# Real-Time Cooling Management System for Efficient Data Center Operations

Team 31
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## Problem Statement

Data centers consume significant energy, with cooling accounting for ~40% of total power usage. Most facilities rely on static cooling strategies designed for worst case scenarios. Static cooling approaches lead to overcooling, wasted energy, and reduced efficiency.

## Objective

This project develops a real-time cooling management system that dynamically adjusts cooling output based on rack-level thermal demand to improve power usage effectiveness by 5-10% and reduce overcooling.

## Methodology

The cooling control system operated by simulating thermal conditions across multiple server racks and reading inlet and outlet temperature values for each rack. These measurements are used to calculate the temperature differential which serves as an indicator of rack thermal load. The control algorithm then determines the required cooling demand based on the measured thermal conditions and adjusts pump power to allocate cooling accordingly. System behavior is visualized through LED displays that represent rack thermal conditions and pump output in real time.

**Simulate Rack Loads**
Generate rack thermal conditions

**Measure Temperatures**
Read inlet and outlet values

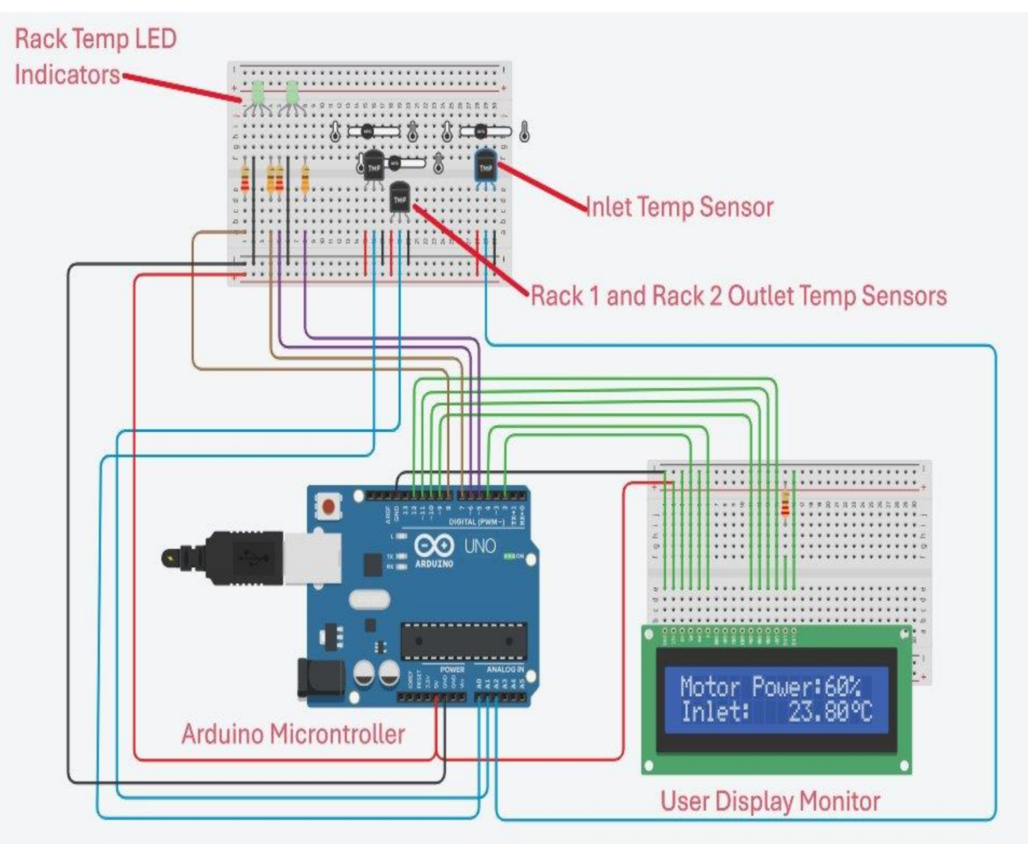
**Compute ΔT**
Calculate rack temperature difference

