rate of thermal dissipation, it performed significantly better than the other Heatsinks with an average value of 0.091K/s (Table 1). This suggests that this heatsink is more effective at quickly lowering the temperature of an object that is already hot. The rate of heat transfer is correlated to the effectiveness of the design at inducing

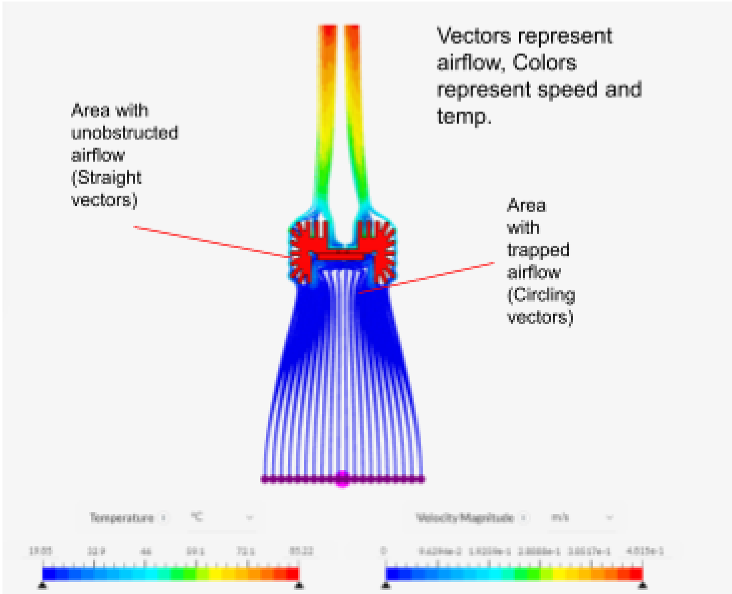


Vector Map of Heatsink B
Diagram 2
(*SimScale*)

convection, which can be shown in Diagram 2. There is a good gradient of colors which represents an effective heat dissipation, and there are very few obstructed vectors. This means that convection is not obstructed which correlates to the high value of heat transfer.

Heat Sink C:

This heatsink was the one with the smallest surface area of 0.043m^2 and is a design used in heatsinks for SSDs and RAM sticks. In terms of performance, this heatsink performed the worst in the lowest temperature maintained with a range of 317-358K (Table 2) across all the power increments. This was significantly worse than the performance of the other two heatsinks and would cause performance issues if used with a CPU. However, this design was meant for SSDs and RAM which produce less heat in a real world setting so this result is acceptable. In terms of rate of thermal dissipation, it performed between heatsinks A and B at a rate of 0.050K/s (Table 1). This performance can be linked to the airflow of this heatsink as the rate of heat loss is directly correlated to the ability of the object to support convection. As seen in Diagram 3, there are areas with trapped air near the bottom of the heatsink which leads to a decrease in the efficiency of convection. This is in line with the performance of Heat Sink C in terms of rate of heat transfer.



Vector Map of Heatsink C
Diagram 3
(*SimScale*)

4.2 Conclusion:

A few trends can be established when looking at the data overall. First, it can be concluded that a surface area is directly proportional to the temperature that can be maintained as shown by graph 5. The trendline was linear and had a negative slope. Furthermore, it can be deduced that the airflow around the heatsinks does not contribute to the lowest temperature maintained. This is demonstrated by graph 3, where heatsink B outperforms both A and C by a clear margin, which can only be attributed to airflow. The heatmap diagrams 4, 5, and 6 in the appendix also help exemplify this. Where Heatsink B had a standard gradient of heat expected from convection while the other two did not. In terms of the different power settings for the experiment, the heatsinks performed as expected. As shown by graph 1, the trend of the graph stayed the same and each power setting shifted the y intercept. This means that the performance of heatsinks stayed the same throughout with the exception of heatsink A which was explored in the individual analysis. This coincides with the background research as due to the property of heat transfer where the rate is also proportional to the difference in temperature between the two mediums.This result supports the hypothesis to a certain extent as it can be inferred that a high rate of temperature change in the heatsink will lead to a lower absolute temperature.

