SOLAR/ELECTRIC HEATING SYSTEMS USING SMART SOLAR TANKS AND VARIABLE ELECTRICITY COSTS

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Abstract

By using forecast based system control and a smart tank design in a solar combi system, the excess electric power production, of for example wind power plants, can be used. This can both reduce the auxiliary cost in the solar combi system and increase the use of renewable power sources. The paper will present work, which will be realized to a product. By using the electricity price variations hour by hour to charge the tank, the auxiliary cost can be reduced by 30% compared to a fixed average electricity price and normal thermostat auxiliary control. By introducing forecast based control in combination with a solar thermal combi system with a smart tank with a variable auxiliary volume fitted to the expected coming heat demand it is expected that the auxiliary energy cost can be reduced below 50% compared to the reference situation.

1. Introduction

It is expected that the already large electricity price variations, existing in Denmark, will remain or even increase in the future. The low electricity prices almost down to zero, see figure 1, are often caused by high wind energy production in the winter period

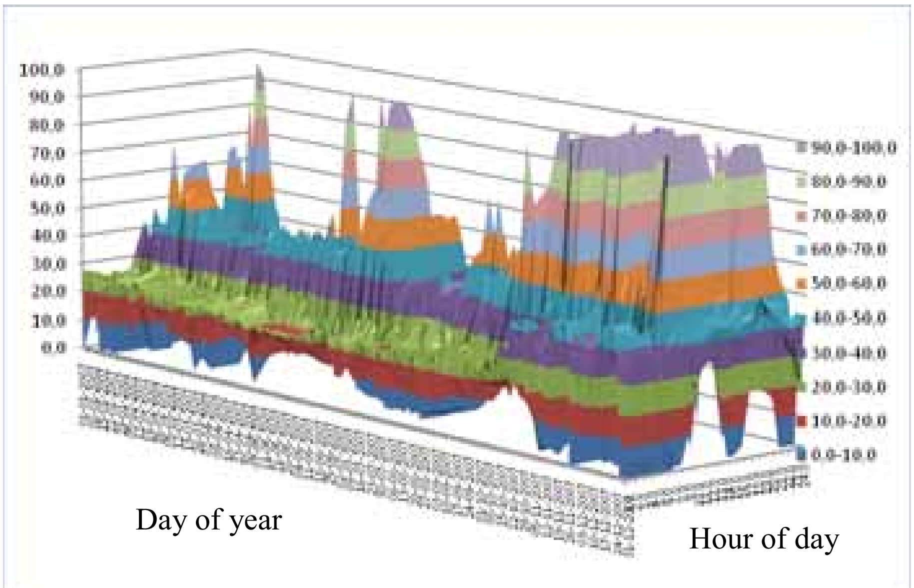

Figure 1. Example of the hourly electricity price variations during 2008 in western Denmark. Data comes from the NORDPOOL electric stock exchange. The unit on the y-axis is Euro/MWh at the production plant level in the system.

Presently 20% of the electricity in Denmark is produced by wind power. It is expected that this share will be increased to 40% in the near future. This will require adapted use of electricity, to the availability and price of electricity in the grid.

These price variations can be used in a solar combi system to charge the auxiliary part of the storage tank in a smart way, when the solar energy production is not large enough to meet the load.

In the high price end, the duration of the peaks in figure 1 are often short, so with a smart control of the storage auxiliary charging, these peaks can be avoided. This also leads to a positive demand side management effect, that is favorable for the electric grid and will give less need for operation of peak power plants, see fig 2.

In the Nordic countries, a common electricity stock exchange NORDPOOL exist, that creates hourly electricity prices 24 hours ahead each afternoon, for all days of the year. By using this information and also forecasts for weather, heat loads and solar heat production, the auxiliary energy cost can be minimized by only using periods with low prices. In this way also renewable energy sources with large variations in power production, can be utilized in a better way in the future.

The low cost electricity can be used both in the form of direct electric heating or via a heat pump system to heat the auxiliary part of the tank. Both variable auxiliary volume and variable auxiliary temperature can be favorable.

