An evaluation of the economical feasibility of seasonal sorption heat storage

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Presented at the the 5th International Renewable Energy Storage Conference IRES 2010, 22-24 November 2010, Berlin, Germany

ECN-M--10-096 DECEMBER 2010

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Abstract
An evaluation is presented of the economical feasibility of seasonal heat storage of solar heat with sorption materials. The seasonal sorption heat storage is shown to pay itself back over its lifetime, under the assumptions presented. Attention is given to the verification of the assumptions, since these have a large effect on the conclusions.

Introduction

Heat is traditionally stored in water (e.g. boiler). Although water has many advantages as a storage medium, it also has some disadvantages such as a relatively low storage density and heat loss to the ambient. An alternative option is to store heat by means of a sorption material by making use of the reversible reaction: A + B ⇔ C + heat. By storing heat using sorption materials, significantly higher energy density can be achieved. Additionally, although some energy losses are associated with charging and discharging the material, once the material is charged, the heat can be stored for a long time without losses. Potentially interesting materials should be cheap, non-toxic, non-corrosive, have sufficient energy storage density and have reaction temperatures in the proper range (roughly 50-150°C). An example is magnesium chloride hexahydrate ($MgCl_2.6H_2O$) that can be used to store heat by means of the following reaction:

$$MgCl_2.6H_2O(s) + heat \Leftrightarrow MgCl_2.2H_2O(s) + 4H_2O(g)$$

An important issue is the techno-economical feasibility of the application of such sorption materials for seasonal heat storage; under what conditions is the use of such a system cost-effective? This question concerns not only the cost of the material itself, but also the additional system costs required for the use of these materials, such as heat exchangers and fans (assuming market maturity), as well as running costs such as maintenance costs. These costs should be compared to the predicted cost for fossil energy over the lifetime of the sorption system. Finally, the sensitivity of the result to the interest rates and the increasing energy prices should be taken into account.

Seasonal storage system value

To get some basic insight into the perspective of cost effectiveness of seasonal heat storage, it is necessary to start with calculating the annual heating cost.

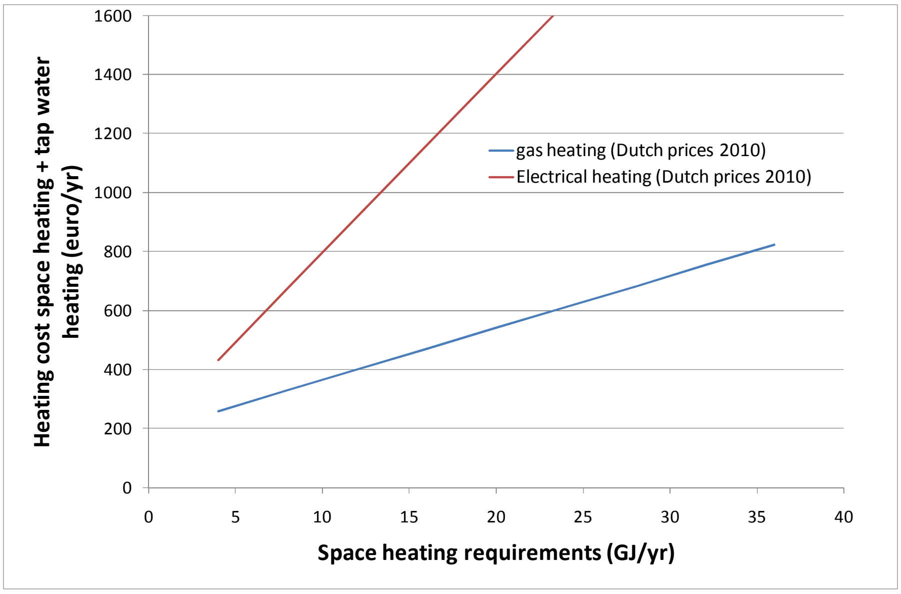

Figure 1: Annual energy cost for heating (space heating and tap water heating). For tap water heating, a fixed demand of 9 GJ/year is assumed.