**Adjust Pump Power**
Allocate cooling dynamically

**Visualize System State**
Display rack thermal outputs and pump power

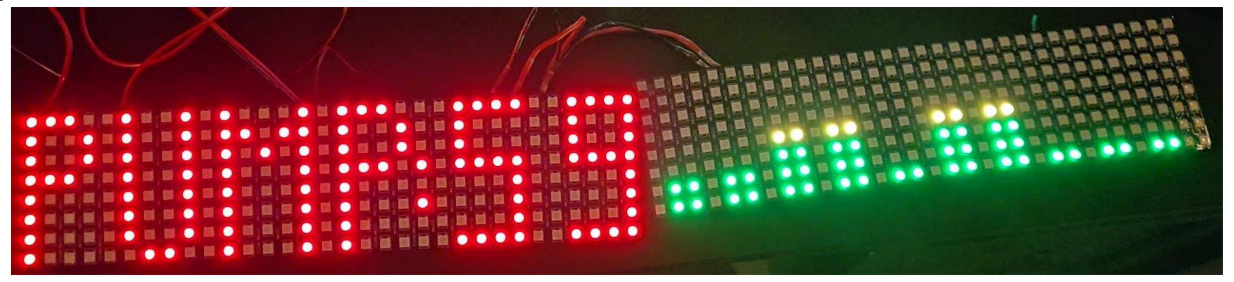
### Hardware Prototype

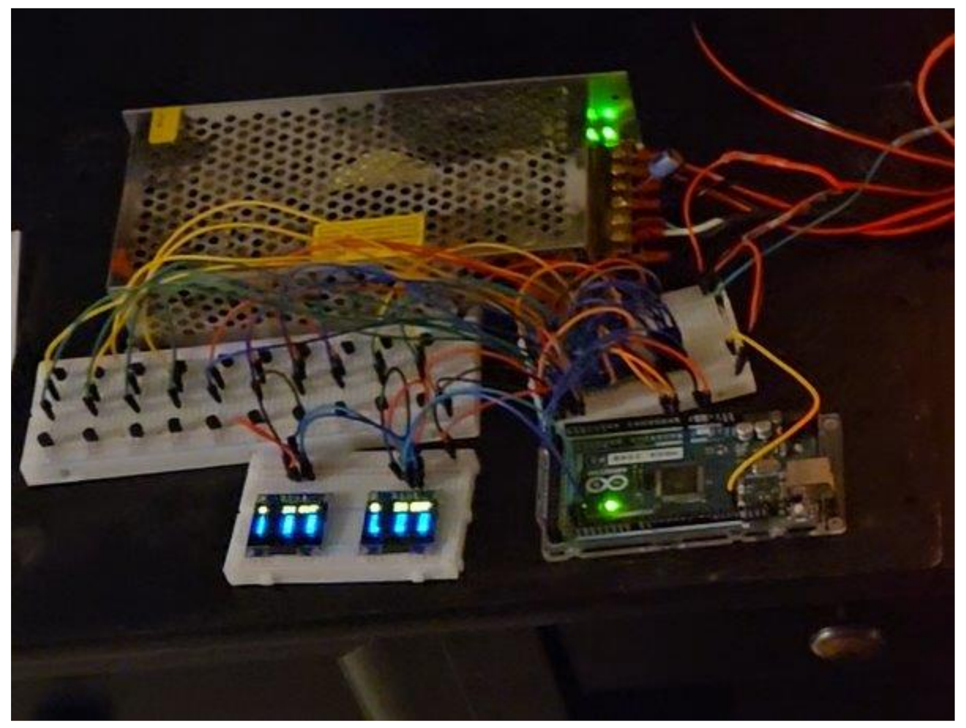
Proof-of-concept prototype circuit uses an Arduino controller, temperature sensors, LEDs, and an LCD display to monitor rack temperature and motor power. The system demonstrates accurate temperature monitoring and the ability to adjust motor power in response to changing temperatures.

