Build Simul (2014) 7: 89 – 106
DOI 10.1007/s12273-013-0142-7

A real-time model predictive control for building heating and cooling systems based on the occupancy behavior pattern detection and local weather forecasting

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Research Article

Architecture and Human Behavior

Abstract

Current research studies show that building heating, cooling and ventilation energy consumption account for nearly 40% of the total building energy use in the U.S. The potential for saving energy through building control systems varies from 5% to 20% based on recent market surveys. This papers introduces and illustrates a methodology for integrated building heating and cooling control to reduce energy consumption and maintain indoor temperature set-point, based on the prediction of occupant behavior patterns and local weather conditions. Advanced machine learning methods including Adaptive Gaussian Process, Hidden Markov Model, Episode Discovery and Semi-Markov Model are modified and implemented into this study. A Nonlinear Model Predictive Control (NMPC) is designed and implemented in real-time based on dynamic programming. The experiment test-bed is setup in the Solar House, with over 100 sensor points measuring indoor environmental parameters, power consumption and ambient conditions. The experiments are carried out for two continuous months in the heating season and for a week in the cooling season. The results show that there is a 30.1% measured energy reduction in the heating season compared with the conventional scheduled temperature set-points, and 17.8% energy reduction in the cooling season.

Keywords

model predictive control,
occupancy behavior patterns,
weather forecasting,
real-time implementation

Article History

Received: 19 August 2012
Revised: 15 April 2013
Accepted: 13 May 2013

1 Introduction

In 2007, the World Business Council for Sustainable Development published the first report on energy efficiency in buildings stating that buildings are responsible for at least 40% of energy use in many countries, energy mostly derived from fossil fuels. Worldwide building energy consumption is expected to grow 45% over the next 20 years (WBCSD 2009). In the United States, commercial buildings consume almost 17% of national energy use. 76% of the services used by buildings (e.g. heating, cooling, lighting, etc.) are powered by electricity, and these account for 35% of the total electricity consumed nationally (EIA 2009). Heating, ventilation and air-conditioning (HVAC) systems in commercial buildings account for nearly 37% of the total building energy.

According to the market surveys done by Brambley et al. (2005), building controls can potentially reduce energy consumption significantly in commercial buildings. Their study shows a traditional Energy Management and Control System (EMCS) can save between 5% and 15% of a building's energy with an 8 to 10 years return on investment for the system, while occupancy sensors for lighting control can save 20% to 28% energy with 1 to 5 years payback on the initial investment. In addition, one of the objectives of almost every control system is to improve temperature control and provide thermal comfort for occupants.

Typical control implementations in buildings can be divided into two main categories: local control and supervisory control. Local control provides basic control and automation functions, such as ON/OFF control and proportional-integral-derivative (PID) control that allows building services to operate properly. Many studies show that local controls can provide thermal comfort and satisfy goals for indoor air quality (Moore and Fisher 2003; Nassif et al. 2005; Zhang and Hanby 2006). Supervisory control functions are higher level controls that include local control

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