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Effects of intelligent strategy planning models on residential HVAC system energy demand and cost during the heating and cooling seasons

Nima Alibabaei [a,*], Alan S. Fung [a], Kaamran Raahemifar [b], Arash Moghimi [b]

[a] Department of Mechanical and Industrial Engineering, Ryerson University, 350 Victoria Street, Toronto, ON M5B 2K3, Canada
[b] Department of Electrical and Computer Engineering, Ryerson University, 350 Victoria Street, Toronto, ON M5B 2K3, Canada

HIGHLIGHTS

- Enhancing TRNSYS control process by developing a Matlab-TRNSYS advanced controller.
- Developing a novel smart dual fuel switching system for residential HVAC system.
- Improving load shifting strategy by selecting optimum pre-heating/cooling time.
- Minimizing residential HVAC system energy cost.
- Assessment of developed strategy planning models during heating and cooling seasons.

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ABSTRACT

Based on their structure, residential houses/buildings (RHs) can offer excellent opportunities for managing their internal energy demand and subsequently lowering their energy cost. Demand management and energy cost saving can be achieved by taking advantage of RHs/buildings capabilities in storing thermal energy. Thermal energy can be stored utilizing intelligent Strategy Planning Models (SPMs) which are applied in the heating, ventilating and air conditioning (HVAC) system as one of the largest energy consumer in RHs buildings. This study discusses the development of three different strategy planning models including Smart Dual Fuel Switching System (SDFSS), Load Shifting (LSH), and LSHSDFSS, a combination of load shifting and fuel switching SPMs. In order to facilitate the implementation of the developed SPMs on the HVAC system of the house used in this case study, an advanced controller was designed by connecting both TRNSYS-Matlab programs. The HVAC system energy demand as well as the corresponding saving on the HVAC system energy cost are analyzed in-depth numerically using each of the strategy planning models during both the heating and cooling seasons. Simulation results showed that in the heating season, the operating/energy cost of HVAC system decreased significantly (23.8%) by implementing SDFSS-SPM. LSHSDFSS-SPM reduced the HVAC system operating cost by 15.8%. In the cooling season, LSH-SPM reduced the HVAC system operating cost by 6.63%.

1. Introduction

Residential houses/buildings (RHs) must be seen as significant elements of a larger, dynamic network of energy system. Therefore, a network of energy system is significantly affected by the behavior of RHs [1,2]. For example, based on Pagani and Aiello [3] energy model simulation result, disruption in demand management can be detrimental to energy systems. In contrast, as Siano and Sarno [4] shown in simulation result, RHs enable to improve the management of energy network. The network energy saving is improved significantly using the distribution locational marginal price (D-LMP) model developed in [4]. What makes the RHs' roles prominent in managing the energy network, is their energy structure. They are capable of storing thermal energy that results in managing their energy demand. Arteconi et al. [5] have investigated the load shifting potentials of thermal energy storage (TES) in a residential building. The simulation result showed energy cost saving using on and off peak tariffs. Thermal energy storage and energy demand management can be achieved by employing smart Strategy Planning Models (SPMs) in the HVAC system as one of the largest energy consumers in RHs/buildings. In Vakiloroaya et al. [6]

* Corresponding author.
E-mail addresses: nima.alibabaei@ryerson.ca (N. Alibabaei), alanfung@ryerson.ca (A.S. Fung), kraahemi@ryerson.ca (K. Raahemifar), arash.moghimi@mail.utoronto.ca (A. Moghimi).

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Nomenclature

ASH	Archetype Sustainable Houses	LSHSDFSS	load shifting and smart dual fuel switching system
AHU	Air Handling Unit	OEB	Ontario Energy Board
ASHP	Air Source Heat Pump	OT	outdoor temperatures
BCS	Best Case Scenario	RH	residential house
COP	Coefficient of Performance	SDFSS	Smart Dual Fuel Switching System
DEC	Daily Energy Cost	SPM	strategy planning model
DHW	Domestic Hot Water	TC	time constant
DSO	Distribution System Operators	TOU	time-of-use
HVAC	heating, ventilating, and air conditioning	TRCA	Toronto and Region Conservation Authority
LEED	Leadership in Energy and Environmental Design	ZT	zone temperature
LSH	load shifting		