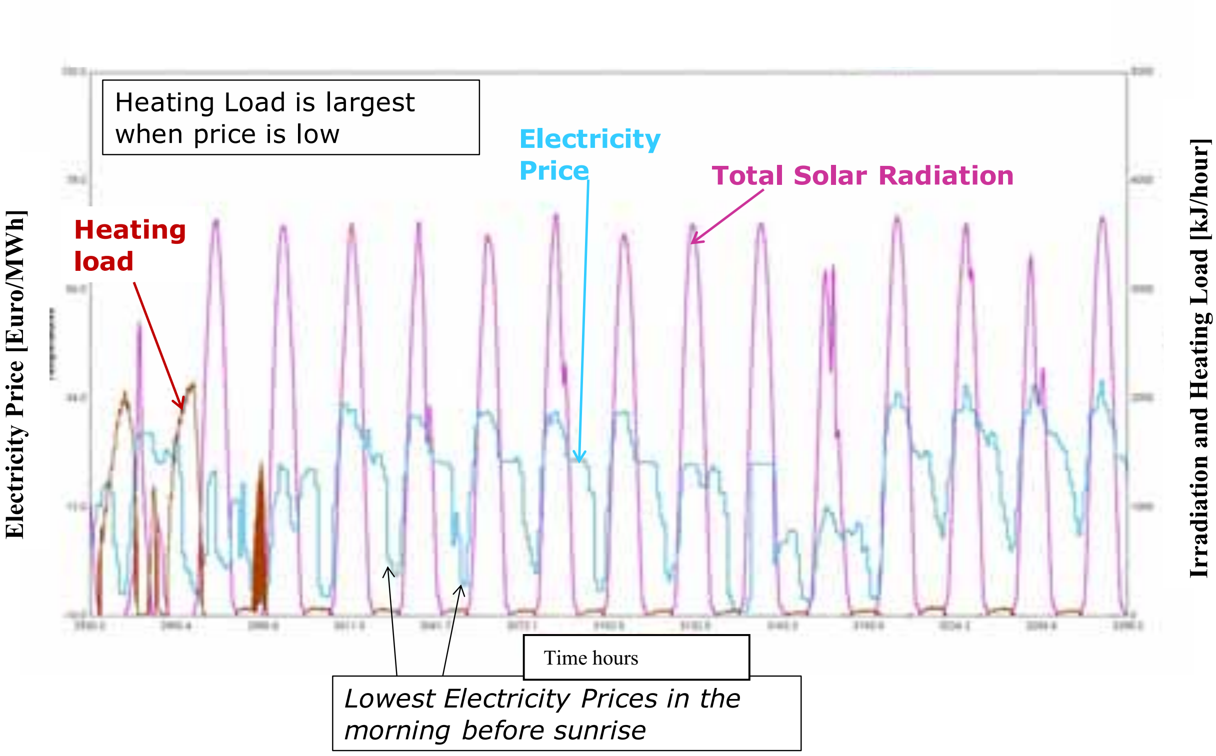

Figure 2. An example of positive covariation between high electricity prices and solar radiation availability. Also a good match between high heating load and low prices can be seen.

A TRNSYS model from IEA SH&C Task 32 (Ref [2] Heimrath and Haller) has been further developed to simulate a single family house with a solar combi system (Ref [1] Perers, Furbo, Andersen, Fan). The system can use a heat pump or direct electric backup system in combination. The control in the simulations are still according to electricity prices only. But forecasts for weather and price are planned to be used also in the real systems later.

The project is carried out in a cooperation between Department of Civil Engineering, Technical University of Denmark, Danish Meteorological Institute (DMI), DTU Informatics, Technical University of Denmark, ENFOR A/S, AllSun A/S, Ohmatex ApS, Ajva ApS and COWI A/S.

2.1. Description of the TRNSYS system model

The simulation model is based on the advanced TRNSYS deck created for IEA SH&C Task 32 for a single family combi system. Figure 3 shows the principal system layout. The TRNSYS deck is described in the IEA Task 32 work (Heimrath and Haller 2007).

