

Mechanical Engineering Thesis Defense

Physics-Guided Grey-Box Modeling for Building Thermal Performance: Integrating RC Networks with Data-Driven Optimization

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Abstract

Accurate modeling of building thermal performance is essential for designing energy-efficient systems, evaluating retrofit strategies, and enabling advanced control. While white-box models like EnergyPlus offer high fidelity, they require extensive inputs and calibration. In contrast, black-box machine learning models often lack interpretability and generalizability.

This thesis presents a physics-guided grey-box framework combining the interpretability of resistor-capacitor (RC) thermal networks with the flexibility of data-driven optimization. A lumped-parameter RC model is developed to simulate transient conduction through multilayered roof assemblies and zone interactions. Key parameters—thermal resistances, capacitances, solar absorptance, and HVAC gain—are calibrated using Particle Swarm Optimization (PSO) with experimental data from a test facility in Arizona.

To reduce persistent residual errors, especially during nighttime cooling and morning heating, a Physics-Informed Neural Network (PINN) is introduced. The PINN applies corrections to RC model outputs while enforcing energy balance via embedded physical constraints.

Results show PSO calibration reduces Mean Absolute Error (MAE) compared to uncalibrated baselines, with the PINN further improving prediction fidelity during thermal transients. The combined RC + PSO + PINN framework balances accuracy, adaptability, and physical consistency across all thermal zones.

This work demonstrates the effectiveness of hybrid modeling in enhancing building energy simulations. It provides a scalable approach for real-time prediction, control-aware modeling, and integration with advanced envelope technologies like phase-change materials and adaptive coatings.

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