TECHNICAL CASE STUDY

Liquid Cooling · System Optimization

Analytical and CFD Optimization of a 1600 W Liquid-Cooled Rack Chassis

At a Glance

Advanced Thermal Solutions, Inc. (ATS) used analytical calculations and CFD to optimize a liquid-cooled rack chassis integrating dual cold plates and an internal air-to-liquid heat exchanger. The work identified the governing bottleneck and guided architecture-level improvements for 1600 W heat rejection at 55°C ambient.

CUSTOMER OVERVIEW

The customer was developing a liquid-cooled rack chassis that combined upper and lower cold plates with an internal air-to-liquid heat exchanger. The design required coordinated management of high component heat loads, internal airflow, and coolant-side performance within one chassis architecture.

- Upper and lower cold plates integrated into one chassis
- Internal air-to-liquid heat exchanger for system-level rejection
- Airflow path and vent geometry strongly influenced HEX performance (Figure 1)

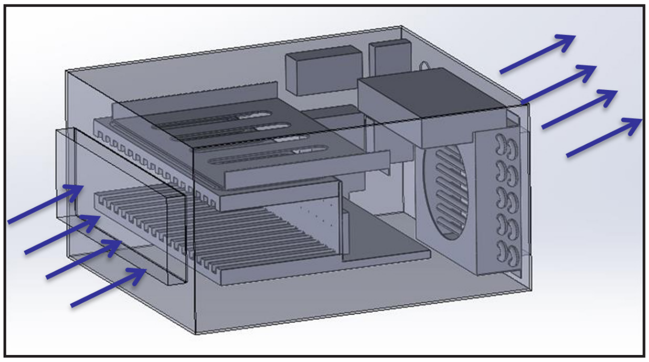

Figure 1. Dual Cold Plates with Internal Air-to-Liquid HEX and Directed Airflow Path

CHALLENGE

The system needed to reject 1600 W at 55°C ambient while keeping cold plate surface temperatures at or below 80°C. Although the cold plates carried 750 W and 850 W respectively, the more difficult constraint was achieving enough air mass flow across the internal heat exchanger.

Thermal requirements and loads:

- Total heat rejection target: 1600 W
- Ambient temperature: 55°C
- Upper cold plate load: 750 W
- Lower cold plate load: 850 W
- Cold plate surface limit: ≤80°C
- Coolant flow target: approximately 1 GPM

The key challenge was optimizing both the liquid cooling hardware and the chassis airflow path so the HEX could reject the full load under real operating conditions, including altitude effects, bending limits or creating high pressure drop.

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METHODOLOGY

ATS combined analytical calculations with CFD simulations in two phases: first validating cold plate performance, then focusing on airflow, vent geometry, fan operating point, coolant selection, and HEX performance limits.

System Architecture and Baseline Analysis

- Modeled upper and lower cold plates at 750 W and 850 W respectively
- Analyzed airflow from intake plenum through the cold plate area and across the internal HEX core
- Validated cold plate thermal resistance using analytical and CFD methods (Figures 2 & 3)
- Assessed baseline HEX heat rejection capability under the original airflow condition

Optimization Investigation Areas

- Coolant comparison including PAO and EG 50/50
- Vent enlargement to increase available airflow
- Fan operating point behavior and knee-region avoidance
- Altitude derating effects on air density and mass flow
- Potential need for an alternative or custom heat exchanger design

This approach separated component-level cold plate performance from the broader chassis-level air-side limitation and identified the true path to meeting the 1600 W target.

CFD Data (PAO Fluid)			
Flow Rate (GPM)	Max Cold Plate Temp (°C)	Thermal Resistance (°C/W)	Pressure drop (Psi)
0.5	78.8	0.032	3.2
1	68.6	0.018	7.9
1.5	64.8	0.013	13.6
2	62.9	0.011	20.2
2.5	61.6	0.009	27.6

- **Ambient Temperature = 55°C**
- **Cold Plate Max Surface Temperature = 80°C**

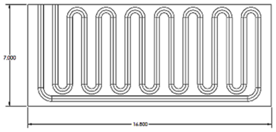

Figure 2. Baseline CFD Data for the Upper Cold Plates

CFD Data (PAO Fluid)			
Flow Rate (GPM)	Max Cold Plate Temp (°C)	Thermal Resistance (°C/W)	Pressure drop (Psi)
0.5	84.1	0.034	4.8
1	72.9	0.021	11.28
1.5	68.3	0.016	19
2	65.7	0.013	27.7
2.5	63.9	0.010	37.4

- **Ambient Temperature = 55°C**
- **Cold Plate Max Surface Temperature = 80°C**

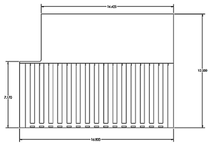

Figure 3. Baseline CFD Data for the Lower Cold Plates

SOLUTION

ATS validated that the upper and lower cold plates could satisfy the surface temperature requirement, then shifted optimization to the system-level airflow and HEX bottleneck. The solution path included coolant selection, enlarged intake vent area, fan operating point improvement, and a custom HEX architecture sized for the full 1600 W requirement.