Assume now a renewable energy system for a residence, providing the domestic heating demand for tap water and space heating with a 100% solar fraction and having a lifetime of 30 years. Ignoring for the present a rise in energy price or interest rates, the value of such a system would be the forgone energy costs over the system lifetime. Household energy costs vary widely over Europe. In the EU statistical pocketbook (2007), electricity prices including taxes are indicated for 2007, ranging from 0.069 euro/kWh in Latvia to 0.245 euro/kWh for Denmark (Netherlands 0.223 euro/kWh) and for gas ranging from 7.4 euro/GJ in Hungary to 30.8 euro/GJ in Denmark (Netherlands 22.6 euro/GJ). In the Netherlands, the current 2010 household price for gas is 0,58 euro/m3 and for electricity 0.22 euro/kWh (NUON, 2010), including taxes. For an energy efficient Dutch house (passive house standard) with a 6 GJ/yr space heating demand and a 9 GJ/yr tap water demand, this amounts to about 9000 euro if a gas heating system is replaced, or 17000 euro if an electrical heating system is replaced, as shown in Figure 1. The figure clearly shows the large impact of the cost of the fossil energy replaced.

This value has to be compared to the costs of the system. Since all costs of such a system have to be financed upfront, the effective interest (being the interest rate minus the inflation rate) increases the effective system cost and therefore affects these results in a negative way. The total accumulated cost including interest i over a period of N years can be calculated from the equation

$$F_{total} = F_{initial}(1+i)^N \qquad \text{(i=interest, N=number of years)}$$

As can be seen in Figure 2, the effective system cost over the 30 year lifetime increases tenfold if an effective interest of 8% has to be paid; this implies that the investment cost of the system should be six times lower to arrive at the same overall cost. Of course, this is an extreme example. For a more realistic effective interest of 4% the effect is roughly a factor two.

Interest increases the effective system cost, but also the effective running costs, which mostly affects the conventional fossil fuel option. If the owner has to pay a certain sum for the running cost (e.g. for energy or maintenance costs), he will forfeit the interest he would have obtained over this sum if he would have put it in his savings account. Therefore, if one saves on fossil energy, the effective value of these savings over 30 years is larger than just the annually saved fossil energy costs times 30. The formula is given as:

$$F_{total} = \sum_{n=0}^{N-1} F_{annual,t=0} \, (1+i)^n \qquad \text{(i=interest, N=number of years)}$$

The curve for this ratio is similar to the curve for the effective system cost, but substantially less steep, as also shown in Figure 2.

Typical interest rates may vary strongly in time. If we may assume that this renewable energy system may be financed as part of the mortgage, it is interesting to compare historical mortgage interest rates with inflation rates, as shown in Figure 3. Typically, the effective interest, being the difference between inflation rate and mortgage rate, averages 4.6% over the last 20 years for 10 years fixed interest. If a variable interest would have been chosen, the difference would have been about 3.9%.

