JOINT INSTITUTE FOR NUCLEAR RESEARCH

Veksler and Baldin Laboratory of High Energy Physics

FINAL REPORT

Heat Transfer Simulation for the Current Version IPD

Supervisor: Mr Maciej Czarnynoga
Submitted By: Tushar Choudhary
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1   Abstract

Heat transfer simulation for the current version of Intelligent Power Distributor (IPD) is was conducted in order to determine the temperature distribution inside the IPD module and understand the airflow inside the IPD module due to density gradients as a result of the temperature distribution. The simulation served as an insight for improvement in the geometry of the IPD module and also placement of cooling devices.

2   Introduction

Nucleotron-based Ion Collider Facility - Intelligent Power Distributor (NICA-IPD) is a module consisting of various components which ensure a correct form of power delivery is maintained throughout the system. The Phase Switching module consists of Legrand MCBs which are responsible for ensure derating for the components in order to increase the reliability and life expectancy of the components and also provide a margin of safety. Each and every module listed in the IPD has its unique function which collectively leads to increase in safety and prolonging the life of the components inside the IPD module. All of these components when performing their respective function generate heat as a result of their working which is referred to as the heat generated by the component. Since each component present inside the IPD has an optimum working temperature range and also critical temperature range, it is highly essential to predict the temperatures of each and every component inside the module. For the fulfilment of this purpose we conduct a Heat Transfer Simulation in order to determine the critical temperature areas inside the IPD module and also simulate the effect on the temperatures after installation of a cooling fans inside the IPD module.

3   Component Information

3.1   Siemens S7-1200 CPU 1214C (6ES7214-1AG40-0XB0)

The 6ES7214-1AG40-0XB0 is a compact CPU manufactured by SIEMENS and belongs to the 1214C class of CPUs. The operating voltage for this CPU is 20.4-28.8V DC and has memory of 100KB. The operating temperature for this CPU range from 0-55 deg C and the power loss or the heat generated by the CPU during its operation is 12W.

Figure 1: Siemens S7-1200 CPU 1214C (6ES7214-1AG40-0XB0)

3.2 SIMATIC S7-1200, Digital output SM 1222 (6ES7222-1BH32-0XB0)

The 6ES7222-1BH32-0XB0 is digital output module transistor which is used to expand the digital outputs of the S7-1200 CPUs. The operating range for this device is 20.4-28.8V DC and the heat generated by the device at its peak operation is 2.5W. The operating temperature range for this device lies from -20 to 60 deg Celsius.

3.3 Meanwell DRC-100B

The DRC-100B is Power Supply with built in short-circuit/ over-voltage/ overload protection. The operating voltage for this device is 27.6V DC and the optimum operating temperature ranges from -30 deg to 70 deg Celsius.

3.4 MeanWell DDR-15-G-12

The DDR-15-G-12 is an ultraslim, industry grade DIN rail converter. The operating voltage for this device is from 9-36V DC with single output of 12V DC at 1.25A. The optimum working temperature for this device ranges from -40 to 80 deg Celsius.

3.5 WAGO 787-1671

The 757-1671 by WAGO is a Lead-acid AGM battery module. The input voltage for this device is 24V DC with and output of 5A. The optimum operating temperature for this device is -15 to 40 deg Celsius.

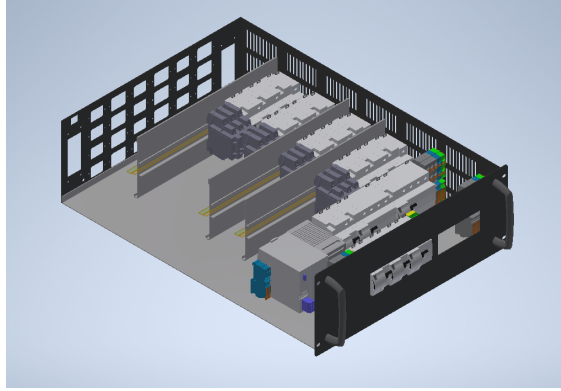**Figure 2:** SIMATIC S7-1200, Digital output SM 1222 (6ES7222-1BH32-0XB0)

Figure 3: MeanWell DRC-100B

Figure 4: MeanWell DDR-15-G-12

Figure 5: WAGO UPS Module

Figure 6: Current IPD Geometry

3.6 Legrand TX3 10000

The Legrand MCB are used for the derating, have the operating temperature range for the single pole devices ranges from -25 to 70 deg Celsius and that for the 3 pole devices ranges from -40 to 70 deg Celsius.

