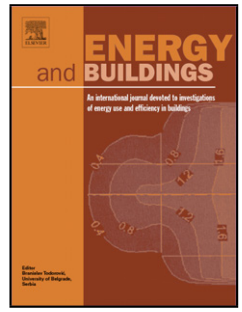

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Practical implementation and evaluation of model predictive control for an office building in Brussels

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Abstract

A model predictive control (MPC) has been implemented in a medium-sized office building in Brussels, Belgium. This paper presents the implementation of the controller and the measured performance in comparison with the default, rule-based control (RBC). The building has two floors and a total size of 960 m^2. The controllable system is the hybrid heat production consisting of two air/water heat pumps and a condensing gas boiler. The practical situation does not allow controlling end-units in the different zones of the building. The MPC makes use of a Modelica grey-box control model resulting from a system identification with monitoring data. The paper covers the monitoring, model identification, forecasting of disturbances, state estimation, formulation and solving of the optimal control problem (OCP) and transmission of the control signals. The performance is evaluated on a daily basis based on analysis of heating degree days, thermal comfort, energy costs and primary energy consumption. The results show that the model predictive controller is able to provide a similar or better thermal comfort than the reference control while reducing the energy costs by more than 30 %. This is due among others, to a better use of the heat pumps and an adapted hot water supply temperature.

Keywords: model predictive control (MPC), grey-box models, field test, validation, Modelica

1. Introduction

Bad control of energy systems in buildings is responsible for large energy efficiency losses. Even in new and modern buildings, inefficient control and operation often increases the primary energy consumption for heating, cooling and air-conditioning (HVAC) by 20 % or more [1, 2].

Model predictive control (MPC) is one of several solutions to improve building control efficiency [3, 4, 5, 6, 7, 8, 9, 10]. By specifying high-level objectives and using the power of numerical optimization, a model predictive controller can automatically adapt to new operating conditions and take into account expected future building dynamics. The controller can also incorporate the delivery of additional services like reserves [11] or peak load reduction [12].

The core of the MPC concept is the optimal control problem (OCP). This mathematical problem is formulated in continuous time as

$$\underset{u}{\text{minimize}} \quad J \tag{1a}$$

$$\text{subject to} \quad F(t, \dot{x}, x, w, y, u) = 0, \tag{1b}$$

$$g(t, \dot{x}, x, y, u) = 0, \tag{1c}$$

$$h(t, \dot{x}, x, y, u) \geq 0, \tag{1d}$$

$$x(0) = x_0. \tag{1e}$$

In this formulation, $t \in [0, t_h]$ is time with t_h the prediction horizon, $u \in \mathbb{R}^n$ is the control signal, J the objective, $F(\cdot)$ is the system model with states x, algebraic variables y and disturbances w. $g(\cdot)$ and $h(\cdot)$ are additional equality and inequality constraints. $x, \dot{x}, w, y$ and u are all time-dependent but for readability we have omitted the time dependency notation.

MPC is based on the solution of an OCP at every control time step. The OCP is initialised from an estimated state of the system based on measurements (= feedback) and takes into account forecasted disturbances and dynamic system behaviour (= feedforward) [13].

Figure 1 shows a general overview of the MPC framework that will be detailed and implemented in Section 3.

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