Another trend to be examined is shown in graphs 1, 6, and 7. As shown, all three heatsinks had an initial rise in temperature until a local maxima. The temperature then begins to fall to a local minimum where it is maintained for the remaining duration of the experiment. It is unknown why this occurred and should be further investigated in a further experimentation. A possible explanation could be the change in the velocity of the air, which would change its shear rate. This could affect the speed at which the heat is dissipated, which would be in line with the background research.

Finally, the relation between the rate of heat dissipation and surface area which was outlined in the hypothesis needs to be examined. Consider graph 4, the trend line suggests a linear relationship between the rate of heat dissipation and surface area that is negatively proportional. However, that trend line cannot be considered an accurate representation of the data as the first two data points indicate a positively proportional relationship. Furthermore, when each individual data point is examined, it can be shown that the rate of heat transfer did not follow any trends when plotted against surface area. However, when the rate is examined with heatsinks that exhibit turbulent flow, it is shown that a higher turbulent flow causes a lower thermal dissipation rate, which is in line with background research. Thus it can be concluded that the airflow of the heatsink is also a major aspect that affects the rate of heat transfer. In conclusion, the surface area of a heatsink does directly affect the rate of heat dissipation of a heatsink, but it is not the sole deciding factor of the rate. This is in line with the background research as convection is largely dependent on the fluid's property and the ability of the structure to facilitate it. This result also provides valid justification for the designs of most industry standard heat sinks as there is a significant focus to both maximize airflow and surface area.

4.3 Evaluation:

There are various potential systematic errors that exist within this experiment. Firstly, the design of this experiment could have been more focused specifically on the effect of surface area and heat dissipation. This would require the heatsinks used to be the same in design but with thinner fins. However, this is not realistic in a real world context as thinner fins lead to fragile designs which would break extremely easily. Furthermore, it is well established that a higher area leads to a higher rate of heat transfer as explored in the background research, therefore the lab was designed instead to feature different designs which would better establish their feasibility in the real world. The downside of this experiment design is that the results became harder to interpret and therefore caused some reliability issues as there are more than one variable to consider. Furthermore, the lab question could have been better designed to provide a more holistic view of the performance of a heatsink rather than just the rate of heat dissipation. As found in the lab, the lowest temperature maintained in the lab followed a different trend than the rate of heat transfer, which could be arguably more indicative of the effectiveness of a heatsink design.

