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Phase change materials in hot water tank for shifting peak power demand

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Abstract

The increasing variations in building energy demand and consumption which includes hot water tanks, space heating, and cooling applications, calls for the need to investigate different potential options of meeting these needs with as little dependence as possible on the use of non-renewable energy sources. One of such approach involves the use of phase change materials (PCMs). This paper investigates the potential of using PCMs to improve the thermal performance of residential hot water tanks (HWT) and to shift the peak power demand. Field-measured hot water consumption profiles (low, medium and high) were used to study the impact of the amount of PCM utilized, control strategies on the HWT thermal performance, and peak power demand shift. The study was carried out using a model that included a validated hot water tank integrated with PCMs.

The results show that the combined use of PCMs and sensible heat in a HWT resulted in an improvement in the thermal energy storage compared to the HWT without PCMs (only sensible heat). The improvement in thermal energy storage and potential peak power shift are directly proportional to the amount of PCM added in the HWTs.

Keywords: Phase change materials; Demand shift; Simulation; Thermal improvement; Hot water tank

1. Introduction

The increasing variations in building energy demand and consumption which includes hot water tanks, space heating, and cooling applications, calls for the need to investigate different potential options of meeting these needs with as little dependence as possible on the use of non-renewable energy sources. One of such approaches involves the combined use of sensible and latent energy storage reported by Nkwetta et al. (2014) and Pérez-Lombard et al. (2008). They reported that sensible energy storage is commonly used in the building sector to meet the primary energy growth of about 49% with an average annual energy increase of 2% and a resultant increase of 43% and 1.8% average annual CO_2 emissions, respectively. The International Energy Agency (IEA) estimated that the building sector in developed countries is consuming over 40% of the global energy with a resultant 24% of greenhouse gas emissions (IEA, 2008). Hot water tanks

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(HWT) are used in commercial, institutional and residential buildings mostly due to their simplicity, installation, and operation convenience (Long and Zhu, 2008). But hot water demands directly coincide with the peak power demands in the morning and evening hours, and it is a critical problem for the utility providers. Thus, it needs further investigation.

During peak energy demand periods, the cost of generating, distributing and maintaining electricity by the utility companies is higher compared to non-peak periods and the associated costs in most countries is passed onto the consumers (Long and Zhu, 2008; Bourke and Bansal, 2012; Nkwetta and Haghighat, 2013; Agyenim and Neil, 2008, 2010). This cost to consumers is likely to increase in the near future due to emerging technologies such as electric gadgets and electric cars. Allard et al. reported that hot water demand in over 90% of homes in Québec (Canada) is provided by electric water heaters, totaling over 2.7×10^6 units which in total are a great contributor to the electrical grid peak power demand (Allard et al., 2011), therefore representing an opportunity to reduce and/or shift peak power demand. In addition, accurate control strategies are needed both to avoid creating another peak demand once the heating elements are re-activated, as well as to prevent the growth of bacteria if the heating elements are deactivated for a long period of time. In North America, standardized residential electric water heaters are cylindrical with nominal storage capacities of 180 L or 270 L, representing almost 45% and 47% share of the market, respectively of domestic electric water heater usage (Moreau, 2011).

A reduction in the PCM prices and an increase in the cost of peak demand are amongst the reasons for the need for this research. The proposed system ensures that the combined sensible heat and PCMs in the storage tank are heated during off-peak periods and the combined sensible and latent heat are effectively stored and re-used during the peak periods. If the combined sensible and latent heats are effectively stored in large quantities, it should help to reduce the peak hour energy requirement and the associated cost, and may further result in potential availability of hot water throughout the day.

For this objective to be met, Nkwetta et al. (2014) investigated the potential energy storage of different PCMs in HWTs with TRNSYS type 860 (Nabavitabatabayi et al., 2014; El-Sawi et al., 2013) used in modeling hot water tanks with PCMs included. Type 860 was developed based on type 60 and involves modeling of PCM-hot water tanks either in spherical, rectangular and or cylindrical shape using a nodal approach. The PCM modeling is a 2 dimensional model with an 'onion peel' approach (constant thickness layers from center to the border of the PCM). The modeling of the TRNSYS type 860 with PCM involves the use of the enthalpy method, and has been validated (Nkwetta et al., 2014; Nabavitabatabayi et al., 2014; El-Sawi et al., 2013).

Furthermore, it is imperative for a detailed and critical analysis of the energy storage potential of different amounts of PCM that a composition of 90% sodium acetate trihydrate and 10% graphite be used. It has been reported as an ideal PCM candidate for such an application (Nkwetta et al., 2014). When used with a control strategy, it has the potential to shift or smooth the peak power demand in comparison to HWTs without PCMs. The use of sodium acetate trihydrate (90%) + graphite (10%) in combination with sensible HWT energy storage plays an important role in conserving energy and reducing the mismatch between energy supply and demand as well as improving the performance and reliability of energy systems.

Earlier research reported on the merits of using latent heat storage compared to sensible heat including its smaller unit size due to large heat storage capacity per unit volume, capability of maintaining constant temperature during the charging and discharging phases, storage of thermal energy during off-peak periods to be used during the peak hours, night time storage and daytime release to alleviate grid load in electricity based system, and extends the grid capacity in district and cooling sets (Nkwetta et al., 2014; Bony and Citherlet, 2007; Nabavitabatabayi et al., 2014; El-Sawi et al., 2013; 2014; Chidambaram et al., 2011; Cabeza et al., 2006a,b, 2011; Zalba et al., 2002; Sharma et al., 2006; Agyenim et al., 2010; Chan, 2011). Thus, greater potential exist by combining latent and sensible heat in one system. Furthermore, thermal stratification during the charging and discharging phase is key to increase the overall HWT efficiency and helps shorten the charging time with resultant reduction in the electricity consumption. The integration of PCM into HWTs has the potential to further improve the thermal stratification (Chidambaram et al., 2011).

This paper reports on the potential to shift peak power demand using a validated TRNSYS model of combine sensible and latent heat storage in a 270 l HWT. The simulation was carried out using the real measured hot water consumption data. A control strategy was employed and the potential shift period based on different amounts of PCMs is compared to a reference HWT without PCM. An improvement in the energy storage and reduction in the total charging time resulting from the combined use of sodium acetate trihydrate + 10% graphite and sensible heat in the HWT is compared to the sensible heat alone. The peak power shift resulting from the combined use of sodium acetate trihydrate + 10% graphite and sensible heat is directly proportional to amount of PCM.

2. Hot water profiles and different amount of PCM

The direct coincidence of peak power demand and hot water consumption in the morning and evening hours promotes the concept of using alternative methods and strategies to heat and store hot water during non-peak electricity consumption and using it during peak power