Applied Soft Computing 46 (2016) 407–423

Contents lists available at ScienceDirect

Applied Soft Computing

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

Predictive control of a building hybrid heating system for energy cost reduction

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ARTICLE INFO

Article history:
Received 16 April 2015
Received in revised form 22 April 2016
Accepted 3 May 2016
Available online 12 May 2016

Keywords:
Hybrid system
Cost optimization
MPC
Genetic algorithm

ABSTRACT

Today, the buildings' energy consumption is considerable amount of whole. Therefore, optimizing energy in buildings leads to a noticeable decrease in total energy consumption of the world. Energy-efficient buildings have developed by carrying out great research effort. The control procedures serve as a privileged method to help new buildings to comply with the most optimal system as an energy consumer and thus meet 'nearly zero-energy'.

The purpose of this paper is to present a method of controlling the building temperature and simultaneously reducing the cost of providing the hybrid heating systems with sufficient energy. Investigating a room in Tehran city on a day as an example, methods of (a) Model Predictive Control (MPC) with economic optimization (MPC consecutively with On-Off), (b) MPC without economic optimization, (c) Proportional-Integral-Derivative (PID) controller optimized by Genetic Algorithm (GA) in presence of gas thermal source, (d) PID controller optimized with GA in presence of electric thermal source and (e) PID controller optimized with multi-objective GA in the presence of two gas and electric thermal sources have been designed and implemented in this research. Furthermore, the effect of each of these methods on cost reduction and temperature regulation of inside of the room has been studied. Eventually it has been specified that using MPC method with economical optimization has the highest influence on cost reduction and keeps the temperature of inside of the room in the predefined range. This method achieved cost saving of 50% compared to the MPC and GA. But the main targets of this study are both of regulating inside temperature and cost optimization. According to the main targets of this study, using MPC methods without economical optimization and multi-objective genetic algorithm would be more effective.

1. Introduction

Nowadays, the consumed energy in buildings consists about 40% of the energy used in the world [1]. Therefore, utilizing renewable energy for buildings' consumed energy is very useful. On the one hand, hybrid systems are one of the methods which use renewable energy to supply thermal energy of buildings [1]. On the other hand, buildings spread 33% of carbon dioxide in the world while renewable energy does not cause any pollution [2]. Among these systems, solar systems have a significant role in providing the required energy of buildings [3]. Although using solar collectors lead to lower energy consumption, changing from the employed thermal systems is handled manually today which could lead to a challenge for making a more optimum state. Therefore, using Building Energy Management Controller (BEMC) for optimizing these systems would be essential. One of the best types of such controllers is the predictor one based on MPC model which plays an effective role in controlling the temperature in different weather conditions [4].

Alternative way of controlling the system is using PID controller. In order to determine the controlling parameters, numerical methods are employed whose their time of solving the problem is much lesser [5]. One of the methods used for modifying the controller parameters has been multi-objective genetic algorithm. Genetic algorithm is the most well-known method among the algorithms of system evaluation [6].

In a general investigation, Attia et al. considered different types of building optimization and as a result of evaluating 165 papers and 28 optimization methods, GA was known as one of the best methods and also is able to properly optimize each system according to the situation [7].

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http://dx.doi.org/10.1016/j.asoc.2016.05.005
1568-4946/

Nomenclature

C	Thermal capacity (J/kg °C)
D_1	Price of electric energy unit
D_2	Price of solar energy unit
D_3	Price of gas energy unit
$\dot{E}_{gen}$	Generated energy inside the system (W)
$\dot{E}_{in}$	Input energy to the system (W)
$\dot{E}_{out}$	Output energy from the system (W)
$\dot{E}_{st}$	Energy changes inside the system (W)
k	The amount of sample in the current time
$k+i$	The amount of sample in the next time
$k+i-1$	Sampling time
K	Heat conduction coefficient (W/m °C)
M	Control horizon
n_y	Number of system outputs
P	Predictor horizon
$\dot{q}$	Thermal energy produced inside the system (W)
$\dot{q}_{cond}$	Input heat to the system by conduction
$\dot{q}_{electrical\_heater}$	Power of electric thermal source
$\dot{q}_{gas\_heater}$	Power of gas thermal source
$\dot{q}_{out}$	Thermal energy loss through the walls by heat conduction (W)
$\dot{q}_{rad}$	Amount of gained radiation from the walls and windows (W)
$\dot{q}_{solar\_collector}$	Power of solar collector
$r_j(k+i)$	The amount of real output
S_y	Deviation from the final state
$S_{\Delta u}(k)$	Weighed sum of control coefficients
T	Inside temperature
T	Time (s)
u_1	Coefficient of electric source usage
u_2	Coefficient of solar collector usage
u_3	Coefficient of gas source usage
U	Overall heat transfer coefficient (W/m^2 °C)
V	System volume (m^3)
$w^y{}_j$	Weight of jth output
X,y,z	Cartesian coordination
$y_j(k+i)$	The amount of final adjusted output
ρ	Density (kg/m^3)
$\Delta u(k+i-1)$	Amount of predicted adjusting coefficient

