INDIAN INSTITUTE OF TECHNOLOGY MADRAS

DEPARTMENT OF MECHANICAL ENGINEERING |

Ph.D. Seminar Talk 1

Title of the Seminar: Reduced-order modeling of air-cooled data center using data-driven proper orthogonal decomposition.

Speaker: Mr. Shailesh Kushwaha (ME22D038)

Ph.D. Research Scholar, Department of Mechanical Engineering, IIT Madras.

DATE & TIME	VENUE	ONLINE
10 November 2026, Tuesday, 03:00 PM - 04:00 PM	**Online.**	**Join via Google Meet** https://meet.google.com/meet/ejx-icwx-cgj

Guide: Dr. Chakravarthy Balaji, ME

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ABSTRACT

High-fidelity computational fluid dynamics (CFD) simulations are widely used for thermal analysis of air-cooled data centers; however, their high computational cost limits their applicability for large parametric studies, real-time assessment, and optimization. This study evaluates a proper orthogonal decomposition Random Forest (POD-RF) reduced-order modeling framework for rapid temperature-field prediction in an air-cooled data center. A database of 714 steady-state CFD simulations was generated using a pairwise independent combinatorial testing (PICT) sampling strategy to efficiently sample the operating parameter space involving server power distribution, airflow rates, and cooling-unit operating conditions. Proper orthogonal decomposition (POD) was employed to extract the dominant modes from temperature-field snapshots and achieve substantial dimensionality reduction. A POD mode-sensitivity analysis demonstrated that prediction accuracy converged beyond approximately 50 retained modes, while 63 modes were sufficient to capture more than 99.9% of the total snapshot energy. The resulting POD modal coefficients were predicted using Random Forest (RF), least-squares regression (LSR), and multivariate adaptive regression splines (MARS). The predictive performance of the models was assessed using 114 independent test cases. Among the investigated approaches, POD-RF demonstrated the highest prediction accuracy, achieving a mean absolute error (MAE) of 0.62 K, a root mean square error (RMSE) of 0.83 K, an \uD835\uDC3895 error of 1.71 K, and a coefficient of determination (\uD835\uDC452) of 0.958. Field-level comparisons and cumulative error analyses further showed that POD-RF more accurately reconstructed temperature distributions and reduced localized high-error regions compared with POD-LSR and POD-MARS. Controlled extrapolation studies involving up to a 20% increase in server power demonstrated that the POD-RF model maintained stable error growth while preserving the dominant temperature-field characteristics. From a computational perspective, a single CFD simulation required approximately 5 h, whereas the POD-RF model reconstructed the complete temperature field in less than 1 s, corresponding to a computational speed-up of approximately 2.5 × 104. These results demonstrate that the POD-RF framework can provide an accurate, robust, and computationally efficient surrogate model for rapid thermal assessment and operational decision support in air-cooled data centers.