Sustainable Cities and Society 32 (2017) 366–374

Contents lists available at ScienceDirect

Sustainable Cities and Society

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

Performance and feasibility analysis of electricity price based control models for thermal storages in households

Argo Rosin[a,*], Siim Link[b], Madis Lehtla[a], João Martins[c], Imre Drovtar[a], Indrek Roasto[a]

[a] Department of Electrical Power Engineering and Mechatronics, School of Engineering, Tallinn University of Technology, Ehitajate tee 5, 19086, Tallinn, Estonia
[b] Department of Energy Technology, School of Engineering, Tallinn University of Technology, Ehitajate tee 5, 19086, Tallinn, Estonia
[c] Electrical Engineering Department, Universidade Nova de Lisboa (UNINOVA-CTS), 2829-516, Monte de Caparica, Portugal

ARTICLE INFO

Keywords:
Energy management
Load management
Temperature control
Thermal storage
Demand response

ABSTRACT

Electricity price based control models for thermal storages to balance fluctuations of price have become increasingly important. A number of previous studies in the field of demand side management deal with price based load control to balance the power grid. However, inadequate attention has been paid to comfort and profitability issues of end users. Therefore, insufficient solutions towards profitability and comfort issues may be a serious barrier to demand response. The aim of our paper is to analyse the performance and feasibility of electricity price based control models for thermal storages in households taking into account aspects of comfort. We simulated and compared existing control models and our models. The influence of different models and volatility of the real-time electricity price on the energy cost and electricity consumption of studied loads (i.e. water heater, freezer) have been estimated. While the cost and electricity reduction calculations do not take into account comfort issues, a performance calculation methodology has been developed. The performance is ensured when by minimized temperature change, as compared to maximum comfort settings, the cost reduction/ electricity saving is maximized. The control models showing the best performance (incl. electricity or cost savings) under different comfort situations are described.

1. Introduction

According to the U.S. Department of Energy (2009), 74% of the nation's electricity consumption occurs in buildings. This represents 39% of the total energy consumption among all sectors. There are two general approaches to energy consumption management in buildings: reducing consumption and shifting consumption (Mohsenian-Rad, Wong, Jatskevich, & Schober, 2010; Ontario Home Builders' Association, 2006). The former can be achieved through raising awareness among subscribers for more careful consumption patterns as well as constructing more energy efficient buildings (Mohsenian-Rad, Wong, Jatskevich, Schober, & Leon-Garcia, 2010). In the household, the main cost reduction possibilities are shifting of loads and/or replacing less efficient loads with more efficient ones. Household consumption is not a homogeneous group, as different appliances have different regimes, priorities and roles (Kadar, 2009). Occupants influence the use of electricity both by their purchase of more efficient electrical appliances and through use of those (Firth, Lomas, Wright, & Wall, 2008). Kadar (2009) has divided household electrical appliances into three groups: critical load, flexible load, and autonomous flexible intelligent load. Flexible loads with energy storage characteristics play a key role in shifting loads. Storages in households are mainly divided into those of electrical heating and cooling. Flexible loads (e.g. electrical water heaters and freezers) have high electricity consumption (high costs), composing about 30% − 50% from total electricity consumption (total cost) (Rosin, Hõimoja, Möller, & Lehtla, 2010). Therefore, most of the analyses and developments of demand side management systems cover price based flexible load scheduling models/algorithms, as described in (Handa et al., 2008; Mauri, Moneta, & Gramatica, 2008; Molderink, Bakker, Bosman, Hurink, & Smit, 2009; Molderink, Bakker, Bosman, Hurink, & Smit, 2010; Nyeng & Ostergaard, 2011; Paull, Li, & Chang, 2010). However, there is lack of literature focused on the comparison of feasibility and performance of different demand side (customers) control algorithms. In general, main objectives of customers are to minimize their energy consumption and costs (Auväärt, Rosin, Belonogova, & Lebedev, 2011; Drovtar, Niitsoo, Rosin, Kilter, & Palu, 2012; Drovtar, Rosin, & Kilter 2016; Rosin, Hõimoja et al., 2010; Rosin, Möller, Lehtla, & Hõimoja, 2010). Though the review of different control models composed by (Du & Lu 2011) is exhaustive and very interesting, it does not consider

* Corresponding author.
E-mail addresses: argo.rosin@ttu.ee (A. Rosin), siim.link@ttu.ee (S. Link), madis.lehtla@ttu.ee (M. Lehtla), jf.martins@fct.unl.pt (J. Martins), imre.drovtar@gmail.com (I. Drovtar), indrek.roasto@ttu.ee (I. Roasto).

http://dx.doi.org/10.1016/j.scs.2017.04.008
Received 30 December 2016; Received in revised form 17 April 2017; Accepted 17 April 2017
Available online 22 April 2017
2210-6707/ © 2017 Published by Elsevier Ltd.

