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The effect of weather forecast uncertainty on a predictive control concept for building systems operation

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HIGHLIGHTS

- Effects of weather forecast uncertainty on a predictive control concept is investigated.
- Two different years in a temperate climate are simulated for 24 building scenarios.
- Energy savings demonstrated despite of weather forecast uncertainties.
- Thermal indoor environment improved despite of weather forecast uncertainties.

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ABSTRACT

This paper investigates the effects of weather forecast uncertainty on the performance of a concept for predictive control of building systems operation. The concept uses a computational physically-based building model and weather forecasts to predict future heating or cooling requirement. This information enables the building systems to respond proactively to keep the operational temperature within the thermal comfort range with the minimum use of energy. The effect of weather forecast uncertainty was assessed using weather data from two different years in a temperate climate in the simulation of 24 building design scenarios. Despite the uncertainty in the weather forecasts, the predictive control concept demonstrated a potential for energy savings and/or improvements in thermal indoor environment when compared to a conventional rule-based control.

1. Introduction

The recast of the European Performance of Buildings Directive (EPBD) in 2010 states that all new buildings constructed after 2020 should consume “near zero energy” for building operation [1]. Furthermore, it is expected that the demand for better comfort in buildings will continue to increase as it has within the last few decades. This leads to an increasing pressure on the building industry to produce low-energy buildings with a high quality of indoor climate. In this relation, the reduction of energy for heating, ventilation and air conditioning (HVAC) is essential as HVAC currently accounts for approximately half of the energy consumed in buildings corresponding to around 10–20% of the total energy consumption in developed countries [2]. Minimising the energy use for HVAC is a combination of (1) reducing the overall energy needed for building operation using non-energy-consuming means such as building orientation and geometry, insulation, thermal mass and solar shading, (2) designing energy-efficient HVAC plants and routings, and (3) optimizing building systems operation. In the latter case, the current research efforts evolve around the concept of predictive control. The basic idea of predictive control for building systems operation is to use a virtual model of the building and weather forecasts to predict the future evolution of the indoor climate. This information is used to compute control actions which anticipate this evolution by fulfilling indoor climate requirements while minimising utility and energy costs.

There are a number of different approaches to predictive control for building systems operation. The approaches can in general be divided into the use of statistically derived models (“black-box”) [3–5], physically-based models (“white-box”) [6–8]and combinations hereof (“grey-boxes”) [9,10]. However, no matter the modelling technique, the performance of predictive control depends on the accuracy of the weather forecasts, modelled system dynamics and predictions of occupant behaviour. This paper aims at

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investigating the effect of weather forecast uncertainty in a predictive control concept for building systems operation.

1.1. Literature review

Existing predictive control concepts for building systems operation have shown a theoretical potential for energy savings and improved indoor climate compared to more conventional systems operation. Wittchen et al. [11] identified a theoretical annual energy saving of 5% and thermal indoor climate improvements in a Danish office building by using predictive control. A test case for a predictive control concept developed by Petersen and Svendsen [12] shows a theoretical energy saving of 7% for heating and ventilation while improving the quality of the thermal indoor environment. In the more comprehensive OptiControl project [13], a theoretical energy saving potential of 16% to 41% was identified varying with location, building case, and technical system characteristics [14]. How much of an identified theoretical potential that can be achieved depends on the effect of uncertainty in weather forecasts, predictions about user behaviour and precision in the thermal modelling. The rest of this literature review focuses on the effect of uncertainty in weather forecasts in predictive control concepts for building systems operation.

