



# **JOINT INSTITUTE OF NUCLEAR RESEARCH**

Veksler and Baldin Laboratory of High Energy Physics

FINAL REPORT ON THE INTEREST PROGRAMME

# **Simulation of the NICA-MPD Platform's Rack Cooling System**

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## **Abstract**

The NICA complex at JINR, Dubna has a Multi-Purpose Detector (MPD) for studying the properties of hot and dense nuclear matter formed during collisions of high-energy heavy ions. The accompanying NICA-MPD-Platform houses the electronic equipment necessary for the operation of, and data acquisition, processing from the MPD. These equipment are temperature sensitive, and it is thereby of utmost importance to devise a cooling system for the same. The project involved the CFD simulation of the Cooling Unit for the NICA-MPD-Platform's Rack Cabinet, by modelling the Cooling Unit and evaluating the performance parameters considering various dependencies. The subsequent research and project results invoked a deeper understanding of the Cooling Unit, its operation and functioning, to a fundamental level. The cooling parameters were studied and their variation and dependencies on parameters like Suction Fan Speed were recorded. Further scope of research in the same domain was also proposed.

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# 1. Introduction

The Joint Institute for Nuclear Research (JINR), Dubna, Russia houses a new scientific programme on heavy-ion physics devoted to the study of in-medium properties of hadrons and nuclear matter equation of state. The Nuclotron-based Ion Collider Facility (NICA) is an ionic collider based on the Nuclotron to study nuclear matter in a hot and dense state. The main objective of the programme is the creation of an accelerator complex of ions with high luminosity in the energy range up to 11 GeV/nucleon and a modern multi-functional detector for the study of heavy ion collisions. The NICA complex has multiple components, which include various types of accelerators: a linear accelerator, an intermediate energy storage accelerator (booster), the Nuclotron and a collider, out of which the focus of this study is on the Multi-Purpose Detector (MPD) and the NICA-MPD-Platform, more specifically on the implementation and performance of the cooling system for the rack cabinet housed within the NICA-MPD-Platform.

## 2. Background - The MPD and NICA-MPD-Platform

### 2.1 Multi-Purpose Detector (MPD)

The MPD is designed as a  $4\pi$  spectrometer capable of detecting charged hadrons, electrons and photons in heavy-ion collisions in the energy range of the NICA collider. It comprises of a precise 3D tracking system and a high-performance particle identification system based on the time-of-flight (TOF) measurements and calorimetry, enabling acquirement of new scientific knowledge.

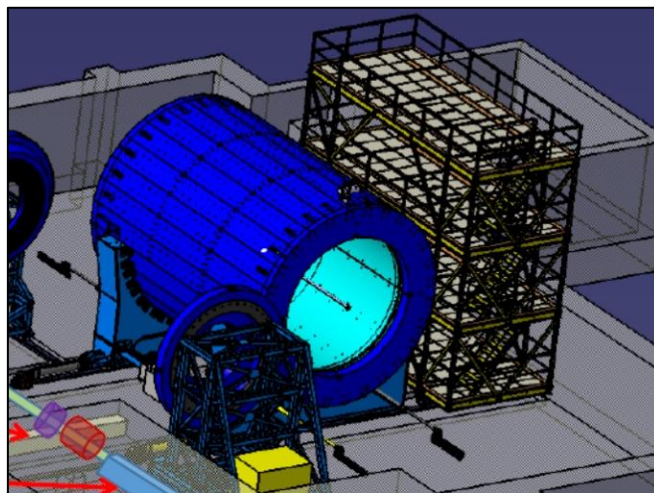


Fig. 1: The NICA-MPD (left) and the NICA-MPD-Platform (right).

The purpose of the MPD is to study the properties of hot and dense nuclear matter formed during collisions of high-energy heavy ions, in particular, to search for effects

associated with deconfiguration and/or restoration of chiral symmetry and to study the properties of phase transitions and mixed hadron and quark-gluon phases.

## 2.2 NICA-MPD-Platform

The NICA-MPD-Platform is designed as a mobile device to be integrated with the MPD, as described in Fig. 1. It is a mechanical construction designed to house the various electronic equipment essential for operational control, data acquisition and processing related to the MPD. The platform has 4 floors - the lowest, LEVEL 1, is intended for power equipment supplying MPD and the platform itself. The next three levels (2, 3, 4) are for the Slow Control System (SCS) and Detector Control System (DCS) for the NICA-MPD project.

