Thermal Management for Power Electronics

CFD Analysis with Solidworks Flow Simulation

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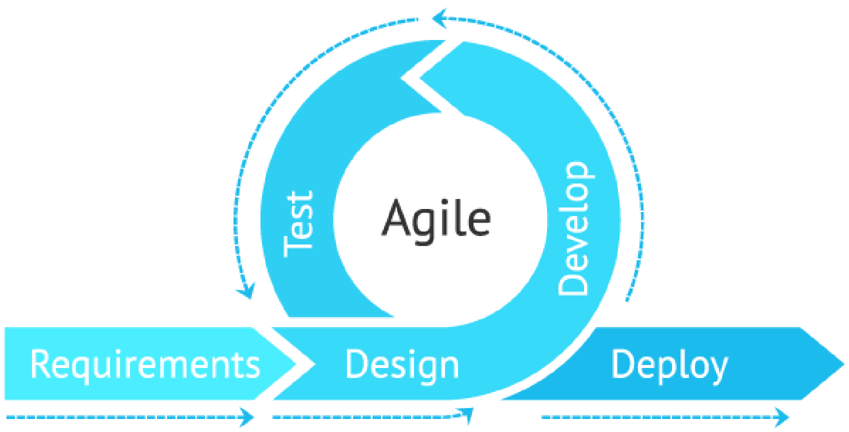
Objective

The objective of the project is to dissipate the heat load from power electronics with various methodologies.

New Product Development Process



Diag 1 Source: DevCom

There are several true and tested models in the new product development processes such as the stage-gate process, spiral model, sequential waterfall model, concurrent engineering, and iterative development (Minderhoud, Fraser).

Throughout this project, the modular iterative development model will be used which will follow the agile design sprints for each modular designed component starting with requirements, design, development, testing, and deployment to form the complete product. This project is an engineering design project which may take several iterations and simulations before reaching to the final functional product. Based on the modular component, the entire project will be divided into modules and each module will go through the agile development process and will be deployed only when the required conditions will be satisfied. This model is used extensively in software product development, however, with the current high-end CAD software it is possible to eliminate several prototyping iterations and reduce the testing times by conducting FEA and CFD simulations which makes it possible to use in the hardware design of this project.

The following are the benefits of using the proposed model:

- Modular product architecture
- Early detection of failure and corrective action
- Short iteration cycles
- Lean methodology
- Concurrent engineering [1]

Requirements

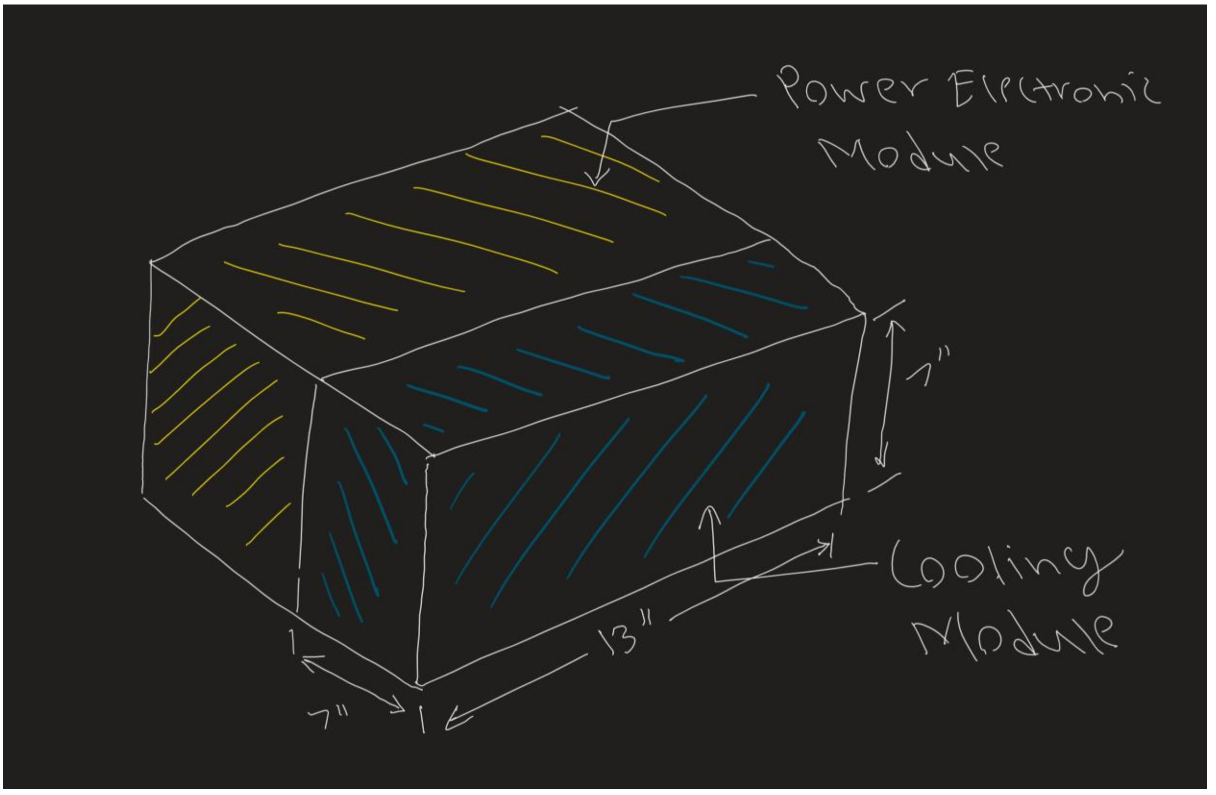
The product should be capable of carrying the heat generated by power electronics maintaining an operating temperature below the maximum rated capacity of the IC. This has to be accomplished by using any type of cooling technology available in the market or by using market available products. The following table shows the necessary system requirements (SR) for the cooling system.

Standard components can be considered for readily available material and custom components can be designed for

Table 1

Ref. No.	**Description**	**Specification**
SR1	The heat needed to be extracted from the IC (Maximum power dissipation)	P_{Dmax} = 1000 W
SR2	The maximum possible volume of the cooling system. Refer Diag 2	13”x7”x7” inches^3 330x178x178 mm^3
SR3	The surface area of the IC for heat extraction	4”x5.5” inches^3 100x140mm
SR4	System eclosure	Sheet metal enclosure
SR5	Ambient temperature	T_a = 25 to 35 degrees C
SR6	Cooling Technology	Any
SR7	Maximum Allowable IC temperature (Maximum junction operating temperature)	T_{OPmax} = 80 degrees C

Diag 2: System Overview



Product Design

Iteration 1.1

Requirements

The requirements given in table 1 will be considered for the design process.

For finding the ideal design it is important to understand the resistance offered by the surrounding for heat transfer which is given by R_{total}

$$P_{Dmax} = \frac{T_{op,max} - T_A}{R_{total}}$$

Where:

P_{Dmax} – Max Power Dissipation

T_a – Ambient Temperature

$T_{op,max}$ – Maximum Junction Operating Temperature

R_{total} – Total Thermal Resistance to Surroundings

…………...Eq1

Substituting the available values, we can get:

$1000 = (80-25) / R_{total}$

$R_{total} = 0.055$ C/W

This is the best possible condition where it is assumed that the surrounding temperature is at 25C however, it may not be the case in all situations.

Calculating for worst conditions with the surrounding temperature at 35 C and the taking T_{opmax} at 70 C to design for worst possible conditions and having some wiggle room for uncertain circumstances.

$1000 = (70-35) / R_{total}$

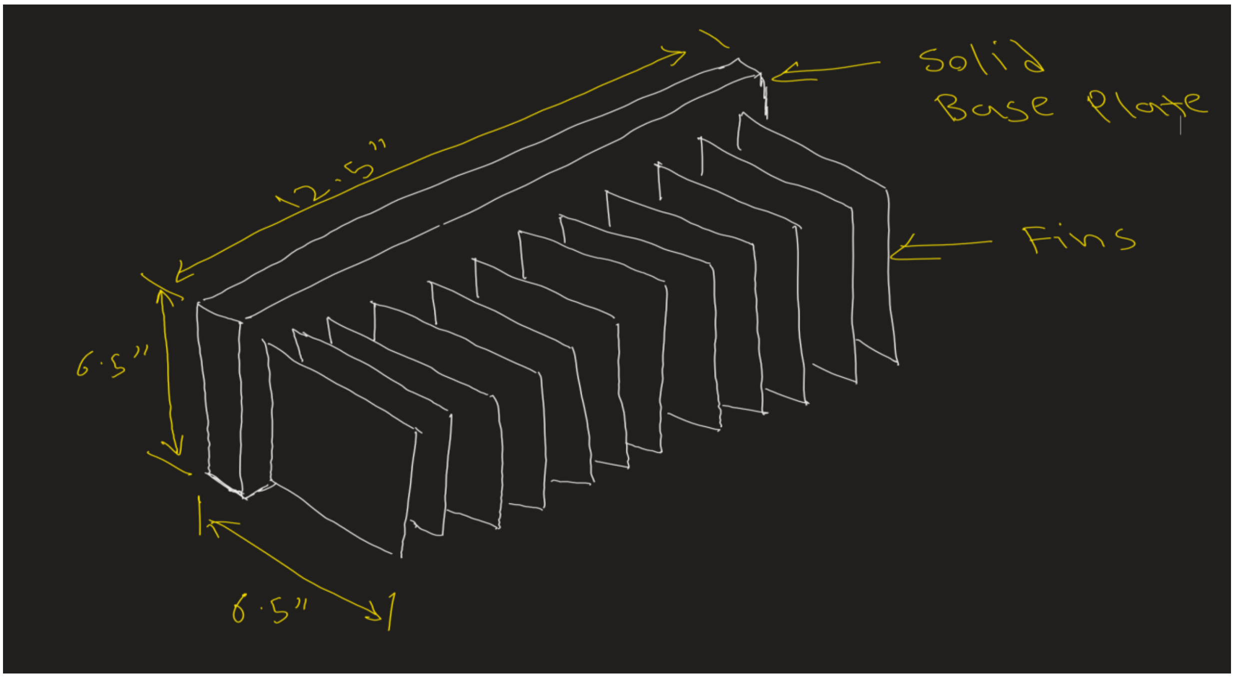
$R_{total} = 0.035$ C/W

This indicates that for the best possible condition the heat dissipation system should have a thermal resistance of 0.055 C/W for satisfying the given condition. However, for the worst possible condition, the thermal resistance of the system demanded by the conditions is 0.035 C/W. The required thermal resistance is 0.035 C/W or lower.

This value of thermal resistance is substantially lower than the market available solutions. It is recommended to custom design a heat dissipating system.

For this iteration let us consider that the heat sink is using passive heat dissipation technology which dissipates the heat using the natural circulation of the ambient air with convective heat transfer.

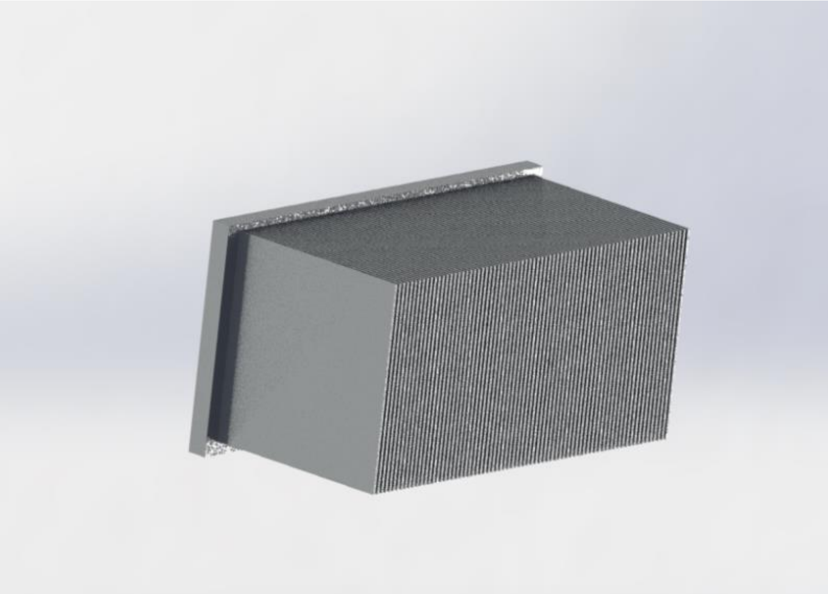
Diag 3: Design of the custom heat sink.



