Energy management of HVAC systems and its implementation

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Abstract

This study introduces a novel data-driven online energy management framework for HVAC systems that integrates symbolic regression and model predictive control (MPC). By leveraging these advanced techniques, the system optimizes HVAC operations to achieve a balance between reduced energy consumption, minimized peak power demand, and maintained thermal comfort. Unlike traditional methods, the framework capitalizes on readily available data from built-in HVAC sensors, ensuring cost-effectiveness and broad applicability. Experimental results validate its efficacy, showing remarkable reductions in energy consumption—up to 49.3% during cooling and 73.9% during heating. Peak power demand was also significantly reduced by 25.8% and 35.1%, respectively, highlighting the framework's potential to transform energy management practices in building systems.

Background & Results

Buildings account for approximately 30% of global energy consumption, with HVAC systems being the primary contributors, responsible for 45% of this usage. Despite their importance, traditional HVAC management techniques struggle to accurately capture the complex thermodynamic behaviors influenced by external and internal conditions. The need for precise, adaptable models has led to the emergence of data-driven methods. This study employs symbolic regression to model building thermodynamics using minimal data inputs such as indoor/outdoor temperatures and HVAC power consumption. Unlike conventional physics-based models, symbolic regression simplifies the modeling process and improves prediction accuracy, particularly in complex environments. The proposed framework was tested in a laboratory setting that replicates typical office conditions. During heating operations, it achieved energy savings of up to 73.9%, with a corresponding peak power reduction of 35.1%. Cooling operations demonstrated similar success, with energy savings reaching 49.3% and peak power reductions of 25.8%. Moreover, the framework significantly shortened HVAC runtime by leveraging indoor heat sources and predictive control mechanisms. Symbolic regression consistently outperformed traditional models in both accuracy and computational efficiency, offering a robust solution to address energy and power management challenges.

Significance of the research and Future perspective

The proposed framework provides a cost-effective and easily deployable solution for optimizing HVAC performance, requiring only data from standard HVAC sensors and no additional hardware. This accessibility makes it a scalable option for diverse building types and settings. The integration of symbolic regression ensures model transparency and interpretability, a critical advantage over traditional machine learning approaches. Future research aims to enhance symbolic regression speed, extend multi-zone support, and integrate factors like occupancy and energy pricing for smarter management. This approach offers potential for broader application in energy-efficient building management.

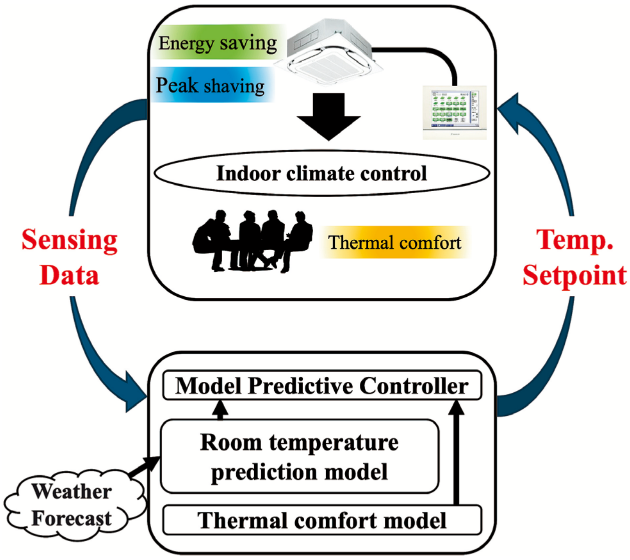

Fig. 1 HVAC Energy Management Framework

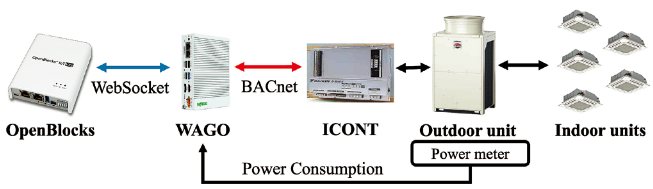

Fig. 2 System Structure

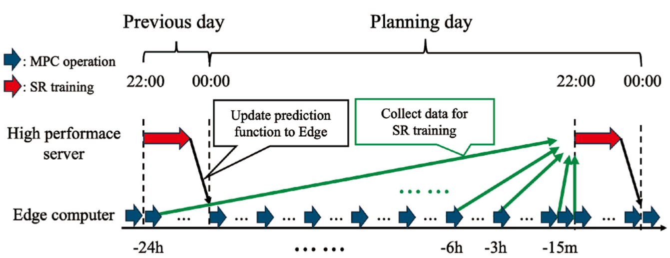

Fig. 3 Operation Timeline

Patent

Treatise
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Keyword symbolic regression, energy efficiency, data-driven energy management