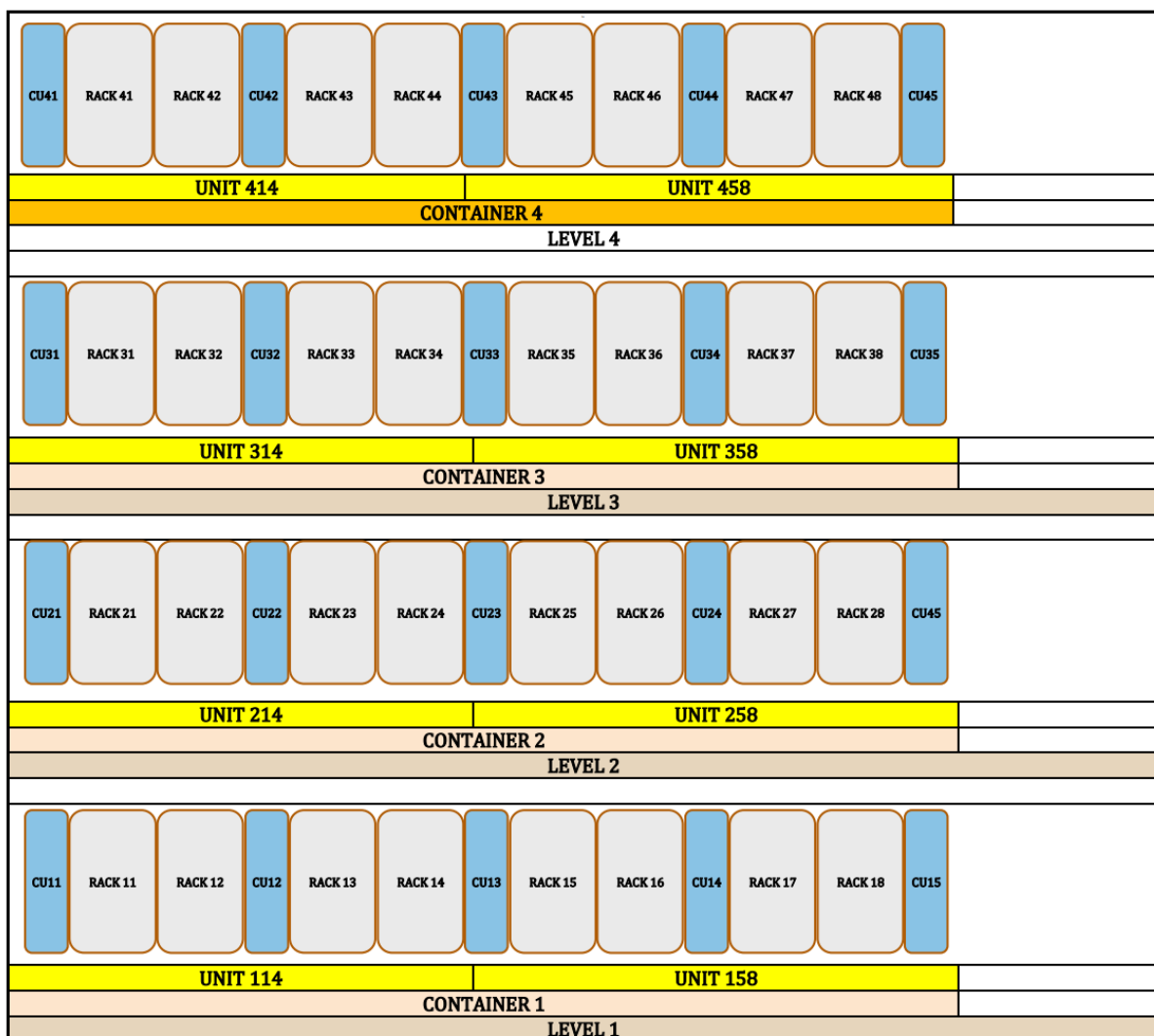


Fig. 2: NICA-MPD-Platform Architecture.

The NICA-MPD-Platform's architecture consists of an arrangement of racks and cooling units which responsible for absorbing the heat generated by the components within the rack. The rack is a mechanical enclosure which houses the electronic

components. The contents of a rack aren't essential to the study being presented, it is sufficient to note that the components within the rack are temperature sensitive and the same poses the need for a cooling system for efficient and safe functioning.



Fig. 3: Rack Cabinet of NICA-MPD-Platform.

### 2.3 NICA-MPD-Platform: Cooling Unit

The racks are air-cooled with the help of a cooling unit. The study in question is modelled after the *STULZ Prodigy iROW DX* (High Density Air Conditioner) with R410A (HFC) as the refrigerant. It has a modular and scalable structure that can be fitted into a wide range of rack layouts and sizes, in addition to being versatile with respect to operating configuration.

The system operation can be modelled by a *Vapor-Compression Cycle* consisting of a compressor, condenser, throttling valve and evaporator, as follows: The compressor brings the refrigerant to a higher temperature and pressure. The hot gas passing through the condenser is cooled and liquefied, releasing heat to outer air. The refrigerant fluid, pushed through the thermal expansion valve, loses pressure and prepares for evaporation. Evaporation takes place in the evaporator where the refrigerant absorbs the heat of inner hot air and as a consequence cools down this air. Circuit components are connected together by copper pipes that are welded to guarantee an excellent seal. The thermodynamic nuances of the above-mentioned

cycle aren't of any value to the numerical simulation involving the study, and are hence not discussed.

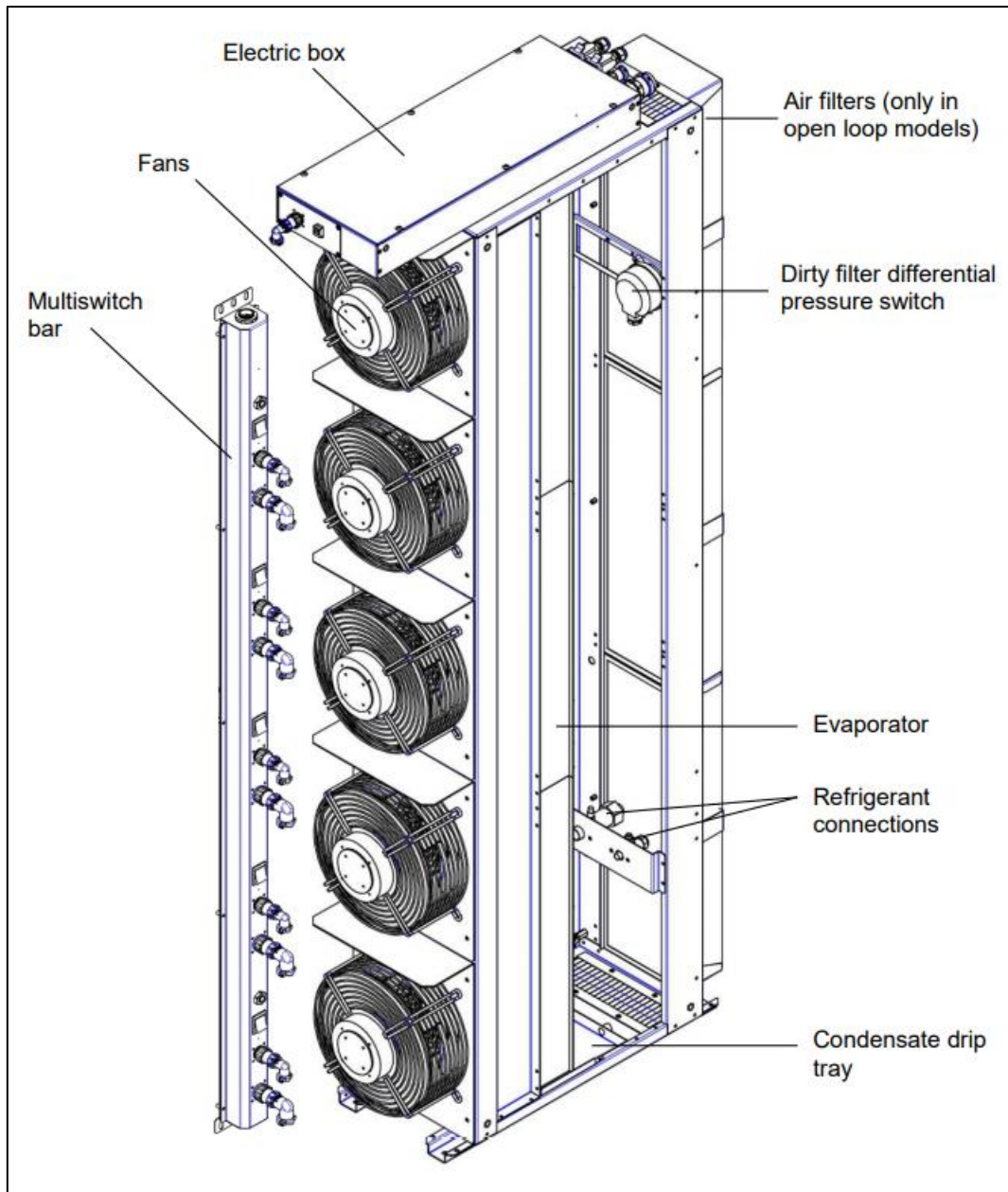


Fig. 4: *STULZ Prodigy iROW DX's Schematic Diagram.*

These units are made of self-supporting galvanized sheet metal parts that offer good corrosion resistance. A condensate tray made of aluminium sheet is placed below the evaporator to collect water condensing on its surface during cooling mode. A hydraulic injection circuit is present for delivery of water into the heat exchangers.

These heat exchangers are where the heat from inner air passes to the refrigerant gas. It is a heat exchanger with copper pipes and aluminium fins. This is the most

important component in the numerical simulation and is primarily responsible for controlling the temperature of the rack volume.