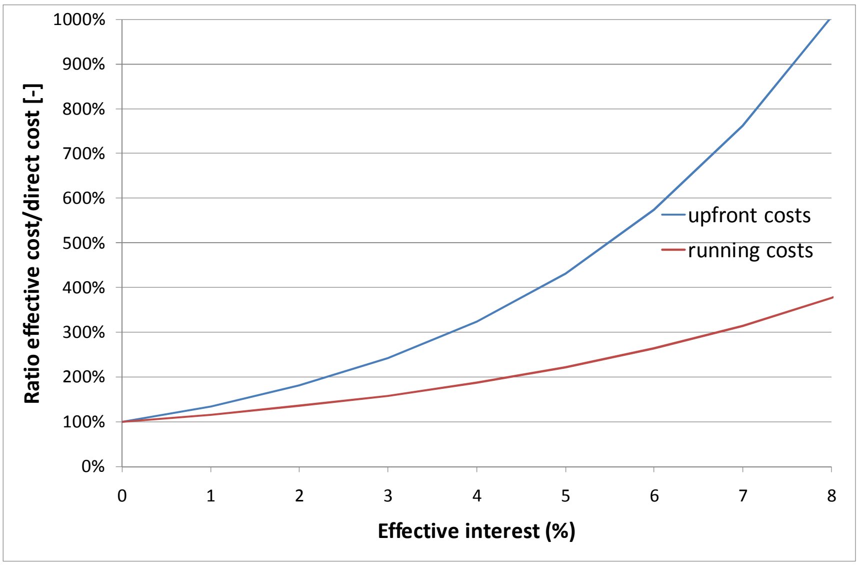

Figure 2: Effective increase in system cost over lifetime due to effective interest rate.

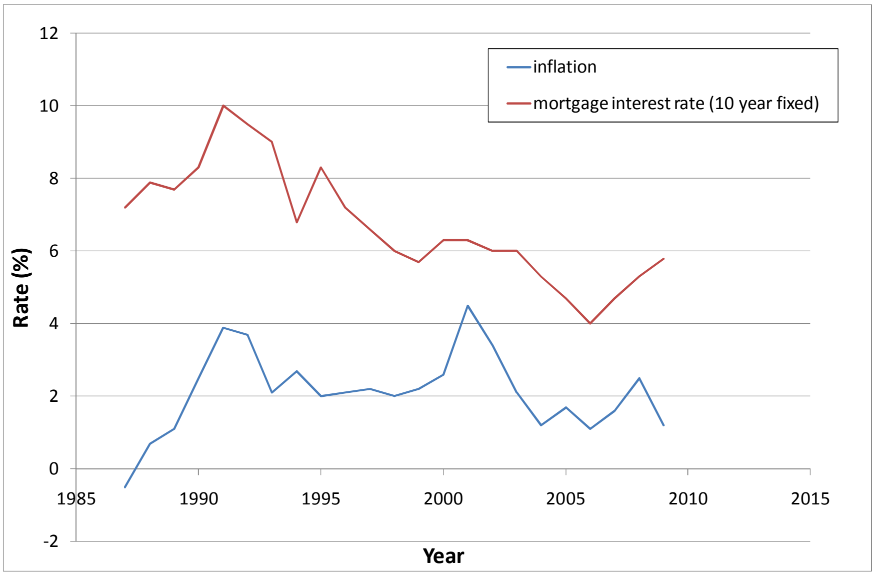

Figure 3: Inflation rate and mortage interest rate in the Netherlands. Data from CBS and Vereniging Eigen Huis.

The last assumption that has to be taken into account is the rise in energy prices. This effect is similar to the effect of interest on running costs, making the conventional system more expensive. Again Figure 2 can be used; for a 4% annual rise in energy prices the system investment costs may be roughly twice as high.

It is far from easy to give a typical value for the annual energy price increase. The historical price of crude oil is shown in Figure 4 showing the oil price up to 2009. Since mid-2009, the oil price has stabilized at a level between 70 and 80 US dollar per barrel. It can be seen that the change in energy price over a short time period may be about anything. However, over the last 10 years, the energy price has increased about fourfold, which would amount to an average annual price increase of almost 14%. On the other hand, over the last 40 years, the energy price has increased about fivefold, amounting to an average annual increase of 4%. For the remainder of this paper, an average annual increase of 7% is assumed. For comparison, Eurostat gives an average rise in Dutch end user gas prices over the period 1999-2009 of 7% annually, while the roadmap by Holland Solar (2007) shows an average annual increase in the Dutch gas price of 8% over the period 1972-2004.