Table 1: Operating Temperature ranges for components of the IPD module

Components	Operating Temperature Range
Siemens S7 1200 CPU 1214C	0 to 55
SIMATIC S7 1200, Digital output SM 1222	0 to 60
MeanWell DRC 100B	-30 to 70
MeanWell DDR 15 G 12	-40 to 85
WAGO 787-1671	-15 to 40
Legrand TX3 10000 1P	-25 to 70
Legrand TX3 10000 3P	-40 to 70

4 IPD Geometry

Figure 6 shows the current version of the IPD module. All the phase switching modules are mounted on industry standard DIN rails. The arrangement of components inside the IPD module is such that the heat generated by each component is bound to affect the temperature of its surroundings due to the closely packed nature of the components. Hence it becomes extremely important to determine the maximum temperature inside the IPD module.

5 Objectives
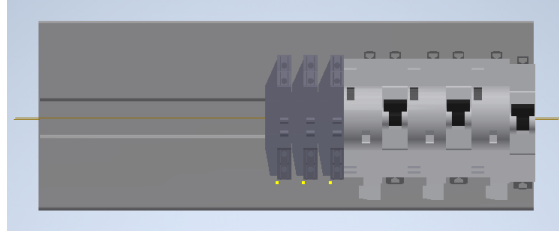
Figure 7: Phase Switching Module

5.1 Heat Transfer Simulation

Understanding the heat transfer inside the IPD module is essential to determine the flow direction of the heat and also to identify the components which are operating at their critical temperatures to prevent damage to the components.

5.2 Minimizing Temperature

After identifying the temperature distribution inside the IPD module, the arrangement need to be looked at so as to separate out the components which are operating at their critical temperatures and others which need not require any change in their placement inside the IPD module.

5.3 Natural Convection

Since the current version of the IPD module has no external or internal fan installed; the cooling of the components is dependent only on the flow of the air surrounding the components. So an understanding of the airflow based on the Natural Convection Model needs to be done to understand the flow of air due to temperature changes.

5.4 Effect of Fan

Due to the space constraints of the IPD module, it was figured that the placement of an external fan was not a viable option so we used an internal fan instead. A forced convection model was used to understand the airflow inside the module after placing an internal fan.

6 Simulation Preparation

6.1 Part Simplification

The existing part geometry consists of all the complex 3D models of the components. However for the CFD Simulation such complex geometries greatly increase the computing time and also the meshing times. The

elimination of complex holes, fillets and extrusions do not affect our computational results but help save a lot of simulation time.

Hence in order to achieve our goal, the 3D models of the parts were simplified (example Figure 8).

