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Advanced Control Strategies For Transparent Adaptive Building Envelope Systems

By

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Declaration

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Abstract

Adaptive building envelope systems are an effective solution for enhancing building flexibility and performance since affect different building domains such as energy use, indoor thermal and visual comfort and indoor air quality. These systems include various technologies able to regulate heat and mass transfer between indoor and outdoor environments, such as shading technologies, smart glazing, and double-skin façades. Nevertheless, to use the whole capability of such adaptive façades and really optimize the building performance effective control strategies are necessary. Model-Based controls (MBCs) offer a superior approach compared to Rule-Based controls (RBCs), as they can balance multiple performance requirements more efficiently.

This study explores the potential of MBCs for complex adaptive façades and proposes a novel control framework that utilizes distributed intelligence for real-world implementation. Two case studies were conducted: one involving an electrochromic façade that modulates solar gains (medium complexity), and the other involving a highly flexible DSF capable of modulating multiple factors, i.e. short-, long-wave radiation and convective heat exchange with a high number of possible states (high complexity).

The research begins with a literature review of adaptive building technologies and control strategies. The review examines dynamic building envelopes for ventilation and solar gains modulation, identifying the influence of adaptive façades on indoor environmental conditions. Several control strategies were investigated in order to understand the most common for operating dynamic façades, the technological gaps and potential development paths.

Based on these findings, a simple case study was designed and tested to explore control alternatives - from RBC to MPC - for an adaptive EC glazing façade within an experimental test cell, with the aim of understanding the requirements for implementing model-based control strategies in real applications. The study reveals

the need to shift from centralized control architectures to decentralized ones for managing complex adaptive façades. While decentralized control is widely used for HVAC systems, its potential for adaptive façades in terms of building performance and real-world implementation is relatively unexplored. The research establishes an experimental infrastructure for implementing and testing model-based controls for dynamic façades, integrating the field layer (sensors and actuators), automation, and decision-making layers.

In order to understand the full flexibility and potential of dynamic façades, the thermal behaviour of a novel flexible DSF is investigated to comprehend its potential for controlling the indoor environment. Extensive experiments are conducted to evaluate the DSF's thermal behaviour under various boundary conditions and operations. A comparison of different Building Energy Simulation (BES) tools is performed, revealing the limitations in accurately predicting the DSF's behaviour. To address this, a numerical model based on the ISO 15099:2003 standard is developed, accounting for additional physical quantities (i.e., the thermal capacity of the glazing system, heat losses in the cavity, and increasing of the internal convective heat transfer coefficient). The model is validated with experimental data and integrated into EnergyPlus by means of a Python-based co-simulation environment for accurate prediction of complex façade thermal behaviour.

A decentralized control framework is designed for the flexible DSF, employing high-level decision-making by the Building Management System (BMS) and decentralized low-level controllers for façade configuration. Component-level models are utilized to predict façade-related quantities, enabling accurate and efficient control. A specific indicator called Façade Total Heat Transfer (FTHT) is developed to provide valuable information to the BMS. The proposed control framework is tested in an outdoor facility through real-life experiments using model-based control for a DSF.

To conclude, this research has (i) investigated and characterized the thermal behaviour of complex dynamic façades; (ii) defined a control framework for the design and implementation of MBC for such façades; (iii) demonstrated the potential of a novel approach to measure and calculate component-level information for supporting the high-level decision-making; (iv) presented the advantages and demonstrated the implementation of advanced control strategies for adaptive façades, by means of both simulation and experimental campaigns.