



## Ph.D. DISSERTATION DEFENSE

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**Title:** Nonintrusive Multimodal Sensing and AI-Driven Occupant Analytics for Human-Responsive Building Operations

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## ABSTRACT

Buildings are fundamental infrastructures that support human habitation by providing safety, enabling productivity, and ensuring comfort. Achieving sustainable building operation necessitates an integrated approach that accounts for both technical systems and human behavior. To address this need, this study proposes a novel nonintrusive multimodal sensing and AI-driven occupant analytics framework to enable human-responsive, sustainable building operation. The proposed framework comprises five components: (1) a nonintrusive multimodal sensing system is developed to capture indoor environmental, gaseous, and volatile organic compound (VOC) signals for privacy-preserving occupant sensing, without collecting personally identifiable information or imposing long-term user adherence requirements; (2) a noise-aware contrastive learning method is introduced to resolve inherent similarity-dissimilarity ambiguity in the multimodal sensing data, enabling robust prediction of occupancy levels; (3) a spatially-informed deep learning method is designed to infer occupant daily activities by leveraging dilated convolutions to model cross-feature interactions and attention mechanisms to capture cross-zone dependencies; (4) a physics-constrained agentic AI method is proposed, integrating retrieved evidence and physical rules with AI-driven structured reasoning to detect energy-use behaviors; and (5) an EnergyPlus-based simulation platform is developed to incorporate human-responsive operational schedules – based on occupancy, activity patterns, and energy-use behaviors – into comprehensive analyses of building energy consumption and occupant comfort. Experimental results showed that the framework is effective: saving heating energy by 1.2% and cooling energy by 17.0%, while improving thermal comfort, as measured by predicted mean vote (PMV), by 88.5% in winter and 83.3% in summer.



The results demonstrate the promise of the proposed framework in supporting human-responsive building operations towards simultaneously enhanced energy efficiency and occupant comfort.