(a) Standard 3D model

(b) Simplified 3D model
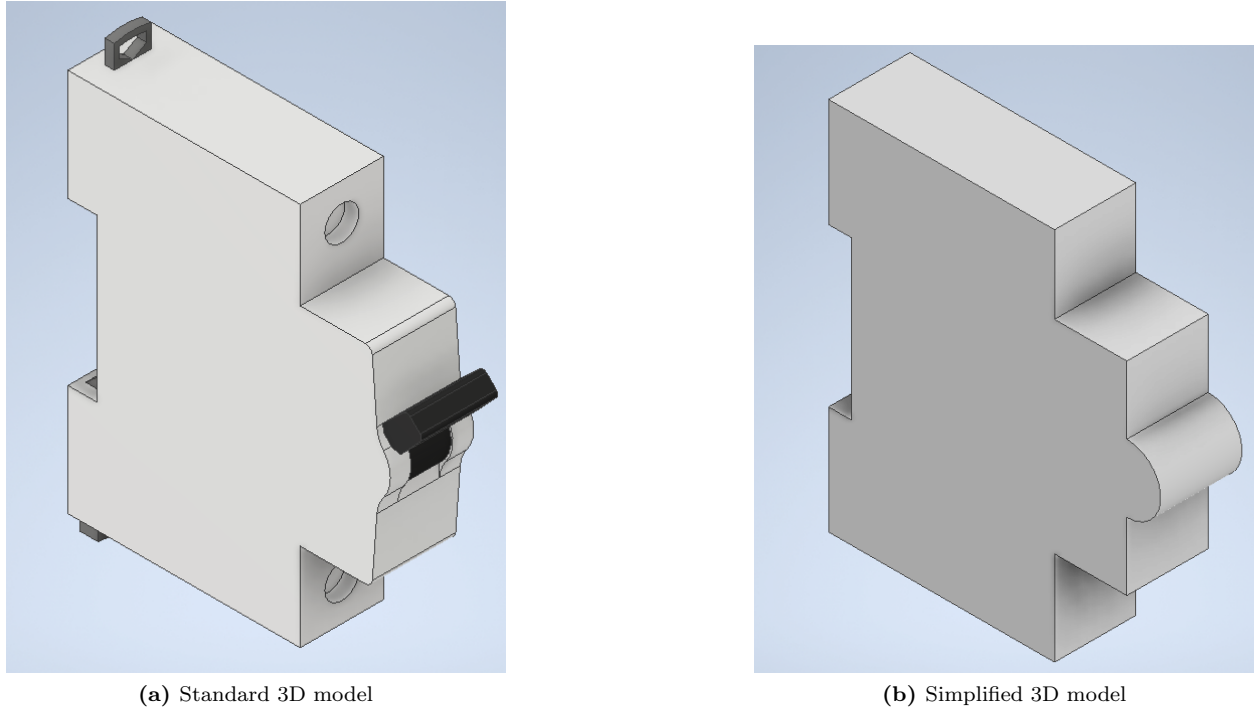
Figure 8: The two images shows the part simplification done on the Legrand MCB. (a) is the standard part model of the MCB and (b) is the simplified MCB for CFD
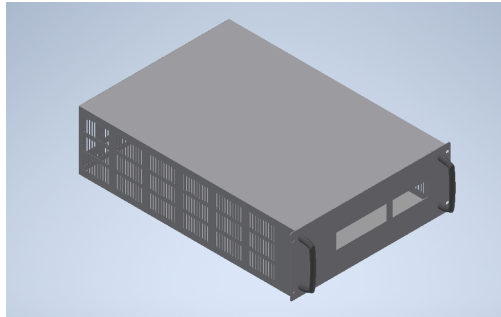
6.2   Enclosure Simplification

Since the original enclosure has a lot of sheet metal parts,holes and cuts in order to facilitate air-flow through the IPD module, the meshing of the enclosure and consecutively the solving would use up a lot of computational power. In order to cut short our computational time; the enclosure was modelled in a simple way as indicated in Figure 9.

6.3   Resistance Boundaries

As it is evident from Figure 9 (a), the enclosure of the IPD module has various vents to facilitate air flow. However modelling these vents in the CFD enclosure would defeat the purpose simplification of the enclosure. So we use the feature of resistance boundaries which simulates the flow of air across the walls by taking in account of the free area ratio. The value of free area ratio taken for modelling was 0.65.
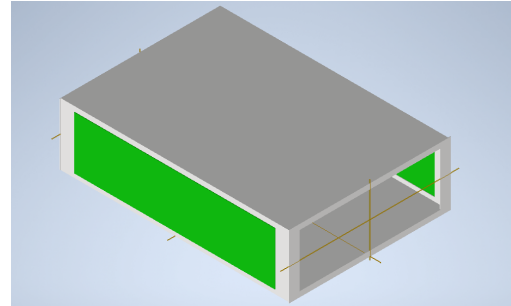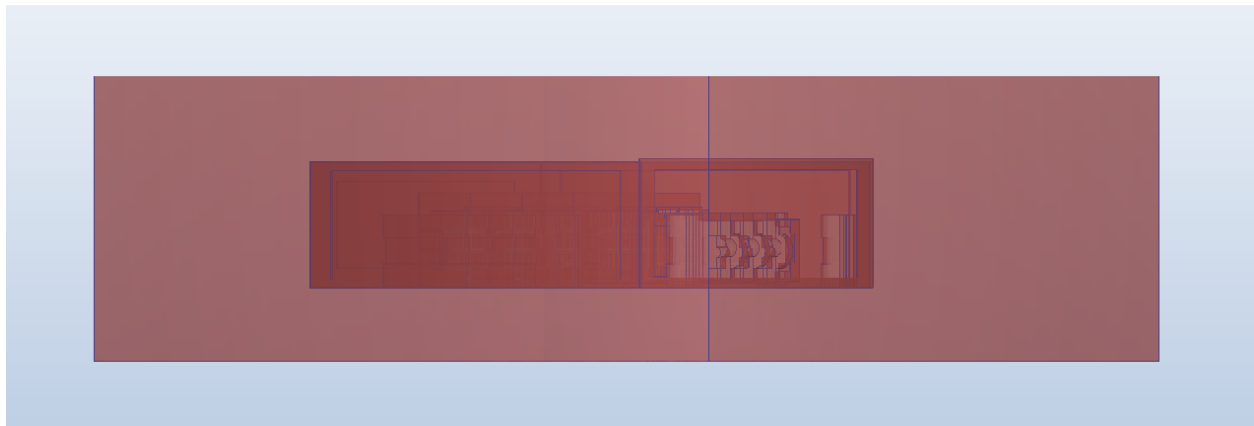
(a) IPD Enclosure   **(b)** Simplified Enclosure

