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IFAC PapersOnLine 51-2 (2018) 79–84

Identification of dynamic models for the short-term temperature prediction in a single room

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Abstract: This contribution illustrates an approach for the generation of a linear dynamic discrete time model for the short term prediction of the room temperature in a single conference room. The model is extracted from recorded measurement data by means of system identification. After a brief description of the considered room and the modeling approach the model is validated by statistical analysis and by its prediction performance.

Keywords: System Identification, Model Predictive Control, Building automation, ARMAX

1. INTRODUCTION

Approximately 40% of the energy consumption in Germany and the United States is caused by the building sector [see BMWi (2014), McQuade (2009) resp.]. Due to temporal unavailability of renewable energy sources, an increasing use of thermal and electrical storage technologies, and improved thermal insulation of the buildings a predictive control strategy is becoming increasingly important for efficient building operations.

Because model predictive control (MPC) has proven its ability to solve complex control problems cost-effectively in areas such as chemical process automation, it has attracted a lot of attention in building automation as well. Thus in recent years many approaches have been made to apply MPC to heating, ventilation, and air conditioning (HVAC) [Gyalistras et al. (2010), Oldewurtel et al. (2010), Paschke et al. (2016)] or also to energy storage and distribution systems [Ma et al. (2009), Prívara (2013), Lamoudi et al. (2012)], where saving potentials ranging between 5% and 40% had been reported.

Although many contributions have been made which clearly demonstrate the advantages of MPC in building automation by means of simulation studies, actual implementations are still rare. One of the major drawbacks for a wide-ranging applicability seems to be the time-consuming modeling, because the MPC-model needs to be adapted to each situation individually. Furthermore in many practical situations a physically motivated modeling using energy balance equations is problematic due to unknown parameters, such as heat capacities and heat transfer coefficients. These and other problems lead to the fact that practical usage of MPC still isn't profitable in many cases from an economical point of view.

Considering the increasing availability of sensor and data storage technologies in modern buildings, it seems promising to use measurement data for the generation of MPC models by employing methods from machine learning and system identification. Empirical modeling and parameter estimation for building systems had been studied extensively during the last decades [see for example Penman (1990), Madsen and Holst (1995) or Kramer et al. (2012)] and has regained attention due to the efforts to apply MPC in the building sector [Žáčeková et al. (2011), Prívara (2013), Sturzenegger et al. (2014)].

Besides other topics, identification of simplified thermal and hygric room models has been of interest consistently [Penman (1990), Madsen and Holst (1995), Sturzenegger et al. (2014)]. In many references results are presented that indicate good *simulation* performance for selected data, which is gathered from experimental setups. However the question whether the model performs well in real-time applications often remains ignored. Furthermore for MPC-applications the model requires good *prediction* performance, i. e. it should produce low errors within a certain prediction horizon [see Ljung (2012) Sec. 3 for discussion of *simulation* and *prediction*]. Since the prediction error is a statistical quantity, an appropriate analysis should be performed to assess the quality of the model.

In this contribution we want to share our identification results of a thermal model for a conference room, where the data which is used for the identification was gathered from a non-experimental setup. This means that the room was in normal operation. The article is organized as follows: Section 2 gives a short overview of the considered room and its relevant hardware equipment. In Section 3 we discuss our modeling approach including the selection of model inputs and outputs, the chosen model structure and the identification criterion. The next chapter presents a

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2018.03.014

detailed discussion of the prediction performance of the identified model, while in the last section a summary of our results and the focus of next research topics are given.

2. SETUP DESCRIPTION

2.1 Description of the Room

The considered conference room is located in the ground floor of Fraunhofer IIS/EAS in Dresden and is part of a massive office building, which was constructed in the late 1950's. The size of the room is approx. 9.2m ×5.7m and it's automation system consists of the following components:

- Temperature, humidity, and air quality sensors
- Three separate windows aligned to the west and one inner door, all equiped with binary switching contacts to detect opened state
- Binary occupancy sensor
- Three radiators with local PID controllers (unknown parameters) sharing a common heating setpoint
- Three fancoils at the ceiling of the room with three discrete cooling levels controlled by 3 point proportional controllers sharing one cooling setpoint
- External electric blinds
- Two separate heat meters for measuring heating and cooling power supplied by the radiators and fancoils resp.
- Central database for storing timeseries data of all available sensors, actuators, and setpoints

A schema of the considered room is depicted in Figure 1.

