

Master's Thesis Defense
Mechanical and Aerospace Engineering Department
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Experimental Thermal Characterization and Comparison of Direct
Liquid Cooling and Air Cooling for a High-Density GPU Server Thermal
Test Vehicle

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Abstract

As the power density of artificial intelligence (AI) and high-performance computing (HPC) servers escalates, air cooling is approaching fundamental scaling limits set by air's low convective heat transfer coefficient and rising parasitic fan power. This thesis presents an experimental comparison of direct-to-chip liquid cooling and air cooling for a high-density GPU server, using a Thermal Test Vehicle (TTV) that replicates the layout and heat flux of an 8-GPU SXM5-class baseboard (eight emulated GPU blocks and four NVLink Switch modules). The liquid configuration was tested at 8.8 kW (8.0 kW GPU, 800 W switch) across three Coolant Distribution Unit (CDU) inlet setpoints (25, 35, 45 °C) using a 25% propylene-glycol coolant; the air configuration was tested across an airflow sweep (170–370 CFM) at 1.32 kW, with flow measured per ANSI/AMCA 210 / ASHRAE 51-1999. Cooling performance is compared using thermal resistance, $\theta = (\text{device temperature} - \text{inlet temperature})/\text{power}$, on a consistent per-GPU basis. Liquid cooling achieved $\theta \approx 34$ K/kW, roughly 4.6 to 6 times lower than air cooling ($\theta \approx 157\text{--}303$ K/kW across the flow sweep). The liquid result was found to be independent of coolant inlet temperature: device temperature tracked coolant inlets at near-unity slope (≈ 0.990) across all three setpoints, so thermal resistance remained essentially constant as inlet temperature rose from 25 to 45 °C. This inlet-independence is the key data center-relevant finding, as it enables warm-water and free-cooling operation without thermal penalty. Even at the 45 °C inlet, mean device temperature remained near 79 °C, within safe operating margin. These results quantify both the magnitude of liquid cooling's thermal advantage and its robustness to elevated coolant temperatures, supporting its adoption for energy-efficient high-density data center cooling.