Applied Energy 101 (2013) 521–532

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Importance of occupancy information for building climate control

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HIGHLIGHTS

- ▶ Investigation of occupancy information for energy efficient building climate control.
- ▶ Simulation study with different buildings, HVAC systems, seasons, and occupancy patterns.
- ▶ Adjusting lighting and ventilation to instantaneous measurements has large energy savings potential.
- ▶ Additional occupancy predictions do not provide significant energy savings potential.

ARTICLE INFO

Article history:
Received 7 November 2011
Received in revised form 6 June 2012
Accepted 7 June 2012
Available online 24 August 2012

Keywords:
Building climate control
Energy efficiency
Occupancy information
Model predictive control

ABSTRACT

This paper investigates the potential of using occupancy information to realize a more energy efficient building climate control. The study focuses on Swiss office buildings equipped with *Integrated Room Automation* (IRA), i.e. the integrated control of *Heating, Ventilation, Air Conditioning* (HVAC) as well as lighting and blind positioning of a building zone or room. To evaluate the energy savings potential, different types of occupancy information are used in a *Model Predictive Control* (MPC) framework, which is well-suited for this study due to its ability to readily include occupancy information in the control.

An MPC controller, which controls the building based on a standard fixed occupancy schedule, is used as a benchmark. The energy use of this benchmark is compared with three other control strategies: first, the same MPC controller which uses the same schedule for control as the benchmark, but turns off the lighting in case of (an instantaneous measurement of) vacancy; second, the same MPC controller which uses the same schedule as the benchmark for control, but turns off lighting and ventilation in case of (an instantaneous measurement of) vacancy; and third, the same MPC controller as the benchmark but using a perfect prediction about the upcoming occupancy.

This comparison is carried out for different buildings, HVAC systems, seasons and occupancy patterns in order to determine their influence on the energy savings potential.

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1. Introduction

Approximately 40% of the global used energy is consumed in buildings [1], of which roughly half is used for *Heating, Ventilation, and Air Conditioning* (HVAC) in industrial countries [2]. At the same time the building sector has a large potential for cost-effective reduction of CO_2 emissions and most investments in building energy efficiency can be expected to pay back through reduced energy bills [1]. Amongst other possibilities, such as improved insulation and more energy efficient appliances, one way to address the problem of reducing the energy consumption of buildings is improved HVAC control. Focusing on building automation is particularly interesting since in industrialized countries the main building stock is already in place and refurbishments are expensive, whereas an improved control system can be implemented at comparatively low costs.

One of the most important influences on the thermal behavior of buildings originates from its occupants, both in terms of the heat gains and in terms of the constraints describing the occupants' comfort requirements. Today, occupancy information is used only in form of *schedules* in building climate control, often in addition with instantaneous adjustments of lighting, sometimes in addition with instantaneous adjustment of both lighting and ventilation based on occupancy sensor measurements. The question arises whether the use of occupancy predictions has a significant energy savings potential.

In [3] the authors showed that significant energy savings can be achieved by employing a nighttime-setback strategy, i.e. the relaxation of comfort constraints during the night. This gives rise to the hypothesis that information about *long-term vacancies* (business trips, holidays, illnesses) also provides an energy savings potential.

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http://dx.doi.org/10.1016/j.apenergy.2012.06.014

This work aims at quantifying the savings potential of this long-term occupancy/vacancy information by means of simulations.

1.1. Control approach

The focus of this investigation is on office buildings, since these buildings are usually equipped with a more sophisticated building automation and have more actuation possibilities compared to residential buildings, which raises the expectation of a larger energy savings potential. Furthermore, the focus is on *Integrated Room Automation* (IRA), i.e. the integrated control of HVAC, lighting, and blind positioning of an individual building zone[1] or room, such that different zones can be actuated independently from each other. Due to the independent actuation, the knowledge of vacancies in particular zones can be used to adjust the actuation and corresponding energy use accordingly.

The standard goal of an HVAC control system is to keep temperature, illuminance and indoor air quality in a given comfort range while minimizing energy use. Current control practice is to use *Rule-Based Control* (RBC) for this, which determines all control inputs based on a series of rules of the type "if *condition* then *action*". The control performance with RBC depends on the choice of these threshold values, which are more and more difficult to tune with the rising complexity of HVAC systems.