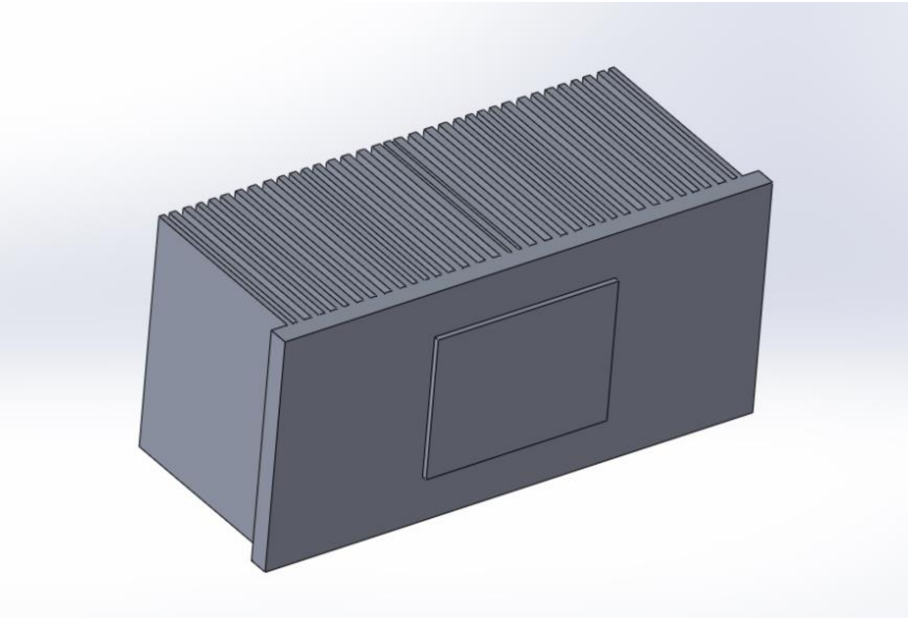
The heat sink base plate is made from solid Aluminum to lower the weight and the fins are 4 mm apart to increase surface area and allow natural convection.

CAD Modelling

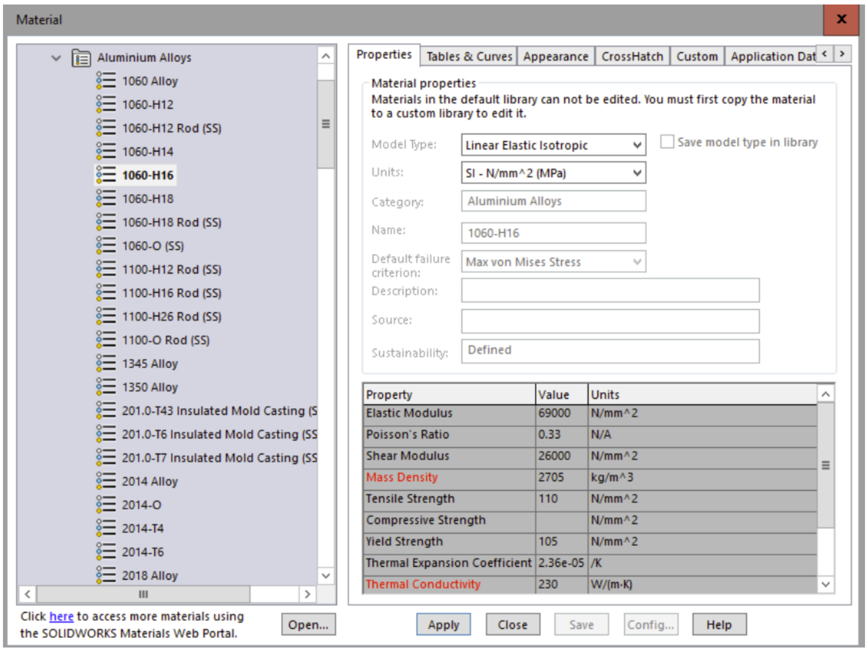
Diag 4: CAD



Diag 5: Backside

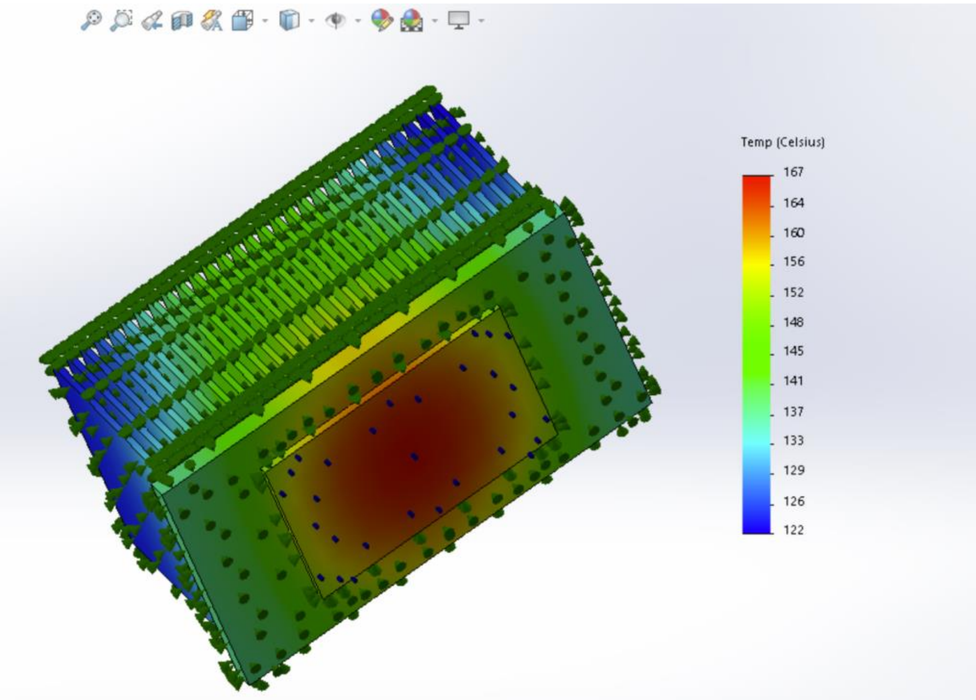


Diag 6: Material properties

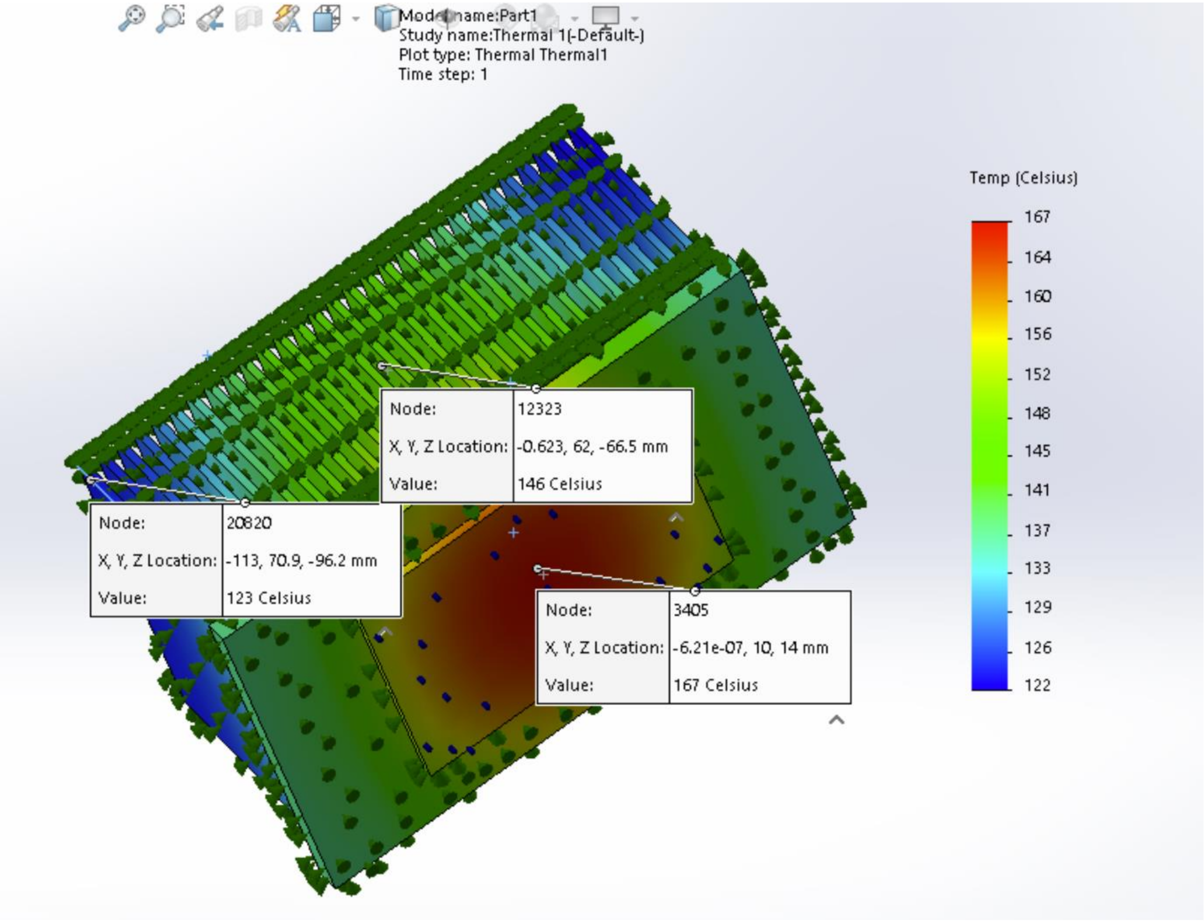


Finding thermal resistance offered for heat transfer. For conducting calculations, a thermal modeling study is required. Conducting thermal simulations by applying the 1000W heat source at the base.

Diag 7: Thermal analysis with natural convection



Diag 8: Results



For the simulation, it is assumed that the surrounding temperature is 35 degrees C and it is natural convective heat transfer. The base section of the heat sink is applied 1000W heat. This thermal simulation indicates that the maximum temperature obtained by the IC will be 167 degrees C as indicated by the red colour in the chart and the lowest temperature along the corner of the heat sink is 123 degrees C.

From this, we can calculate the thermal resistance of the system. Using equation 1, we get.

$R_{total} = (167 - 35) / 1000$

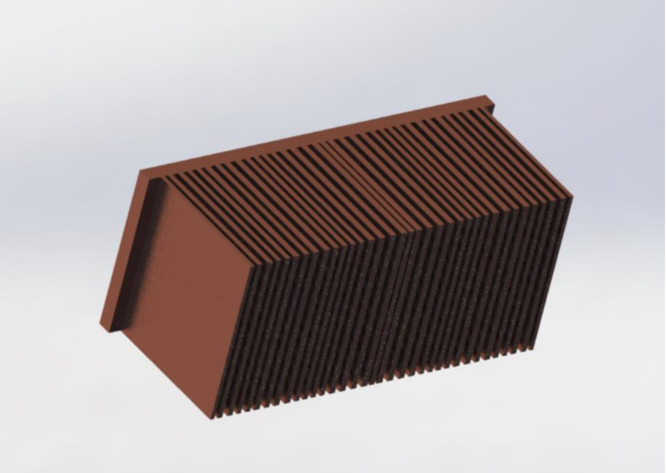
$R_{total} = 0.132$ C/W

Since this is higher than the required 0.035 value we will move to next design sprint.