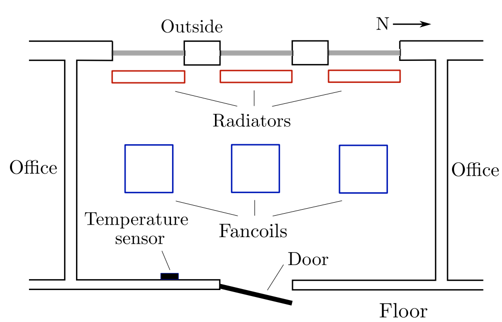

Fig. 1. Schema of considered conference room

2.2 Description of the Data

As already mentioned all available time series data of the conference room is stored in a central database and can be used for analysis and modeling. Additionally we used measurements from a local weather station located approximately 3km from the considered building, which provided values for the outside temperature and the global radiation sampled all 15min. All setpoints, sensor and actuator measurements are logged on change, meaning that a data sample is stored only if it has changed with respect to its previous value. Because of noise some sensors change their values rapidly thus the sampling time was limited to a minimum of 1min.

We considered a one year batch of data which was gathered between Sept. 1st, 2015 and Aug. 31st, 2016. Because of obvious logging errors, especially stuck sensor values, it was necessary to preselect the data leaving at most 51% of the data for modeling and further analysis only. Furthermore using the binary occupancy sensor, we were able to determine that the room was occupied approx. 11% of the overall time span.

Figure 2 illustrates an 18h long exemplary batch of data recorded in November 2015. Observe that the room temperature sensor shows significant quantization noise with a step size of approx. 0.32K. Furthermore we'd like to mention that both heat meters provide measurements of the volume flow, as well as the supply and return temperatures of the heating medium, whereof the heating power can be calculated. Notice that the measurements of the heating power show erroneous peaks at the beginning of each heating period [see Fig. 2], which have been ignored throughout the paper and are caused by the measurement principle. The reason for this behavior is that the difference of the supply and return temperature, which are measured before and after the radiators, is comparably high at the beginning of each heating period, because cool water is stored in the radiators. Once they had been flowed completely with "fresh" heating medium, the measurement of the heating power drops instantly and displays reliable values.

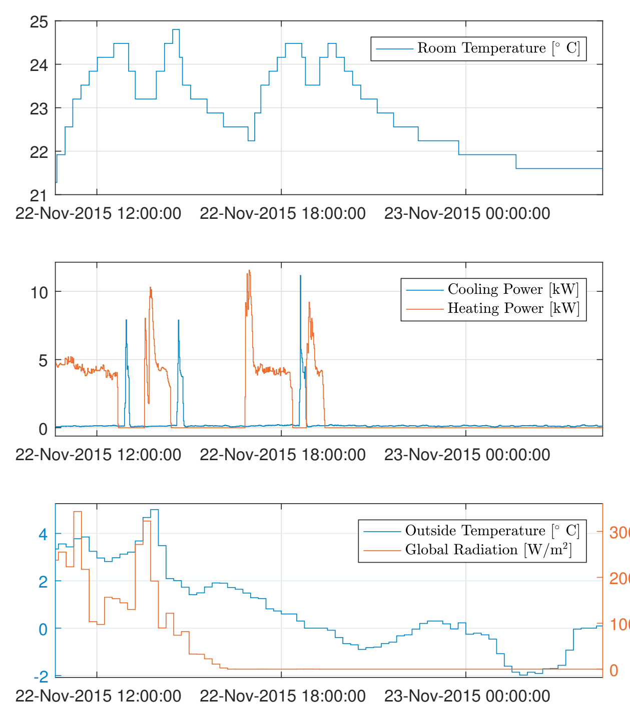

Fig. 2. Recorded data from November 2015

3. IDENTIFICATION APPROACH

3.1 Modeling Assumptions and Constraints

The goal of this paper is to obtain a strategy for the identification of short term prediction models for the temperature within a single room. Although we pursue an empirical modeling approach, it is always helpful to examine the actual physical nature of the system using energy balance equations. A simplified differential equation for the room temperature $\vartheta_r(t)$ can be stated as