Task 52
Solar Heat and Energy Economics
in Urban Environments

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

COST PERFORMANCE FOR SMALL SMART SOLAR THERMAL SYSTEMS OUTSIDE DISTRICT HEATING NETWORKS

Input to IEA SHC Task 52 Subtask A and C

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IEA Solar Heating and Cooling Programme

The Solar Heating and Cooling Technology Collaboration Programme was founded in 1977 as one of the first multilateral technology initiatives ("Implementing Agreements") of the International Energy Agency. Its mission is

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Content

1 Introduction

Other than for solar district heating, solar thermal systems attached to individual buildings face a significant market downturn all over Europe for several years already. On the other hand, every solar thermal technology enables CO_2-free heat supply and hence has the potential to contribute to future low-carbon energy systems in cities.

In this respect, this report aims to critically reflect on past solar thermal developments on the one hand side and to show opportunities and innovative ideas for future product developments in the field of small smart solar combi systems on the other side. The work is based on 40 years of research and development experience at Danish Technical University (DTU) and driven by the conviction that there is large potential for solar thermal applications in urban environments also outside of district heating supply areas.

Typical uses cases e.g. refer to new low-energy standard buildings or building blocks in cities or highly efficient single- and multi-family houses and housing areas in the suburbs. In order to exploit this potential, cost performance ratio, lifetime and reliability of these systems need to be competitive. New business models considering today's energy markets and market mechanisms need to be applied and last but not least an image upgrade highlighting modern and innovative aspects of this technology has to be put on the agenda.

1.1 Critical reflection on the evolution of domestic solar thermal applications

The individual or domestic solar thermal system type has been available for more than 100 years in different variants depending on climate, local conditions and traditions. The sometimes low reliability and low cost performance of *early* solar thermal products, introduced too fast, without appropriate testing, development and warranties, for example when subsidies have been introduced, have been a significant market barrier in the long run, when competing to well proven traditional heat sources like oil, gas, biofuels and electricity.

Too short term and fast changing subsidy systems without stable long-term policies have damaged the product and market development, rather than supporting in the long run. Companies cannot adapt quickly enough to sudden subsidy changes. The market also most often overreacts to such changes.

Oversizing of the systems, in an attempt to reach unrealistically high solar fractions, has also been a problem in some countries, leading to reduced cost performance and overheating problems in summer. This, in turn, has led to operating problems by fast glycol deterioration, high repair costs and shortened system lifetime. Now there are proven solutions to this developed by focused research.

During the last decades, a tendency has been to make the systems more advanced and complicated to reach high solar fraction. This has attracted some early customers. But it also has been less favourable for improving cost effectiveness and widening of the market. The Installers have also been left alone with difficult system solutions to build.

In most climates these small individual solar systems cannot give 100% solar fraction. They normally work more like an energy saving product for the house. An economically based sizing and system components adapted to that, is therefore very important to reach an acceptable cost performance and a larger market.

However, besides of the tendency to make systems more complicated but highly efficient also developments focussing on simplification and reduced material and installation effort evolved:

For example, in Denmark cost/performance ratio of solar thermal applications could be significantly improved by means of so-called drain back systems [1] where hydraulic system components are reduced to a minimum and hydraulic set-up is less prone to errors (Figure 1).

Figure 1: Drain back demo solar combi system in Sorø, Denmark (Source: DTU). This drain back system type, has the potential to improve the cost performance ratio significantly by eliminating glycol, one heat exchanger, one pump, check valves and two membrane expansion vessels for the storage tank and the collector loop. The storage tank is non-pressurized and can be made much cheaper and the tank-in-tank solution for hot water storage eliminates a separate heat exchanger and control for this part of the load.

1.2 New generation of smart small domestic solar thermal applications

Recent developments in electricity market mechanisms (deregulation) as well as the introduction of smart electricity meters in several European countries enable new business models for the heating sector.

More specifically, thermal energy storage capacities attached to solar thermal applications may be utilized as buffer for surplus resp. cheap electricity and hence provides flexibility to the operator.

Against this background, a project was initiated at DTU in order to demonstrate the smart utilization of excess electricity as an added value for owners and operators of domestic solar thermal systems and is explained in detail in the following chapters.

The investigations in this report are carried out as a part of the EUDP 13-ll project: Solar Thermal & Energy Economics in Urban Environments, j.nr. 64013-0533.

