Performance improvement in a combined water heater

In numerous energy systems there are discrepancies between energy supply and demand. One such system is the domestic water heater. The water heater utilizes sensible heat storage and if combined with latent heat storage there are benefits to gain, both at an individual and on a system level. This study analyses a domestic water heater combined with a latent heat storage, focusing on the number of phase changing materials.

FANNY LINDBERG
B.Sc., The Royal Institute of Technology, Stockholm, Sweden
Faculty of Industrial Engineering and Management
fannyli@kth.se

The use of hot water

In 2008 Swedish Energy Agency and Statistics Sweden performed a study on hot water use in single-family-households. This study resulted in, among other things, a user profile for hot water use presented in **Figure 1**. The profile shows that the hot water use is relatively constant during a day except for a time period of 15 minutes when 110 litres of hot water is used [1].

This brings us to one of the big energy challenges in today's energy system, to find a sustainable balance between energy supply and demand. Shifting peak load through demand side management would be beneficial for the energy system as this would enable a more even consumption and hence production. This would further come with economical advantages, as the electricity price typically is higher at peak load.

One of the biggest energy consumers in Sweden is space heating including tap water heating, accounting for 25% of the national energy consumption [2]. The tap water heating in Sweden is often conducted through a

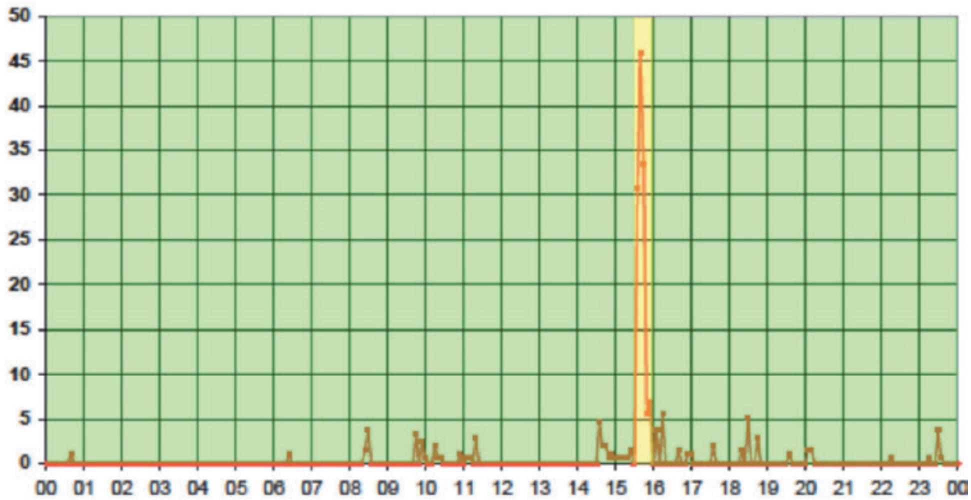

Figure 1. User profile for hot water (Stengård L, Levander T, 2009).

Sensible heat storage
– The storage of thermal energy by changing the temperature of a medium.

Latent heat storage
– The storage of thermal energy by change of physical state of a medium, e.g. liquid to the solid phase.

water heater where the thermal energy is stored through sensible heat storage until demand rises. However, there are several disadvantages with the sensible heat storage such as low energy density. This leads to the requirement of a big water heater to supply enough hot water for a sudden use, e.g. a shower or a bath. A large storage size does also come with higher thermal losses and larger space requirement, which can be undesirable.

A combined water heater

There are room for improvement and development of the widely used domestic water heater that could effect the energy situation both at an individual and on a system level. An opportunity is to combine the water heater's sensible heat storage with latent heat storage. The latent heat storage is considered to be a more efficient and compact storage method. For example, the phase change of water from solid to liquid require the equal amount of energy as heating water of the same mass from 0° C to 80°C.

The market offers a wide range of material for latent heat storage application called phase change materials (PCM). These have the advantages of isothermal phase transition, high energy density and can be tailor made for each system to meet the temperature requirements.

The proposed system would ideally consist of a small water heater to meet the average demand during the day combined with a PCM unit to meet the peak load demand. The PCM unit ought to be charged when demand is low and discharged when peak arises to shift peak load.

