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Airflow and Thermal Analysis of a Small Data Center under Varying Load Conditions Through Computational Fluid Dynamics in Steady-State Conditions

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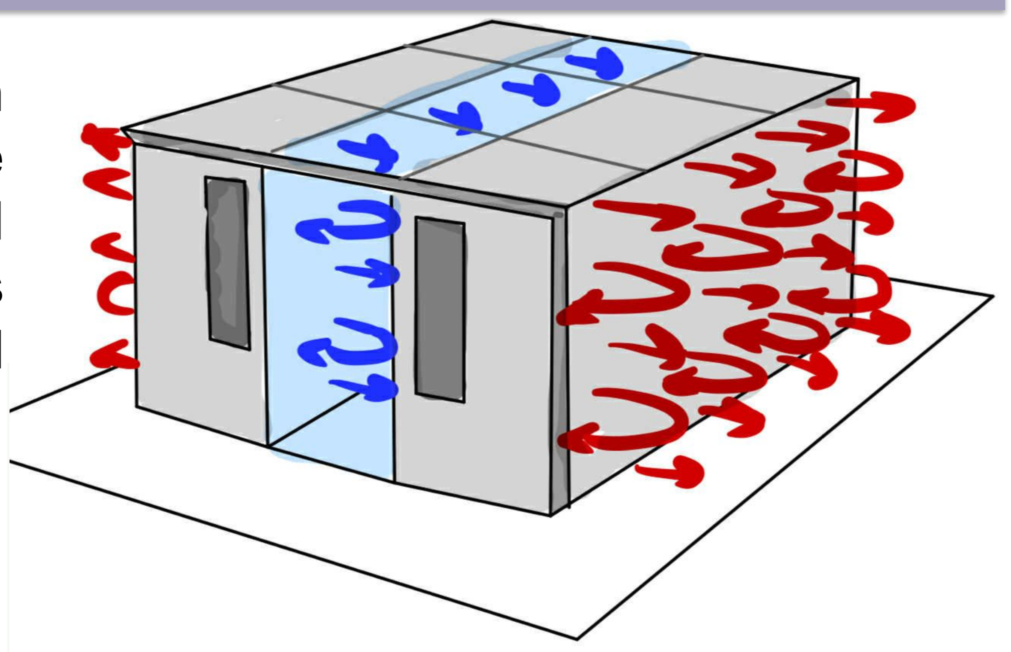
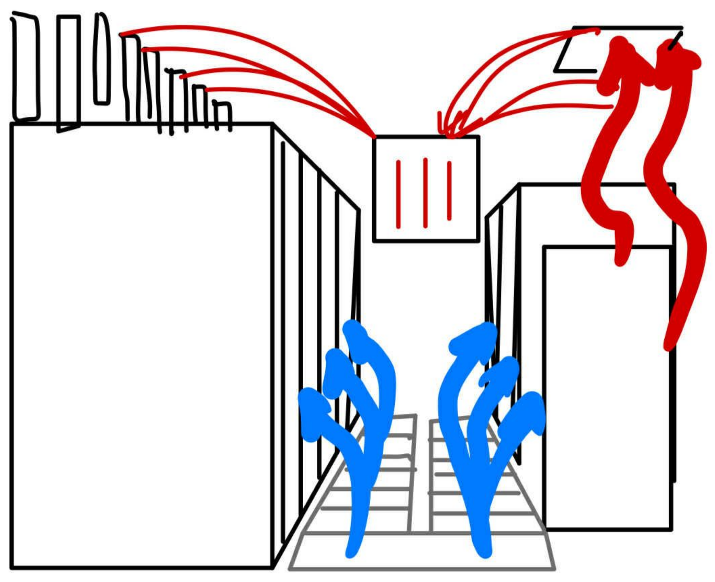
INTRODUCTION & AIM

Data Centers consume high energy for cooling, driving the need for advanced technologies to reduce costs while maintaining optimal temperatures.