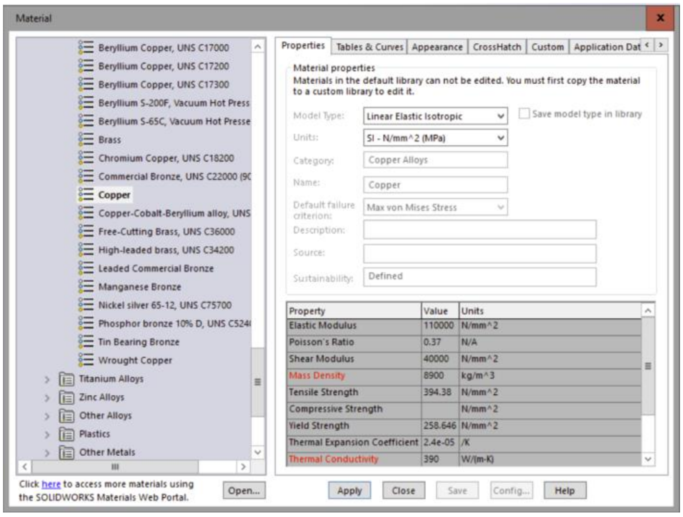
Iteration 1.2

Keeping the conditions, the same, changing the material to copper for improved thermal conductivity.

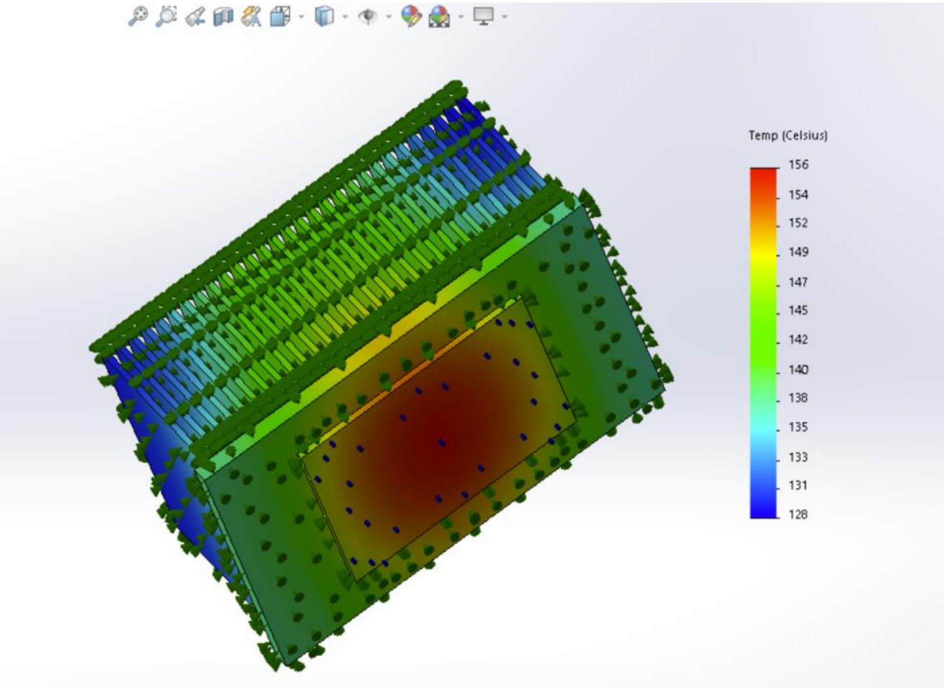
Diag 9: CAD model, change of material



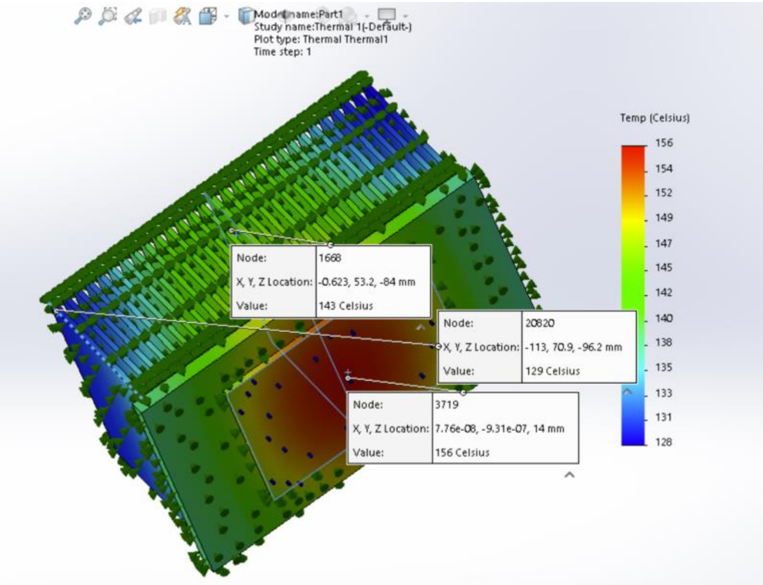
Diag 10: Material Properties



Diag 11: Conducting thermal simulations



Diag 12: Results



This study suggests that the change of the material from aluminum alloy to copper has made significant changes and lowered the maximum temperature to 156 degrees C.

Using equation 1, the thermal resistance can be calculated as follows:

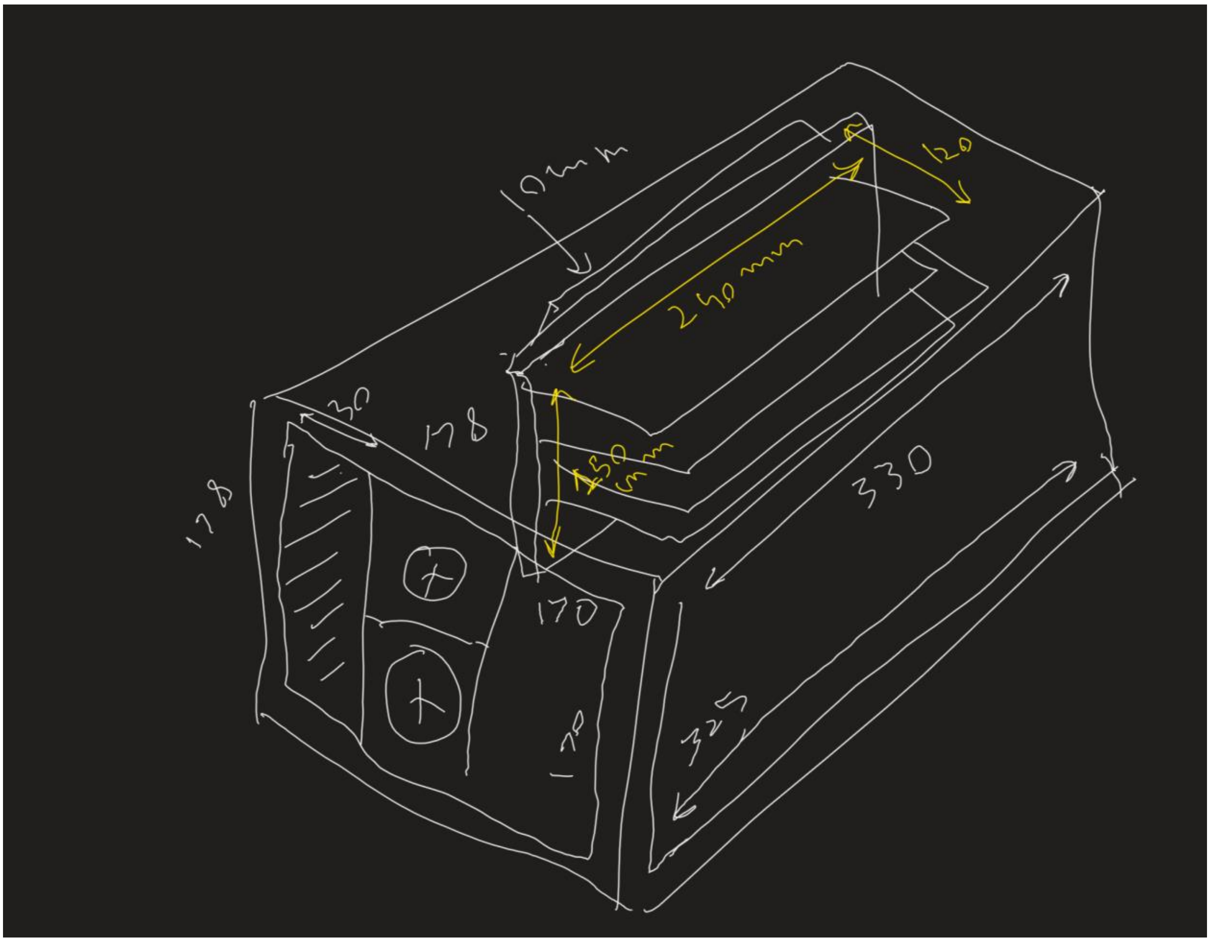
R_{total} = (156 - 35) / 1000

R_{total} = 0.121 C/W

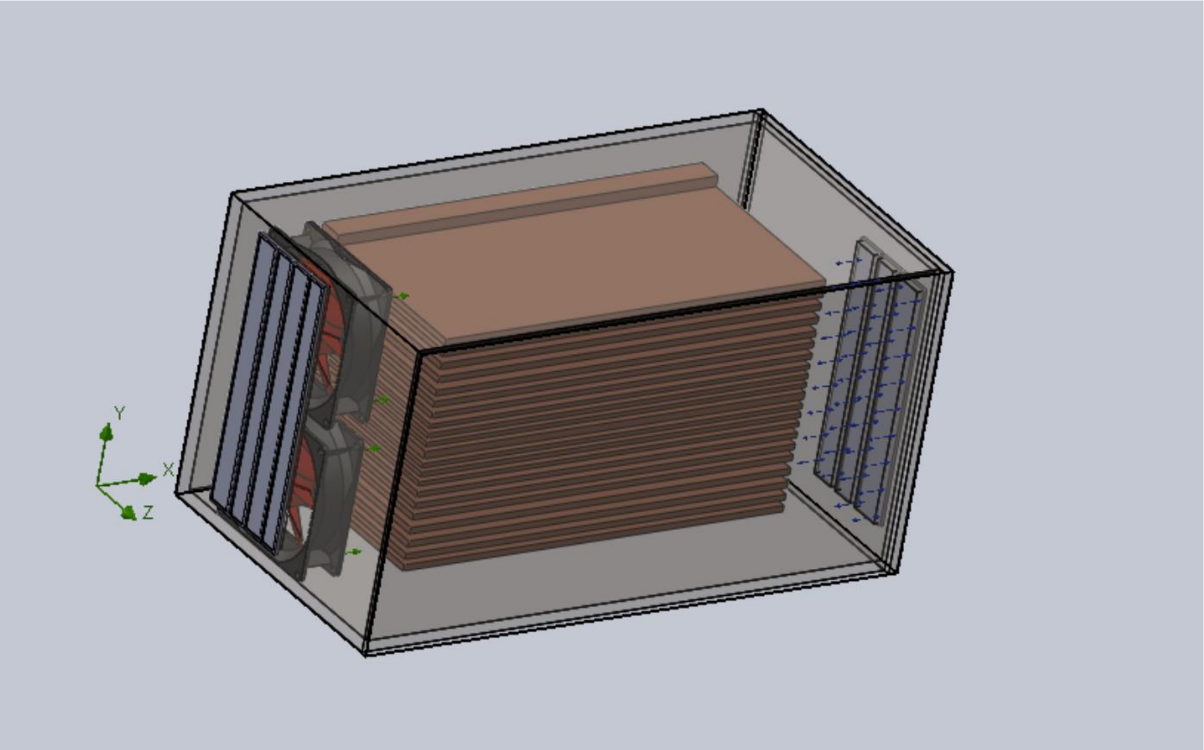
In order to choose the right heat sink, it is very important to have a thermal resistance of 0.035 W/C or lesser value. It is necessary to move to the next design iteration since iterations 1.1 and 1.2 are unsuccessful in providing the necessary result.