In practice, hot water from the water heater circulates through the PCM unit melting the PCM during average load. When peak load occurs the water from the traditional water heater will drop in temperature and become cold. Cold water circulates through the PCM unit and thus starting a solidifying process. In this process the PCM will be discharged, transferring stored energy from the PCM to the water and thereby heating the tap water.

Schematics of the described system are presented in **figures 2–4**. Adopting the proposed system would enable the water heater to work at a more constant temperature whilst being able to provide enough hot water at all hours. Thus, a combined water heater will be smaller, have less losses and work at a lower, constant energy rate.

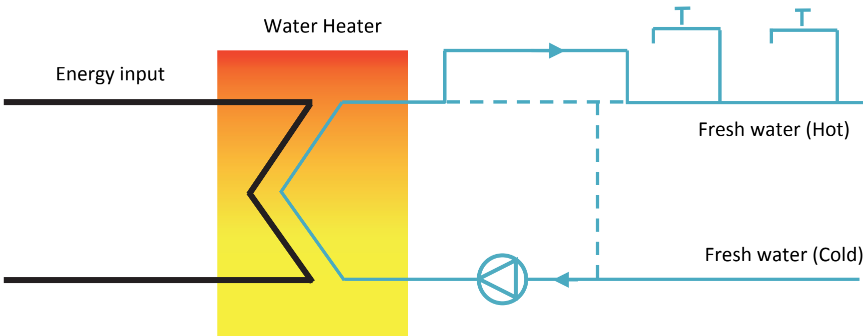

Figure 2. Uncharged PCM.

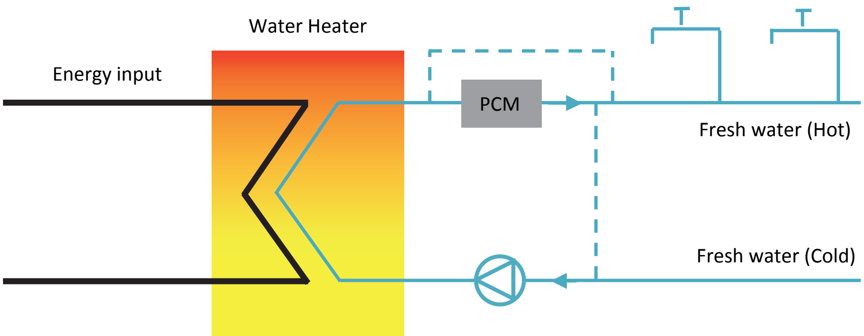

Figure 3. PCM Discharging: Cold water flow through the PCM unit (Fanny Lindberg).

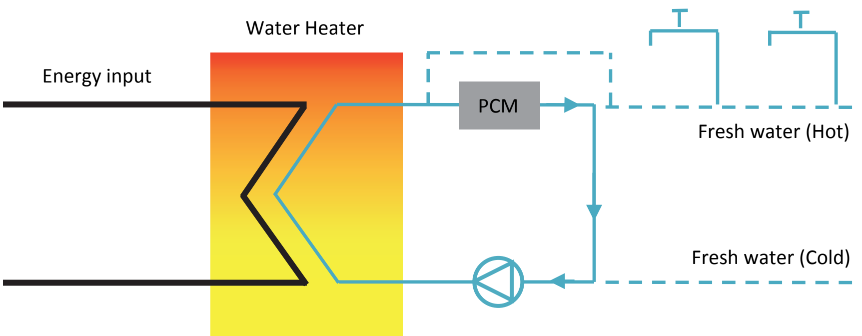

Figure 4. PCM Charging: Hot water from water heater circulates the PCM unit.

Modelling

COMSOL Multiphysics [3] was used to create a model and simulation of the system. The model created is a development of a verified model created by Justin N.W. Chiu and Viktoria Martin in 2013 [4]. The user profile in **Figure 1** formed the basis for the simulation. The green area represents the charging and the yellow the discharging cycle. The system studied is a water heater with a water inlet temperature of 8,6°C [1] and outlet temperature of 61°C [5]. Place note that the aim for the combined water heater is to shift peak load (yellow) to the average load period (green).