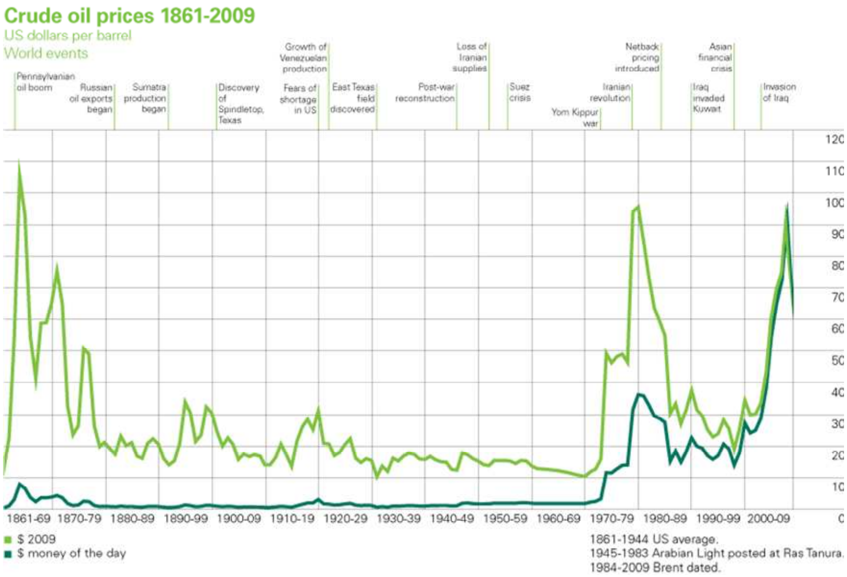

Figure 4: Crude oil prices 1861-2009 (source: BP).

In summary, we have made the following assumptions: (1) a passive house with 6 GJ/yr heating demand and 9 GJ/yr tap water demand, (2) Dutch gas prices, (3) an effective mortgage interest rate of 4%, (4) an effective savings account interest of 2%, and (5) a technical system lifetime of 30 years, in which the system should pay itself back. Under these assumptions, we would arrive at a total maximum system cost of 300 euro/yr x 30 years x effective running cost ratio (=1.4) x energy increase ratio (=3.1) / upfront interest ratio (=3.2), which is about 12200 euro. Note that we have ignored here the interaction between the rise in energy price and the interest forfeited over the paid energy costs (one forfeits most interest over the payments made longest ago when the energy costs were lowest). Therefore, it is more accurate not to calculate the effects of interest on running cost and the energy price rise independently, but to calculate their combined effect according to the equation

$$F_{total} = \sum_{n=0}^{N-1} F_{annual,t=0}\,(1+r)^n(1+p)^{N-n}$$

(i=interest, p= energy price rise, N=number of years)

When this interaction is taken into account, we arrive at a 12% lower maximum system cost of 10700 euro.

Of course, this calculated maximum system cost depends strongly on the assumptions. If we would require a much shorter payback time, the system cost would have to be much lower (see e.g. Hauer, 2010, requiring a system payback time of 5 years). However, if we assume that the reduction of fossil energy use is the main goal, and not primarily the economic return, it seems sensible to install a system that pays itself back within its lifetime. In this calculation, we have assumed that the maintenance for the seasonal sorption storage system is similar to the maintenance for a conventional system; if the maintenance would be more expensive, the maximum investment cost has to be lower to compensate for this. At present, it is not yet clear what realistic maintenance costs for this system would be, but it is not expected that the sorption storage itself will require significant maintenance. In addition, we have assumed no foregone costs for the installation of the conventional energy system, which means that we have the full conventional system installed next to the sorption storage system as backup. It may be argued that this backup is not necessary, or has a longer lifetime than a conventional backup heater in normal use; in either case the net investment costs of the sorption system would be reduced.