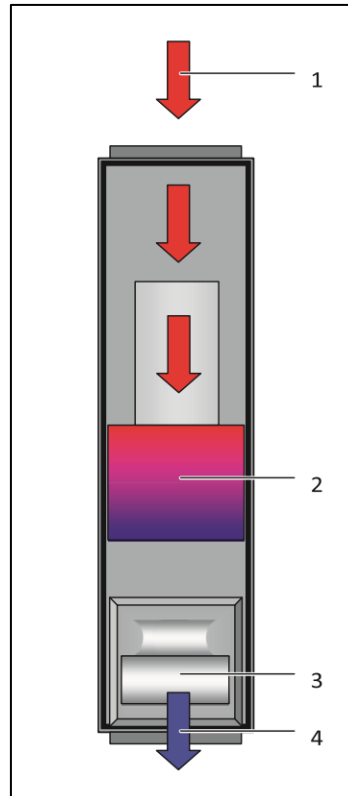


Fig. 5: Top view of the Air Routing within the Cooling unit. 1, 2, 3 and 4 represent the Air Inlet, Heat Exchanger (Evaporator), Fan Module and Air Outlet respectively.

Air is sucked in by the radial fans, is filtered (only in open loop units) and then it is cooled passing through the evaporator. After treatment, air is delivered through the frontal opening. Cooling capacity is modulated by the external motor-condensing unit, which is equipped with an inverter driven compressor.

In the NICA-MPD-Platform, the *STULZ Prodigy iROW DX* is operated in the closed-loop configuration, to avoid entry of contaminants into the rack. Heat generated by the components in the rack remain inside the cabinet and is disposed without entering the room.

There are more components present inside the *STULZ Prodigy iROW DX*, which aren't relevant to the numerical simulations in the study. These include the differential pressure sensors, temperature and humidity sensors, water unit pipework, connection lines, fan hot swap, C2020 Electronic Control System and so on. This unit cools the rack when placed beside in the closed loop configuration.



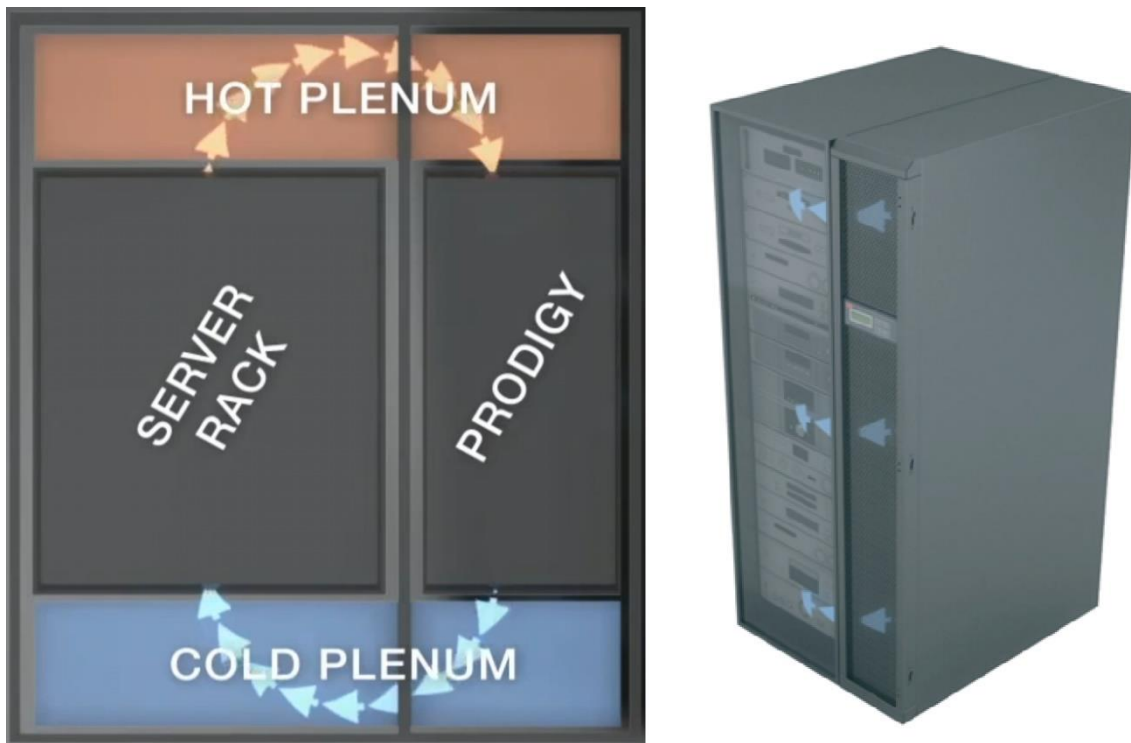


Fig. 6: Description of the Closed-loop Operating Configuration.



Fig. 7: Cooling Unit and Rack Cabinet arrangement.