Figure 9: The two images shows the part simplification done on the Enclosure of the IPD module. (a) is the actual 3D model of the IPD enclosure and (b) is the simplified model for the CFD Simulation

Figure 10: External Volume of Air surrounding the model

7 Methods

7.1 Natural Convection Model

For the first leg of the simulation, the Natural Convection Model is utilized. Since the geometry does not comprise of any external or internal fan/pump to facilitate air-flow; the cooling is achieved by the buoyancy-driven flow caused by the density gradients due to difference in the temperature.

The air modelled around the model has variable density (Figure 10) so as to simulate the Natural convection model and the direction of gravity is chosen as positive Y-axis (0,1,0).

7.2 Forced Convection

Since a fan was installed during the final stages of the simulation; to model the airflow of the air inside the IPD module, the Forced Convection model was used. The fan installed in the module had the properties as
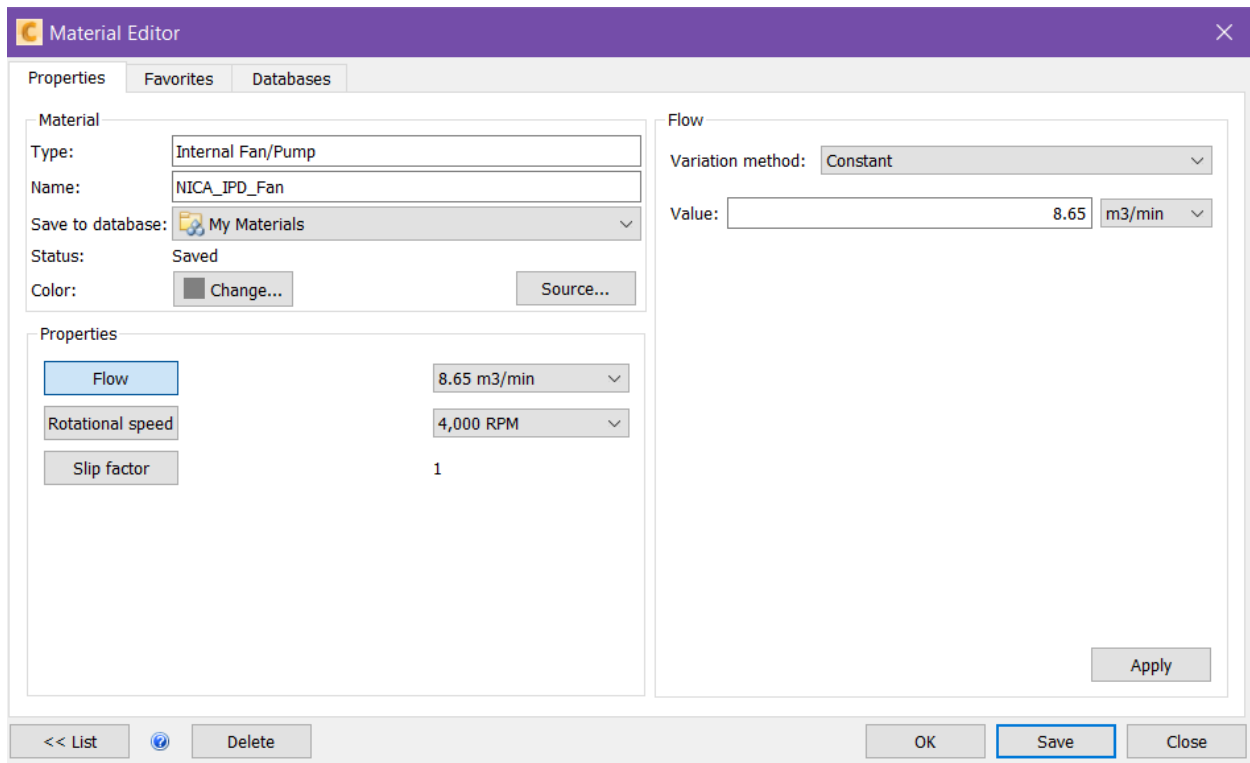
indicated in Figure 11.