Modelling assumptions of materials

- Isotropic properties
- No thermal resistance through surfaces
- Incompressible fluids
- Newtonian fluids
- Adiabatic surfaces facing ambience

The model was created as a finned pipe with two times two storage units for the PCM and is illustrated in **Figure 5**. When analysed, the model is downscaled to a two-dimensional axial symmetric module. The biggest challenge in the development of the model was to create a design with a manageable calculation time, less than 24 h, but with acceptable accuracy.

The finned pipe material was set to aluminium due to good heat exchanging and manufacturing properties. The PCM was set to paraffin. It is interesting to investigate the number of PCM in the energy storage unit and their optimal phase changing temperature. The driving force for heat transfer is proportional to the temperature difference. Therefore, it is advantageous to use PCMs with low phase changing temperature for the charging cycle. The reverse applies for the discharging cycle. Using a combination of PCMs with varying phase changing temperatures preserves the driving force. At the same time the water can reach higher temperatures when discharging and lower when charging. This difference between single and multi PCM systems is presented in **Figure 6a and 6b**. The focus of the study has been to compare PCM units containing one and two PCMs and to find the most advantageous case for the given application.

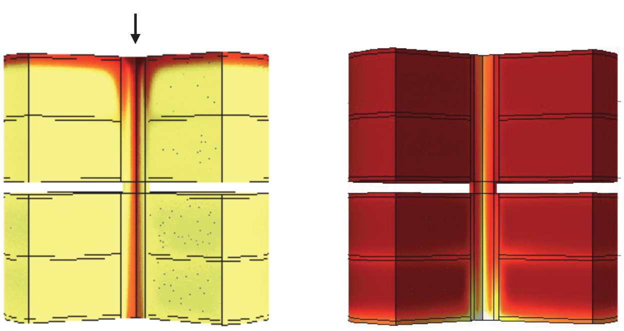

Figure 5. Model in COMSOL Multiphysics.

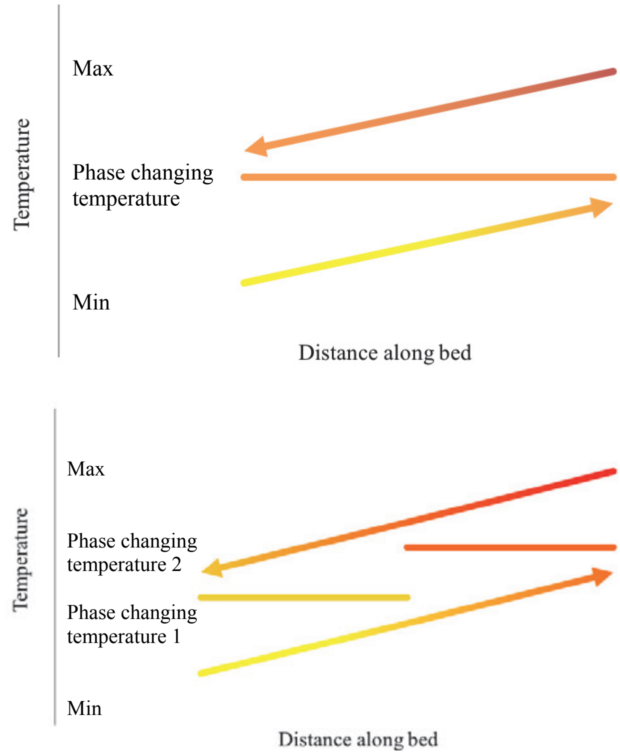

Figure 6a and 6b. Single vs multi PCM heat exchange.

Furthermore, two temperature zones for phase changing temperatures was studied. One higher and one lower. To summarize, four cases were studied for the charging and discharging cycle, respectively. The materials studied in each case are represented in **Table 1**.

Table 1. Material composition for each case.

	One PCM	Two PCM
High phase changing temperature	PCM 50	PCM42 & PCM60
Low phase changing temperature	PCM44	PCM35 & PCM55

Results and conclusions

The results of the simulation are presented as the outlet temperature. The outlet temperature describes the temperature of the water at the outlet of the PCM unit. The outlet temperature of the water during the charging cycle is presented in **Figure 7**. The water temperature at the end of all cases equals the incoming temperature of 61°C. Thus one can make the conclusion that all cases provide a fully uploaded PCM unit. Furthermore, one can conclude that the PCM units holding two PCM materials provide a faster charging as the maximum temperature is reached faster. Hence, the system engineering challenge lies in the discharging cycle.