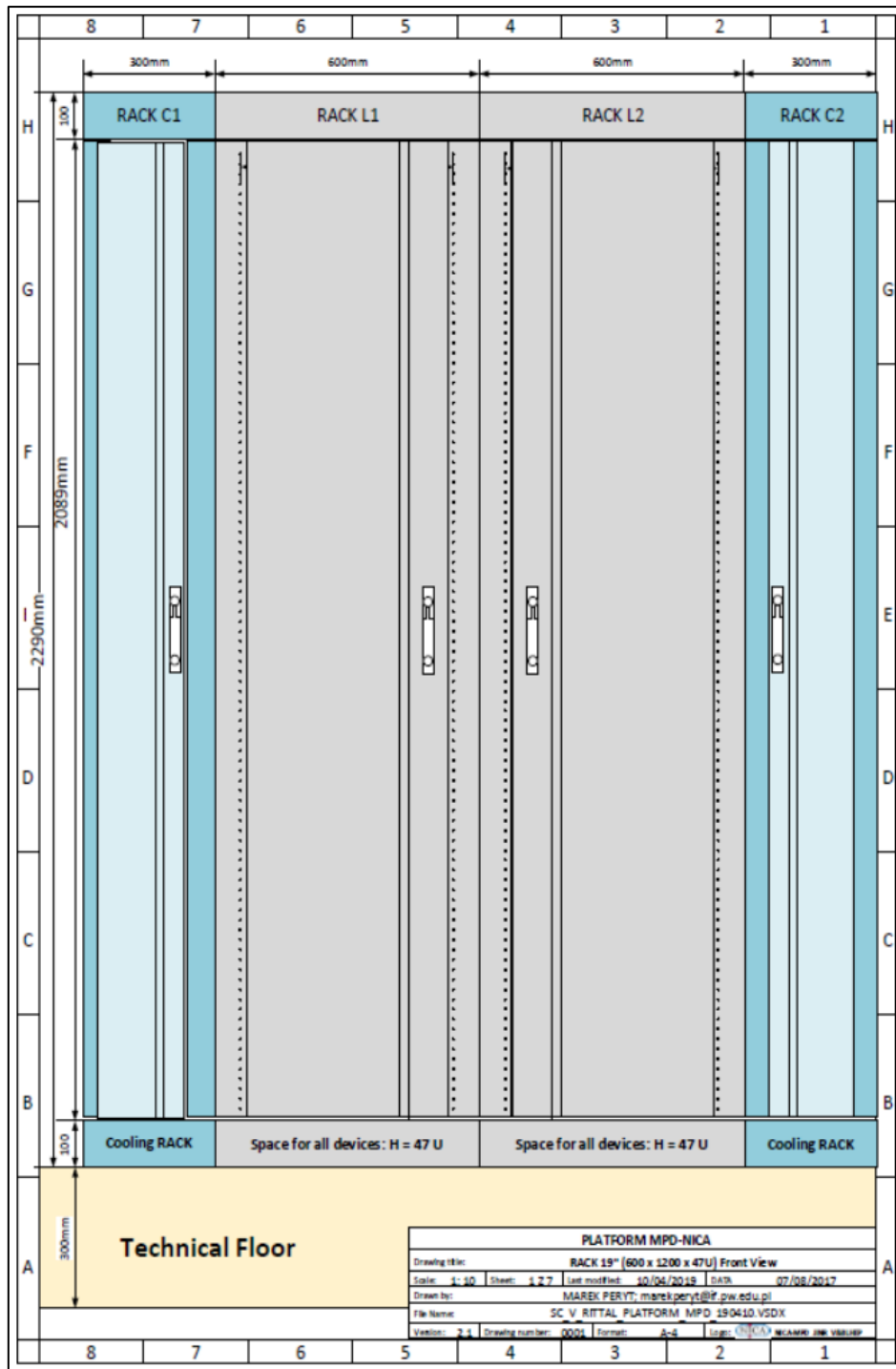


Fig. 8: Technical Drawing describing the dimensions of the Rack Cabinet and Cooling Unit arrangement.

### 3. Study Methodology

The study involved simplifying the geometries of the rack cabinet and identifying the components in the cooling unit that are relevant to the numerical simulation, thereby preparing simple CAD models of the same and assembling, all based on the dimensions provided in the technical drawings. Further, appropriate boundary

conditions were determined and provided for the simulation to provide physically relevant results.

### 3.1 Geometry

The simulation assembly consisted of a volume representing the heat generation from the components in the rack cabinet, fans and the evaporator heat exchanger from the cooling unit.

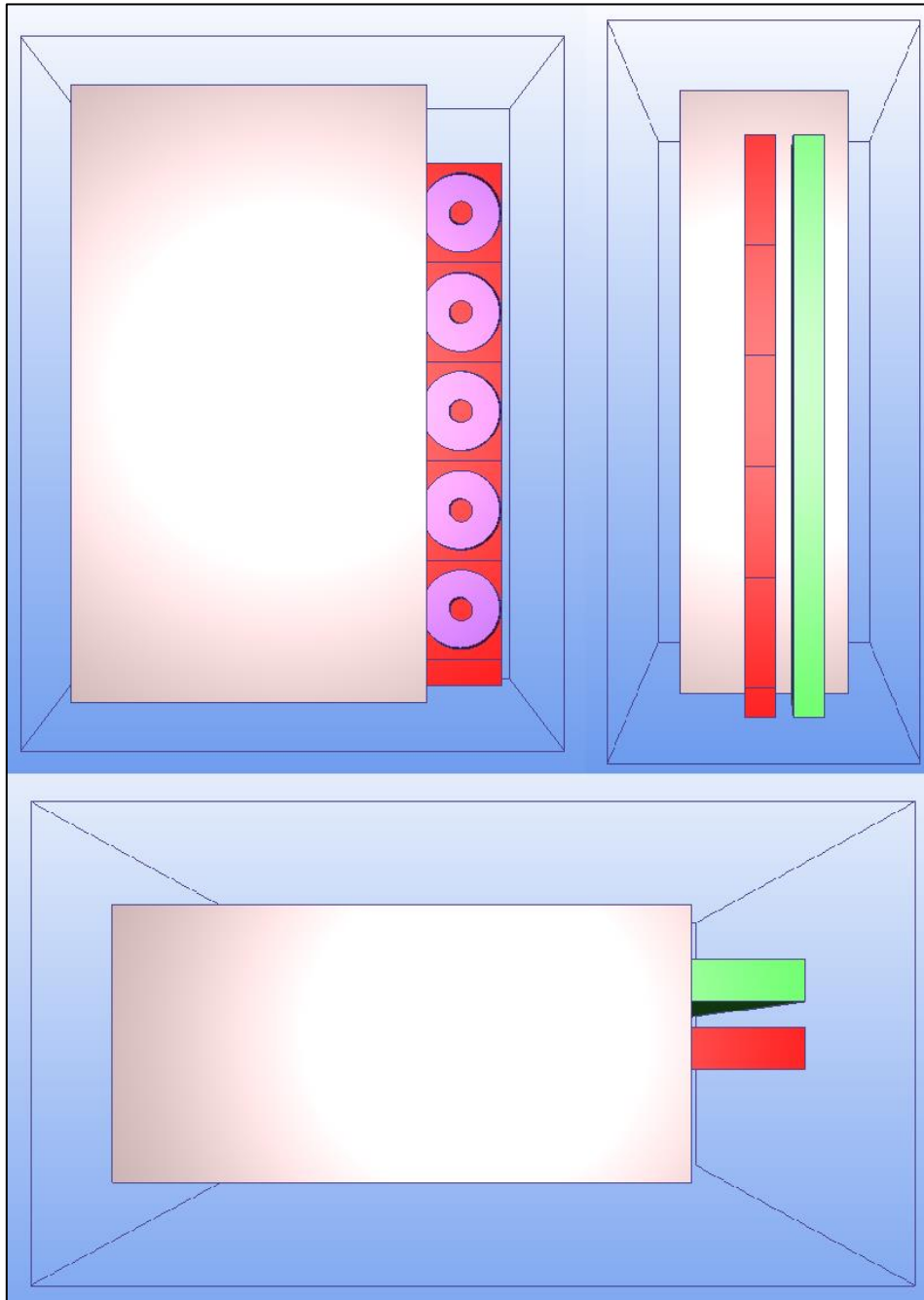


Fig. 9: Front, Side and Top Views of the Simulation Assembly. The external volume is outlined for better visibility of the components.

The dimensions of the assembly are as follows:

- Rack Volume (Aluminium): 600mm × 1200mm × 47U (1U = 1.75in)
- Evaporator (Flow Rate = 90.2448 m<sup>3</sup>/hr, Set Point Temperature = 25°C): 100mm × 290mm × 1870mm
- Fan Housing (ABS Molded): 100mm × 290mm × 355mm
- Fan Material (RPM was varied - chosen values were 2000, 2950, 3500 and 5000):  $\Phi$ 285mm (Outer),  $\Phi$ 80mm (Inner), Thickness = 27mm
- Gap between Rack and Cooling Unit = 5mm
- Gap between Fan assembly and Evaporator = 60mm
- The Fan assembly was placed inside the Cooling Unit at a distance of 238mm, as specified by the technical documentation of the *STULZ Prodigy iROW DX*.
- The external volume was created such that sufficient space was provided for the air to circulate within.

### 3.2 Conditions

The boundary conditions were chosen as follows:

- Ambient Temperature = 25°C
- Total Heat Generation from Rack: 1000W
- Film Coefficient: 200W/m<sup>2</sup>K (Reference Temperature = 25°C, applied at boundary. High value of Film Coefficient was chosen to emulate heat transfer via forced convection.)