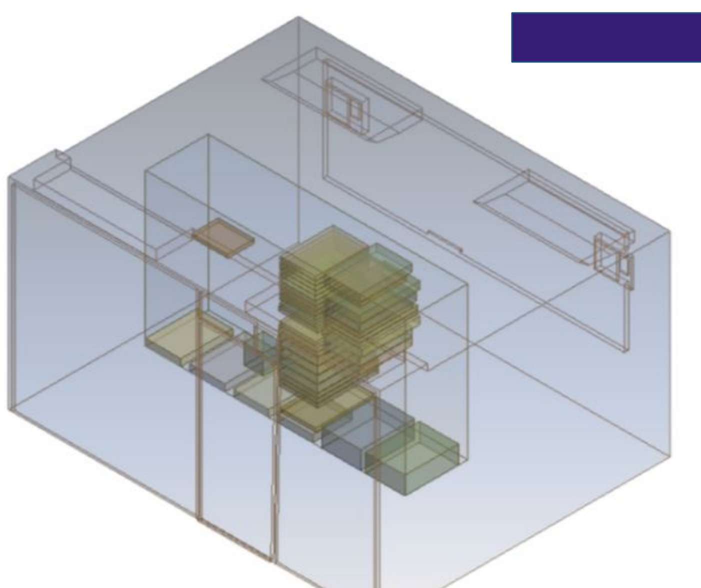


Both large-scale centers with heavy server loads and small-scale server rooms require precise thermal management to conserve energy and ensure reliable operations.

Computational Fluid Dynamics (CFD) helps simulate airflow and thermal distribution, optimizing cooling strategies to minimize energy waste.

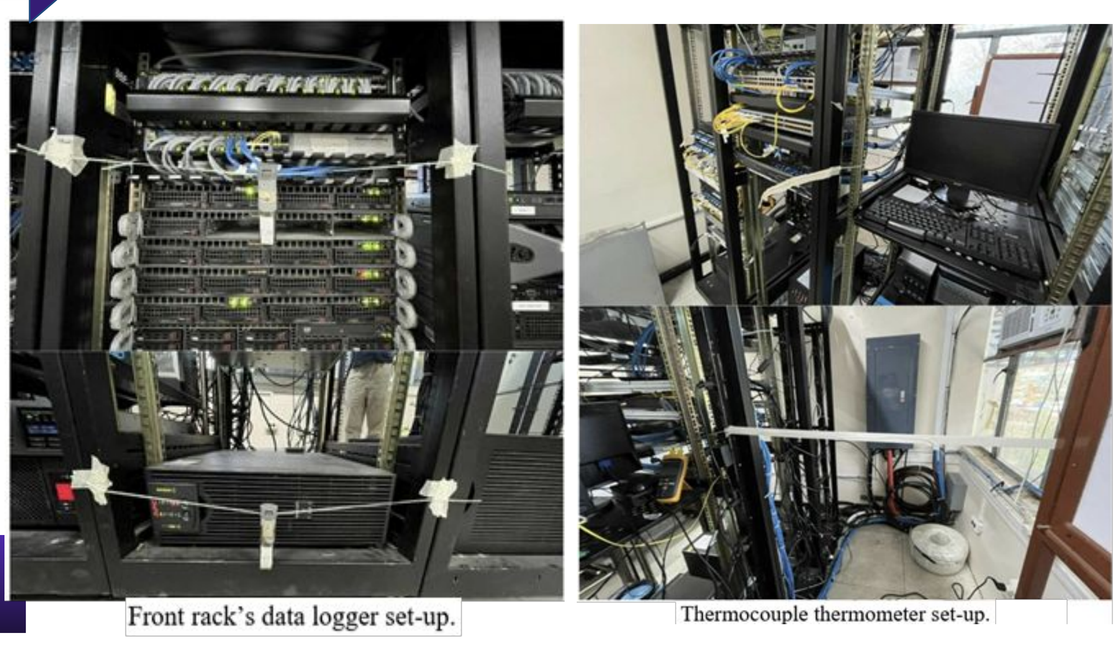
METHOD

Computational Fluid Dynamics (CFD) was applied to a small-scale data center (34 servers, expandable to 42 per rack) using ceiling-mounted AC as the main cooling system and window-type units as back up, with validation via data loggers and room temperature measurements.



