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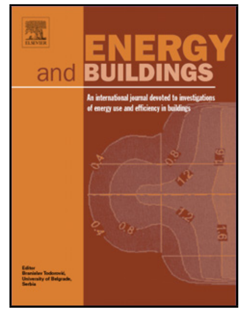

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IMPACT OF THE CONTROLLER MODEL COMPLEXITY ON MODEL PREDICTIVE CONTROL PERFORMANCE FOR BUILDINGS

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Abstract

Model predictive control (MPC) for heating, ventilation and air conditioning (HVAC) in buildings requires accurate controller models of the building envelope and its HVAC systems. Controller models are typically obtained by means of black- or grey-box system identification or using a white-box modelling approach. However, the necessary level of model complexity used by each method in order to obtain good MPC performance remains a priori unknown and no systematic method or examples showing the optimal complexity is available. This paper systematically investigates the required controller model complexity necessary to obtain optimal control performance for a given building. First, a 6-room house is modeled in detail using building energy simulation software. The building model is then linearised to obtain a linear time invariant (LTI) state-space model (SSM) and the upper bound of the control performance is computed using an MPC with the SSM both as controller and as plant model. The accuracy of the SSM (containing more than 250 states) is then artificially decreased by reducing its number of states to different orders ranging from 4 to 100 using balanced truncation model order reduction technique. The performances of MPCs using these controller models are then compared with the upper bound for both a standard MPC formulation (S-MPC) and an offset-free formulation (OSF-MPC) and with the performance of a rule-based-controller (RBC). The procedure is repeated for the same house model with a higher level of insulation and for a lighter weight construction. Furthermore, if the controller model is an LTI model, this paper shows that the CPU time necessary to solve the MPC optimization problem becomes independent of the number of states of the controller model when a dense approach is used. The controller model can thus be as complex as necessary to produce accurate predictions without increasing the computation time of the optimization.

Keywords: building climate control, optimization, model predictive control, model order reduction, controller model

INTRODUCTION

The number of papers about Model Predictive Control (MPC) for building in several journals is increasing every year exceeding more than 100 new papers in the journal Energy and Buildings in 2015. Despite these intensive research efforts the commercialization of MPC is still in its early stages. This is partially due to the lack of direct comparison (i.e., for the same scenario) of different optimization algorithms, of different controller models and their prediction performance, of the simulation parameters such as sampling time, prediction horizon and of climate forecast, as pointed out in the review paper by Hilliard et al. [1]. The main difficulty remains, however, to obtain a good controller model of the whole building with a minimum of effort as it is the most time consuming part [2, 3, 4, 5]. Detailed building energy simulation softwares (BES) such as EnergyPlus [6], TRNSYS [7] or Modelica (`Buildings` [8], `IDEAS` [9]) allow accurate building modeling but generate models which are too complex to be used in efficient optimization algorithms [2, 3]. Low order linear models are usually preferred due to their computational tractability [10]. Therefore, simplified models need to be generated by means of grey-box [11, 3, 12, 13] or black-box system identification such as auto regressive [14], subspace [4] and artificial neural network methods [15] or by simplified white-box modeling [16, 17, 18, 19, 20, 21].

While black-box identification has the advantage that no prior knowledge of the system is required and that it can deal more efficiently with large sets of data, its prediction performance for longer time horizons (e.g., more than 12 hours) is not sufficiently accurate [11]. Grey-box system identification is more suitable for long time horizons but the method becomes very costly for large multiple-input multiple-output (MIMO) systems. As shown by [12, 13, 22] a good choice of the structure of the grey-box model, i.e., its order, its inputs and its states, is crucial for its performance but this choice is very case specific. Therefore authors involved in the opti-control project [16, 17, 23], and others [18, 19, 20, 21] opted for a linear white-box approach where the model is set up based on geometrical and on physical data of the building and simplified physical laws. The authors all showed that this simplified approach could mimic the results (typically expressed as operative temperatures) of the more complex models obtained with BES software within an error margin of $\pm$ 0.5 to 1 K. Both for the grey-box and for the white-box approach, the necessary level of model complexity in order to obtain a good MPC remains unknown and no systematic method to determine this optimal model complexity is available [5, 24].

The main contribution of this paper is the performance comparison of an MPC which uses the same controller model as the plant