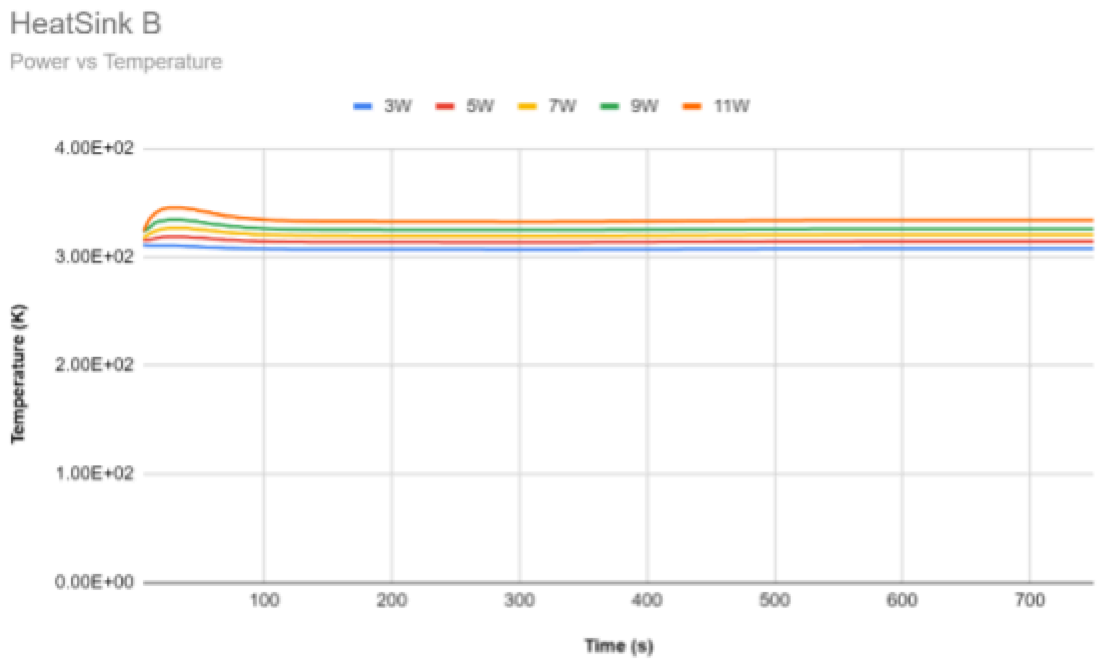
Another limitation of the lab is the fact that it is simulation based, this means that the assumptions made in the simulation settings (section 2.3) could have caused inaccuracies compared to the real world. In particular, the assumption that the material is isotropic likely had the most significant impact on the results. In the real world, materials are not consistently the same throughout, this may be due to impurities in the smelting process or oxidization over time. (*Britannia*). This means that the properties of the material will differ a bit throughout. Furthermore, the simulation still fails to take into account every possible detail, for example, the excess heat from in a computer or constricted airflow of being inside of a case. This lab should thus be repeated in the future in real life and then cross examined with the simulation to increase reliability.

A possible extension to this lab is to explore the reason behind the initial rise in temperature described in section 4.2. This can be done by choosing a specific heatsink and changing other variables to attempt to recreate this behavior.

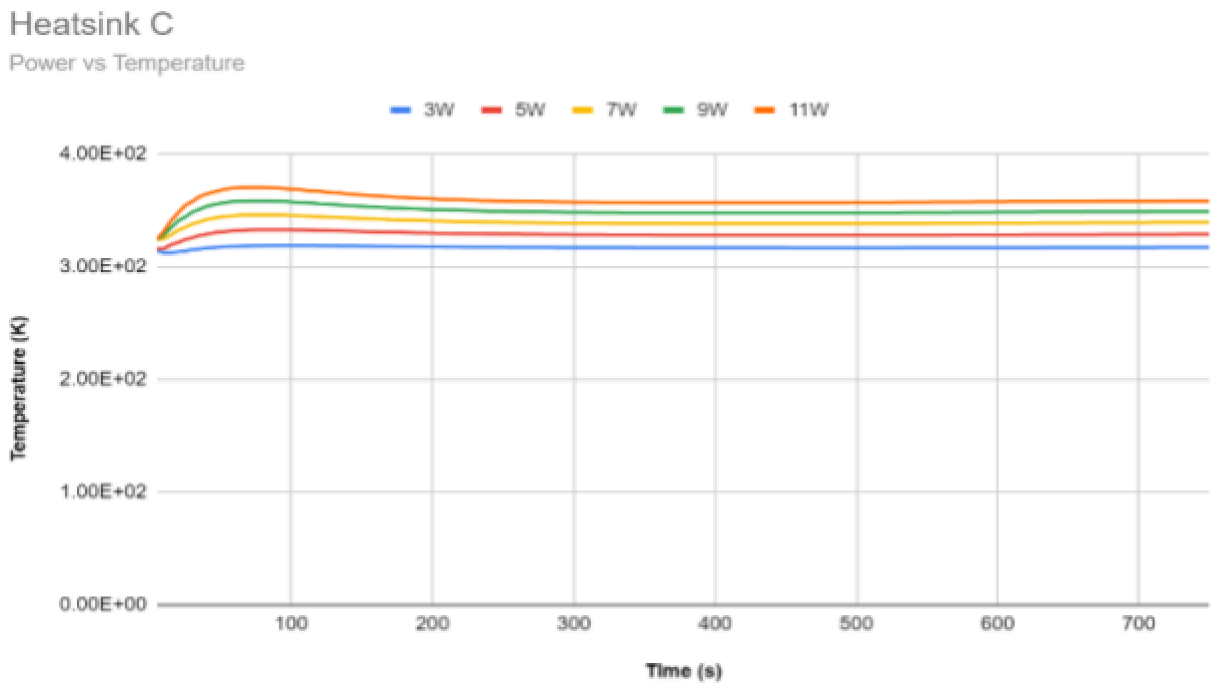
5.0 Appendix

Procedure:

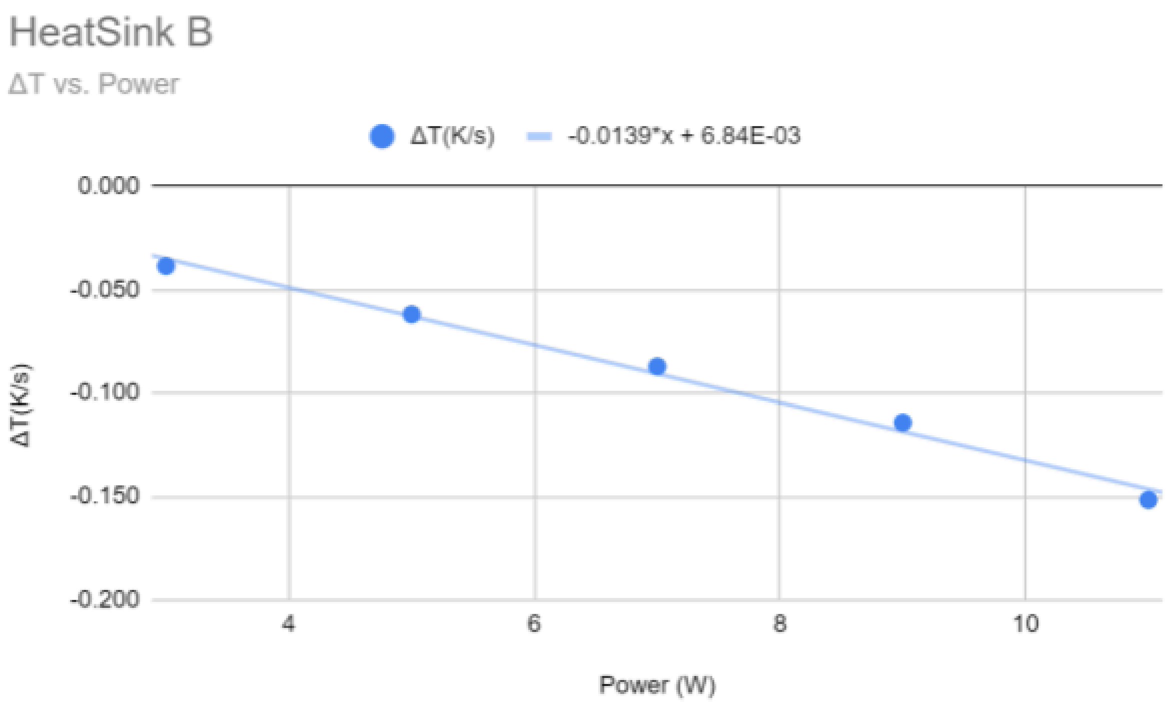
1. Create a new instance on simscale and import the 3D cad files of the heatsinks in “Solidworks” format.
2. Create simulation on the first heatsink and selected “conjugate heat transfer V2”
3. Input the specified settings into the simulation, refer to section 2.2 and 2.3. Ensure the absolute power of the CPU is set to 3W
4. Create a mesh for the heatsink chosen, refer to section 2.2 for settings
5. Create a data collection point on the surface of the CPU connected to the heat sink, set it to average ΔT
6. Run the simulation, and maneuver to the data collected by the data collection point
7. Download the results as a CSV files and copy the data points
8. Graph the data collected and use a curved best fit line in order to pass through every point.
9. Find the tangent of the curve at the steepest point and find the slope of the tangent, this finds the greatest rate of decrease of temperature
10. Repeat steps 1-9 with each increment of temperature and for each design of the heatsink, for a total of 15 rate of change values
11. Plot three separate graphs of W vs Rate of change for each heatsink design and compare the results