Henze et al. [15] investigate a number of short-term weather prediction models and test the effect of their uncertainty on the performance of a predictive control concept. The conclusion is that almost the full theoretical potential in the concept is realised despite the uncertainty in the weather predictions. Furthermore, it is highlighted that this can be obtained using very simple short-term weather prediction models. Oldewurtel et al. [16] report on the development and analysis of a stochastic model predictive control (SMPC) strategy for building climate control that takes into account the uncertainty due to the use of weather predictions. The findings suggest that this control strategy outperforms current control practice both in terms of energy usage and comfort violations. It was also shown that SMPC performed clearly better using a complex weather prediction model compared to simple models. The fact that the performance of SMPC depends on the quality of the weather prediction is in contrast to the previously described findings of Henze et al. [15]. There are, however, various reasons that make the two studies incomparable, e.g. different climates, the chosen concept and/or different investigated buildings. Lamoudi et al. [17] use a modification of one of the simple forecast models from Henze et al. [15] in their predictive controller. The result is a maximum increase of 4% in energy invoice due to weather forecast uncertainty.

There are also a number of studies where the effects of weather forecast uncertainty are not investigated directly, but are indirectly represented in the identified savings. An example is Siroky et al. [18] who investigate the heating savings potential of a model predictive control concept with weather forecasts in three different building blocks. The saving for heating was between 15% and 28% compared to a heating curve strategy depending on mainly insulation level and outside temperature. Another example where weather forecast uncertainty is indirectly represented in the savings is in Henze et al. [19] where a saving of 27% in electrical utility costs is identified.

From the literature it can be learned that it is not always clear how significant the effect of uncertainty in weather forecasts is compared to the theoretical potential of predictive control. The effect seems to depend much on the chosen predictive control concept, climatic region and test cases.

1.2. Aim and outline of the paper

The aim of this paper is to investigate how significant the effect of uncertainty in weather forecasts is when a certain deterministic predictive control concept is compared to the performance of a conventional rule-based control and the theoretical potential (i.e. perfect weather forecast). Section 2 explains the investigated concept. Section 3 presents the data and the process used in the investigation. Section 4 presents and discusses the simulation results, and Section 5 gives conclusions.

2. A predictive control concept for building systems operation

The predictive control concept used in this investigation is as described in details in Petersen and Svendsen [12] and summarised in the following. The concept was initially developed for temperate climates, i.e. climates where free cooling is plentiful compared to solar gains. The concept is deterministic, i.e. it determines control decisions under the assumption that weather forecasts are perfect.

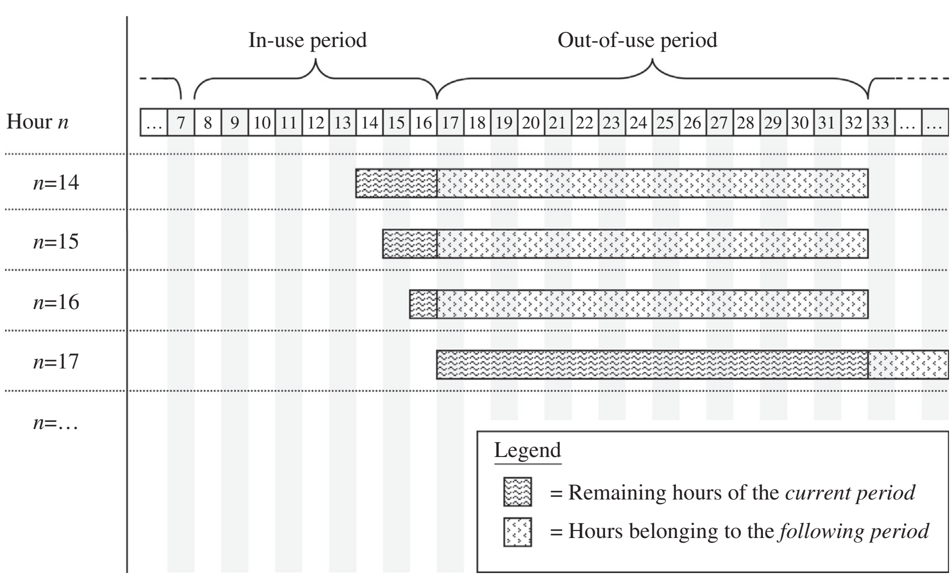

Fig. 1. Illustration of the terminology used in the description of the concept. The prediction horizon for hour *n* is the sum of the remaining hours in the current period and the hours belonging to the following period.