CFD Model Development

Experimental Validation



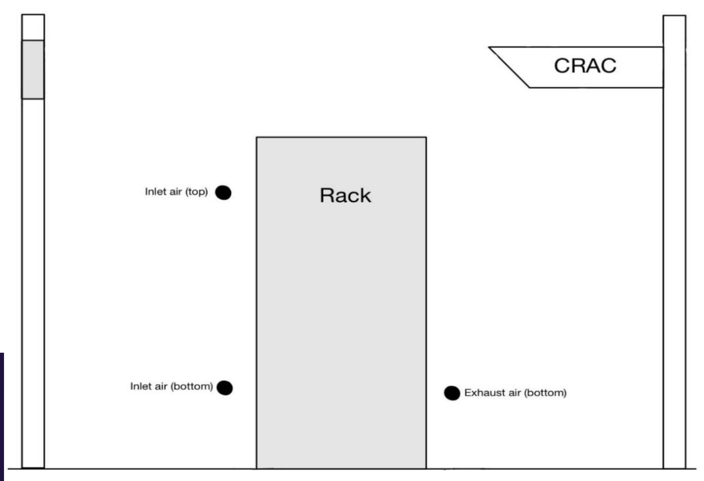
Front rack's data logger set-up.

Thermocouple thermometer set-up.

Data loggers measured heavily loaded rack inlet/outlet temperatures and room conditions (1/600 Hz frequency) to validate CFD results against real-world cooling performance.

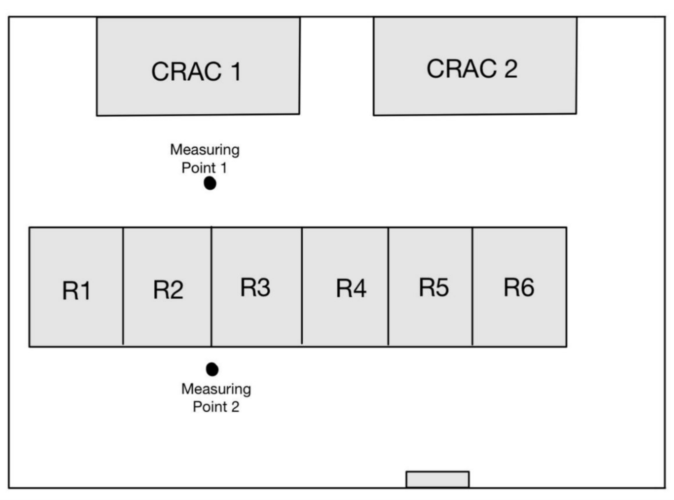
ASHRAE Thermal Guidelines. *Source*: ASHRAE, 2011.

CLASS	EQUIPMENT ENVIRONMENTAL SPECIFICATIONS FOR AIR COOLING Dry-Bulb Temperature (°C)
Recommended	
A1 - A4	18 - 27
Allowable	
A1	15 - 32
A2	10 - 35
A3	5 - 40
A4	5 - 45
B	5 - 35
C	5 - 40