HeatSink B
Power vs Temperature
3W
5W
7W
9W
11W
4.00E+02
3.00E+02
2.00E+02
1.00E+02
0.00E+00
Temperature (K)
100
200
300
400
500
600
700
Time (s)

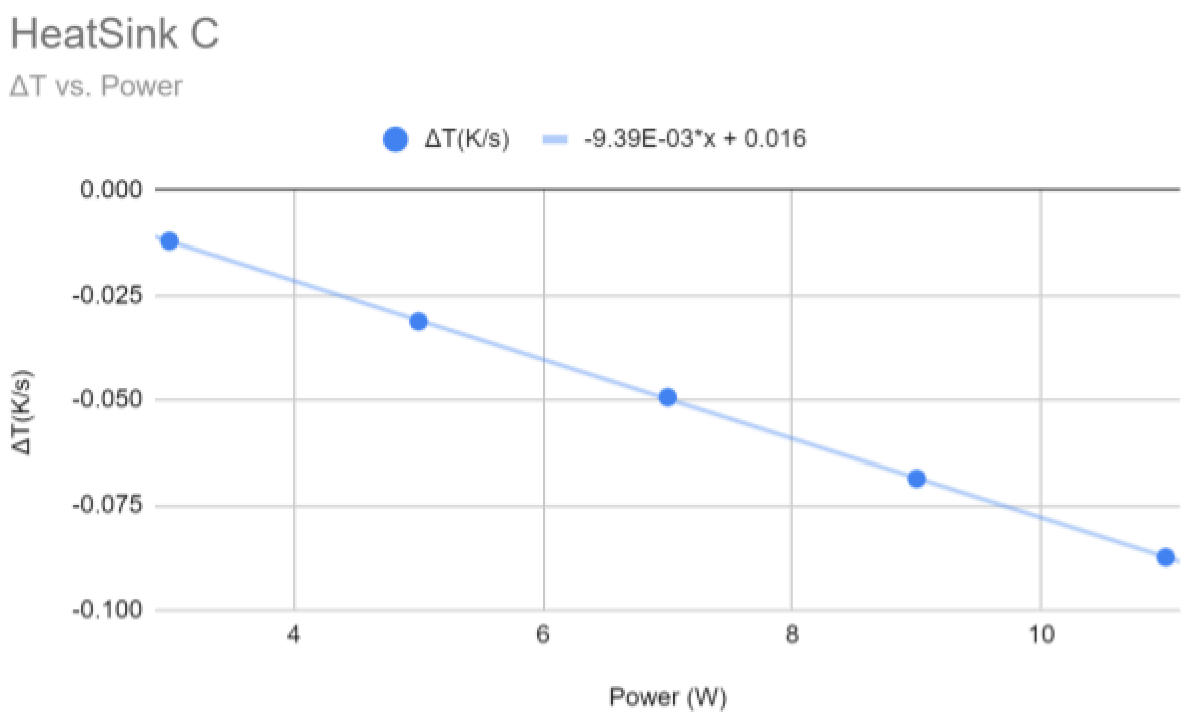
(Graph 6)


Heatsink C
Power vs Temperature
3W
5W
7W
9W
11W
4.00E+02
3.00E+02
2.00E+02
1.00E+02
0.00E+00
Temperature (K)
100
200
300
400
500
600
700
Time (s)