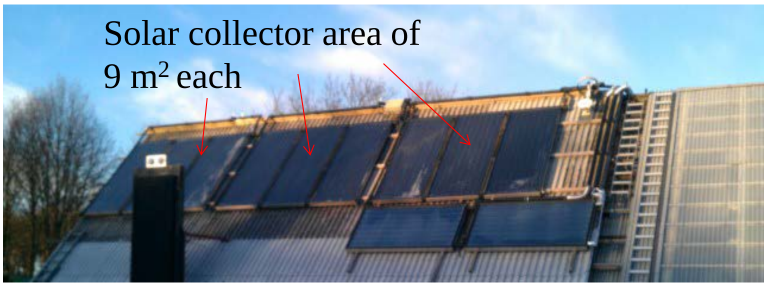
The project is economically supported by the Danish Energy Agency through the energy technological development and demonstration program, EUDP program.

2 Small smart solar thermal system approach

2.1 Ideas and concept

A domestic solar thermal system almost always has to have an insulated water accumulator tank, which can store solar energy for at least one day of energy consumption, to the night and also to the next day if it is rainy. In summer often an electric heater is used as a backup energy source to charge the tank if the solar radiation is not enough for some day. This is because the efficiency of many traditional boilers is very low in this period. This electric heater can be utilized in a smart control system all year round. The deregulation of the electricity market and introduction of "smart" electricity meters in some countries, have led to the possibility to use the relatively large tank in a solar thermal system, as a thermal storage for surplus electric energy. Then low-cost electricity can be used as a backup heat source.

The low-cost periods are expected to be more and more related to overproduction of renewable energy sources such as wind and PV. Therefore, the backup also will be renewable based, if smart control is used. Three demonstrator smart solar combi systems, installed at the lab at DTU are shown in Figure 2.



Dimension of the outer tank	
Diameter [mm]	800
Height [mm]	1568
Volume [l]	788

Figure 2: Small smart solar thermal demonstration system Denmark (Source: DTU). Three smart solar thermal combi systems have been tested and demonstrated at DTU. They use low cost electricity as backup energy. The upper picture shows the three collector arrays. The lower picture shows the three different variants of storage tanks tested I parallel.

Traditionally the low-cost electricity periods are also connected to low load periods at night, when the "society is at sleep" so to say see Figure 3. Therefore, a thermal storage also will help to avoid the high cost/peak electric load periods for example in morning and early evening. Then expensive fossil fuelled gas turbines can reduce their operating time in the electric grid. This action is very similar to battery storage in the grid, but thermal storage is much cheaper per stored kWh. The cost ratio is roughly a factor 5-10 between batteries and thermal energy storage per stored kWh today.

From Figure 3 the very regular pattern of low prices in the morning hours after midnight, when most people sleep can be seen. This is still just an example. The variations can be different from year to year and depending on the fraction of different renewables and traditional power plants.

