Doctoral Thesis

Model predictive building climate control
Steps towards practice

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Model Predictive Building Climate Control -
Steps Towards Practice

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presented by

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Abstract

This thesis investigates the application of Model Predictive Control (MPC) to climate control of buildings with the goal of improving its energy efficiency. Current practice in the control of Heating, Ventilation, and Air Conditioning (HVAC) systems is the use of Rule-Based Control (RBC). RBC control strategies are well-established but limited by the difficulty of consistently integrating weather predictions and systematically coordinating all actuators – both commonly regarded as ways to improve energy efficiency. The research interest into alternative, more energy efficient control strategies in buildings is mainly driven by three factors: i) a large fraction of the world’s energy consumption occurs in buildings; ii) the majority of the building stock is already in place and refurbishments are expensive while control systems can be upgraded at comparatively low costs; iii) computational power is becoming ever cheaper, enabling the cost-effective use of advanced control techniques.

MPC presents a particularly attractive alternative in building climate control. The methodology has been successfully applied in many areas, in particular due to its capability of handling constraints on state and input variables. Applied to building climate control, MPC uses a mathematical model of the building and predictions of disturbances (e.g. ambient temperature) over a given prediction horizon (e.g. two days) to formulate an optimization problem. This is solved to find the control input trajectory that maintains comfort for the occupants over the whole horizon while minimizing some objective (e.g. total energy use or monetary costs). The first step of the control input trajectory is implemented on the building and the process is repeated at the next time step. MPC makes it possible to systematically integrate all available actuators and their interactions as well as predictions of the weather, internal gains, and electricity prices into a control framework that can handle constraints on the room temperatures (states) and on the use of HVAC systems (inputs). In recent years, many studies have analyzed the energy savings potential of MPC in simulations. However, while these studies have demonstrated the potential benefits of MPC, many problems still remain to be solved that relate to the appropriate modeling of real buildings and the practical feasibility of MPC, as for instance its compatibility with pre-installed control systems. This thesis is mainly concerned with addressing these issues.

This document is structured in four parts. Part I gives background information on MPC for building climate control and introduces the MPC formulation considered in this work.

Part II is concerned with the modeling of buildings for MPC. Creating an accurate building model that is simple enough to allow the resulting MPC problem to be tractable is a challenging but crucial task in the control design. In a first chapter, we present the Building Resistance-Capacitance Modeling (BRCM) Matlab toolbox that facilitates the physical modeling of buildings for MPC. The toolbox provides a means for the fast generation of bilinear resistance-capacitance (RC) type models from building geometry, building construction, and building systems data. We describe how the models are constructed and present a case study in which the toolbox was used to create a model that was then compared to the established building simulation software EnergyPlus. In a second chapter, an alternative method for ob-
taining a building model is investigated. We report a study in which we used identification techniques to model a ventilated room. Three models were derived: i) an empirical transfer function estimate (ETFE) derived from a pseudo-random binary sequence input signal; ii) an ETFE derived from a relay feedback closed-loop identification approach; iii) an RC model constructed using the BRCM toolbox. Using additional validation data, the models were compared in terms of accuracy. All models showed a reasonably good predictive performance. The effect of air mixing dynamics was demonstrated in a further experiment to be one of the main differences between the experimentally identified and the RC model. The study shows that an additional pole can be added to the RC model in order to compensate for the differences related to the air mixing dynamics.

Part III reports the results of the predictive building control project OptiControl-II that encompassed seven months of MPC of a fully-occupied Swiss office building. We describe the chosen control set-up, the modeling, the main experimental results, as well as simulation-based comparisons of MPC to the previously installed RBC strategy using the EnergyPlus simulation software. Based on these results, we analyze the costs and benefits of MPC for cases similar to the investigated building. In the experiments, MPC controlled the building reliably and achieved a good comfort level. The simulation results showed a significantly improved control performance in terms of energy and comfort. However, for similar buildings and with the tools currently available, the required initial investment appears to be too high to justify the deployment of MPC in everyday building projects on the basis of operating cost savings alone. Nevertheless, development investments in an MPC building automation framework and a tool for modeling building dynamics together with the increasing importance of demand response and rising energy prices may push the technology into the net benefit range.

Part IV investigates the energy savings potential of improved occupancy information by means of a simulation-based study. To evaluate the potential savings, different types of occupancy information were used in an MPC: i) a standard occupancy schedule (presence during office hours, vacancy otherwise) used to predict internal gains and comfort constraints; ii) the standard schedule used for prediction and additionally instantaneous occupancy measurements used to adjust lighting; iii) the standard schedule used for prediction and additionally instantaneous occupancy measurements used to adjust lighting and ventilation; iv) perfectly predicted occupancy information. Simulations were performed for every controller and over a set of building, HVAC system, internal gains level, and weather combinations. By comparing the energy usage of the individual controllers, we show that taking into account occupancy information in building climate control has a significant energy savings potential. However, a large part of this potential can already be captured by considering instantaneous occupancy measurements.
Zusammenfassung


Dieses Dokument ist in vier Teile gegliedert. Teil I umfasst Hintergrundinformationen zu MPC für Gebäuderegelung und führt die in dieser Arbeit verwendete MPC Formulierung ein.