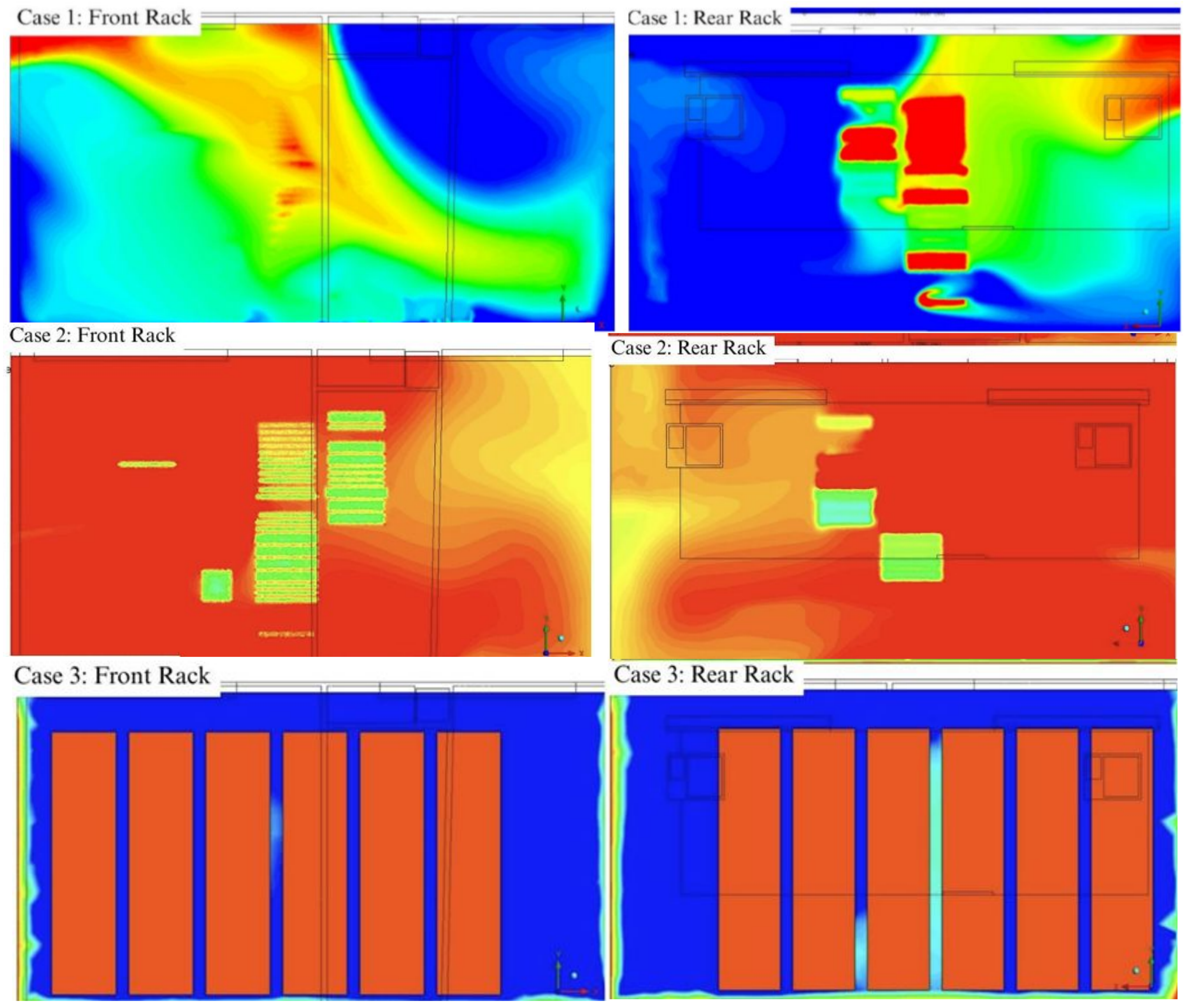
Performance Metrics & Standards

Case analysis conducted using Rack Temperature Index (RTI), Supply Heat Index (SHI), and Return Heat Index (RHI), with thermal compliance evaluated under ASHRAE Class 2 guidelines.