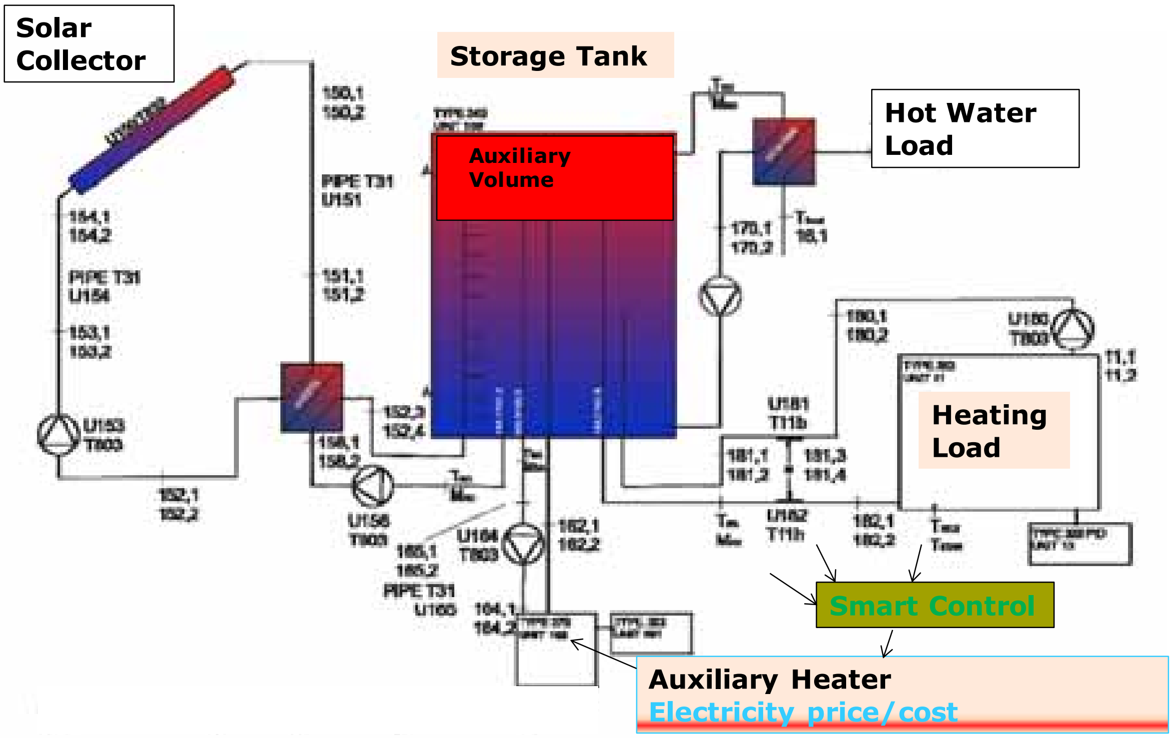

Figure 3. The solar combi system layout with solar collectors, auxiliary heater, storage tank and hot water and heating loads in the house. The diagram is taken from (Ref [2]. Heimrath and Haller 2007)

The system simulated needs more than 100 parameters to describe all details of the components, but the major system data are:

- Single family house. Old house 100 kWh/m^2 or 30 kWh/m2, yearly heat demand
- Electric auxiliary with different control strategies.
- Solar Collectors 5-15 m^2, Tilt 45°, south oriented
- Storage 500-5500 l water tank, stratified
- Climate: 2008 weather data from climate station at Department of Civil Engineering, Technical University of Denmark.
- Electricity Prices: Nordpool 2008. Denmark-East (DK2).