There are multiple kinds of researches in the field of application of evolutionary algorithms on building energy optimization in recent years. Such as Wang et al. optimized combined cooling, heating and power (CCHP) system in three criteria of primary energy saving (PES), annual total cost saving (ATCS), and carbon dioxide emission reduction (CDER) by GA and validation of the optimization method is performed by a numerical example of gas CCHP system for a hotel building in Beijing [8]. Ahmadi and Ahmadi [9] employed Non-Dominated Sorting Genetic Algorithm (NSGAII) to optimize simultaneously specific entropy generation rate and the ecological coefficient of performance in an irreversible refrigeration absorption system. Mauser et al. optimized building energy management systems by evaluations in realistic scenarios [10]. Vera et al. employed GA in order to find optimal design parameters affecting photovoltaic/thermal collectors' feasibility [11]. All of these researches indicate the performance of GA to optimized multi-objective consumed energy system.

Both MPC and GA are the most effective methods in optimizing and controlling Heating, Ventilation and Air Conditioning (HVAC) systems are recently considered by researchers; that is why comparing these methods is very important. Additionally in this paper PID and on-off controller are integrated with novel controlling and optimizing methods including GA and MPC respectively to apply on the building HVAC modeling in MATLAB software. An electrical heating system was utilized alongside the solar–gas hybrid heating system and also the utilizing of nominal power in every heating systems are determined by using aforesaid controlling methods momently. Implementing and comparing MPC and GA, integrating PID and on-off controller with GA and MPC respectively as well as utilizing a triple heating system-electrical heater, solar collector and gas heater are the innovations of this paper.

In this paper it has been attempted to locate the inside temperature of the room into the comfort range by using three methods of MPC, PID controller and multi-objective genetic algorithm and, on the other hand, to minimize the necessary cost of providing thermal energy. The prices employed here are based on the price of electricity and gas in Iran. The influence of using these methods has been evaluated through comparing the results obtained from (a) MPC method regardless of economic optimization, (b) restricting the problem to using gas and solar exchangers only and (c) restricting the problem to using electric and solar heat exchangers only.

2. Literature review

Classes of MPC systems have formed application in many areas. Classical predictive control is utilized to determine input and output signals in the close-loop feedback control plant. Peng et al. implemented MPC to improve efficiency in turbine tip clearance [12]. Li and Sun presented a new turbulence compensating MPC algorithm and implemented this method for controlling the direction of the ship motion and compared the obtained results with those of the modified sample [13]. Gunay et al. have implemented MPC algorithm to control thermal radiative panels and an east-facing variable-air-volume terminal in Ottawa [14].

MPC is also one of the advanced control approach that has developed simulation and modeling of the building and HVAC systems [15]. Salazar et al. used predictor controlling method for controlling the gas/solar hybrid ventilation system to optimize it from economic point of view [1]. Afram and Janabi-Sharifi compared the effect of MPC method on HVAC system with that of other controlling methods [5]. Rogers et al. presented a new group of recursive modeling of MPC model for controllable radiator valves which has led to a cost reduction [16]. Qi and Deng improved the multi-input multi-output control method and studied its effect on the inside temperature and humidity of the room and applied this effect by means of a variable speed compressor [17]. Hazyuk et al. applied MPC method on a hydronic thermal system and presented a new cost function for MPC which could reduce the consumed energy to the minimum possible value by providing the required comfort heat [18]. Huang et al. used hybrid MPC scheme that combined with a neural network feedback linearization method to improve thermal comfort within buildings and reduce energy consumption in a chiller plant [19,20]. Široký et al. minimized energy consumption by using advanced control techniques. They used MPC to achieve energy saving and tested it in a two months experiment performed on a real building in Prague [21]. Privara et al. applied MPC on a large university building and achieved 17–24% energy saving compared to the present controller. Current heating control strategies are on-off and PID systems and MPC compared to these controllers [22]. Preglej et al. applied a Fuzzy Model-Based Multivariable Predictive functional Control (FMBMPC) on a HVAC system and compared it with Proportional-Integral (PI) controller. According to their results, FMBMPC is more energy-efficient and performs better due to the HVACs' nonlinear dynamics [23]. Ma et al. simulated a thermal and power model of building and