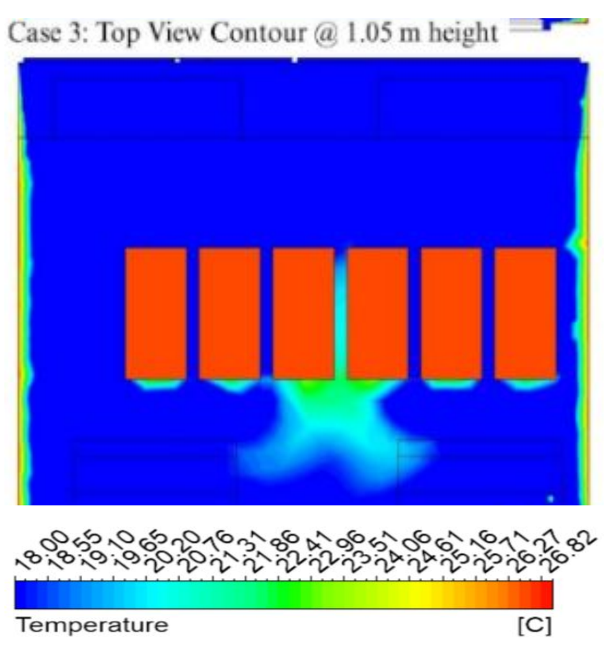


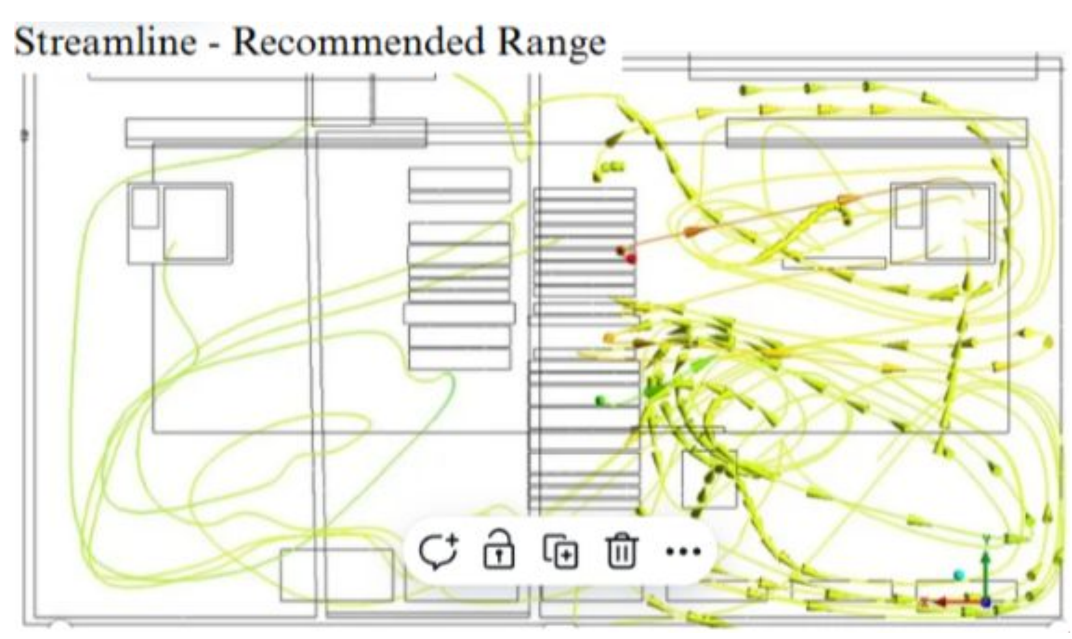
RESULTS & DISCUSSION

- **Thermal Compliance Across Cases:** All three steady-state scenarios remained within ASHRAE Class A2 guidelines (18-27 °C recommended, 10-35 °C allowable).
  - Case 1: Current load, 1 ceiling AC → Avg. rack inlet **22.52 °C**
  - Case 2: Current load, 2 window ACs → Avg. rack inlet **26.93 °C**
  - Case 3: Max load, 2 ceiling ACs → Avg. rack inlet **16.31 °C**



- **Airflow Distribution Findings:** RTI Analysis showed recirculation in all cases; SHI values (0.85, 0.98, 0.60) with corresponding RHI indicated inadequate airflow mixing and distribution.





- **Cases Metrics Findings:** With only six (6) racks in capacity, (considered small-scaled) improved airflow management is advised - specifically, installation of wall fans to mitigate recirculation.

CONCLUSION

The findings showed that the limitation of space and cooling technologies led to recirculation and mixing of airflow. It is significant that their optimal temperature must be maintained, but poor airflow produces high energy waste. This is crucial as it implies higher cost in a small-scale data center that is run by smaller establishments that have less financial budget than large-scale data centers.

FUTURE WORK

- Implement airflow management such as containment or targeted cooling.
- Vary the layout of the cooling system with strategic placement.