- Consumer Electricity Prices assumed to follow Nordpool prices (variable or a fixed average).
- Collector type: Standard Single Glazed Selective Flat Plate Collector.
  F’n0=0.8, F’UL1=3.5, F’UL2=0.015 , b0=0.18, Kdiff=0.9

2.2. Nord Pool data on Electricity price variations

The electricity price is determined each day at the electric stock exchange NORDPOOL. Historical data some years back has been derived and transformed so that TRNSYS can read and use the data in the simulations. Especially in west Denmark with the highest fraction of wind power the prices vary very much during the day and the year. Figure 1 shows an example of the hourly price variation for one year. The high peaks often occur during the day and the low prices in the early morning. Figure 4 shows the daily average prices for three years for Denmark West. It can be seen that the prices vary much from year to year too. There is also a day by day pattern that may be used with a larger storage in the solar combi system.

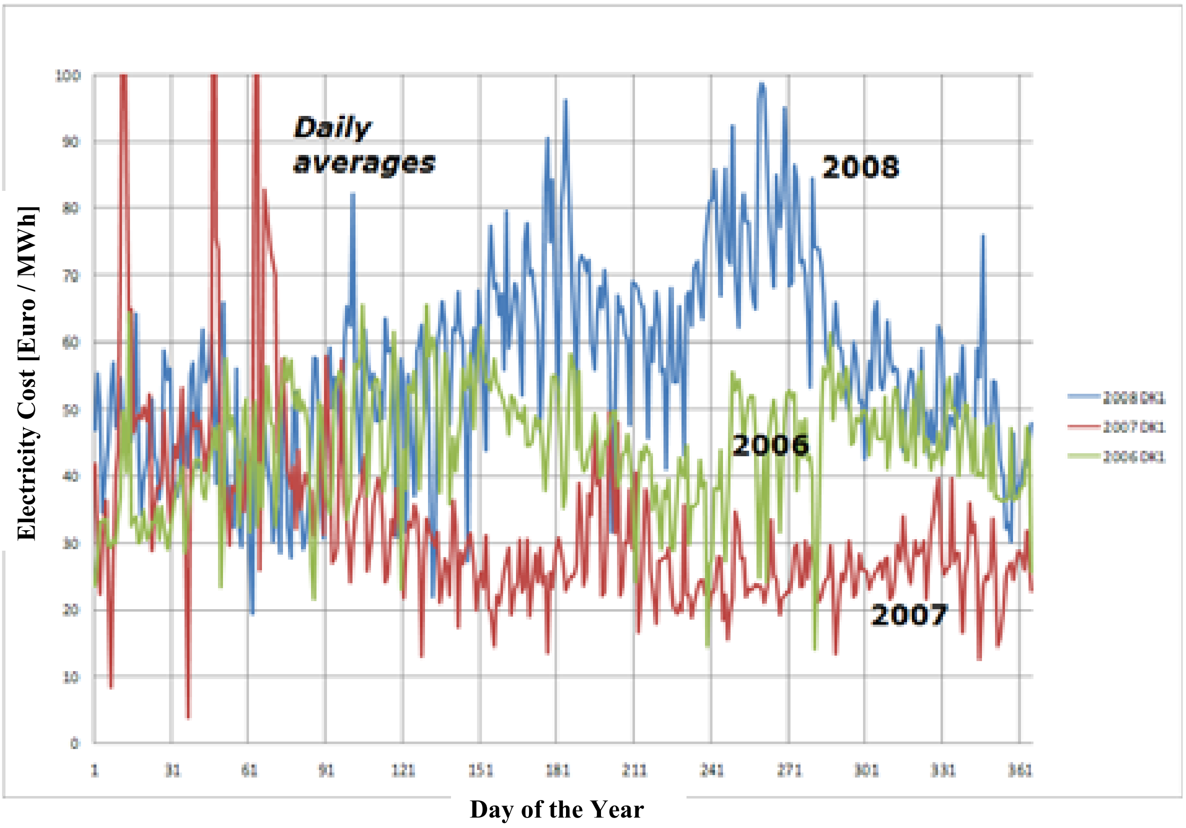

Figure 4. Example of the daily electricity price variations during one year in western Denmark. Raw data from the NORDPOOL electric stock exchange are used. The unit on the y-axis is Euro/MWh at the production plant level (what is paid to the producer) in the system. Final customer prices are much higher.