Iteration 2.1

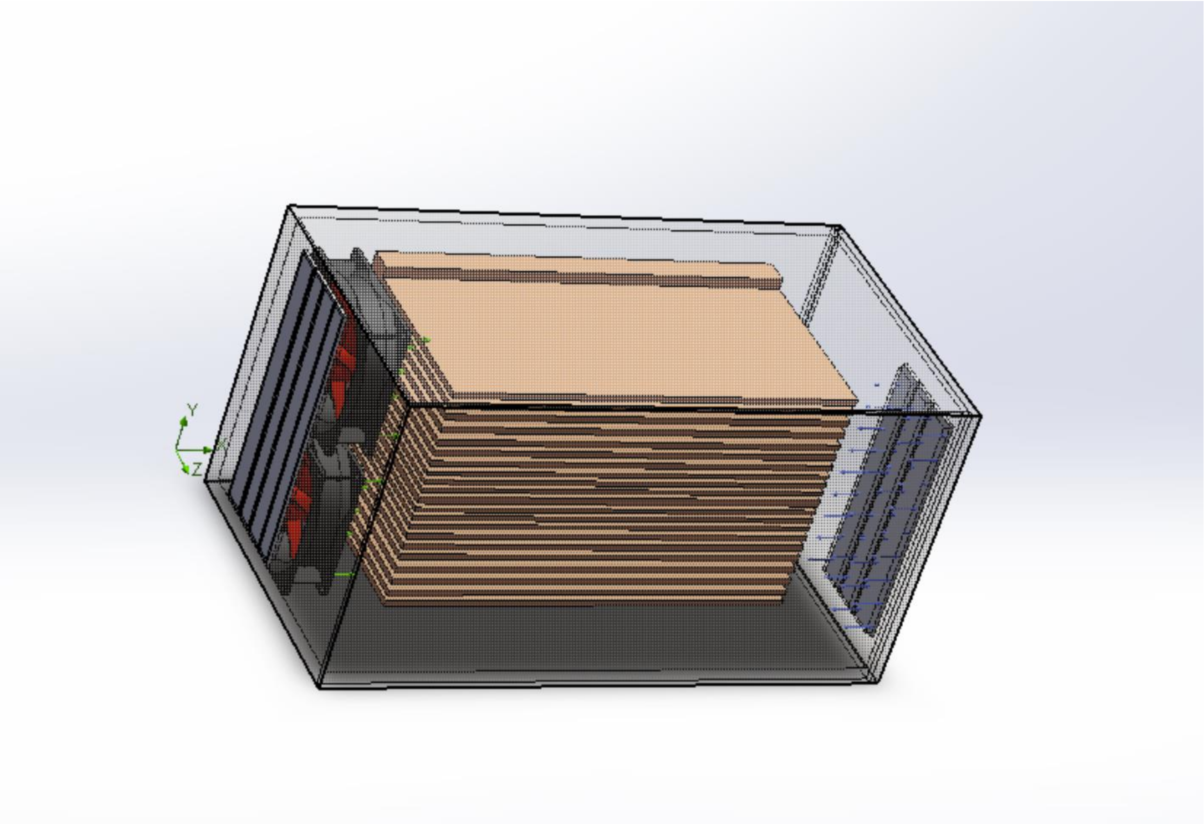
Diag 13: Rough model



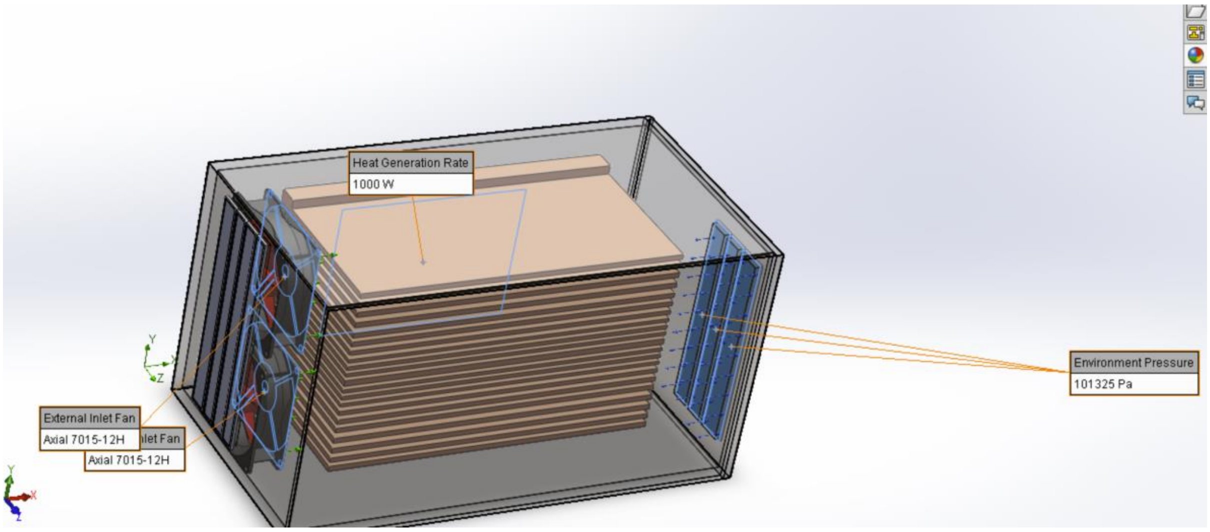
Diag 14: CAD model



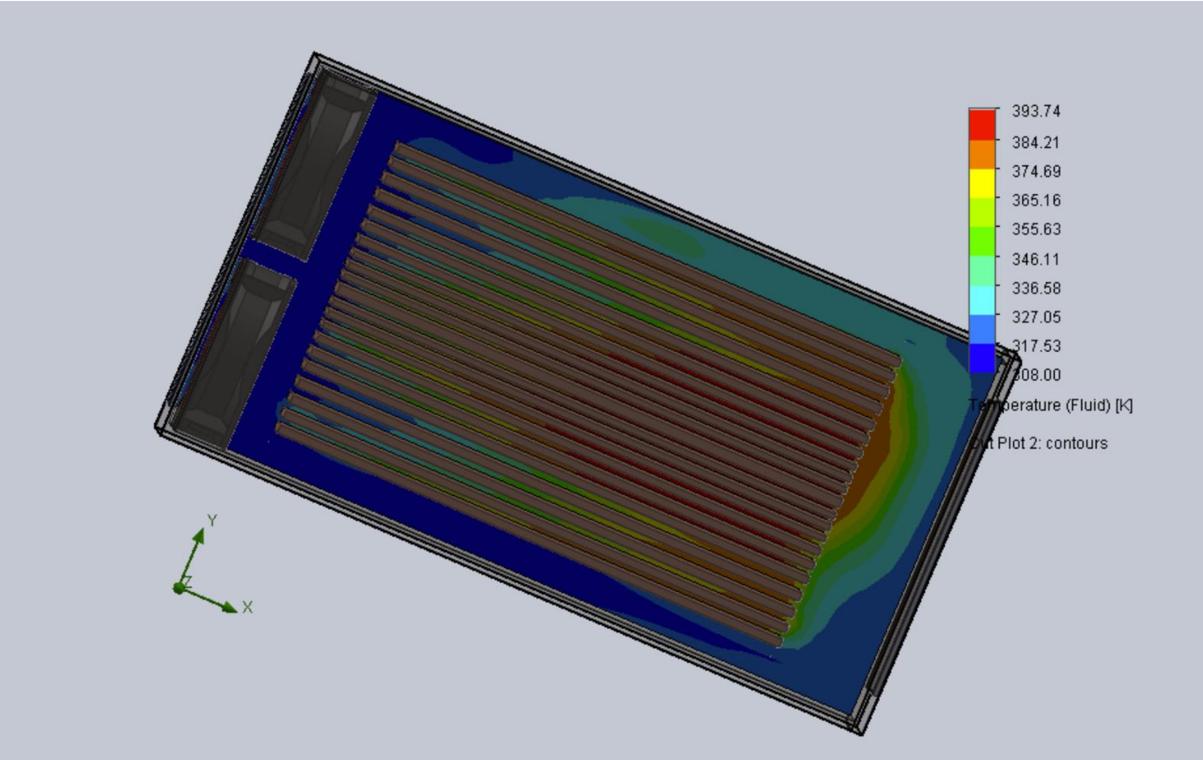
Diag 15: CAD



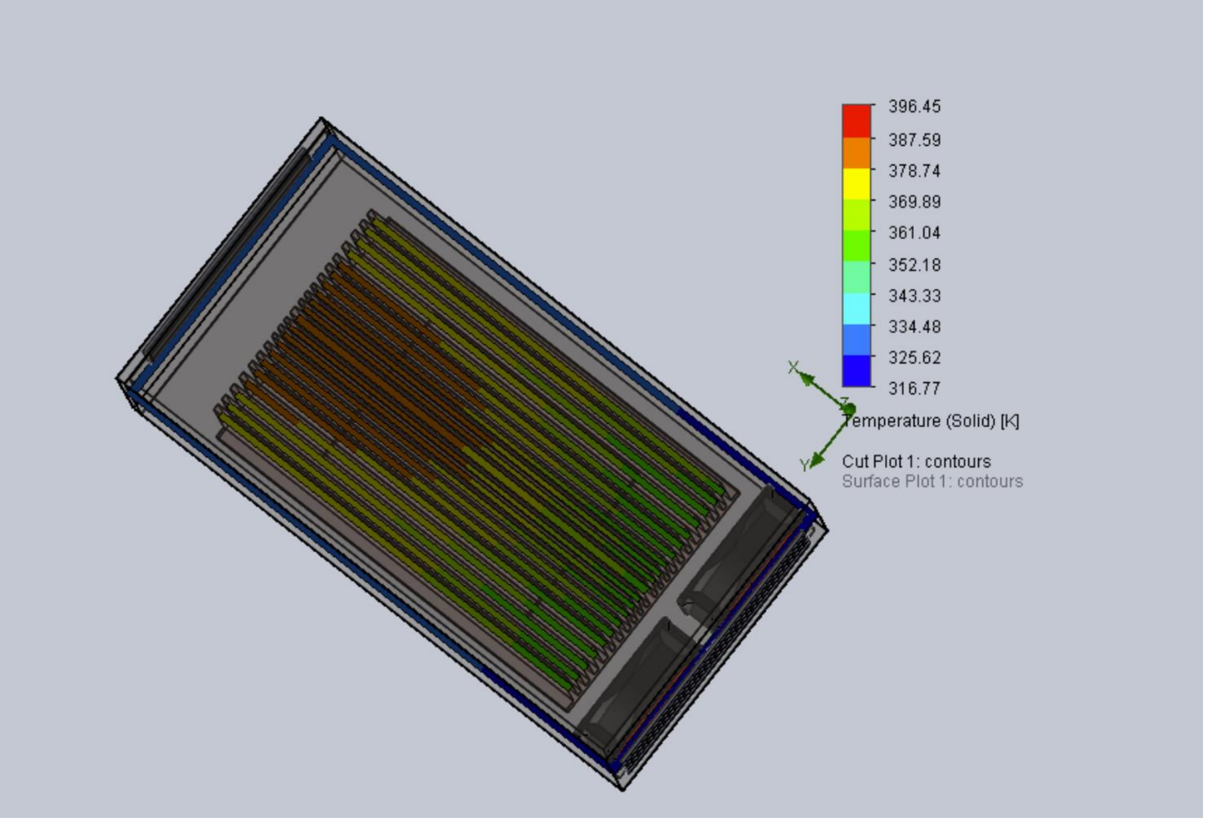
Diag 16: Boundary conditions