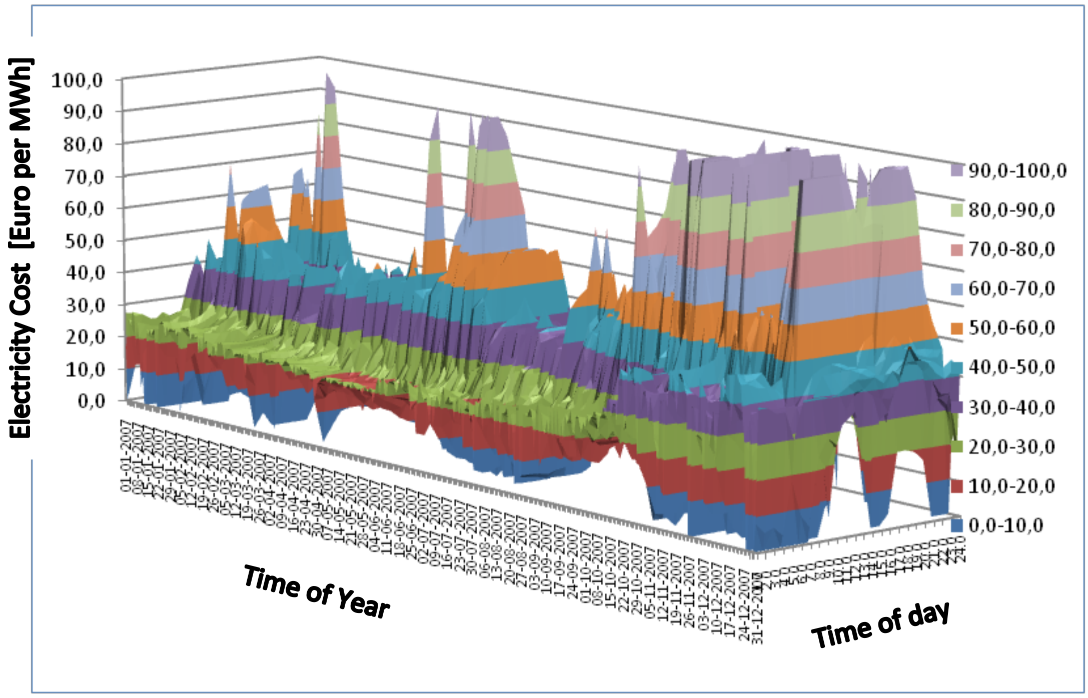


Figure 3: Example of electricity price variations in western Denmark [2] during the day for year 2008.

The use of electricity as backup for the solar thermal system can also involve a heat pump to use the electricity with higher efficiency for thermal use. The drawback is that the heat pump size and then also the low temperature heat source for the evaporator may need to be enlarged, as the low-cost electricity periods are expected to be just for shorter periods during day or night. An extra-large direct electric heater in a tank is comparatively cheap per kW delivered heat as long as the main fuses for the house do not need to be increased too much.

The solar storage tank can also be used to increase the self-consumption of local PV production, if needed. This option is very dependent on policies, taxes and rules for export of electricity from the house compared to self-consumption. The house in figure 1 has both PV and solar thermal systems and the storage might be used for increased self-consumption of PV, at a very small extra cost.

Lastly an often underestimated barrier for solar thermal systems has been that you have to invest a large amount of money in advance and then slowly get the money back during 10 to 20 years, in the form of almost free renewable energy. This is a very different economy, almost impossible to value for a normal house owner, compared to oil, gas or electricity, where you pay a relatively small amount each month that is less visible. *This economy also means that the performance, reliability and lifetime of the solar heating system have to be proven.* This takes time to gain confidence in, on the market. One could compare to the silicon PV technology, which has been on the market for more than 40 years and has showed very high reliability. It is now coming down in investment cost and suddenly the market is booming, even if the payback time still is not far from expected life time of the PV system and much longer than for a modern Solar Combi system.

Solar Thermal systems have from time to time shown many unnecessary small reliability problems both due to wrong material choice, but also wrong design, oversizing and wrong installation practice. The most recent major problem is glycol degradation during stagnation in the solar collectors. This is now solved, but it increases the investment and operating costs a bit. Therefore, other system types can be more favourable for the future, like drain back systems. Drain back systems eliminates the need for glycol and many of the components necessary in a glycol filled solar system. Also the tank can be pressure less and much lower in cost. The demo system in figure 1 is one example of future possibilities to reduce costs and at the same time improve performance as water is a better heat transfer medium than a glycol/water mixture and no heat exchanger temperature losses and reduced collector performance.

An important economic fact is also that when installing a modern solar combi system the savings for the house owner in purchased energy, can be much larger than the solar collector energy production. An investigation at DTU has shown that the savings can be in the range of double the solar heat production due to these reasons. This is often forgotten in economic investigations including solar.

It can be due to replacement of an old inefficient boiler. Especially during the summer an old boiler can have just 50% efficiency when only producing hot water. The standby losses can be large. A modern better insulated well stratified storage tank can also save energy all year round. A slightly oversized combi system can also produce extra energy in summer “for free” via tank losses to keep the basement a bit warmer and drier. It is common in old houses that you get problems with mold and fungi in the cellar when renovating to a modern more efficient boiler as the basement gets much colder in summer. Then solar thermal can contribute to cover this heating load too.

Another neglected economic fact is also that when replacing an existing heating system with a solar combi system, the marginal solar economy should not include the full cost of the storage tank and installation in the basement, as these costs would be there also without solar.

There have also been investigations indicating that a house with a solar combi system can have a marginally higher sales price that can pay back some of the investment and could be considered in a full economic analysis from the house owner situation. Especially if proven long lifetimes are verified in the future for these systems.

Still when contributing to the individual house solar costs for the Subtask A for national simulations, these added savings and economic consideration above, were not included, as there was no means to fill that into the input table. One reason for leaving some of them out is that the national studies are looking at socio economics and not private economy. But they can be seen as a large potential for private cost savings in the future at least by a factor of two, see ref [3], for the true marginal solar cost, if these effects above are considered in the way a house owner could count it economically.