2.3. Climate Data used in the Simulations

Climate data from the weather station at Department of Civil Engineering, Technical University of Denmark in Copenhagen has been used together with Nordpool electricity data for the same time period (2008) and area (Denmark East) in the TRNSYS simulations. This gives a realistic situation in the simulations and also different control strategies can be evaluated with exactly known prognosis data if desired. Figure 5 gives an example of the annual variation of global solar radiation and wind speed data that are used as input in the simulations.

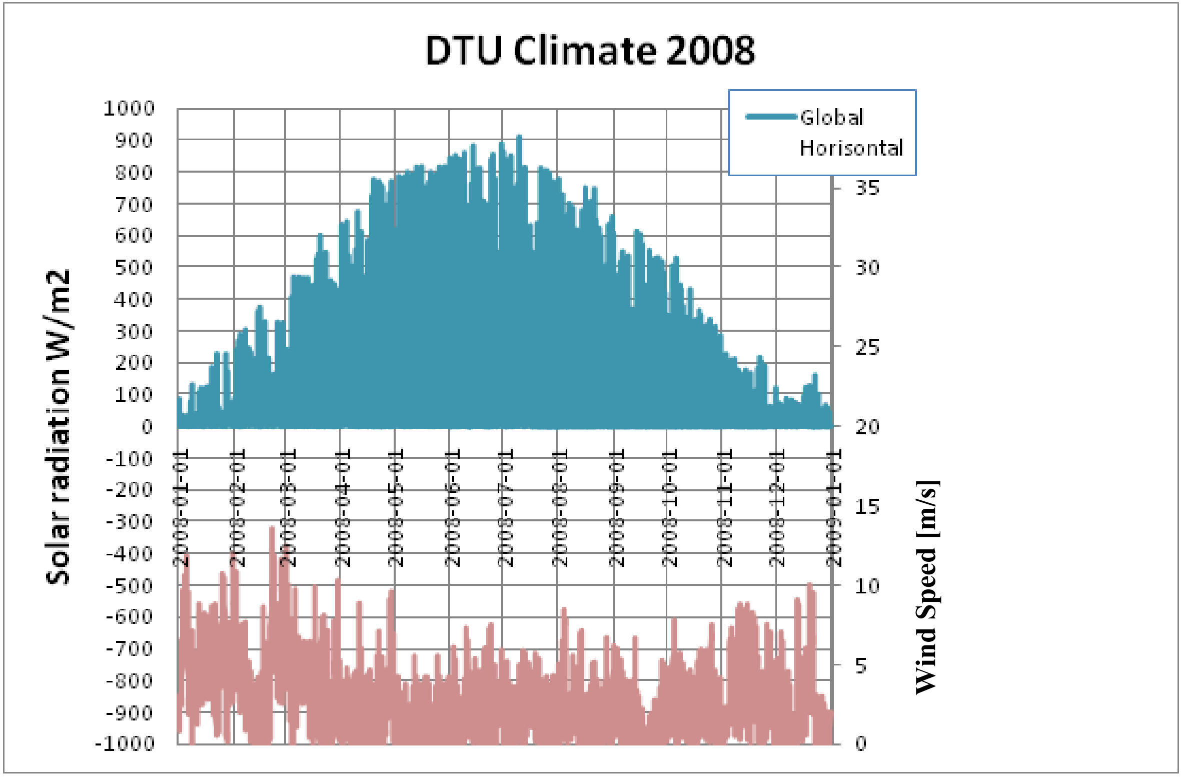

Figure 5. Example of climate data from the weather station at Department of Civil Engineering, Technical University of Denmark for 2008. The lower curve is wind speed with axis to the right.

It can be seen that the wind speed and solar radiation has a positive co-variation with higher wind speeds in the winter, when the solar radiation is low. It should also be kept in mind that the wind power is proportional to the cube of the wind speed so the electricity production will match even better if short term mismatch can be evened out by for example hydropower and a large enough storage in the solar combi system.