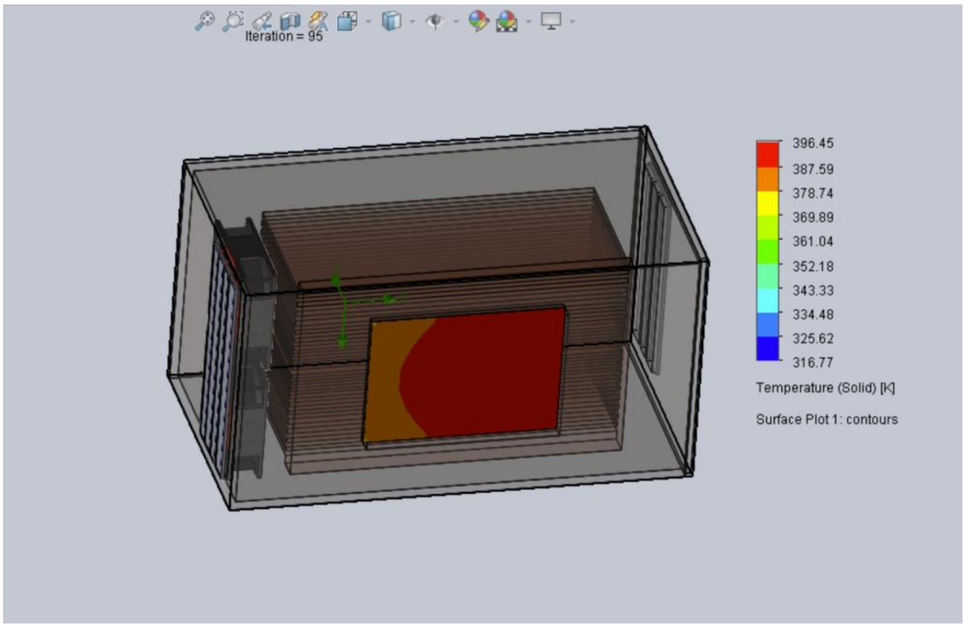
Diag 17: Fluid temperature



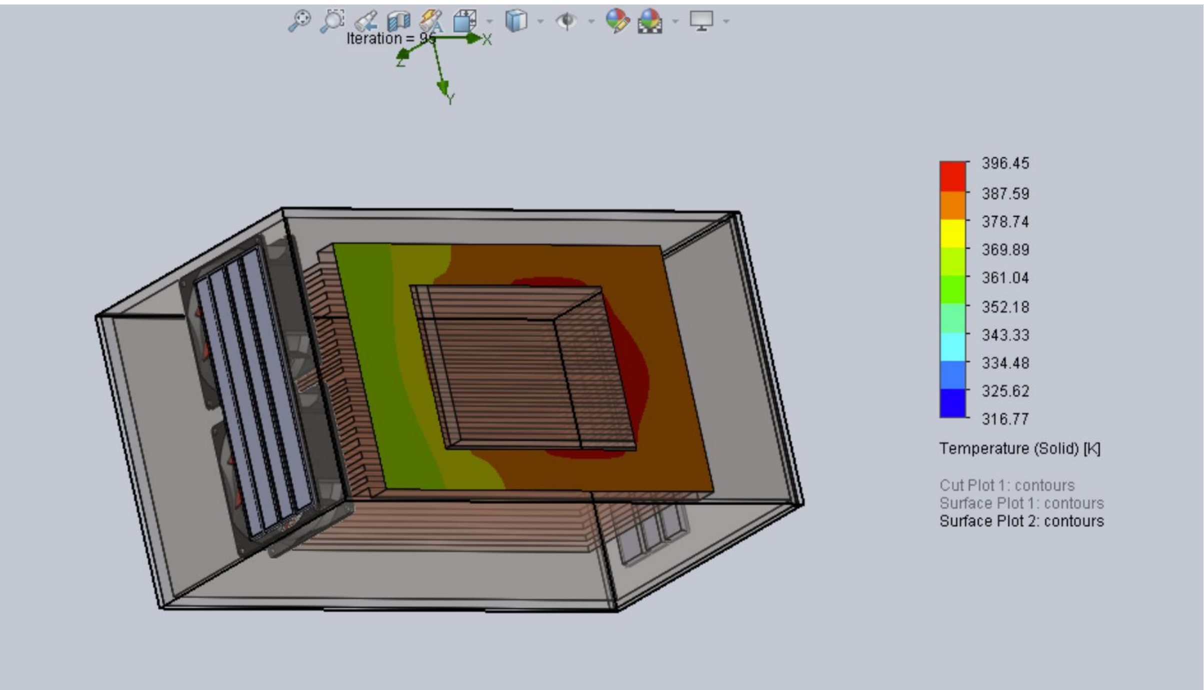
Diag 18: Solid temperature



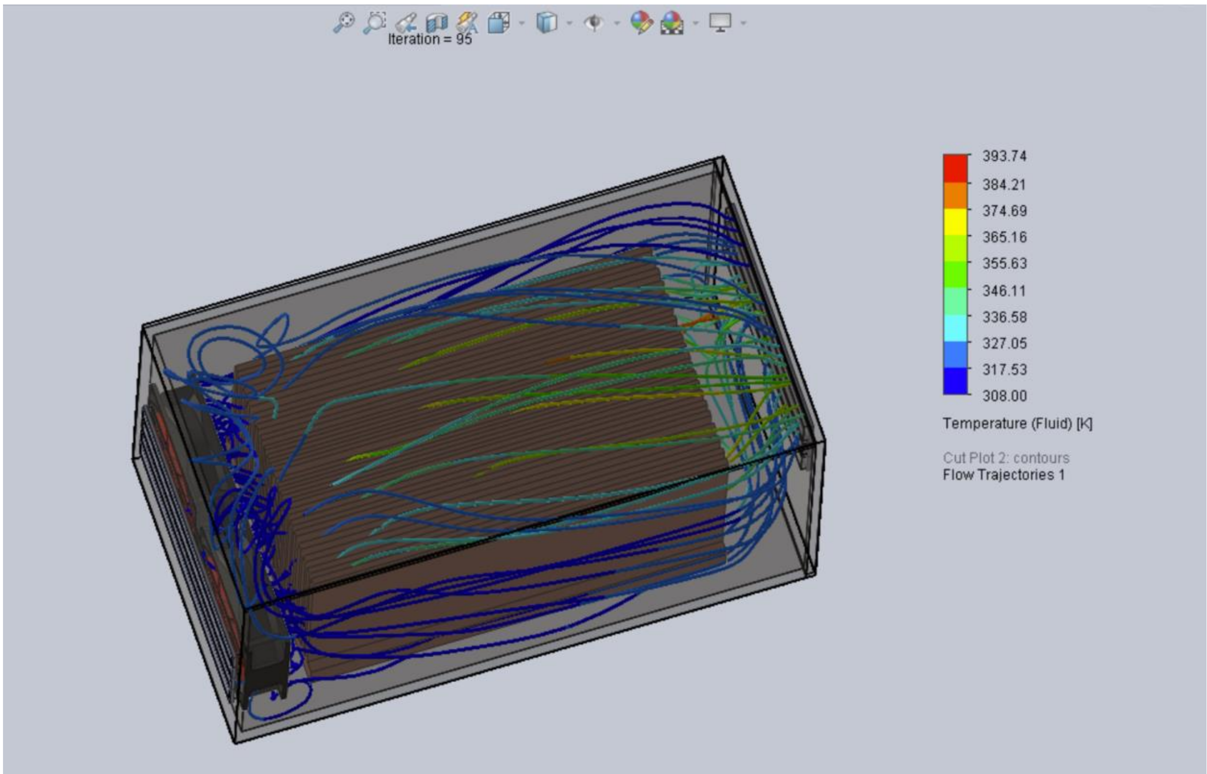
Diag 19: Surface Plot of IC



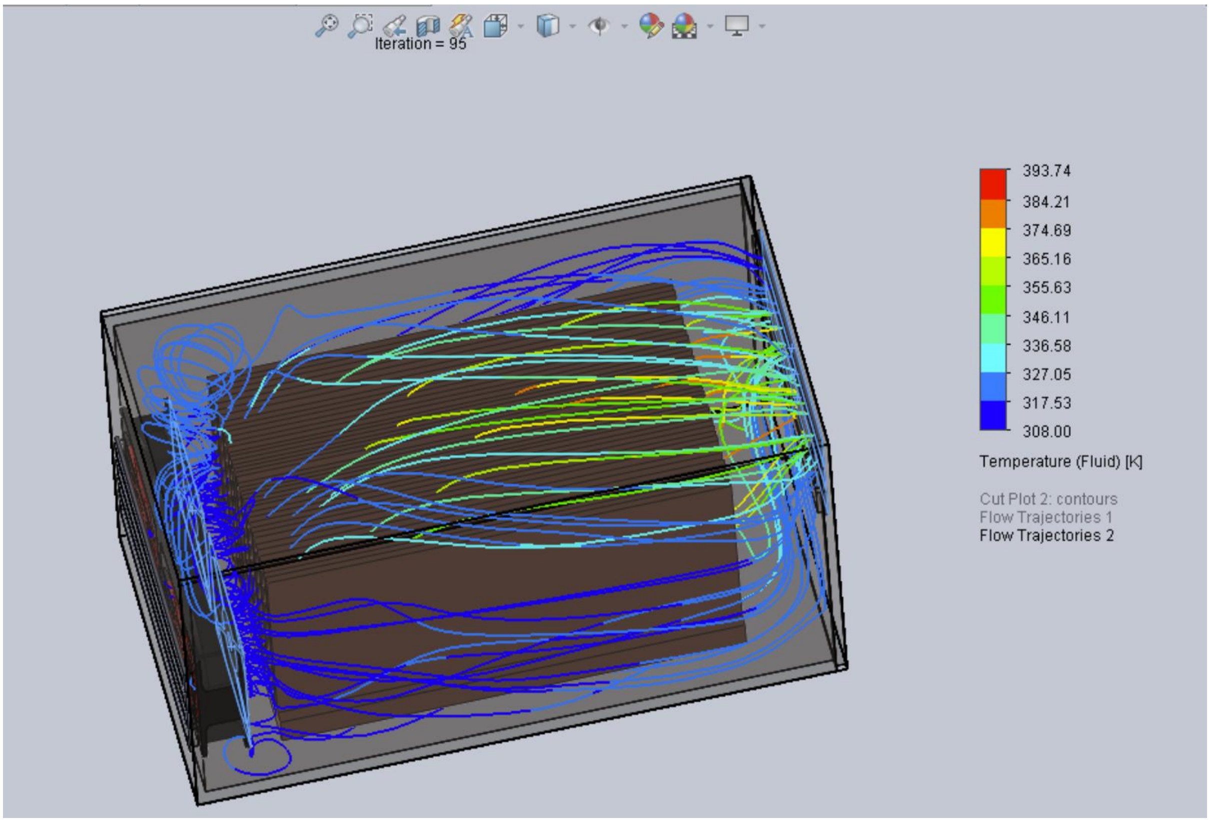
Diag 20: Surface plot of base of heat sink