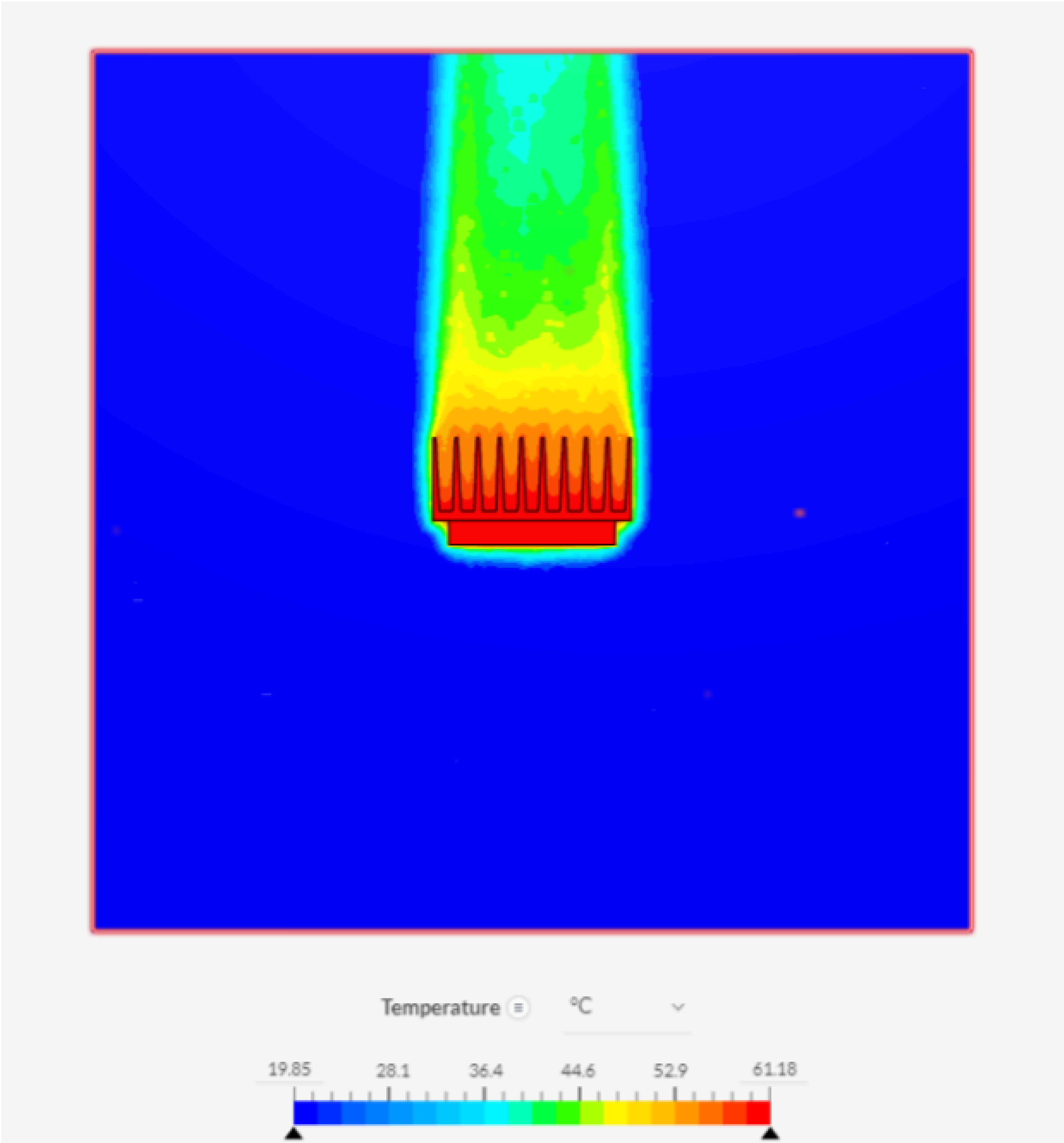
(Graph 7)


HeatSink B
ΔT vs. Power
ΔT(K/s)
-0.0139*x + 6.84E-03
0.000
-0.050
-0.100
-0.150
-0.200
ΔT(K/s)
4
6
8
10
Power (W)