With this background of 40 years of solar research and development at DTU, ***we see a significant potential for improvement of the cost performance of these individual solar thermal systems in the future***, if relevant design improvements are applied and better educated professionals are working with solar thermal and the full economy and performance of solar combi systems are applied. The use of smart technology to let the system interact with the electric grid can further improve the cost performance, at low marginal cost. *To get this to happen also smart sustainable energy policies are very important,* that gives the final energy user full economic credit when acting positively to the benefit for the national energy system.

2.2 Outcomes

A simplified Excel tool has been developed and used to estimate the value of smart auxiliary control in combination with a solar combi system. Figure 4 shows the annual net electricity cost savings both by adding solar and smart control. Results for two different house insulation standards are presented. The results are for the Danish climate and electricity price variations. The tool can also be used to investigate a lot of other conditions but then a lot of parameters need to be specified to get realistic results. Figure 4 should therefore be seen as a typical result for north European conditions.

Taxes and other additional costs of electricity are not included. Most of these additional costs except VAT are fixed in DKK per kWh and will not affect the marginal savings between the alternatives shown in Figure 4.

The point for 0 m² and the smallest tank size, indicates the annual electricity cost without solar and only a small effect of smart control.

The total potential for solar + smart control in raw electricity cost level [4] is about 40 - 50% savings. But the exact value depends on what is cost effective in the individual situation. At present no credit is given to the system type that also reduces peak loads in the electric grid for the house. The calculations here, gives indications about the allowed cost for the different smart control options. Products like smart controllers have to be developed that meets these cost targets.

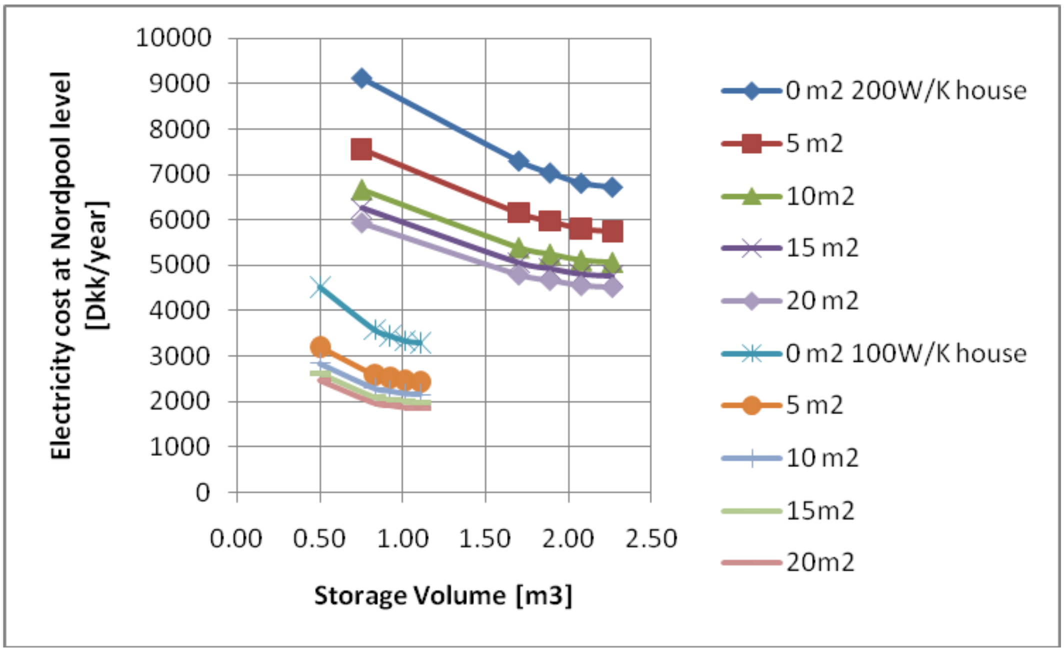


Figure 4: Raw electricity cost at Nordpool level [4] for differently sized solar combi systems. Results for two houses, one old and one modern are shown. The 0 m² and smallest tank size, indicates the annual electricity cost without solar and only a small effect of smart control.

To make an overview sensitivity analysis between different "smart" options and active energy saving measures and also for different geographical locations, a comparison of annual electricity costs is made in figure 5 next. The cost level used is the same as in Figure 3, just the net electricity price without additional taxes or fixed costs for electricity. The same electricity cost time series variation is assumed for all locations to make them comparable.