2.4. Basic System input data

To have limitation of the range of storage tank and solar collector sizes to start from in the project, the system simulations presented in figure 6 and 7 were made. It can be seen that a tank size of 500-1000 l and collector area of around 10 m² is reasonable for this load (100kWh/m2 house). This does not involve costs more than qualitatively, so later on, better estimates of the sizing may be found including more factors. The low flow concept is a matched flow concept. An adaption of the collector flow to the load flow gives the optimum collector output and energy savings.

The optimum volume flow rate in the solar collector loop is a bit higher than for traditional low flow solar heating systems.

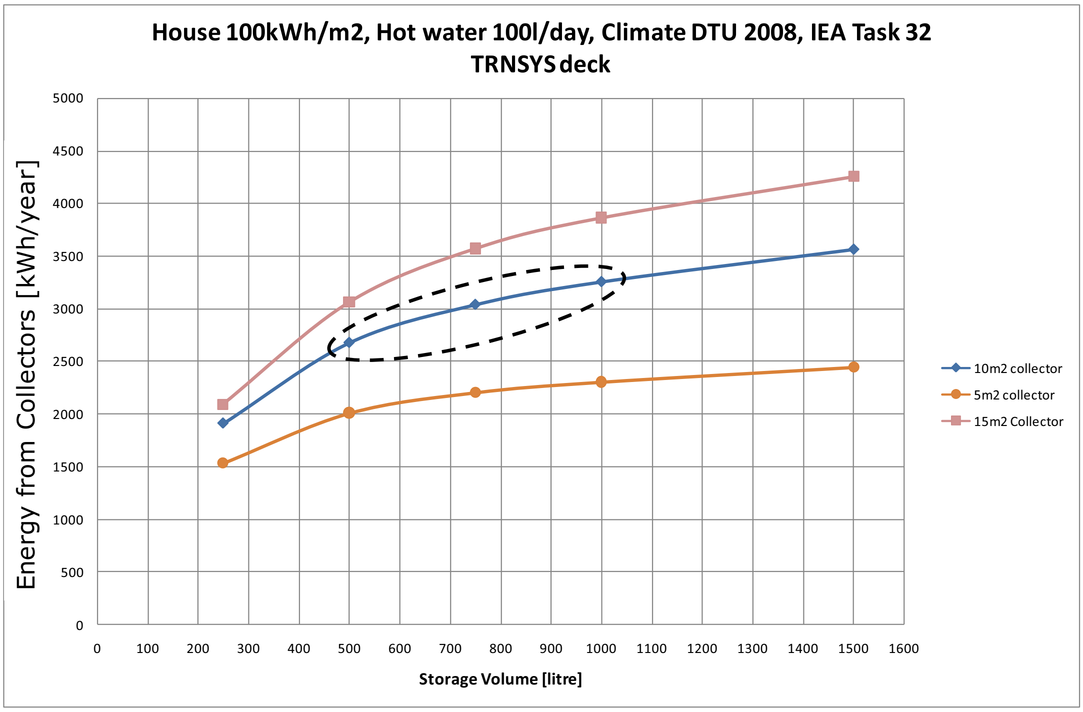

Figure 6. Optimization diagram for tank volume and collector area. A system sizing of 10 m² collector and 500 l storage was chosen as a first estimation of optimum size. Further considerations will probably change this choice somewhat later on.