An alternative approach is to use *Model Predictive Control* (MPC) taking into account weather and occupancy forecasts. The OptiControl research project [4,5] dealt with analyzing in a large-scale simulation study the energy savings potential in building climate control by using MPC [6–8], which was shown to be well-suited for the building application. Most importantly for this study, in contrast to RBC, the MPC framework enables the consistent incorporation of occupancy information in the control, which facilitates the comparison of different types of occupancy information and yields an optimal control of the building for a given occupancy prediction assuming a perfect model and having a sufficiently long prediction horizon; independently of any parameters and threshold values that are required to be tuned for RBC.

MPC is a modern control technique, that has been successfully applied in many areas due to its ability to handle constrained control problems [9,10]. At each sampling time, the optimal control action is obtained by solving a constrained finite horizon optimal control problem for the current state of the plant. When applied in building climate control, this means that at the current point in time, a plan for heating, cooling, and ventilation is formulated based on predictions of the upcoming weather and occupancy for the next several hours to days, which minimizes the energy use while satisfying the comfort constraints. The first step of the control plan is applied to the building, determining the settings for all heating, cooling and ventilation actuators, then the procedure is repeated at the next time instant.

1.2. Use of occupancy information for building automation

As some of the first dealing with occupancy information for building automation, the authors in [11] tried to estimate the benefit of occupancy sensor based lighting control. The same question was addressed in [12] where a more detailed occupancy-based control coupled with an ESP-r simulation was considered. In [13] a learned pattern recognition algorithm was using multi-sensor data to identify how long occupants are typically staying in a room. If this expected period was long enough, the HVAC control would start to bring the room temperature to a certain comfort level while otherwise the room would stay at its setback temperature.

All these works focused on exploiting short-term (in the range of minutes) occupancy information for increasing energy efficiency in buildings. To the best of the author's knowledge, the influence of long-term (in the range of days) occupancy information on the building energy consumption has not yet been investigated systematically.

1.3. Occupancy models

Since occupancy is of stochastic nature, in this study the average energy use of a control taking into account occupancy information was evaluated by means of a Monte Carlo study. In order to generate random sequences of occupancy and vacancy days, a suitable model had to be found. Several works in literature exist on modeling occupancy, some of which are summarized in the following.

The authors of [14,15] were interested in modeling occupancy to fuse sensor data with model predictions of a complex stochastic agent-based model for estimating the number of people present in an office. In [12,16] Markov models were used to model the occupant's behavior over a time period. In [17] a genetic programming algorithm was applied to learn the behavior of an occupant in a single-person office based on motion sensor data. In [18] it was hypothesized that the occupancy and vacancy intervals in a single person office are distributed exponentially. Using motion sensor data collected from 35 single room offices to verify the hypothesis, it was found to hold for the vacancy intervals but had to be rejected for the occupancy intervals.

All of the works on occupancy modeling found by the authors aim at modeling short-term occupancy. Hence for the presented study a new model describing long-term occupancy had to be devised.

1.4. Main idea and outline

The aim of this work was to estimate the importance of occupancy information for energy-efficient building climate control by means of a simulation study. First, current methods of taking into account occupancy information were compared, i.e. the use of occupancy schedules is compared with additionally adjusting the lighting based on instantaneous occupancy measurements and with additionally adjusting both lighting and ventilation according to instantaneous occupancy measurements. This showed the importance of taking into account instantaneous measurements. Second, the question how much an occupancy prediction could improve the energy use at best was addressed by comparing with a controller that had a perfect prediction of the upcoming occupancy (deviating from the occupancy schedule) available.

The focus of the investigation was to determine the energy savings potential in case of long-term vacancies which are not considered in the schedule. A randomized study was carried out with different, random realizations of occupancy. These random realizations were created by sampling from an occupancy model designed for this study.

To ensure comparability of control approaches and to avoid dependency of the results on the numerous tuning parameters of RBC controllers, MPC controllers were used for all simulations.

The simulation study was carried out for different buildings and HVAC systems, the two extreme seasons summer and winter, and different occupancy layouts.

Section 2 introduces the building simulation framework including the formulation of the MPC problem and its components, Section 3 describes the occupancy model, which is used for creating the occupancy time series. A detailed description of the investigations is given in Section 4. The results are presented in Section 5 and discussed in Section 6. Conclusions are drawn in Section 7.

[1] A zone may be a single room or several rooms which are grouped and jointly actuated.

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