Figure 11: Specification of the Fan used in the IPD module

# 8   Results

Figure 12 shows the temperature distribution among the components in the IPD module. The calculation of the individual part temperatures was done and the parts which were in their normal operating range were lift out to maintain focus on the parts which were either operating close to the critical temperature range or above it.

Figure 13 displays the velocity vectors which dictate the direction of the air flow from the boundaries of the IPD module.

After obtaining the relevant information regarding the temperature distribution, another simulation was conducted. The key difference in this simulation was the addition of the fan inside the IPD module in order to cool down the components.
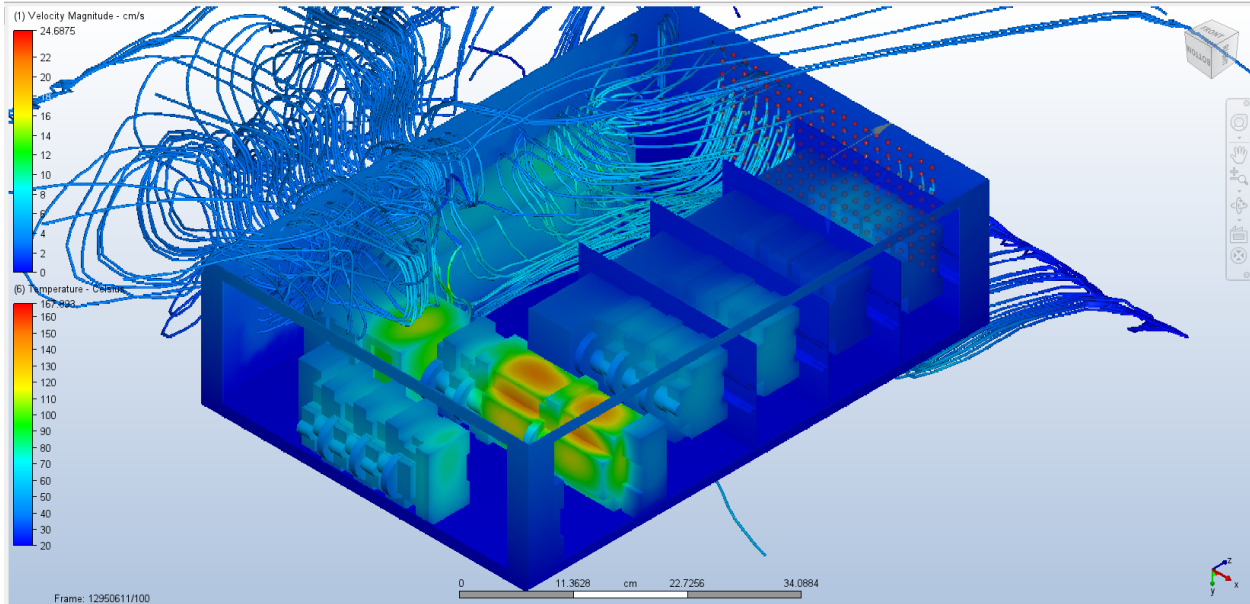
Figure 15 shows the temperature distribution in the IPD module post the addition of the fan and Figure shows the velocity streamlines flowing through the IPD module to provide an insight regarding the airflow.
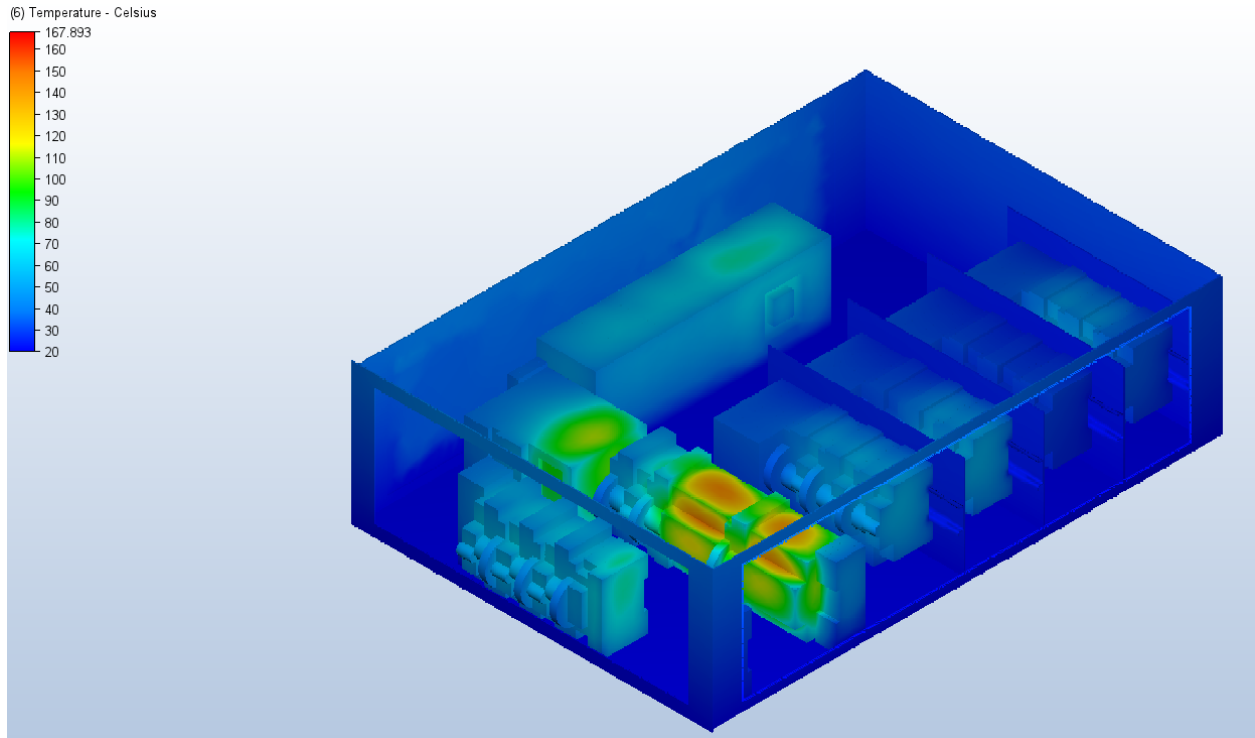
Figure 12: Temperature Distribution in the IPD Module
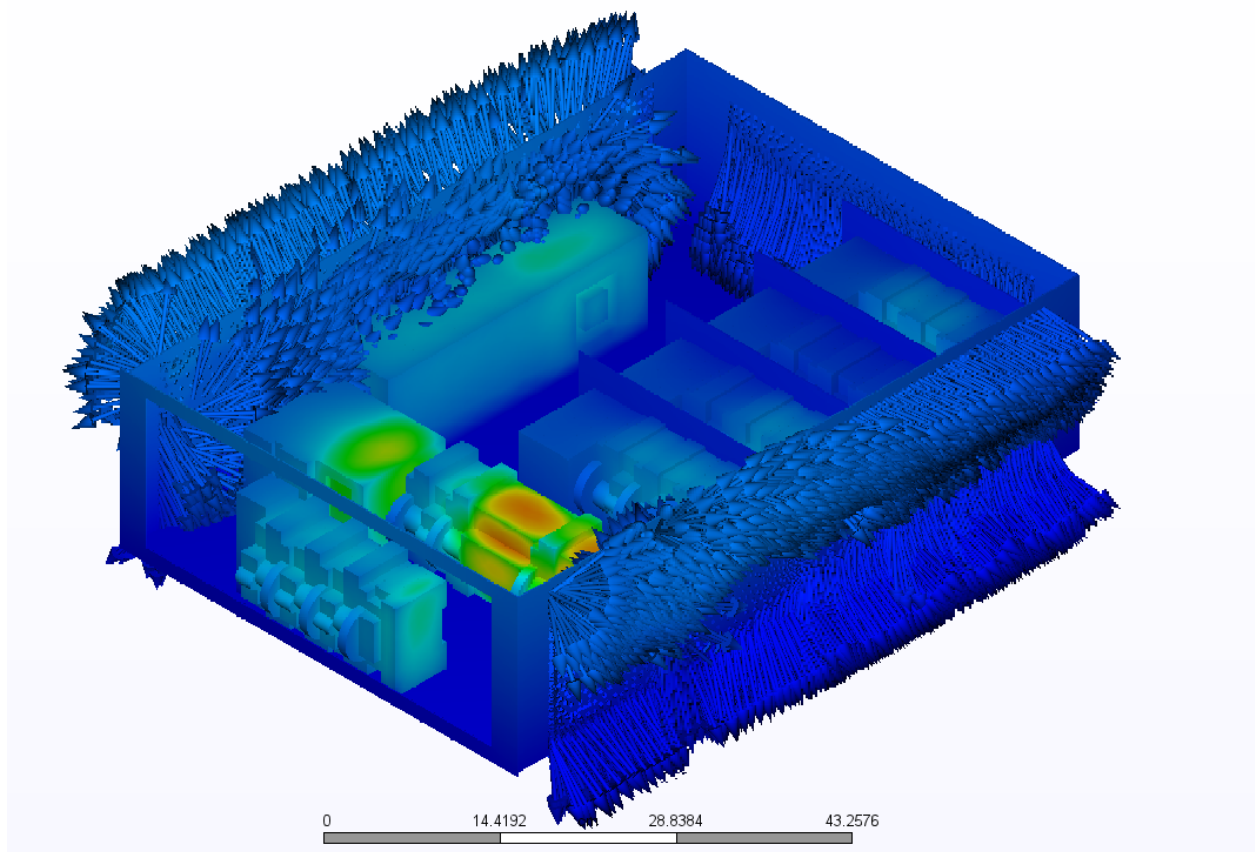
Figure 13: Velocity Vectors dictating the flow of air from the boundaries of the IPD module