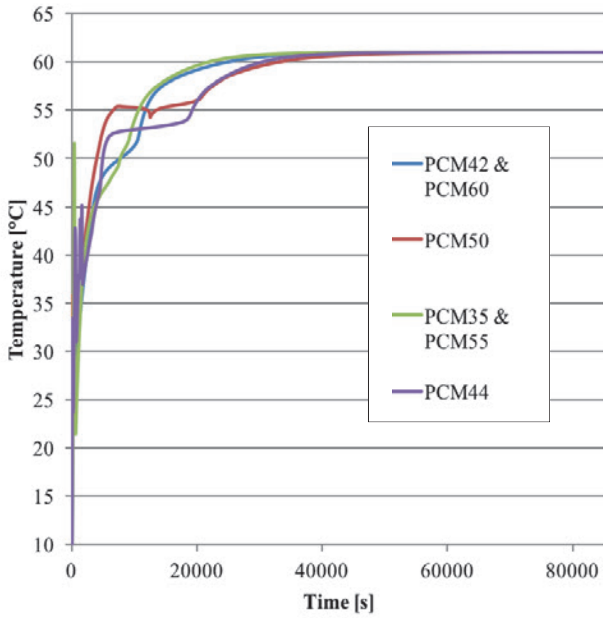

Figure 7. Outlet temperature of water, charging cycle.

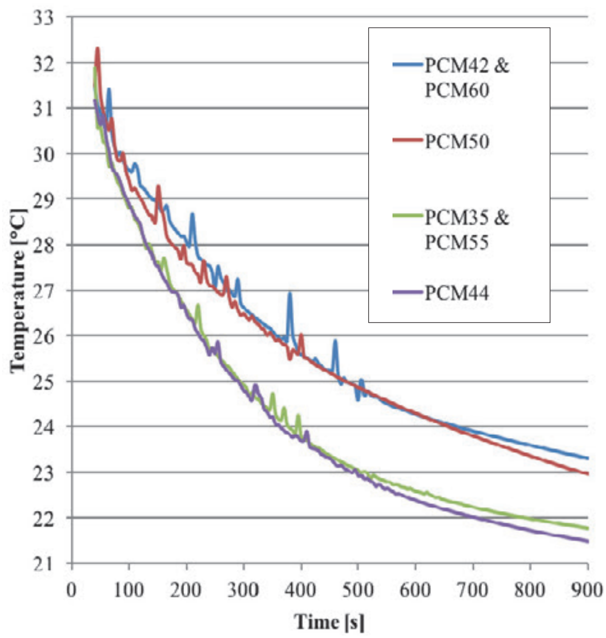

Figure 8. Outlet temperature of water, discharging cycle.

The outlet temperature of the water for the discharging cycle is presented in **Figure 8**. The outlet temperature is lower than the desired one for all cases at all times. However, the inlet temperature is elevated by 15-26°C. Figure 8 presents that the highest outlet temperature is reached for the case of high phase changing temperature and two PCM. The difference between one and two PCM are, however, not significant. To reach an even higher outlet temperature a higher working temperature would be eligible. The system could be further developed if multiple devices were in series or in parallel. This would provide a larger area for heat transfer and a longer contact time which would increase the heat transfer and thus the outlet temperature.

The recommended system for the given application would contain PCM with high phase changing temperature. The charging cycle exhibits full charge for all cases whereas the discharge cycle is critical. For the discharge cycle a sufficiently high outlet temperature is not reached with the developed model. However, a significant rise in temperature from 8.6°C is achieved. The PCM unit with two PCMs provide a slightly higher temperature but more detailed studies of multiple user profiles with a design reassessment should be done to determine which case is most advantageous. It is clear that the system is applicable and feasible in theory, as it allows a shift of the load.

Further studies concerning the possibility of connecting devices in series should be done in order to investigate the circumstances under which higher outlet temperatures can be reached. To summarize, performance improvements can be reached using multi PCM. However, the question whether this is sufficient to outweigh the possible design and construction complications remains. ■

References

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