- Validated cold plate performance against the ≤80°C surface temperature target
- Improved cold plate performance by switching coolant to EG 50/50
- Enlarged vent intake area to increase sea-level airflow from approximately 300 CFM to 330 CFM
- Evaluated fan operating point behavior under altitude-derated conditions
- Recommended a custom HEX sized for 1600 W at 55°C ambient
- Optimized coolant ΔT across the cold plates to increase overall system margin

This redirected the design effort from local component cooling to the architecture-level airflow and heat exchanger limitation that governed full-system performance.

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RESULTS & DATA

The analysis confirmed that the cold plates met their temperature targets, but also showed that the existing internal HEX could not reject the full 1600 W load under reduced-airflow conditions.

Key Findings:

- Cold plates satisfied the ≤80°C surface temperature requirement
- Cold plate performance curves validated analytical Rθ targets
- Existing HEX was insufficient to reach the full 1600 W target (Figure 4)
- Vent enlargement increased sea-level airflow from approximately 300 CFM to 330 CFM
- Altitude-derated airflow dropped to approximately 215 CFM

At the derated airflow condition of roughly 215 CFM, HEX heat rejection fell below the 1600 W requirement unless airflow increased toward approximately 325 CFM or coolant inlet temperature rose significantly above ambient.

System-level outcomes:

- The system bottleneck was airflow across the HEX rather than cold plate capability
- Altitude derating significantly reduced heat rejection margin
- Vent pattern changes improved sea-level chassis airflow (Figure 5)
- Architecture-level HEX redesign was required for full margin at the target load

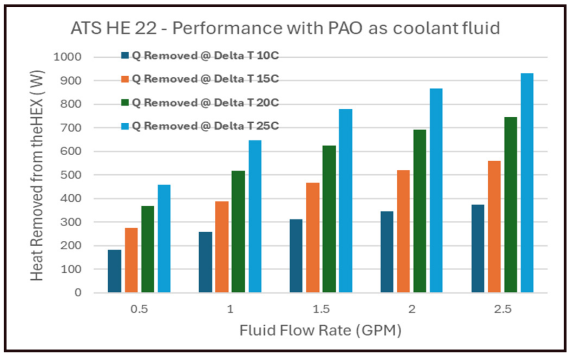

Figure 4. Baseline Heat Exchanger Performance Data. PAO is Polyalphaolefin, a Synthetic Hydrocarbon Oil

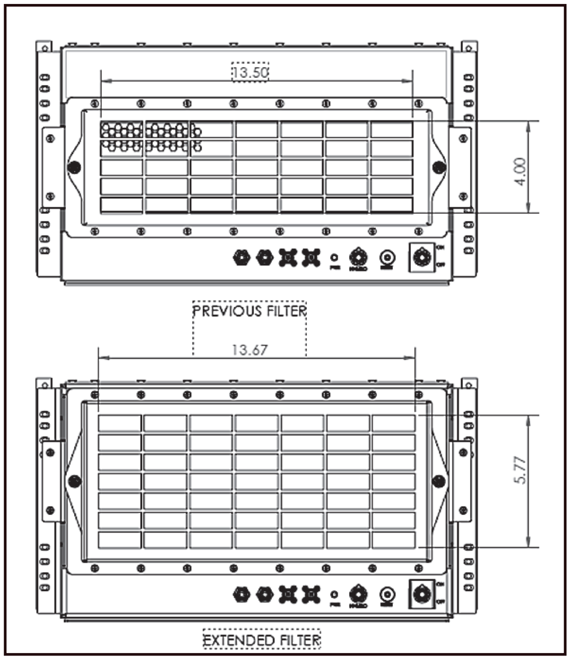

Figure 5. The Vent Intake Area was Increased, Resulting in Increased Airflow to the Chassis

ANALYSIS & CONCLUSION

This study shows that liquid cooling performance in a rack chassis depends on more than cold plate design alone. Even when component-level liquid cooling is successful, the overall architecture can still be limited by airflow delivery and air-side heat exchanger capacity.

- Cold plate performance was validated through both analytical and CFD methods
- The governing bottleneck was air mass flow across the internal HEX
- Altitude derating created a major reduction in available heat rejection margin
- Improved venting, fan operating point control, and custom HEX design were the key architecture-level actions

ATS identified the true system constraint and provided a practical roadmap to achieve the 1600 W target through architecture-level airflow and heat exchanger optimization.