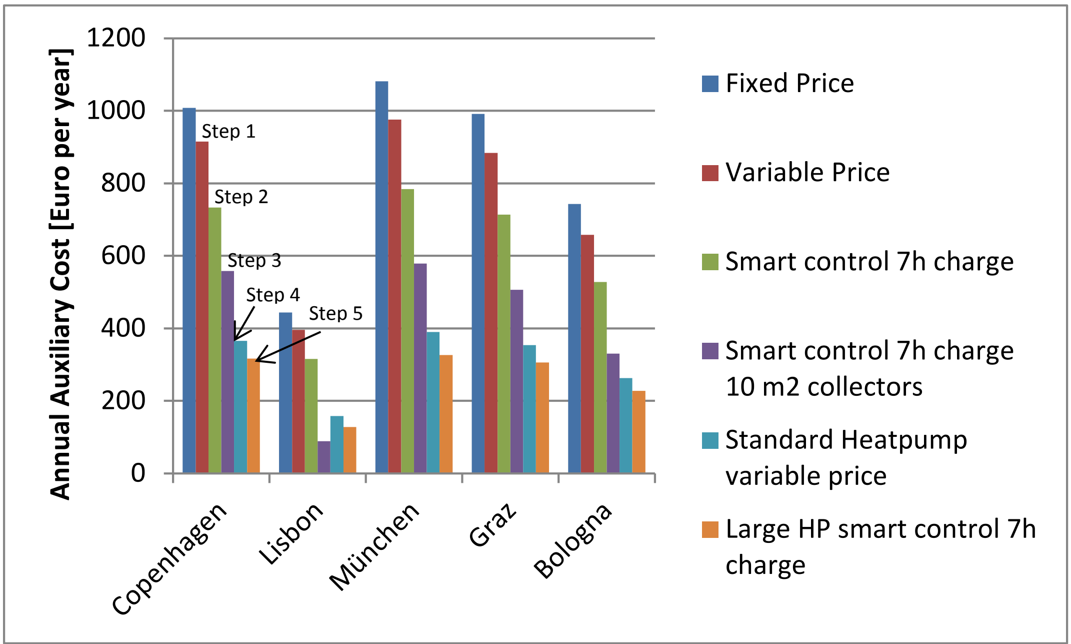


Figure 5: Annual purchased net energy cost comparison for an old house, at five locations in Europe. Five different options for smart control and energy saving measures by solar collectors or heat pumps are compared to the cost in a normal house with fixed electricity price all year. The cost per kWh is according to the Nordpool [4] level. No taxes or levies are included.

In the fig 5 step 1 difference it can already be seen that going from a fixed cost at the annual average price level, to an hour by hour variable electricity price, reduces the auxiliary cost by almost 10%. This is because the heating load of a house is higher at night, when the electricity prices are low.

The step 2 difference is smart control in combination with a larger tank so that all electric energy can be purchased at night with the lowest prices. A 7 hour charging time is chosen to reduce the electric power needed. The total savings is around 25%.

The step 3 difference is adding 10 m^2 of solar collectors and keeping smart control with maximum 7 hours charge at night. The charge is also forecast based using the expected heating load and solar contribution the next day. The total cost savings is then around 50% in most cases except Lisbon, where the favourable solar climate gives an even higher cost reduction.

The step 4 difference is adding a full sized heat pump for the auxiliary charge of the tank, but without smart control and solar collectors, just applying variable electricity prices as they are during the operating time. The heat pump sizing is chosen to manage the highest heating load during the year, so that no direct electric backup is needed. This saves around 65% in auxiliary cost.

The step 5 difference is introduction of an extreme double sized heat pump with a storage size for 7 hour charging time. This saves surprisingly little extra. But this is mainly because the heat pump maximum power is still too small to use the lowest electricity prices efficiently. This is a weak point of heat pumps, concerning smart control, that the maximum power is very limited when considering the cost including larger cold heat source arrangement to meet larger thermal power capacity. (This means larger heat pump, deeper borehole and longer pipes). Another weak point for smart control application of a heat pump is that it has a significantly reduced COP when regularly charging a tank to high temperatures for efficient storage. The store has to be much larger and more costly then, as the heat pump may not even be able to charge the store to above 60°C.

Figure 6 gives an indication of the energy savings potential in kWh for different locations by adding solar collectors. Both total kWh and kWh per m² of collector.