The number of iterations were set to 500 for satisfactory convergence. The simulation was performed for various RPMs of the fan assembly and changes occurring in the average temperature within the volume and amount of heat absorbed by the heat exchanger (evaporator) were noted.

## 4. Results

The results for the distribution of temperature and velocity at different section planes within the volume were extracted, along with average volume temperature and heat absorbed by the evaporator for different fan RPMs.

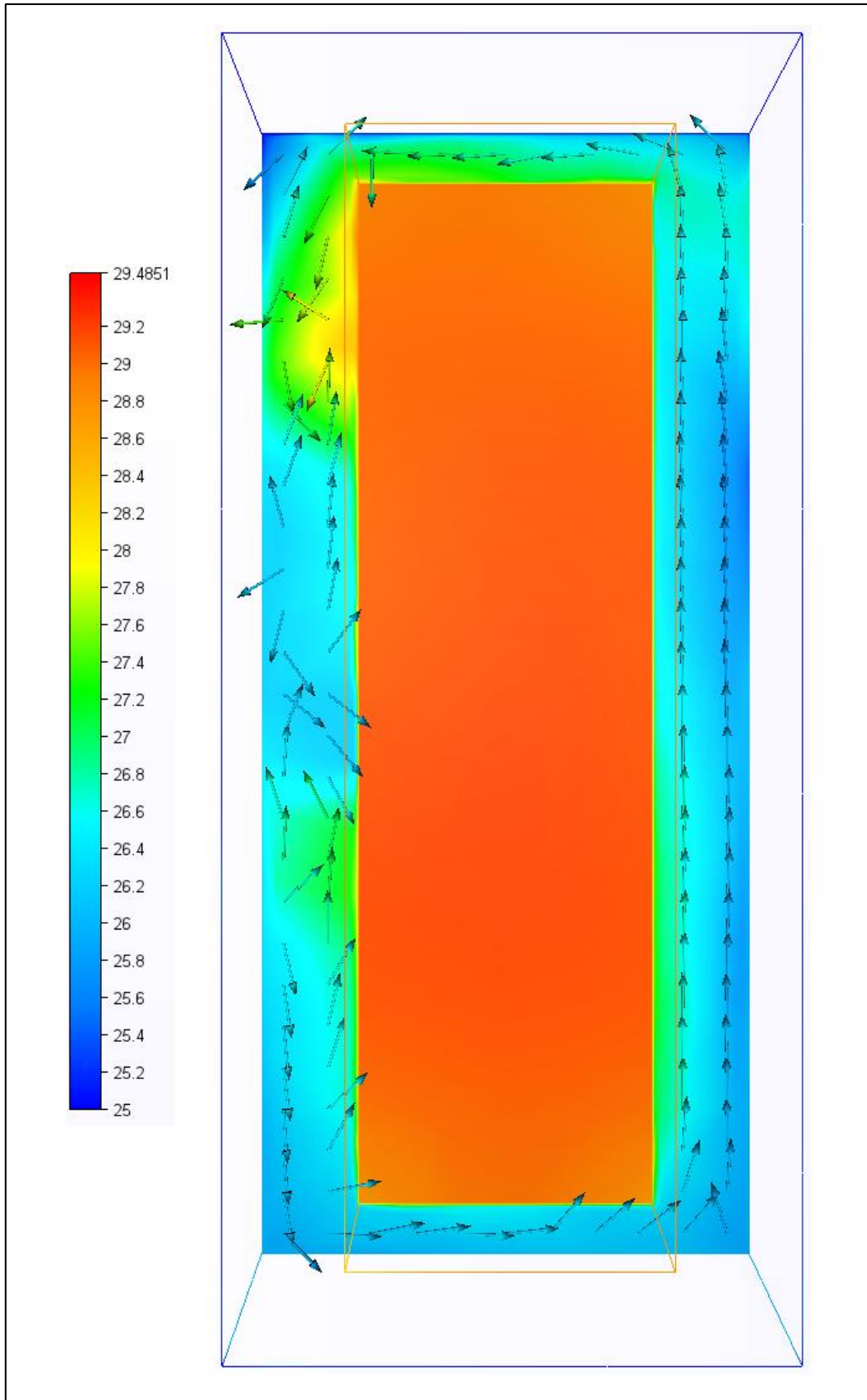


Fig. 10: Temperature (Scale in °C) and Velocity distribution along the side section of the Rack Volume at a Fan Speed of 2950RPM.

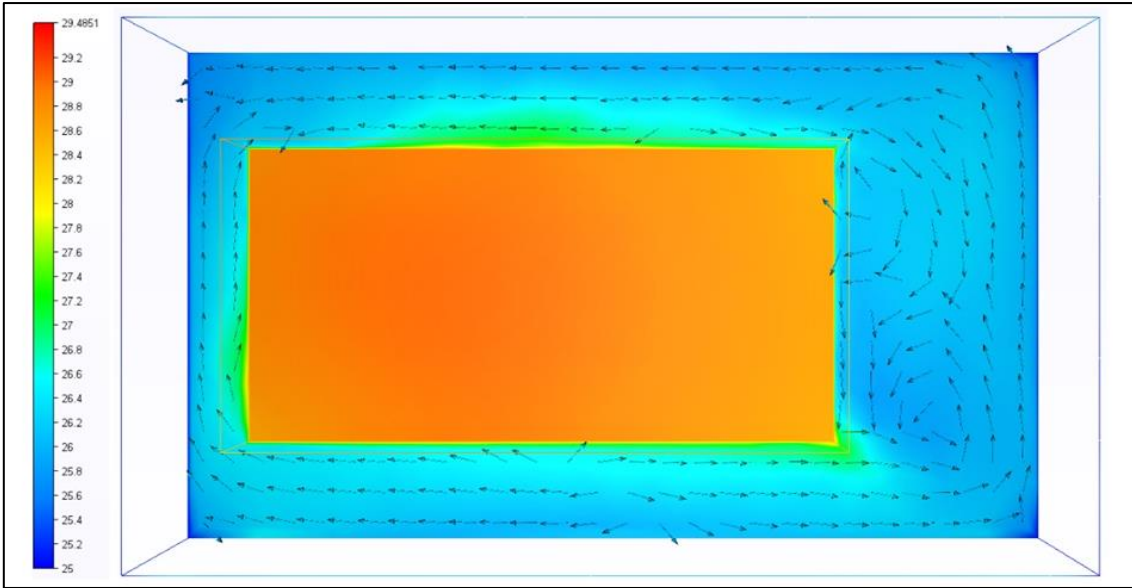


Fig. 11: Temperature (Scale in °C) and Velocity distribution along the top section (above the heat exchanger) of the Rack Volume at a Fan Speed of 2950RPM.

