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Predictive control of a building heating system

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Abstract

In the European Union (EU), it is estimated that the building sector consumes 40 % of the total energy production. The EU has set the goal to reduce energy consumption by 20 % by 2020. This ambitious goal requires to find ways to reduce energy consumption in buildings. When used in heating and cooling systems, an advanced process control methodology – model predictive control (MPC), can be beneficial compared to current control strategies. This control methodology allows to build a multivariate constraint model: key constraints such as the thermal capacity of the building and energy prices can be included while the predictive control uses weather forecasts to optimize resources and prepare for changes in outdoor temperature. Modeled in real time, MPC has reduced both energy consumption and costs.
This paper provides an algorithm for such a model predictive control of multi-family buildings (MFB) based on a case study in Latvia. The building uses two heat pumps and electrical heaters as heat sources for space heating and two thermal accumulation tanks for balancing heat generation and the building's heat demand. Input values are weather forecasts and electricity tariff. MPC is used to improve the operation schedule of heat sources and to achieve financial savings.

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Keywords: model predictive control; heating system; multi-family building; heat pump; Latvia

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1. Introduction

Directive 2010/31/EU on the energy performance of building states that in the European Union the building sector consumes 40 % of the total energy. The EU has a goal to reach 20 % reduction in energy consumption and 20 % energy efficiency by 2020. Because of this there is a need to find ways how to reduce energy usage in the building sector [1–4].

Current heating control strategies include on-off room temperature control, weather-compensated control and proportional – integrative – derivative control [5]. While these strategies have their advantages, all of them have drawbacks. Model predictive control overcomes these shortcomings.

The main part of model predictive control is a building model using mathematical formulas to describe building dynamics. This building model is used in the optimization process. Predictive control can process multiple-input and multiple-output signals [5]. Inputs to the MPC can be design parameters, energy price, comfort criteria and predictions of occupation and/or weather [6]. To find optimal control parameters, model predictive control uses iteration. At each step the open loop control problem is formulated and solved. When solving a control problem, system constraints are taken into consideration [7].

Predictive control can forecast outputs. This helps to avoid sudden changes in the building. The main advantage of MPC is effective utilization of the building's thermal mass [6] because if there is a low outdoor temperature predicted then system can increase the room temperature in advance. That way building walls accumulate the heat which can be used when there is low outdoor temperature and the system cannot provide necessary amount of heat. Another advantage is the ability to set constraints on inputs and outputs and use them directly in the optimization [6]. Model predictive control can be used to control lower level controllers in controller hierarchy [8].

Privara et al. tested MPC in a building of the Czech Technical University. Their model predictive control uses outside temperature prediction and heating water temperature as inputs. Inside temperature and return water temperature are used as outputs. Results with MPC were compared with a finely tuned weather-compensated controller. There were two methods for estimating achieved savings. One method used energy consumption that was based on the difference between heating and return water temperatures. This method showed 17–24 % savings when MPC was used. Using calorimeter measurements, the authors found 29 % savings when MPC was used [5].

Siroky et al. tested MPC in the aforementioned university but this time the authors compared several building blocks – one non-insulated and two insulated building blocks. The buildings have the same construction and they are used the same way. MPC used weather and occupancy predictions, energy price and comfort criteria as inputs. Supply water temperature was used as output. Results showed that buildings with insulation had bigger relative savings – 28.74 % and 26.83 %. But the non-insulated block had more than 17 % in relative savings [6].

Samuel et al. presented MPC for heating, ventilation and air conditioning system in two commercial buildings. One was a three-floor 3322 m^2 office building. Another one was a three-floor 1808 m^2 office building. The model used weather forecasts and temperature set-point as inputs. Occupants had access to an online feedback tool was used to provide feedback and tis was used to measure and compare occupant comfort levels. Feedback was also used for controlling the heating, ventilation and air conditioning system. Results showed 19 % average energy reduction for one building and 32 % thermal energy reduction. During the trial these two buildings maintained occupant comfort levels [9].

In most cases MPC is implemented in office type buildings. These buildings have an occupancy schedule. In this paper, model predictive control is used in a multi-family building, a first. The paper is organized as follows. Section 2 presents the multi-family building characteristics. The predictive control strategy for the multi-family building is described in Section 3. Section 4 discusses findings and conclusions.

Nomenclature

A	area, m^2	T_{re}	return water temperature, K
$A_{r,c}$	solar heat receiving area, m^2	t_{source}	maximal supply water temperature, °C
C_e	electricity tariff, EUR	t_t	necessary supply water temperature, °C
$C_{e,peak}$	electricity tariff – peak time, EUR	t_w	hot water temperature, °C