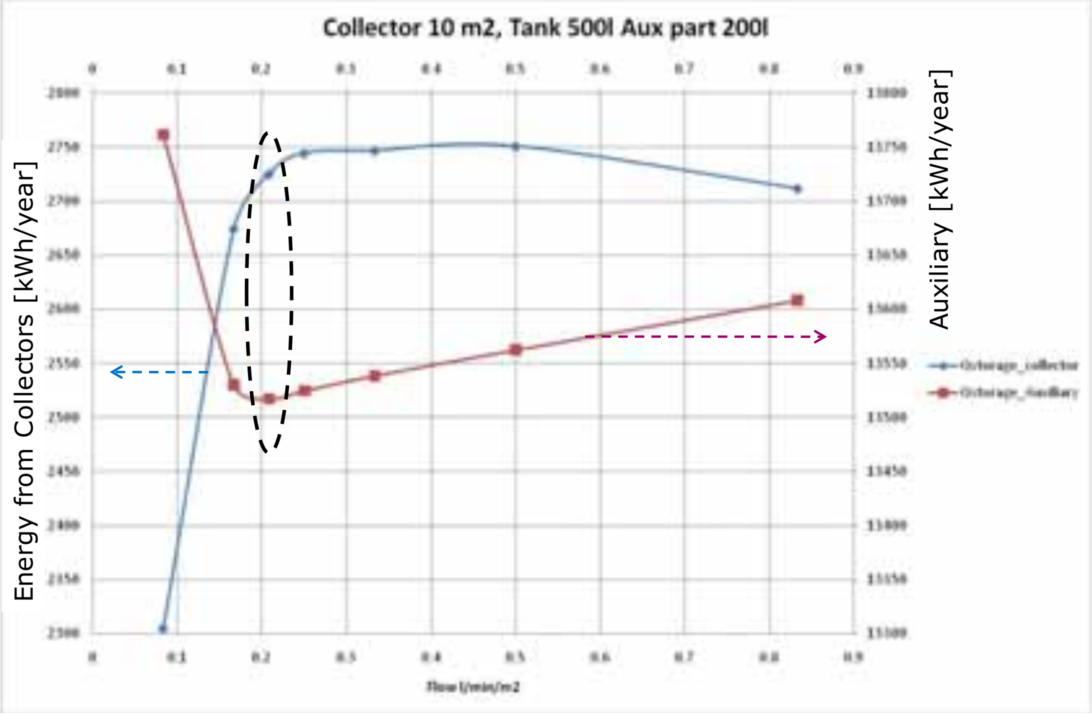

Figure 7. Flow optimization in the collector loop.

3. Simulation Results

This paper presents calculations with the TRNSYS system model to elucidate how best to design solar combi systems with advanced control strategies and smart tank design. The auxiliary energy cost for heating and hot water for different system designs is minimized. Figure 8 shows examples of calculated auxiliary costs for a 10m^2 solar combi system in a house with a yearly heat demand of 15000 kWh inclusive domestic hot water consumption, (DTU Lyngby 2008 climate) and NordPool 2008 electricity costs. The upper curve is a reference case with fixed thermostat control (63^{o}C) and fixed electricity price (annual average price). The middle curve is added to show the effect of only introducing a variable electricity price, but still normal fixed temperature (63^{o}C) auxiliary control. The annual cost reduction is 17% compared to the reference case. The lowest curve is for a proportional auxiliary temperature control strategy that use a higher auxiliary temperature set point during hours with lower electricity price (the hourly price is lower than the 24h average price). This means that more auxiliary energy is charged when the price is extra low during the 24h period. If the tank is too small to store enough energy between the low price periods during cold weather in the winter, a minimum temperature set point will heat the storage auxiliary part, independently of the price, to keep the comfort in the house.

The annual cost reduction with this simple strategy is about 30%. This is just an indication, what may be achieved with more advanced control and a smart storage.