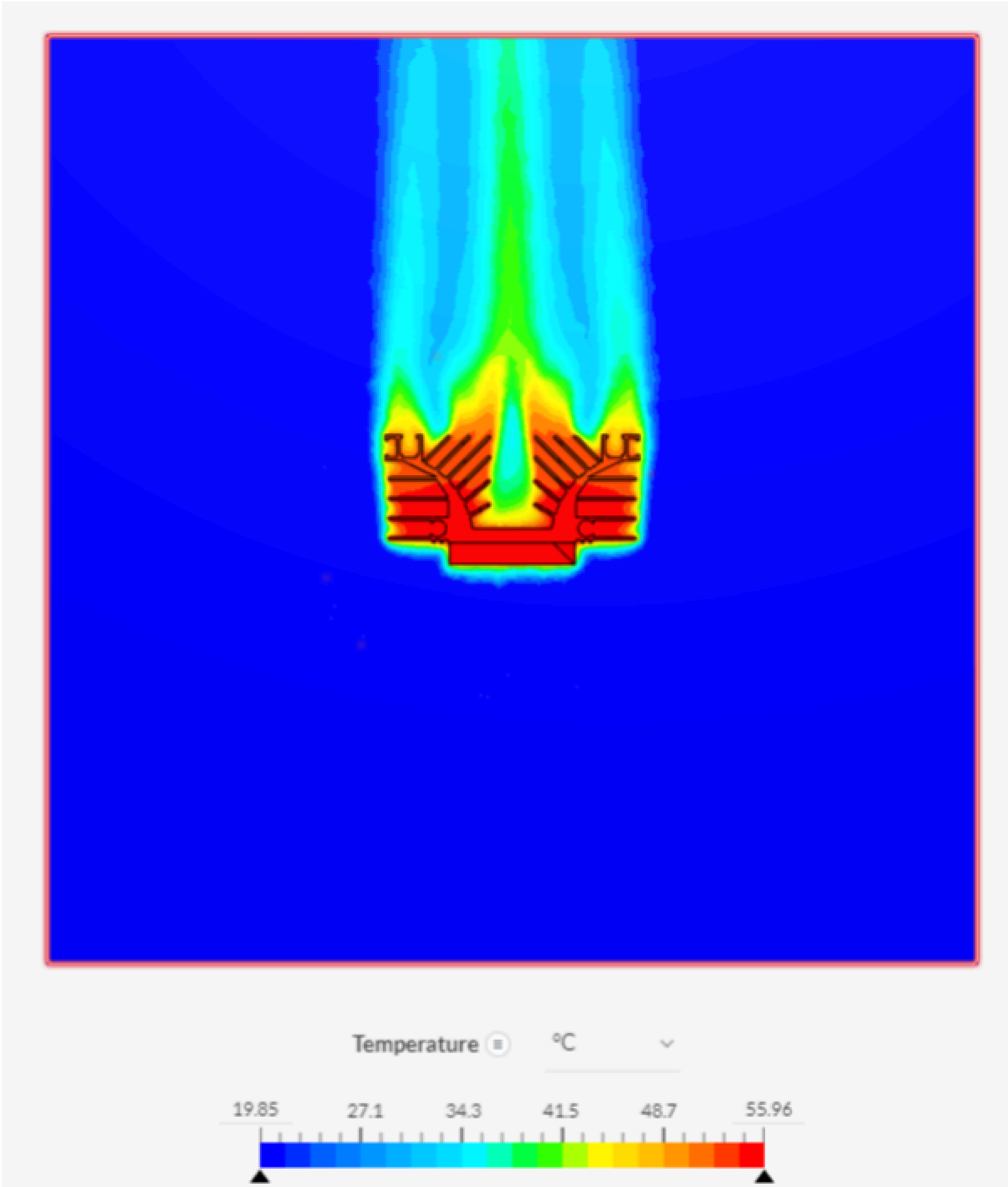
(Graph 8)


HeatSink C
ΔT vs. Power
ΔT(K/s)
-9.39E-03*x + 0.016
0.000
-0.025
-0.050
-0.075
-0.100
ΔT(K/s)
4
6
8
10
Power (W)