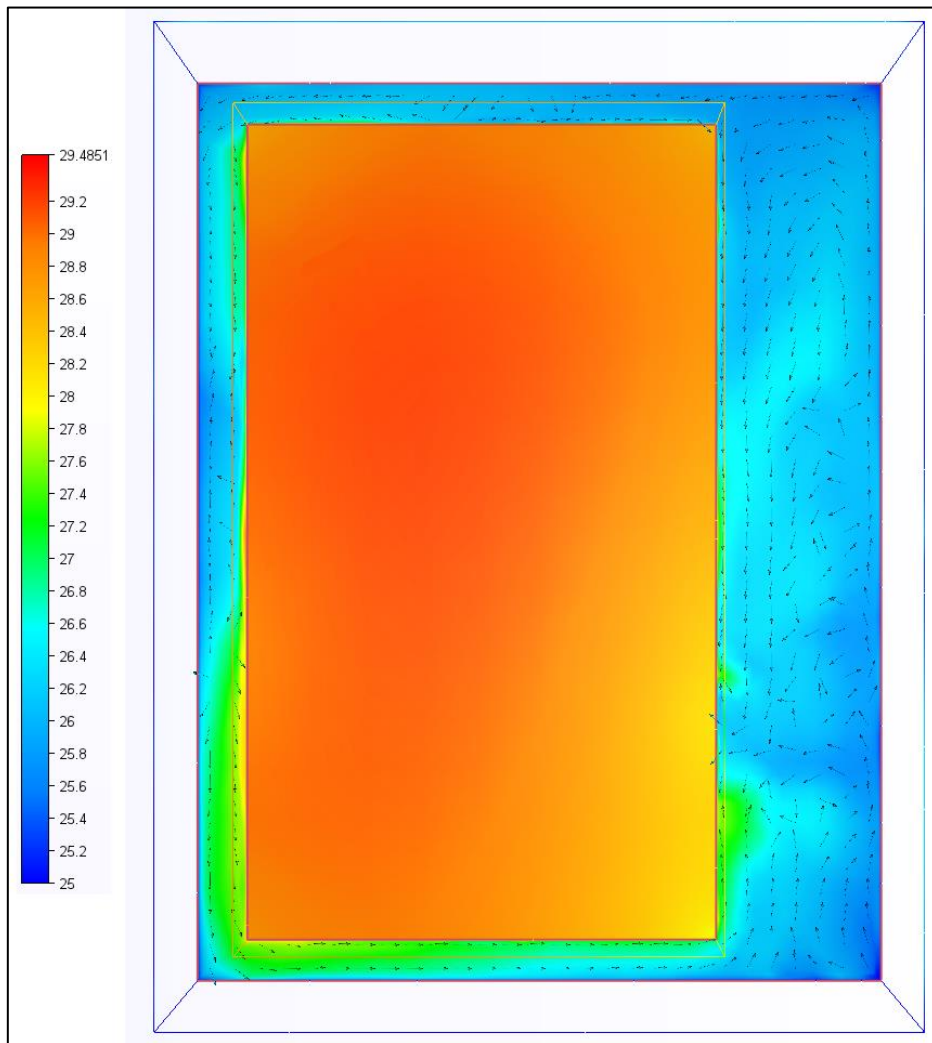


Fig. 12: Temperature (Scale in °C) and Velocity distribution along the front section (in front of the fan assembly) of the Rack Volume at a Fan Speed of 2950RPM.

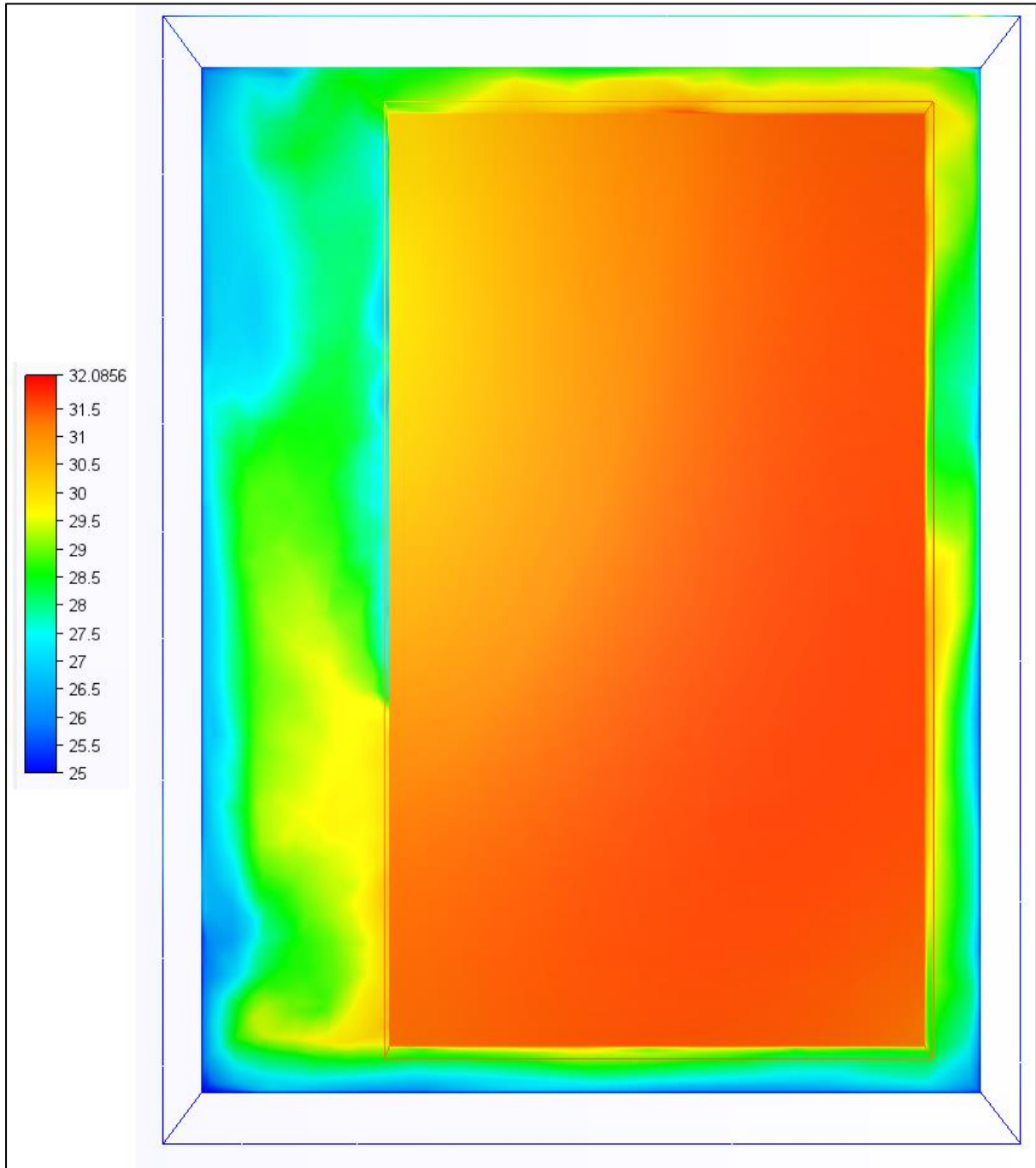


Fig. 13: Temperature (Scale in °C) distribution along the back section (just before the evaporator inlet) of the Rack Volume at a Fan Speed of 3500RPM.