Figure 14: Velocity Streamlines dictating the flow of air inside IPD module

9   Conclusions

After individual calculation of part temperatures the following data was gathered-

**Table 2:** Maximum Temperature attained by the components

Components	Maximum Temperature Reached (degree Celsius)
Siemens S7 1200 CPU 1214C	87.6521
SIMATIC S7 1200, Digital output SM 1222	75.1
MeanWell DRC 100B	126.741
MeanWell DDR 15 G 12	83.845
WAGO 787-1671	101.655
Legrand TX3 10000 1P	23.6524
Legrand TX3 10000 3P	167.893

When compared to Table 1, it is clear that only the Legrand TX3 10000 1P MCB are in their operating temperature range. All the other components attained critical temperatures or else were operating above it. Clearly the current module of IPD cannot rely on Natural Convection for its cooling and hence requires addition of cooling fan along with careful redesign and rearrangement of the components in order to reduce the temperature distribution throughout the components in the module.

After installation of the fan the results obtained clearly show an overall decrease in the temperatures of the components of the module but there is further scope for redesign of the fan and the geometry of the IPD module.
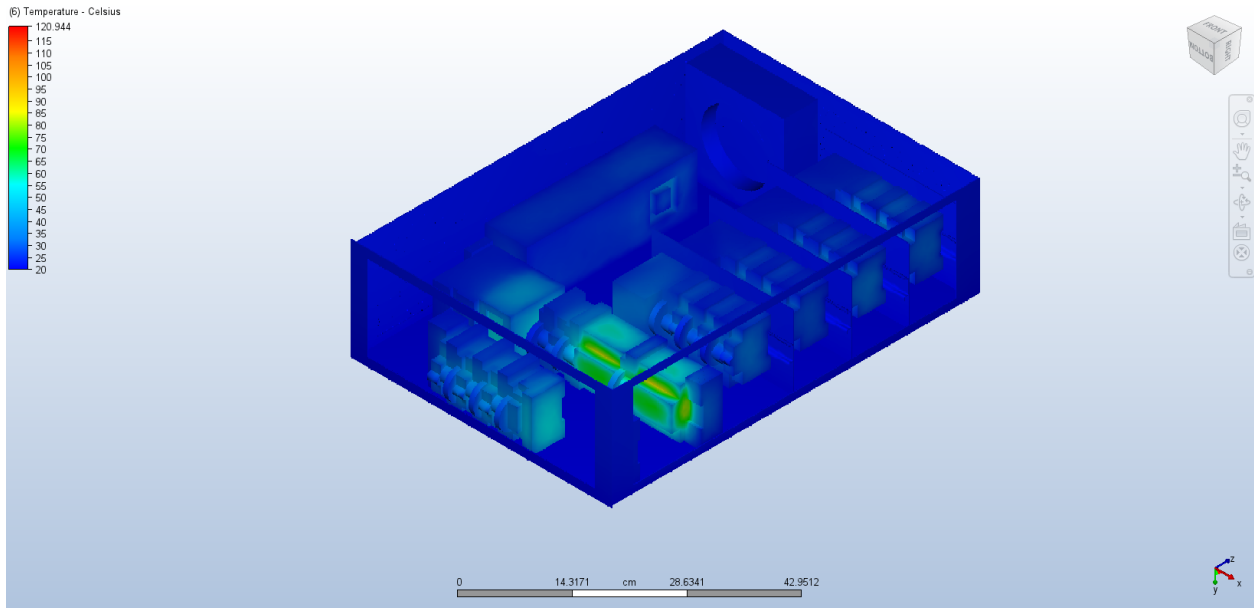
Figure 15: Temperature Distribution after adding fan inside the IPD module
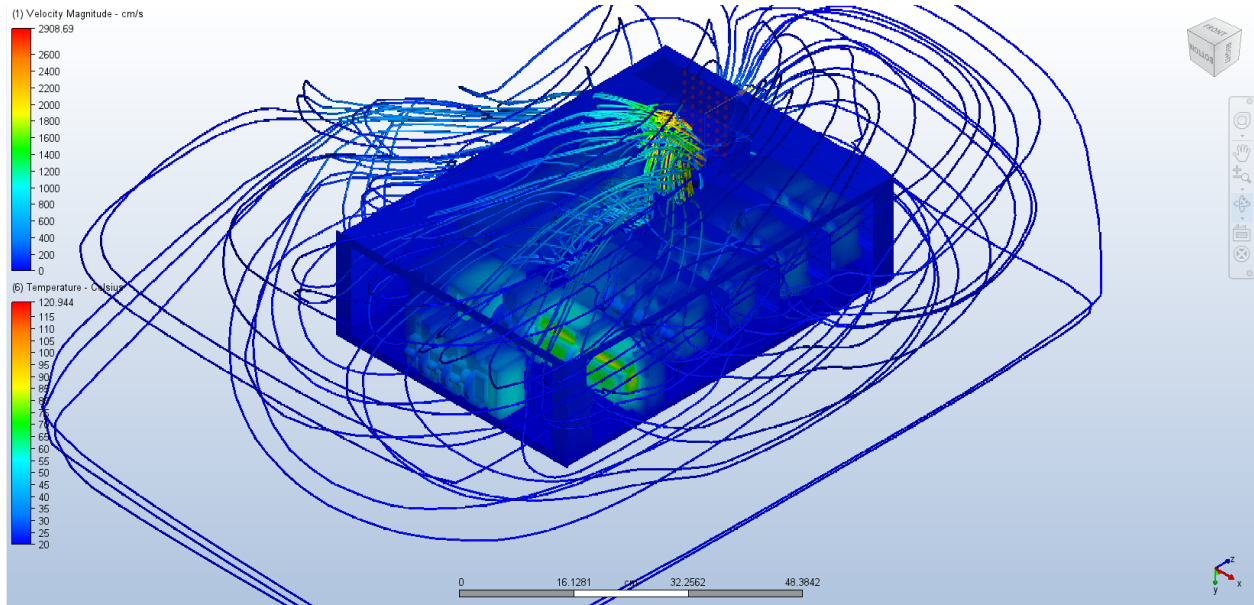
Figure 16: Velocity Streamlines dictating the flow of air inside IPD module post addition of fan

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10   References

1.https://knowledge.autodesk.com/support/cfd/learn-explore/caas/CloudHelp/cloudhelp/2014/ENU/SimCFD/files/GUID-A7E7C4B9-701B-4A4E-9F98-2E7C0BD1CB31-htm.html

2. https://knowledge.autodesk.com/support/cfd/learn-explore/caas/CloudHelp/cloudhelp/2019/ENU/SimCFD-UsersGuide/files/GUID-5DE738D2-BE39-4310-88BF-593451F54588-htm.html

3. https://knowledge.autodesk.com/support/cfd/learn-explore/caas/CloudHelp/cloudhelp/2019/ENU/SimCFD-UsersGuide/files/GUID-BCF33737-497B-47B8-867B-5DF174A7F9D1-htm.html

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