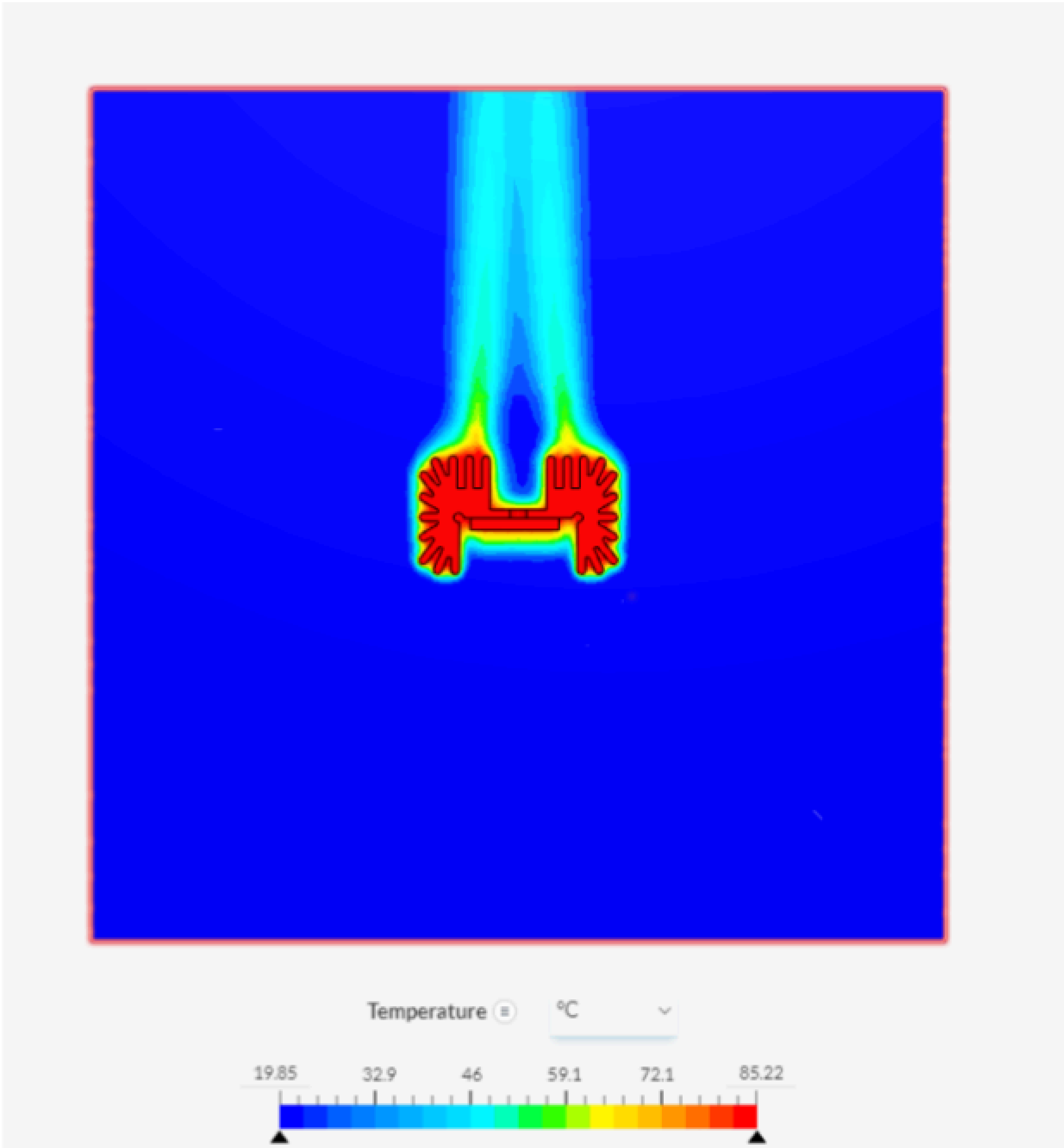
(Graph 9)



(Diagram 5)



(Diagram 6)



(Diagram 7)

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