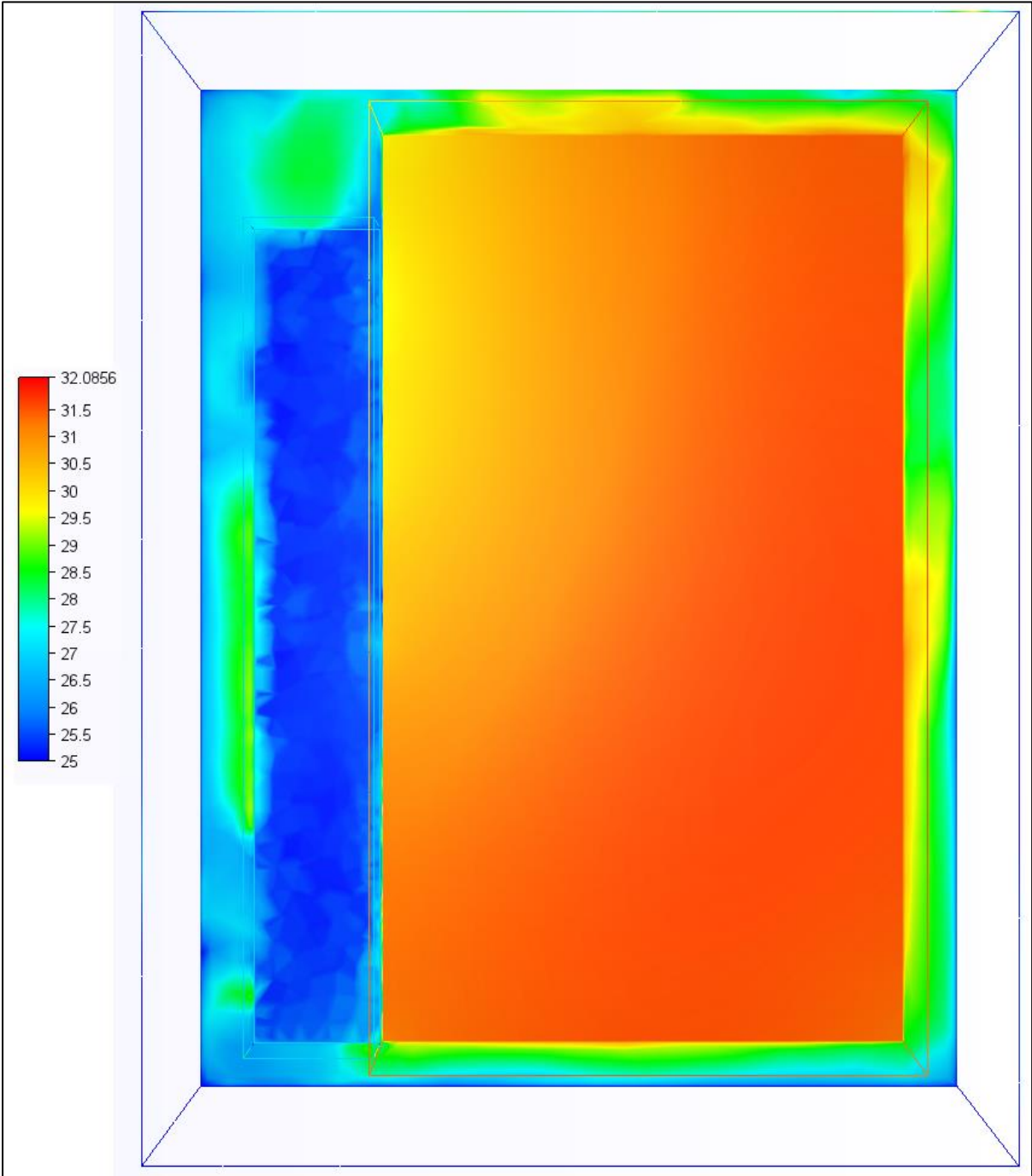


Fig. 14: Temperature (Scale in °C) distribution along the back section (just after the evaporator outlet) of the Rack Volume at a Fan Speed of 3500RPM.



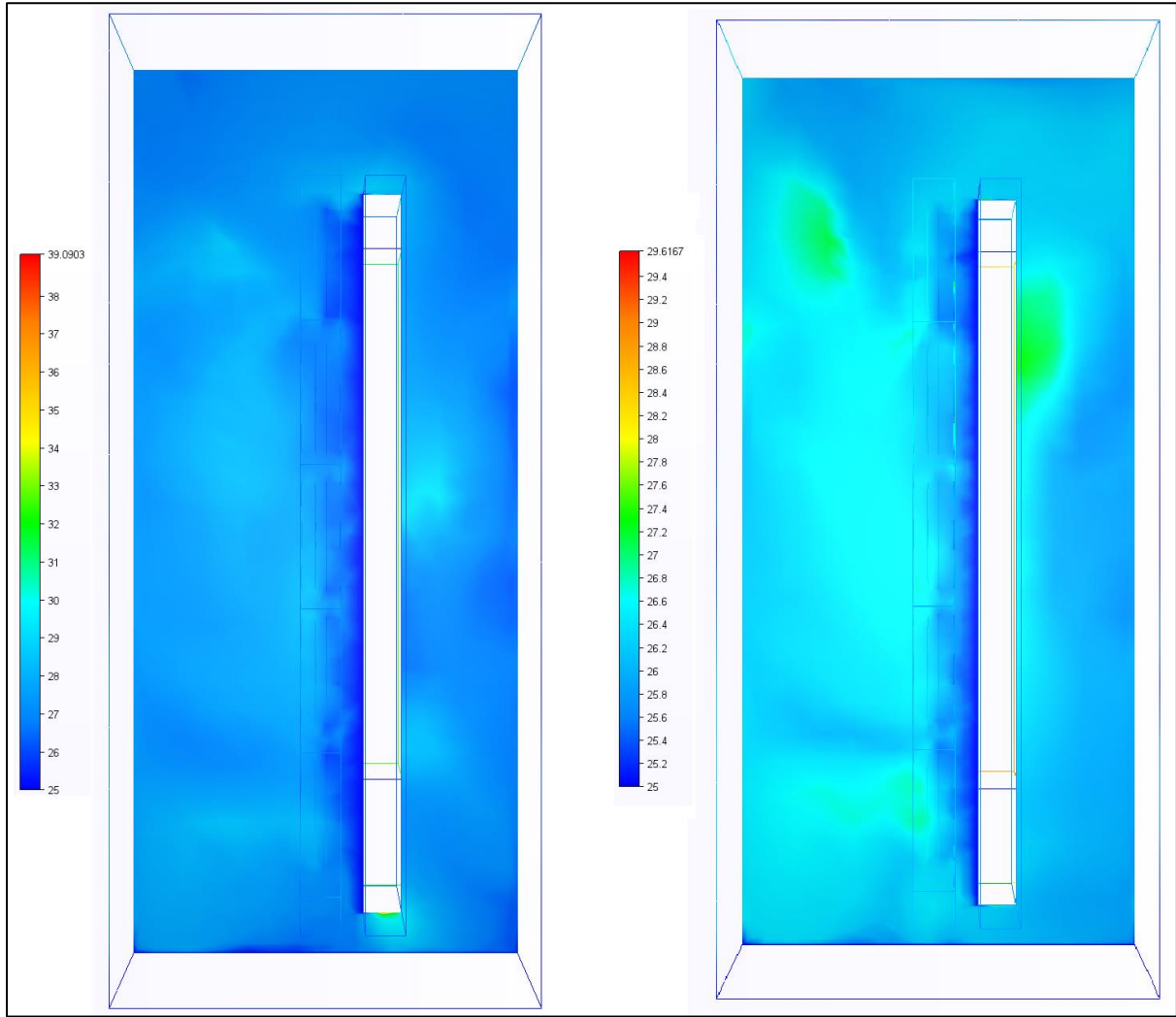


Fig. 15: Temperature (Scale in °C) distribution along the side section (passing through the evaporator volume) of the Rack Volume at Fan Speeds of 2000RPM (left) and 2950RPM (right).