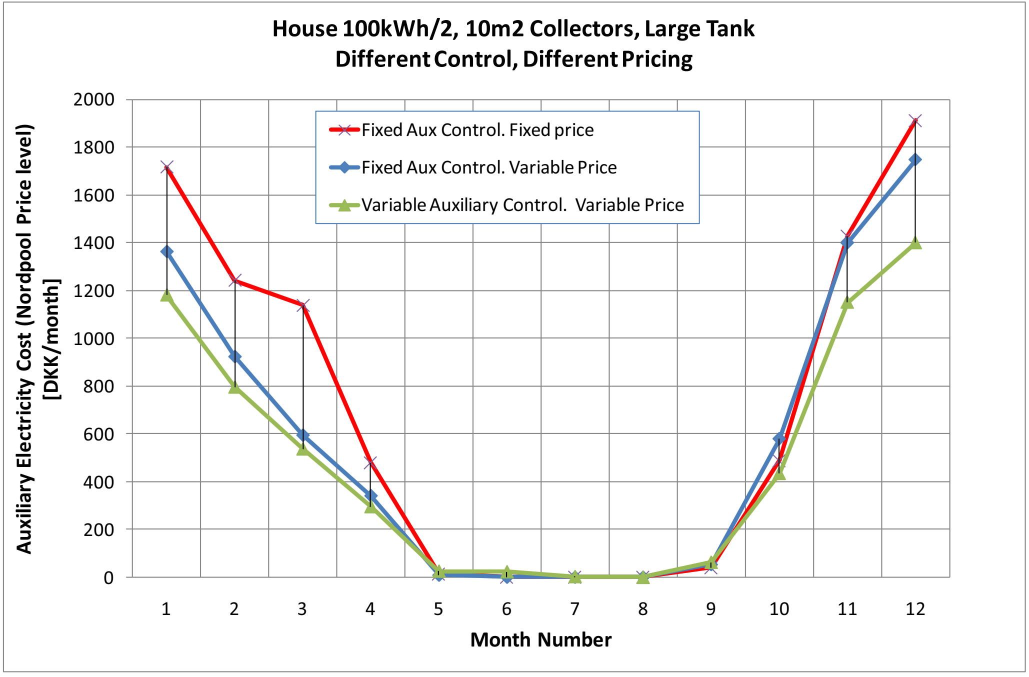

Figure 8. Example of monthly auxiliary costs for: Upper curve - fixed auxiliary temperature control 63C and fixed electricity price. Middle curve - fixed auxiliary temperature control 63C but variable price. Lowest curve - variable temperature control and variable price, but without forecast control.

It can be seen that just by introducing variable electricity price at the final customer a saving of about 17% can be achieved. This saving is dependent on the timing between the price and load, both during the day and year. This timing effect can vary from period to period, as can be seen in the figure following the difference between the red and the blue curve. On the average a customer would gain from variable prices, as the house needs most auxiliary heating power in the night when the electricity prices are low. This applies for both direct electric auxiliary heating and heat pump auxiliary heating as the load pattern is the same.

So far the main work has been spent on adapting the TRNSYS system simulation model, towards this project's requirements for advanced control of the auxiliary: Advanced simulation of the tank, input from local weather and NORDPOOL prices to the control system and forecast based control. Also careful check of the output of the extended system model has been done.

The electricity cost results presented are at NordPool electric stock exchange level. At the final customer the prices are often the double or triple. The future pricing and taxes are hard to predict. The known Nordpool cost level are therefore used and presented in the simulations. In the future system control unit the real customer price will be used as input of course.

Many more aspects can be studied in the future. The next steps in simulation studies for this application is the full implementation of forecast control in the TRNSYS model:

4. Conclusions

A TRNSYS model is available for the investigation of the interaction of a solar combi system with direct electric auxiliary heating or heat pump backup heating. Real climate and electricity prices can be taken into account.

The normal load pattern of a house already uses a significant part of the energy at lower electricity prices in the night and would benefit from a variable electricity price if implemented all the way to the final customer.

This system type would reduce peak loads in the grid due to the solar collector energy input to the tank during daytime when the electricity prices and demands are high. This will give an extra demand side management effect. The system will also use more of surplus wind power.

Much work remains in this project to model the system and components more exactly and find optimum heat storage design and control strategy of the system, based on weather and electricity price forecasts.

References

[1] B. Perers, S.Furbo, E. Anderssen, J.Fan . Solar/electric heating system for the future energy system. ISES Solar World 2009 Congress Proceedings. Johannesburg 2009.

[2] R. Heimrath and M. Haller. The Reference Heating System, the Template Solar System. Project Report A2 of Subtask A. A report of IEA SHC- Task 32. April 2007.

IEA Task 32 homepage: http://www.iea-shc.org/task32/index.html
Nordpool homepage: www.nordpool.com