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Energy efficient building HVAC control algorithm with real-time occupancy prediction

Jie Shi[a], Nanpeng Yu[a,*], Weixin Yao[b]

[a]Department of Electrical and Computer Engineering, University of California Riverside, 900 University Ave., Riverside, CA 92507, USA
[b]Department of Statistics, University of California Riverside, 900 University Ave., Riverside, CA 92507, USA

Abstract

A large amount of energy is wasted through inefficient operation of heating, ventilation, and air conditioning (HVAC) system due to the lack of reliable building occupancy measurement and prediction. To mitigate this problem, an innovative change-point logistic regression model is developed to provide an accurate forecast of building occupancy. A novel building HVAC control algorithm is then developed by embedding the occupancy prediction model into the model predictive control (MPC) framework. The occupancy-based MPC algorithm tries to minimize building electricity consumption and maximize building occupants' comfort at the same time. A penalty factor is introduced which allows building occupants to determine the optimal trade-off between comfort and energy efficiency. Numerical simulation results show that the proposed HVAC control strategy with real-time occupancy prediction not only reduces electricity consumption but also improves building occupants' comfort.

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Keywords: Energy efficient building; HVAC; Occupancy prediction; MPC; Logistic regression

1. Introduction

Buildings account for approximately 40% of the world's energy consumption [1]. In the United States alone, buildings are responsible for nearly 40% of the greenhouse gas emission and 70% of the electricity usage. Adoption of energy efficient building controls can significantly reduce the greenhouse gas emissions and electricity bill for building owners. In residential and commercial buildings, HVAC system, plug loads and lighting loads consume majority of the electricity. In particular, HVAC systems account for around 50% of the total building energy consumption [2]. Given that more and more buildings are controlled by Building Automation System (BAS), one of the most effective ways of reducing the energy consumption of the HVAC system is to improve the existing building control strategies.

MPC has been widely adopted in building HVAC system controls to improve the energy efficiency [3–7]. To accommodate the weather uncertainty, stochastic model predictive control (SMPC) algorithm is proposed for building climate control [8]. Building occupancy prediction is incorporated into a real-time MPC framework for HVAC system

* Corresponding author. Tel.: +1-951-827-3688.
E-mail address: nyu@ece.ucr.edu

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by using Hidden Markov Model based occupancy detection method [9]. In [10] and [11], building occupancy predicted by using simple historical proportion method and inhomogeneous Markov chain are incorporated into the building HVAC control algorithms. The effectiveness of occupancy based MPC algorithms have been demonstrated through simulations. The simulation results in [12] have shown that a higher energy saving level can be achieved with more accurate building occupancy prediction algorithm.

Nomenclature

$R_{s,i}$	Solar radiation on Wall i (W)
T_{out}	Temperature of outside air (°C)
$T_{w,i}$	Temperature of Wall i (°C)
T_{room}	Temperature of the room air (°C)
$C_{w,i}$	Thermal capacitance of Wall i (J/°C)
C_{air}	Thermal capacitance of the room air (J/°C)
$R_{cd,i}$	Thermal resistance of the conduction inside Wall i (°C/W)
$R_{cv,out,i}$	Thermal resistance of the convection between Wall i and the outside air (°C/W)
$R_{cv,in,i}$	Thermal resistance of the convection between Wall i and the room air (°C/W)
Q_{in}	Internal heat gain (W)
C_{sh}	Specific heat of the supply air (J/kg·°C)
$\dot{m}$	Mass flow rate of the supply air (kg/s)
T_{supply}	Temperature of the supply air (°C)
$\boldsymbol{x}$	State vector
$\boldsymbol{D}$	Disturbance vector
$y(k)$	Occupancy state of a building at time interval k
β_0	Intercept term in the logistic regression
$\boldsymbol{\beta}$	Coefficient vector in the logistic regression
$\boldsymbol{x}_c$	Vector of covariates in the logistic regression
Y	Response variable in the logistic regression
h	Time index
β_i	The ith coefficient in the logistic regression with change points
h_i	The ith change point
p	Number of change points
N_k	Number of data points in the testing dataset
$W_{chiller}$	Electric power of the chiller (W)
W_{fan}	Electric power of the fan (W)
COP	Coefficient of performance for the chiller
k_{fan}	Fan power constant
W_H	Electric power of the HVAC system (W)
λ	Penalty factor (W/°C^2)
T_{desire}	Desired room temperature (°C)
u_{min}	Lower bound of the control variable u (J/kg·°C)
u_{max}	Upper bound of the control variable u (J/kg·°C)
T_{min}	Lower bound of the room temperature T_{room} (°C)
T_{max}	Upper bound of the room temperature T_{room} (°C)
T_{TS}	Center of Taylor series expansion for the room temperature T_{room} (°C)
u_{TS}	Center of Taylor series expansion for the control variable u (J/kg·°C)
K	Total number of time intervals in the testing period

In this paper, an innovative building occupancy prediction algorithm based on logistic regression model with change-points is proposed. The logistic regression model with change-points outperforms the historical proportion