Fan Speed (RPM)	Average Temperature of Volume (°C)	Energy Absorbed by the Evaporator (W)
2000	29.8155	188.866
2950	27.2415	133.579
3500	28.1448	106.211
5000	27.3137	79.3644

Fig. 16: Table showing the variation of Average Temperature of Volume and Energy Absorbed by Evaporator with the Fan Speed.

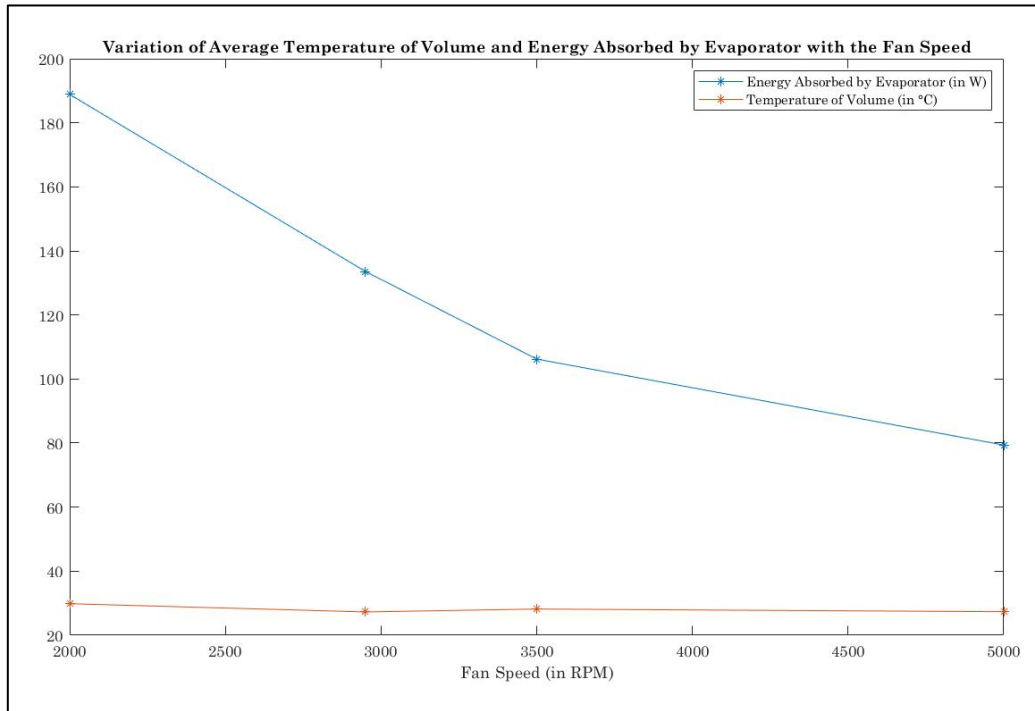


Fig. 17: Plot showing the variation of Average Temperature of Volume and Energy Absorbed by Evaporator with the Fan Speed.



Fig. 18: Visualisation of the Movement of Air (Scale is Velocity Magnitude in cm/s) as forced by the Fans within the Rack Volume at 5000RPM.

## 5. Insights and Conclusion

The following insights were deduced post analysis of the results:

- Fig. 10, 11 and 12 portray the air circulation around the rack volume, which is forced by the effects created by the fans. The flow is well-rounded mostly, except in areas in front of, above and nearby the fans, as evidenced by the recirculations. The circulation can be made more effective by plenums and other suitable installations which will further help the cooling of the rack cabinet.
- Fig. 13 and 14 show the effect the evaporator has on the temperature of the air. The temperature reduction is captured in these two distributions.
- The effect of the evaporator can also be seen in Fig. 15, where the temperature of the air at the outlet of the evaporator is visibly less than that at the inlet, as expected.
- Fig. 16 and 17 point out that the increase in RPM of the fans has led to a decrease in the energy absorbed by the evaporator. This maybe due to the quicker circulation resulting in less effective heat carrying by the air. It points to the existence of an optimum RPM for most effective absorptance of energy from the rack. The simulations however need to consider the variation in Film Coefficient of Air with the increase in RPM via appropriate analytical calculations before any conclusion can be made on the same.
- Fig. 18 effectively portrays the function of the fans in the setup, sucking out the cold air exiting the evaporator and distributing it within the rack volume for effective cooling.

The Computational Fluid Dynamics (CFD) simulations hence show that the cooling unit is capable of maintaining desirable temperatures with one rack cabinet attached to it under the conditions provided.

## 6. Further Scope of Work

The study can be extended to investigate the impact the 3-Fan configuration of the *STULZ Prodigy iROW DX* will have on the result parameters. The geometry of the same can be found below.

The present study was performed for the cooling of one rack cabinet by one cooling unit. The NICA-MPD-Platform also has arrangements where one cooling unit is assigned to two racks. Simulations of the same can also be performed, and can be extended to the simulation of an entire platform level and to the whole platform itself, in a modular manner by using the results from the previous simulation.

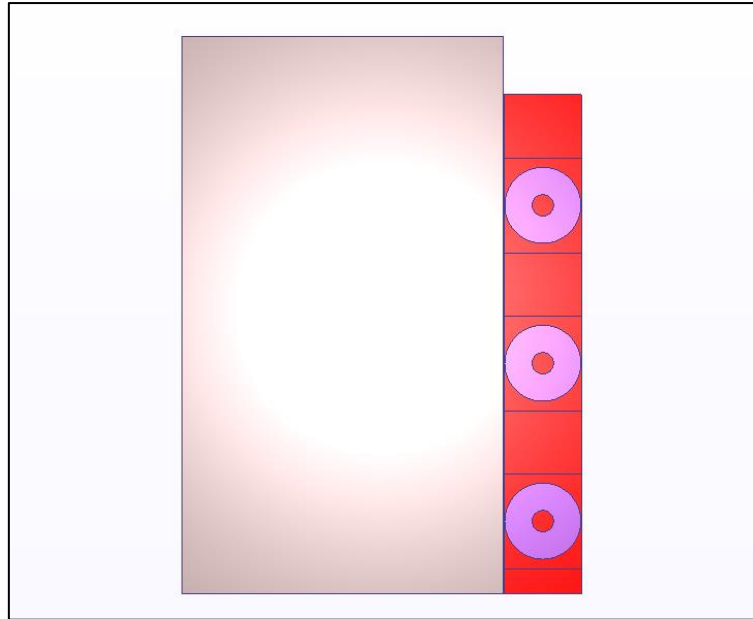


Fig. 19: Simulation Assembly for studying the effects of the 3-Fan Configuration of the *STULZ Prodigy iROW DX* on the cooling of the Rack Cabinet.

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