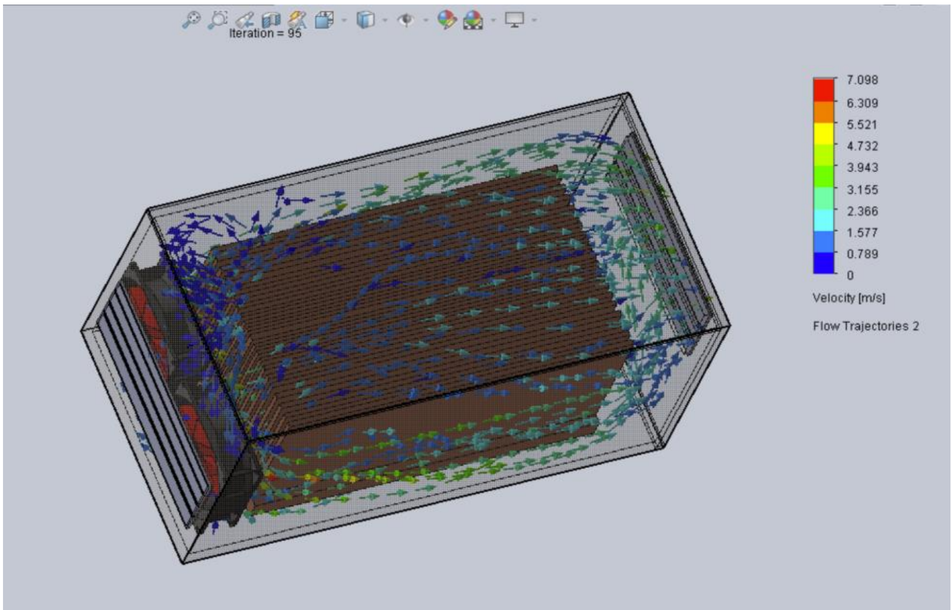
Diag 21: Flow trajectory, temperature



Diag 22: Flow trajectories



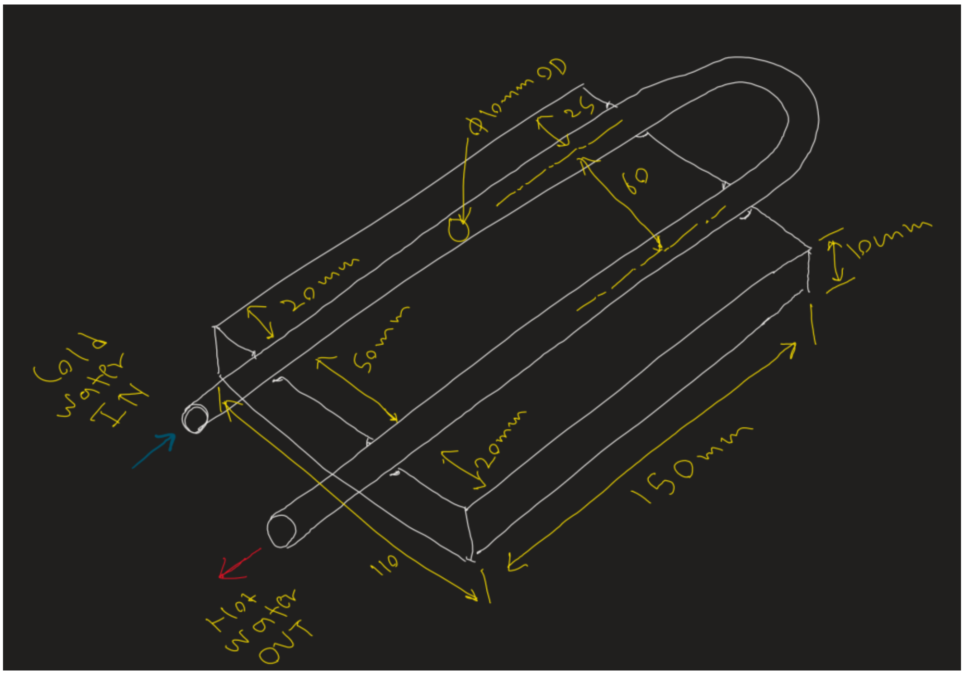
Diag 23: Velocity trajectories



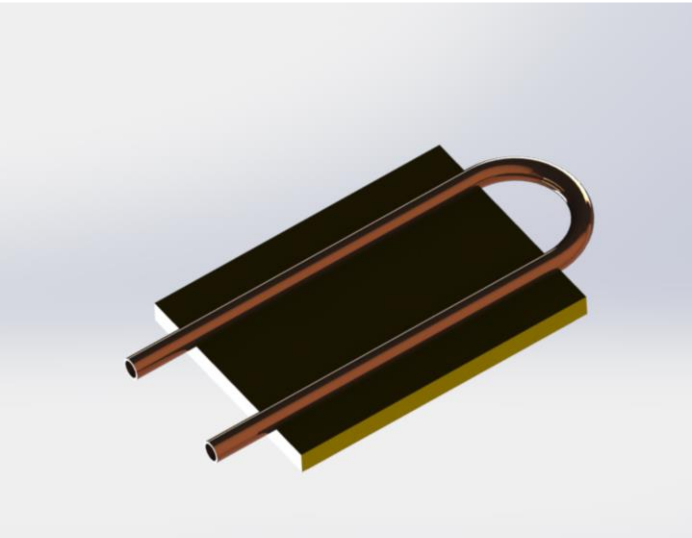
The maximum temperature at the base is 396 K (122.85) from diag 19, which gives R total of 0.087, since this value is not permissible, we will move to next design sprint.