Seasonal storage system investment costs

In the previous paragraph the value of the system was calculated, and in the present paragraph the investment costs will be estimated to see how costs and value compare. The investment costs depend strongly on the maturity of the market. One-of-a-kind systems will be very expensive, while large scale mass production substantially lowers the costs. The same holds for the installation; if only one system is installed, all overhead (travelling time, crane hire, …) will be on the budget of this single project, while for large scale installation of many systems, such costs will be shared. It is important to make these assumptions clear and give an overview of the cost factors taken into account. Since the aim of the present study is to evaluate the economical potential of a fully developed system, one should assess the costs of the system components on the basis of a fully developed market for these systems, assuming large scale production of sorption storage systems that can be integrated plug-and-play into the building. Such a system consists of a solar collector array, a seasonal heat storage and possibly a borehole. For this case, estimated costs are presented in Table 1.

These costs have been estimated for the situation in which a large number of houses can be fitted with such a system, reducing installation costs for storage, collectors and boreholes. Other important assumptions are the use of a low-cost sorption material and low-cost solar collectors. It can be seen that for the present system, the sorption material costs are roughly 25% of the total system cost. This depends critically on the cost of the sorption material, that in this case is only 0,40 euro/kg. Although this cost may seem low, it is already higher than the material that is presently under research at ECN (which is magnesium chloride hexahydrate with a bulk price of 0,15 euro/kg combined with a low-cost carrier material of also about 0,15 euro/kg). Of course, if a more expensive material would have been used of about 3 euro/kg (such as zeolite), the total system costs would have been increased to about 28000 euro, leading to a payback time significantly longer than 30 years. Hence, for the economical feasibility of a seasonal sorption heat storage, it is essential that very low-cost materials are used.

With respect to low-cost solar collectors, it was assumed that mass produced all-glass vacuum tubes could be used. Such tubes have the potential of a high level of automation and substantially reduced costs. Although 100 euro/m^2 seems very low for solar collectors, such prices are already close to prices offered by Chinese vacuum tube collector manufacturers. For the borehole, a price of 750 euro is assumed, based on the estimated extra cost of using foundation piles with integrated heat exchanger. For the installation, it was assumed that the system, including solar collectors, sorption storage and piping, would be installed within 20 hours, due to an increased efficiency of work when multiple systems are installed simultaneously, and a high level of standardization and plug-and-play contacting. It was assumed that the vacuum tube installation would be installed as a standardized prefabricated roofing element placed within the building process. Also, it was assumed that the storage space would be a standardized deepened cellar created in the building process. Finally, it was assumed that all connections would be integrated in the standardized building design as much as possible.

	amount	unit	unit cost	total cost
TC material	7000	kg	0,4	2800
Storage casing	1	[-]	2000	2000
Vacuum Tube collector area	20	m2	100	2000
Collector system components	1	[-]	500	500
Heat exchangers	3		250	750
Borehole	1		750	750
Installation	20	hours	70	1400
TOTAL				**10200**

Table 1: Cost indication for seasonal sorption heat storage system

Comparing the total system cost of 10200 euro to the maximum system cost, that was estimated in the first paragraph as 10700 euro, it appears that the present system can pay itself back within its assumed lifetime of 30 years. This becomes more difficult if the assumed lifetime is taken shorter, but much easier if the fossil energy costs are higher, e.g. when comparing with Danish instead of Dutch gas prices. The largest cost factor is the materials cost, for which price reduction may be possible, given the prices of the material presently under study at ECN.

Conclusions

It is concluded that seasonal sorption heat storage is able to pay itself back within its lifetime under the given assumptions. An important assumption is the cost of the sorption material. It is shown that the cost of the sorption material has a strong effect on the overall systems cost and should be kept very low in order to reach this target. The evaluation method took into account the investment costs (based on future large-scale plug-and-play application of standardized systems and standardized dedicated building concepts) and the system lifetime, as well as interest (a low level for interest received and a high level for interest paid) and energy price scenario.

A large uncertainty exists in the results of this calculation, due to the fact that interest and future energy prices, as well as system lifetime and system investment costs (especially for future large scale application) are only rough estimates, but have a strong effect on the economics.

Literature

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