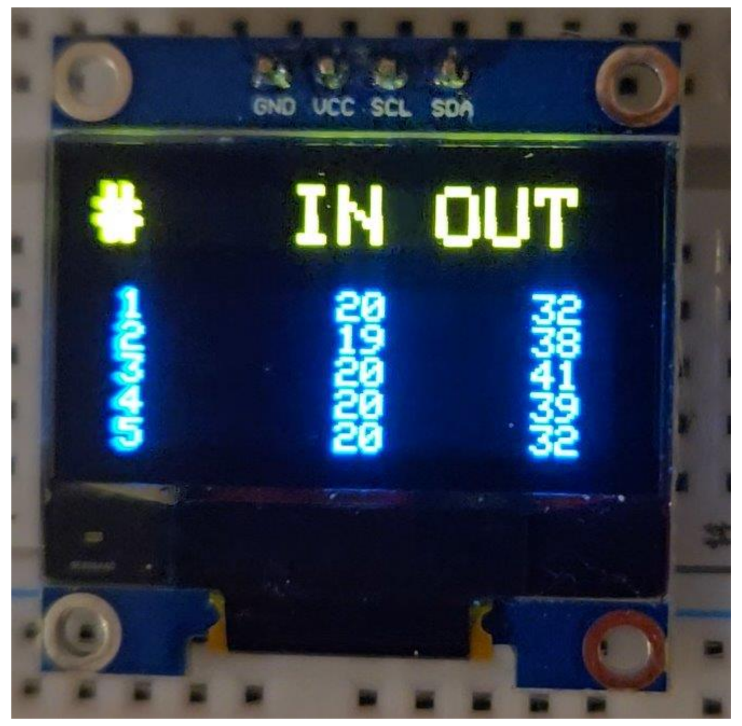



## Implementation

The final hardware implementation expands the proof-of-concept into a 10-rack simulated cooling platform. The Arduino microcontroller monitors twenty temperature sensors representing inlet and outlet temperatures for 10 server racks.16 channel multiplexers are used to manage the sensors and the controller processed rack temperature data in real time to determine cooling demand and adjust pump power output. Rack temperatures, pump power, and thermal conditions are visualized through LED displays and a thermal mapping panel.