review paper, different demand management and energy saving SPMs for typical residential HVAC systems are described in detail and compared. Huang et al. [7] showed the advantage of different energy saving SPMs such as load shifting in a HVAC predictive energy model. The effects of different energy conservative SPMs such as daily optimal deadband and daily optimal set point are investigated in [8] using EnergyPlus program. Kim et al. [9] have developed a daylighting meta-model that has been integrated into a HVAC system to take the maximum advantage of daylighting for preparing thermal comfort. This meta-model offered an average of 13.7% energy saving. Different heat gain reduction methodologies/ SPMs have been developed in [10]. Based on this paper calculation, more than 75% of building heat gain were generated by solar heat gain and lighting system. By managing these heat gains, more than 45% saving on HVAC system energy cost was achieved. Christantoni et al. [11] used EnergyPlus simulation model to implement different demand response SPMs for shifting the building electrical demand. In this research, contribution of HVAC system and building capacitance was evaluated using demand response SPMs. In [12] research, energy saving potentials of various set point strategies were investigated in a museum. Using these strategies led to 77% improvement in thermal comfort while decreased 82% of HVAC system energy demand. Wang et al. [13] have modeled the influence of occupants and its essential effects on building performance by generating mean profiles of occupancy variables in order to increase HVAC system energy efficiency. The role of residential heat pumps and load shifting, and their contribution in network operational cost and CO_2 emission reduction has been investigated in [14]. As Beizaee et al. [15] have shown, the thermal demand of a house can be decreased using zonal space heating SPM. This SPM could reduce the natural gas consumption by 11.2% in only eight weeks. Chassin et al. [16] investigated the impacts of discrete-time SPM on a residential house HVAC system and reported up to 25% reduction in HVAC system energy demand. A dynamic zone modeling system as an energy conservative SPM was developed by Li et al. [17] to reduce the HVAC system energy cost. Different ingenious methods like using tokens (as a surrogate for thermal demand) [18] and demand response potentials of high-raised building ventilation fans [19] have been used as smart SPMs to conserve the network energy.

In addition to supporting the network of energy system, lower overall energy cost could be achieved for the homeowners with such intelligent SPMs. Hence, as Di Giorgio and Liberati [20] concluded, both energy consumers and local grid benefit from such intelligent planning models. Regardless of the fact that numerous research with different criteria have been previously conducted for designing different strategy planning models for residential HVAC systems with the aim of reducing demand and energy cost, less attention has been paid to energy conservative SPMs that use combination of fuels/energies for running the HVAC system. Furthermore, matching and tuning SPMs with the real time dynamic characteristics of the process model (house thermal model) has been poorly noted before.

The main contribution of this study is in developing novel strategy planning models including: (1) Smart Dual Fuel Switching System (SDFSS), (2) Load Shifting (LSH), and (3) LSHSDFSS model as the combination of fuel switching and load shifting strategy planning models. In SDFSS-SPM, a smart controller is developed to select the least expensive hot air supplier (between electrical Air Source Heat Pump (ASHP) and natural gas mini boiler), in each hour, by taking into consideration the house's thermal demand and Time of Use (TOU) pricing scheme during the decision making process. In novel LSH-SPM, an intelligent mechanism is used to select the best pre-heating/pre-cooling starting time based on the outdoor temperature effects and the dynamic characteristics of the case study house. As the third developed SPM, LSHSDFSS-SPM takes advantage of both novel load shifting and fuel switching systems to offer maximum saving on HVAC system energy cost.

An advanced controller is developed by connecting TRNSYS-Matlab programs. This advanced controller facilitates the implementation of novel SPMs on the HVAC system of case study house. The behavior of HVAC system is numerically simulated in-depth during winter (heating) and summer (cooling) seasons. Total saving on the HVAC system energy demand and cost are calculated by implementing developed SPMs in winter and summer seasons.

This paper is consisted of four sections. In Section 2, the methodology and model of the work are described. This section also concludes the architecture and configuration of different operational SPMs in detail. In Section 3, results including the effect of intelligent strategy planning models on the HVAC system energy demand and cost in various sample days and during the whole heating and cooling seasons are presented and discussed. The paper is concluded in Section 4.

2. Model description and intelligent Strategy Planning Models (SPMs) development

2.1. Model description

2.1.1. Methodology

This study is started by running case study house TRNSYS model for a specific day in order to generate the baseline data. The weather file used to calculate the house's thermal demand is the metropolitan Toronto weather given in the TRNSYS library. Different operational command matrices are generated by Matlab advanced controller (according to the baseline data) in order to implement various SPMs on the house's HVAC system. TRNSYS model is run again considering the generated operational command matrices in simulation process. The data generated by imple-