Nomenclature

Variables

p_i^{max} Maximum real-time electricity price of last 24 h (€)
p_i^{min} Minimum real-time electricity price of last 24 h (€)
p_i Real-time electricity price during the time step i (€)
$p_i^{rt,dev}$ Standard deviation of the real-time electricity price of last 24 h (€)
$p_i^{rt,av}$ Average of the real-time electricity price of last 24 h (€)
x_i^{ph} Status of pre-heating (1—on, 0—off)
x_i^{pc} Status of pre-cooling (1—on, 0—off)
m_i Hot water consumption (cold water amount)/pre-frozen food added during the time step i (kg)
T_i^{set} Modified temperature set-point for next 5 min (°C)
T^{set} Temperature set-point defined by the customer (°C)
T^{max} Upper limit for a modified set-point of a water heater/freezer (°C)
T^{min} Lower limit for a modified set-point of a water heater/freezer (°C)
k_i^c Comfort coefficient
T_{i+1} Water heater tank/freezer temperature at the time-step i + 1 (°C)
T_i Water heater tank/freezer temperature at the time-step i (°C)
y_i^h State of a heating element in the water heater (1 – on, 0 – off)
y_i^c State of a cooling element in the freezer (1 – on, 0 – off)
k_i^c Comfort (economy) coefficient (0 – maximum comfort, 0.5 – average comfort, 1 – balanced, 1.5 – average economy, 2 – maximum economy)
$\Sigma E(k_i^c = 0)$ Electricity consumption of a period at maximum comfort ($k_i^c = 0$)
$\Sigma E(k_i^c)$ Electricity consumption of a period at chosen comfort ($k_i^c = 0.5\ldots2$)
$\Sigma Q(k_i^c = 0)$ Total cost of a period at maximum comfort ($k_i^c = 0$)
$\Sigma Q(k_i^c)$ Total cost of a period at chosen comfort ($k_i^c = 0.5\ldots2$)
$T(k_i^c = 0)^{min}$ Minimum temperature of a period at maximum comfort
$T(k_i^c)^{min}$ Minimum temperature of a period at chosen comfort ($k_i^c = 0.5\ldots2$)
$T(k_i^c = 0)^{max}$ Maximum temperature of a period at maximum comfort
$T(k_i^c)^{max}$ Maximum temperature of a period at chosen comfort ($k_i^c = 0.5\ldots2$)

Constants and coefficients

α Water heater/freezer thermal dispersion (kW/°C), $\alpha = UA$
U Heat transfer coefficient of a water heater/freezer, (kW/(m^2 K))
A Surface area of a water heater/freezer (m^2)
ΔT^{th} Pre-defined hysteresis of the electronic thermostat (°C)
η_H Efficiency of the water heating system (%)
η_C Efficiency of the freezing system (%)
T^{init} Initial value of the water heater/freezer temperature (°C)
C Total heat capacity of water/frozen food ($C = m \cdot C_p$) (kWh/°C)
C_p Heat capacity of water (kWh/(kg K))
T^{amb} Ambient temperature of a water heater/freezer (°C)
T^{cw} Temperature of cold water in the water heater inlet (°C)
T^f Temperature of food placed in a freezer (°C)
P^{el} Rated power of a water heater/freezer (kW)
Δt Length of time-step (h)
m Total mass of water in the water heater/total mass of food in the freezer (kg)

different types of dynamic price sensitive thermostat based or time-varying temperature constraint based (considering user comfort) control algorithms. Also, Yoon et al. (2014) describe a dynamic demand response controller, which changes the set-point temperature to control loads depending on the electricity retail price published each 15 min and partially shifts some of this load away from the peak. However, cost reduction possibilities and comfort aspects for an end user are partly covered. As described by (Paterakis, Erdinç, & Catalão, 2017) a basic challenge is loss of comfort because of consumption limitation of the end user. Furthermore, the performance of flexible loads is also related to the comfort of customers that has not acquired sufficient attention in previous studies (Good, Ellis, & Mancarella, 2017).

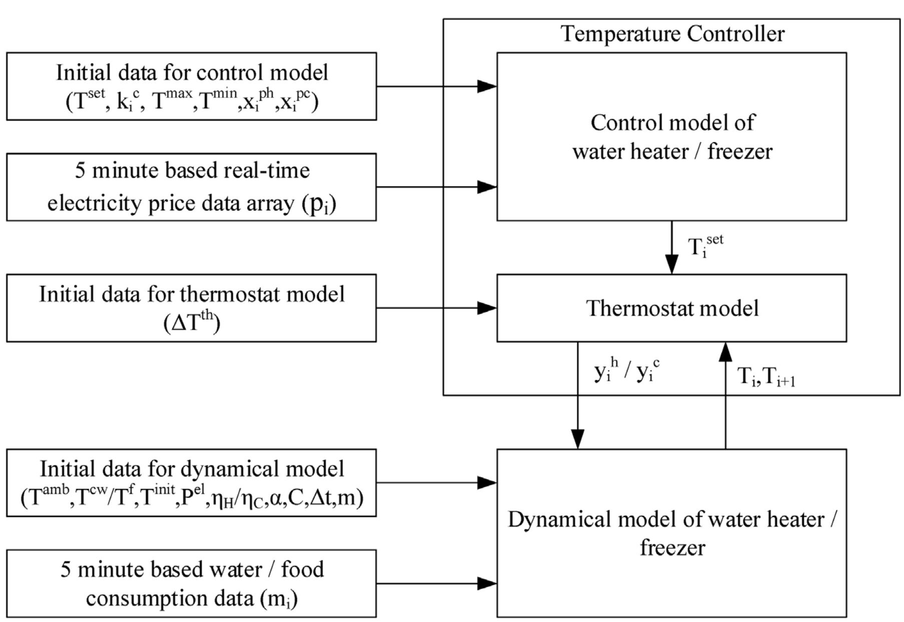

Fig. 1. Overview of system model.

Download English Version:

https://daneshyari.com/en/article/4928019

Download Persian Version:

https://daneshyari.com/article/4928019

Daneshyari.com