Iteration 3.1.1

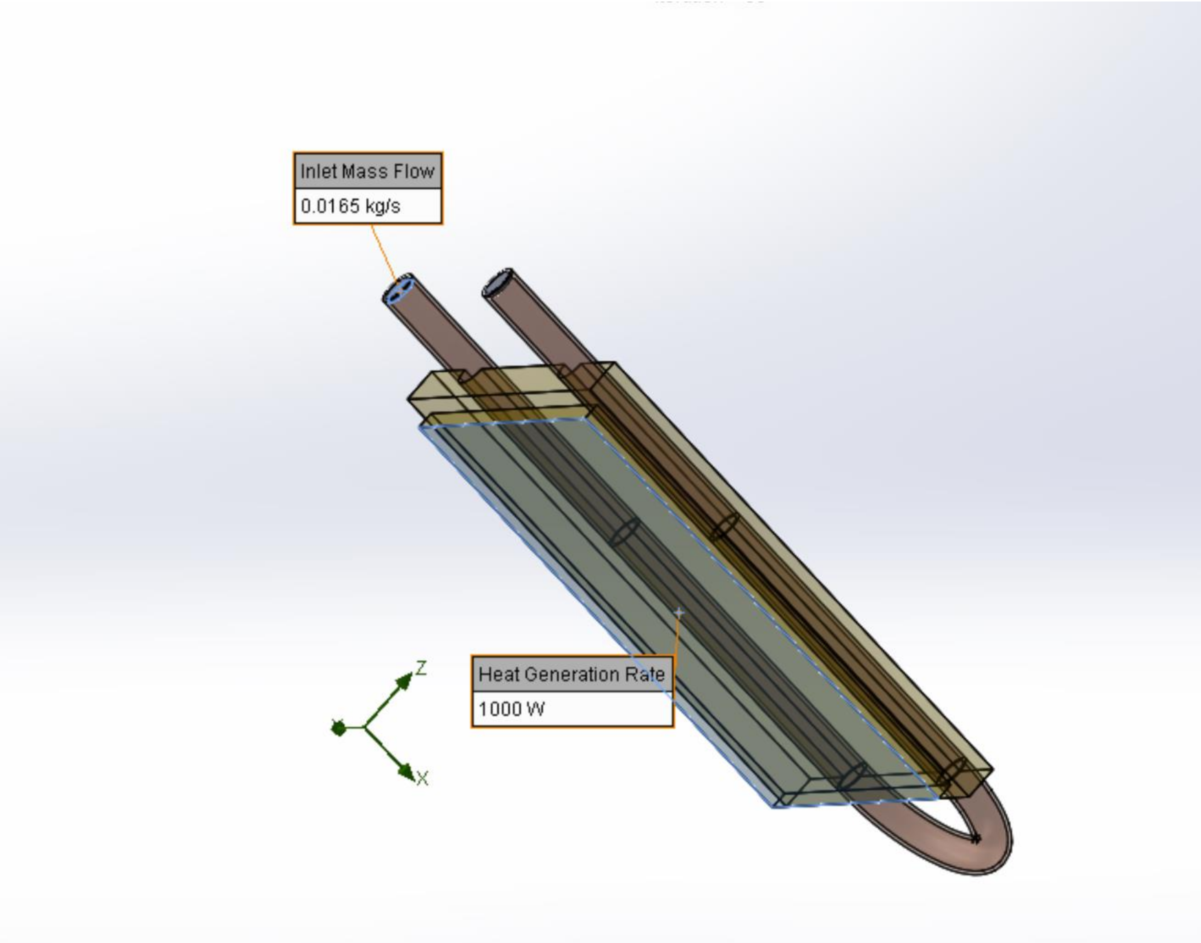
Diag 24: Rough design of cold plate



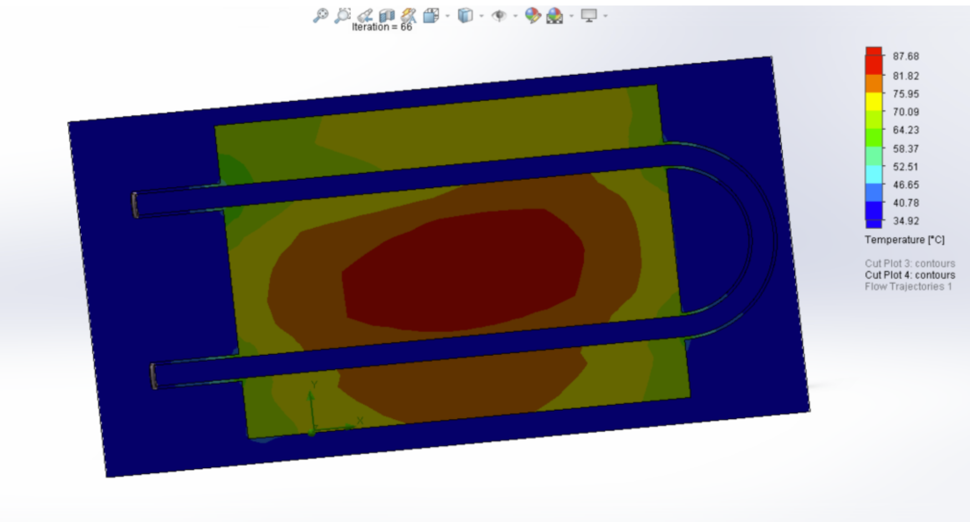
Diag 25: CAD model



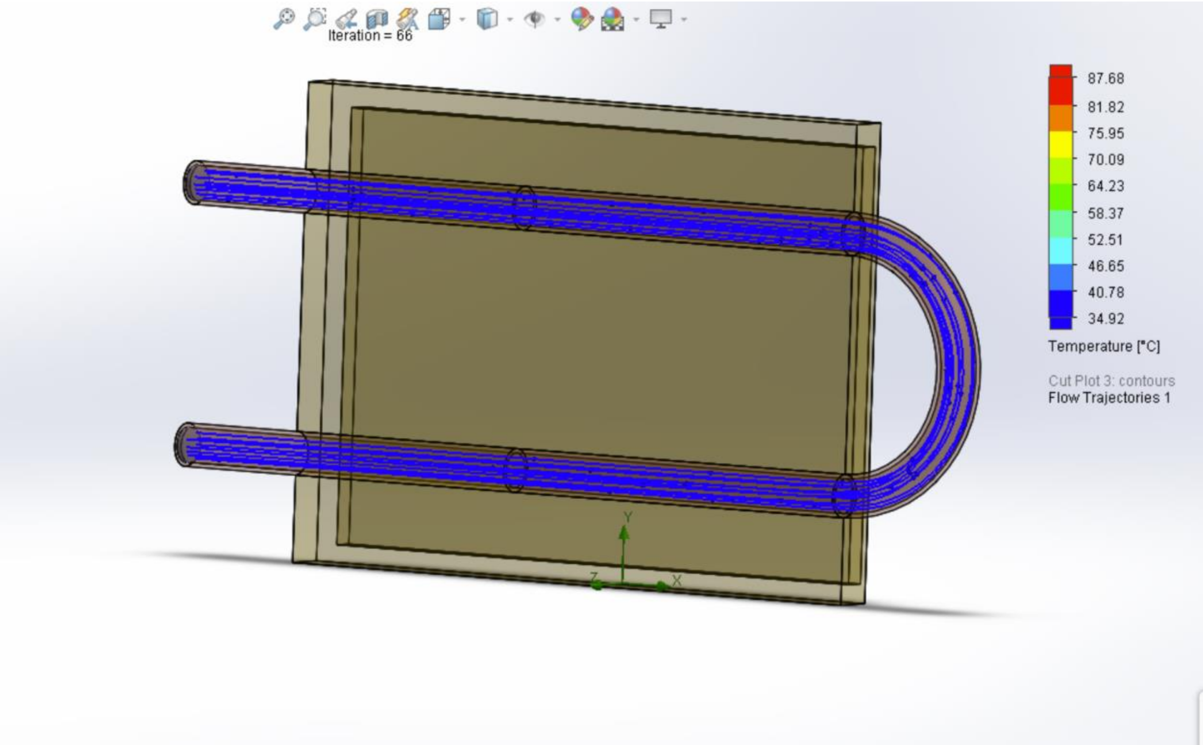
Diag 25: Boundary Conditions



Diag 26: Cut plot

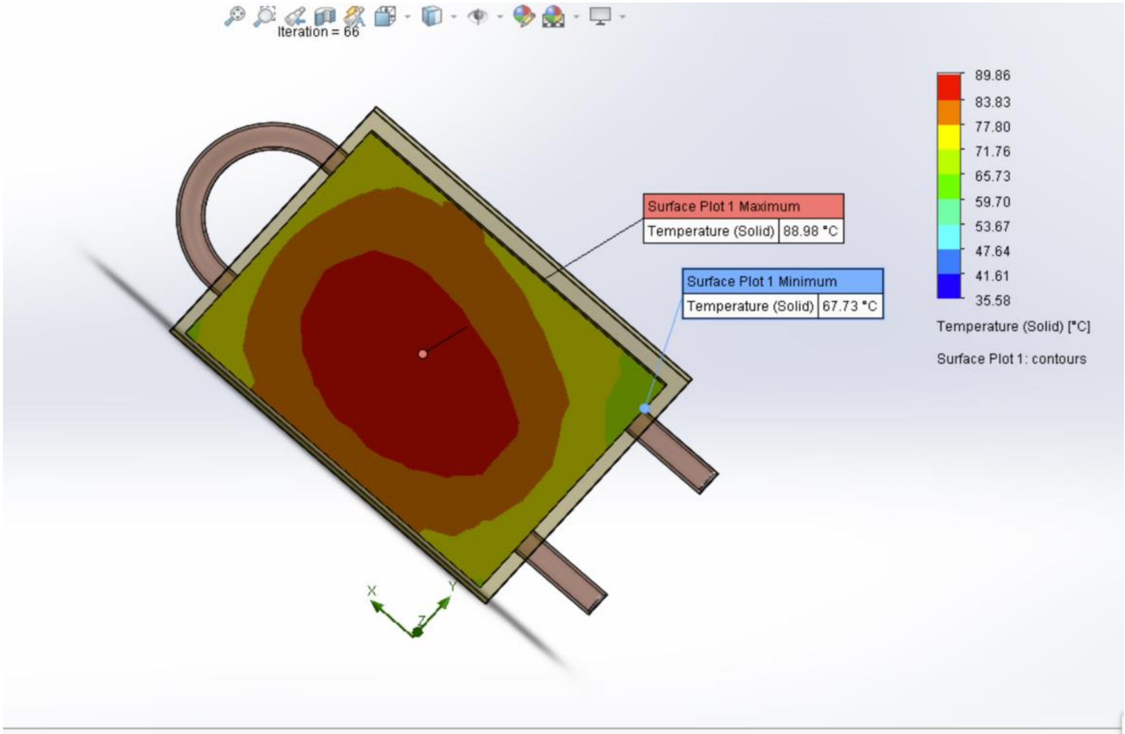


Diag 27: Fluid flow trajectories

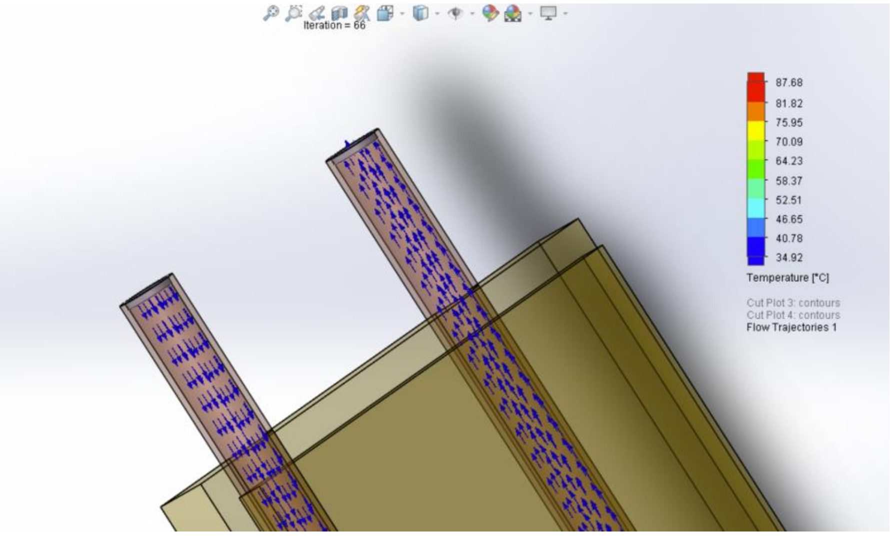


The flow trajectories suggest that there is no significant difference between inlet and outlet temperature of the water coolant and hence it is not able to absorb enough heat from the source. Design has to be made in order to increase the contact area of coolant with heat source.

Diag 28: Surface plot



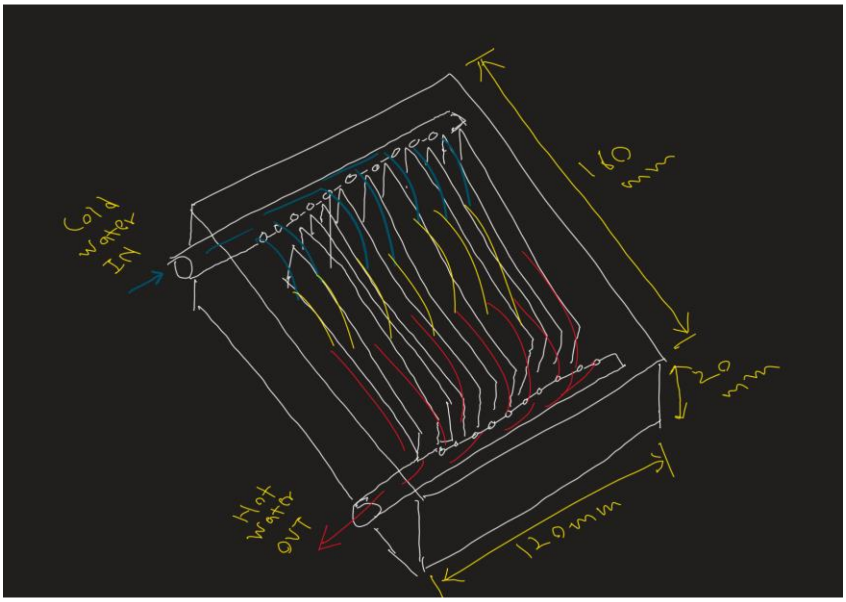
Diag 29: Fluid Flow



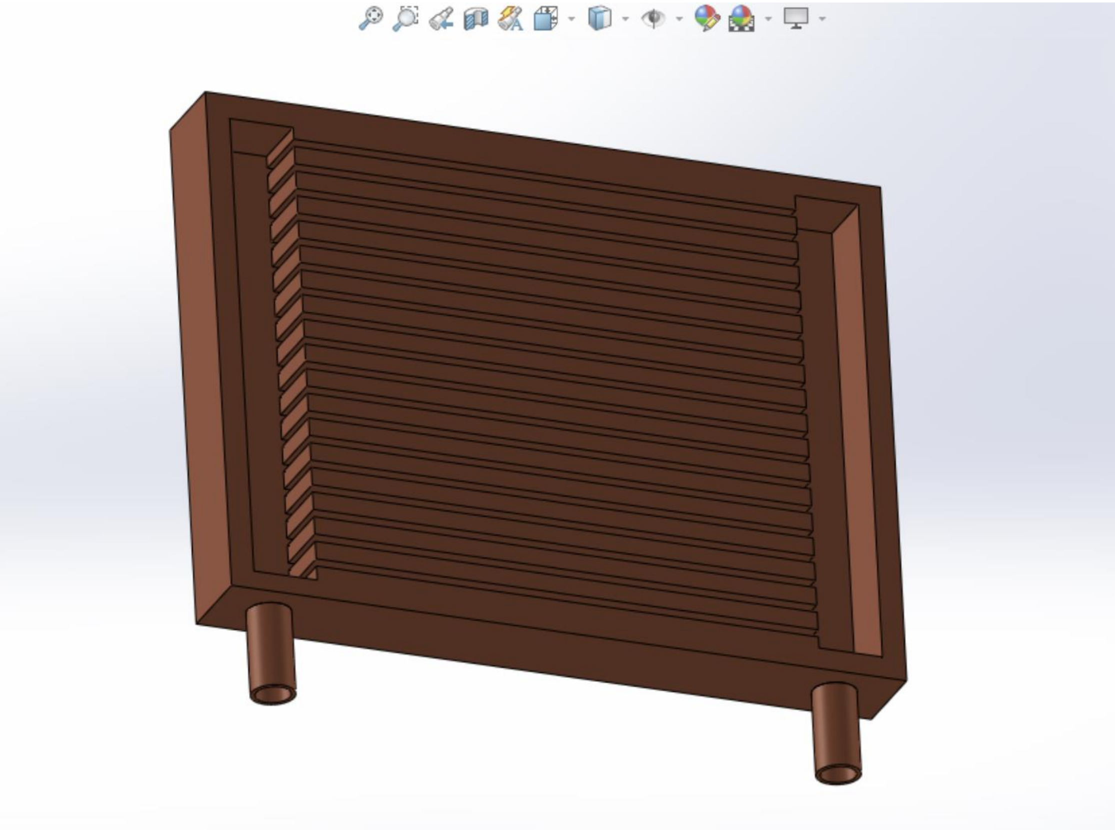
Here the maximum temperature is 88.98 degrees C which gives thermal resistance of 0.05398 C/W which is significantly lower due to liquid cooling however, not enough to approve the design, moving to next iteration.