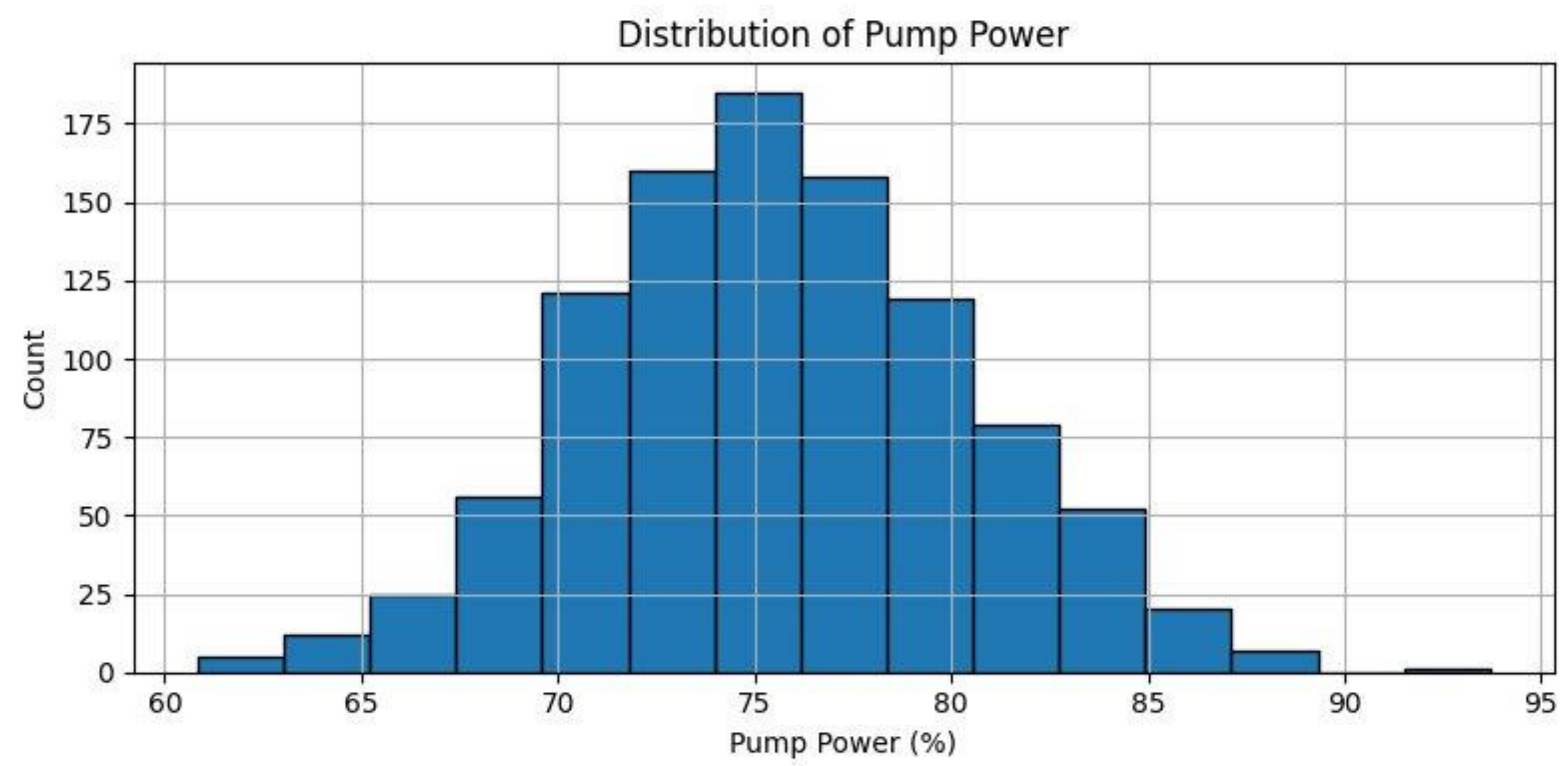






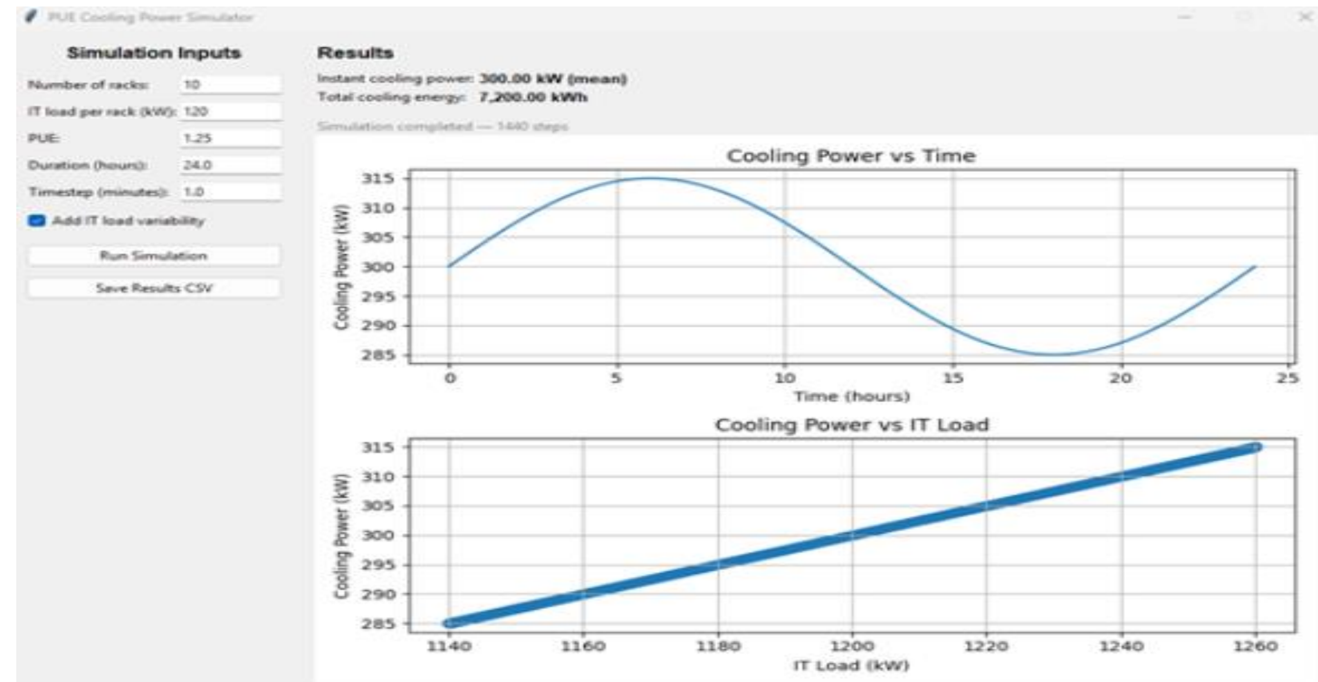

## Experimental Verification

The completed build was evaluated under 1000 simulated thermal conditions to assess the controller behavior across a wide range of temperature scenarios. The pump power distribution shown reflects how frequently the controller operated at each output level during testing. The results indicate the system primarily operates around the 70-80% range of pump power rather than at maximum output, indicating the system adapts to thermal demand rather than overcooling.




## Results

A Python simulation was developed to compare static cooling against the dynamic cooling strategy under equivalent rack load conditions. The baseline model represents a fixed output cooling system operating across 10 server racks at 120 kW IT load per rack, resulting in 7,200 kW of energy consumption over 24 hours.




A second simulation incorporated data logged from the controller from the physical hardware platform to model dynamic cooling performance. Under the same operating conditions, the dynamic cooling strategy reduced total energy consumption to 1,376 kW over 24 hours, demonstrating a substantial improvement in cooling efficiency.


## Conclusion

This project successfully demonstrates that real time adaptive cooling can significantly improve data center cooling efficiency compared to static cooling methods. The developed system dynamically responds to changing rack thermal conditions by adjusting pump output based on measured thermal demand. Results show substantial reductions in cooling energy consumption while maintain responsive system behavior, establishing the feasibility of scalable and smart cooling control for future data center applications.

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