Iteration 3.2.1

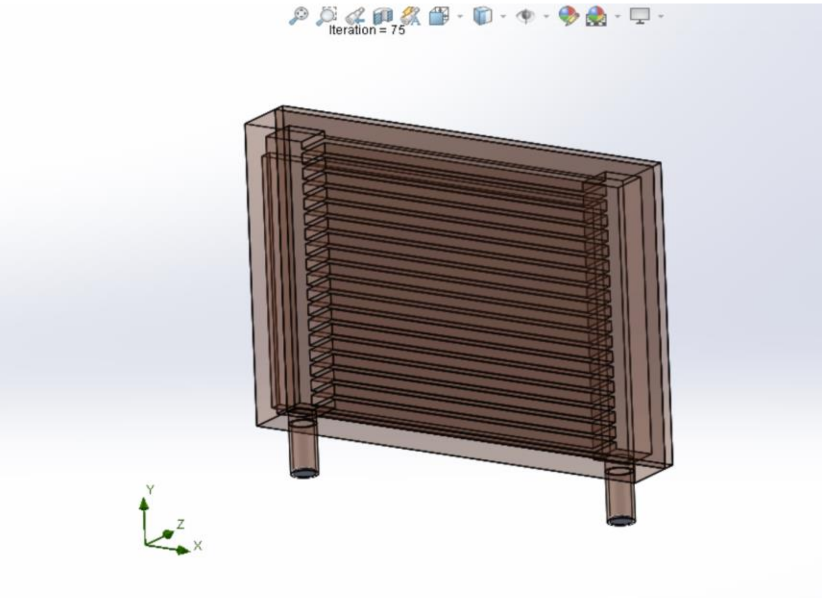
Diag 30: Rough Diagram



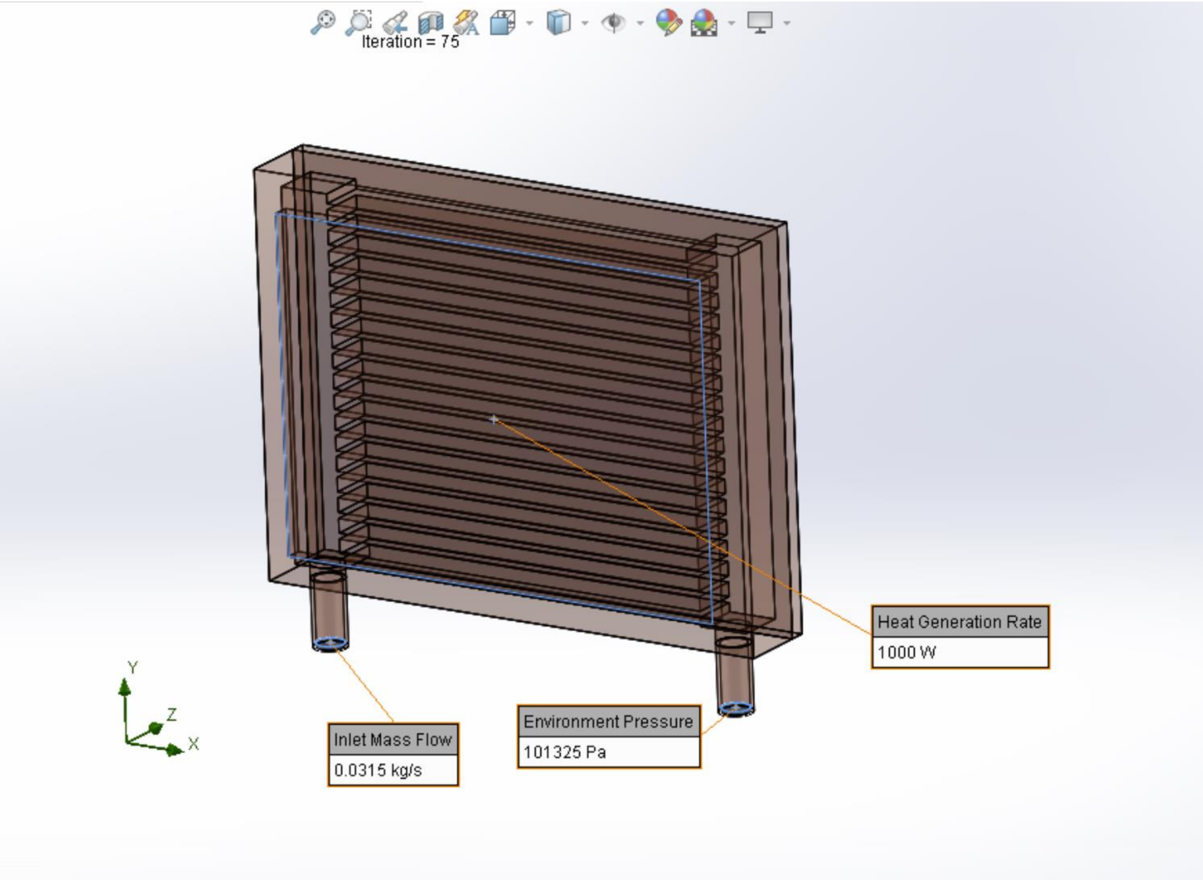
Diag 31: CAD Model Microchannel cold plate



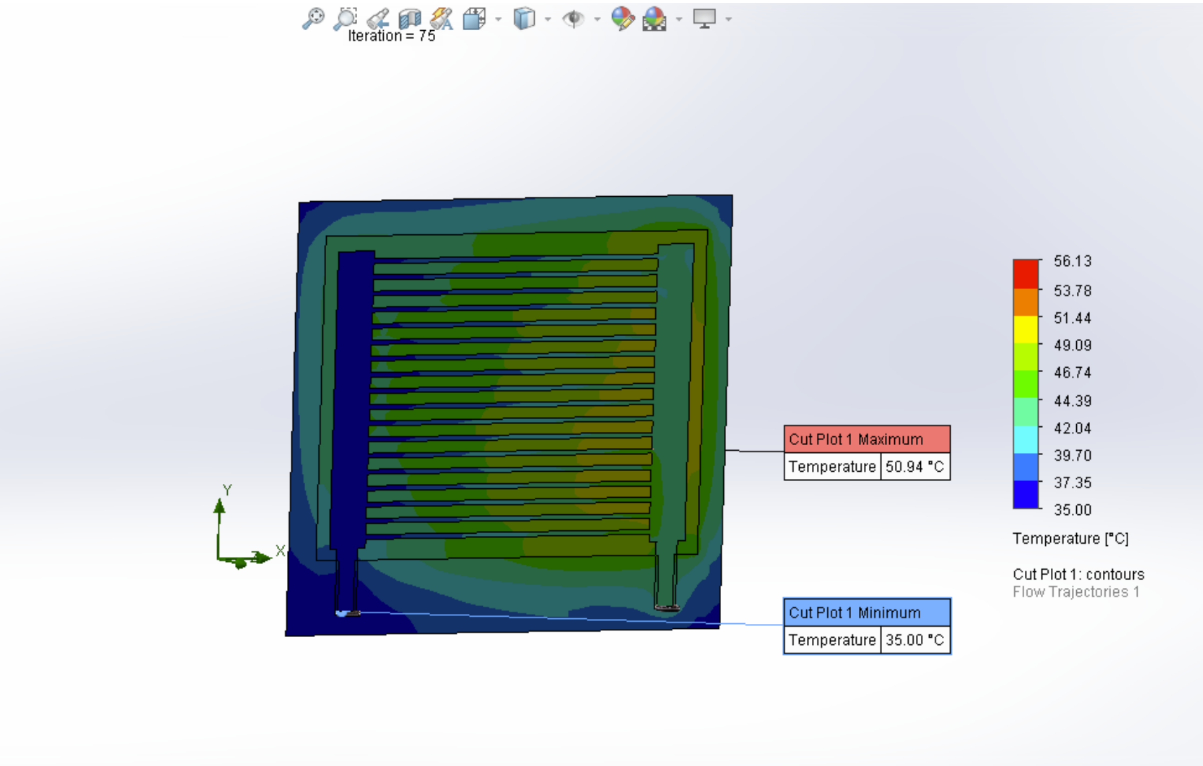
Diag 32: Complete CAD



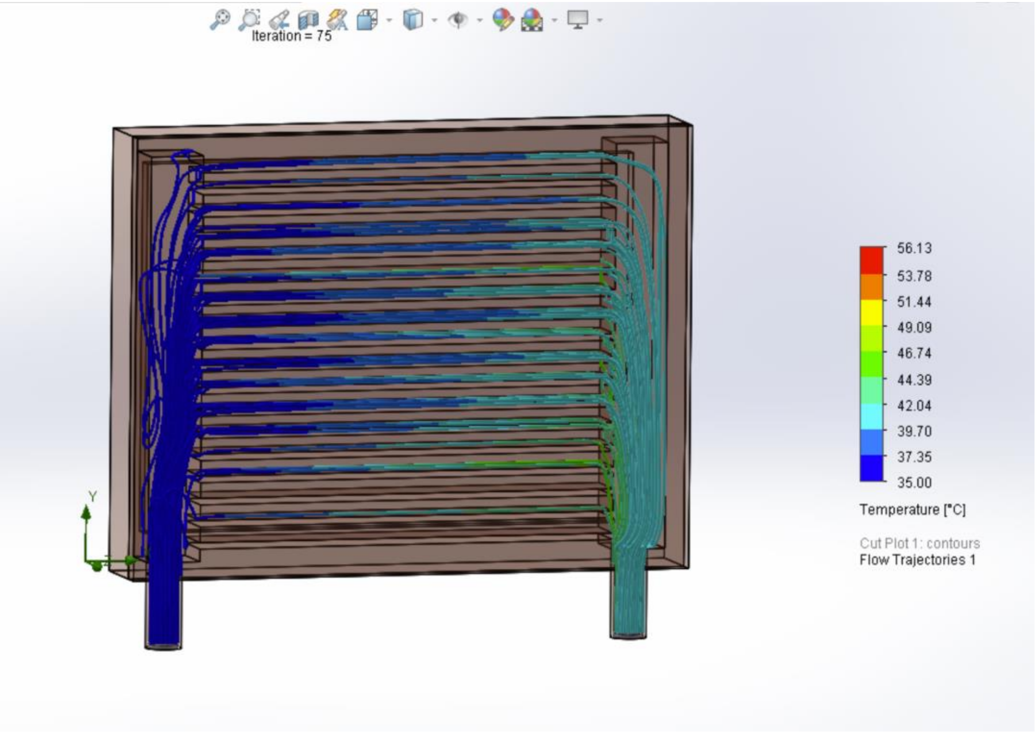
Diag 33: Boundary conditions



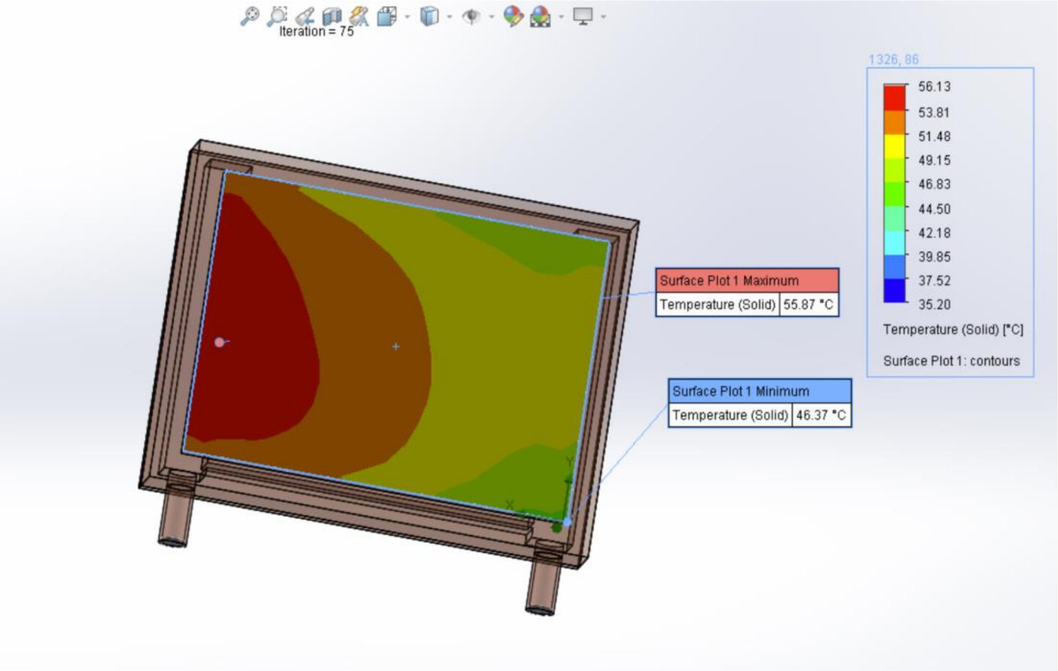
Diag 34: Cut Plot



Diag 35: Fluid Flow

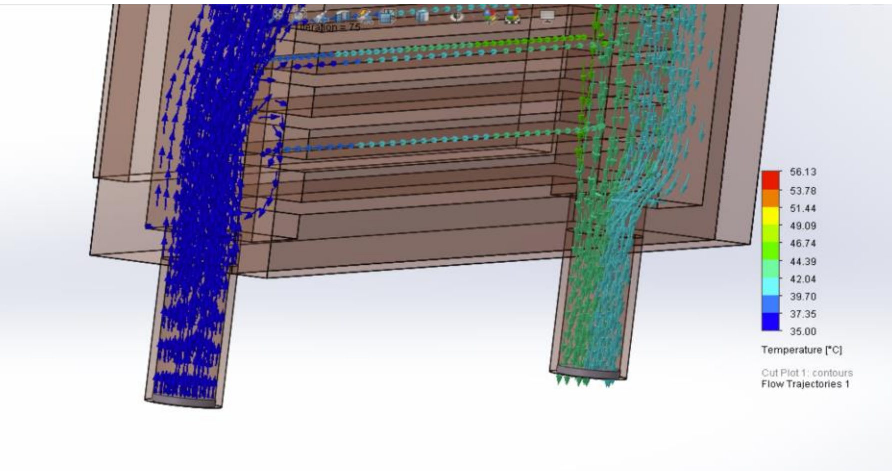


Diag 36: Surface plot



The maximum base temperature is 56.13 degrees C which gives Rtotal = 0.0211 C/W which is significantly lower than other designs and lower than 0.035 C/W value and hence this technology can be approved and accepted. A separate radiator and water pump assembly along with cooling fan system is required for this system to be fully fuctional.

Diag 37: Flow trajectories



This fluid flow shows that the there is significant temperature difference between the inlet and the exit of the coolant flow which indicates that maximum heat is dissipated as compared to the earlier design.

Please refer report 2 for complete analysis using this microchannel cold plate technology for controlling a heat dissipation of 2000 W maintaining temperature below 60 degrees in compact enclosure.

Diag 38: Report 2 diagram