The kWh results in Figure 6 are not so much influenced by smart control. But when the probability is high for sunny weather the next day the controller can charge the tank less the night before to allow for solar charging the next day. Otherwise the overheat protection system of the collector loop will stop the collector charge, if the tank gets fully charged during a sunny day and less solar energy is utilized. This effect of smart control could also be used to minimize the tank size.

But this possibility for fine tuning of the system investment cost and performance has not been considered in this simplified study, focusing on the smart auxiliary control and electric grid interaction to give basis for further product development. This focus is motivated both to improve the private economy of these systems but also to the benefit to the whole electricity system by reducing peak loads and using surplus electricity at night that could for example be wind power overproduction.

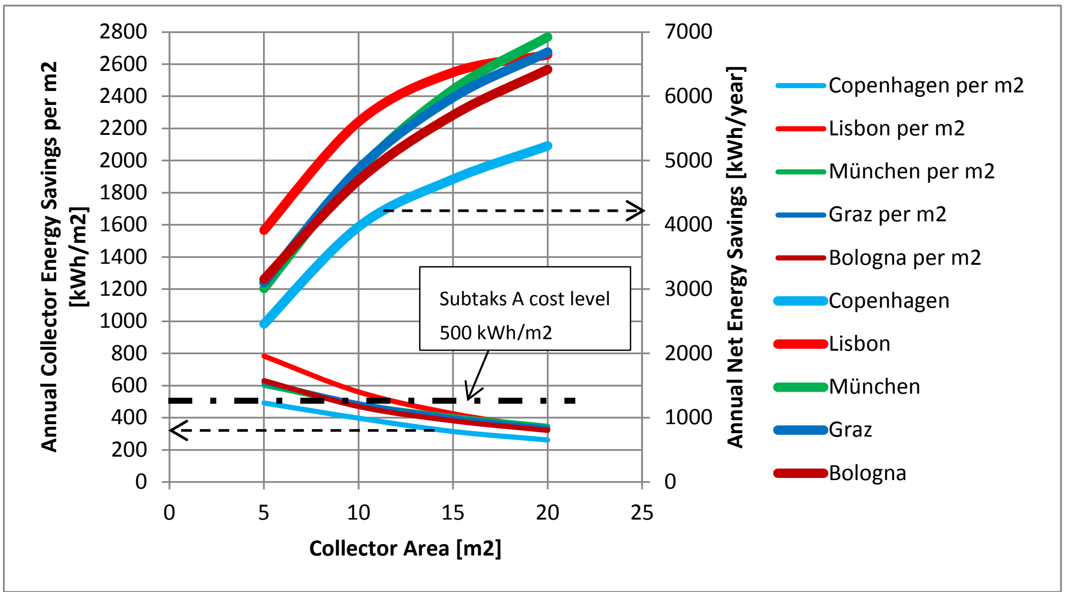


Figure 6: Energy savings by adding solar collectors to an old house (200 W/K)

It can be seen for example that the approximate net energy savings by solar collectors is in the range of 500 kWh/m² for 5-10 m² of collectors for most locations, as assumed for the input for small system to subtask A calculations. A typical flat plate collector efficiency is assumed. Other collector designs may give slightly other results per m². The choice of collector type is an economic optimization and sometimes also an additional visual impression consideration for the house. The total net energy savings is in the range of 4000-5500 kWh per year for 10 m² of collectors depending on location. The high values may come from the smart control that gives more room for solar charge into the tank in the summer period.

Note that net energy savings are used and do not include additional savings compared to an old system that is replaced by the combi system. Then almost the double savings can be the results of the investment, if a traditional inefficient boiler and tank system were assumed. Often the lowest efficiencies of an old traditional heating system occur in summer, when an old boiler can have very low efficiency for hot water production.

A full private level cost/performance analysis should also include these savings starting from an existing system. This report cannot cover all necessary steps for such a study, as the new ideas are not on the market so price and installation cost information are not available.

Therefore the results given in this report should more be seen as basic information for allowed cost levels and may be useful for future product developments. The project [5] was meant to be continued in a follow up project, towards cost effective smart products. But further funding was not approved, so therefore this step still remains.

3 Conclusions and Summary

There is still a significant potential to make small individual house solar heating systems more cost effective.

The systems can be simplified and have a more standardized design. Mass produced prefabricated components can be used making the installation cheaper and more reliable.

Step 1. Just by going from a fixed average electricity price, to an hour by hour variable electricity price, a 10% savings in auxiliary cost can be achieved. This is because the heating load is larger at night, when the electricity prices are lowest during a 24 hour cycle. Daytime passive solar gain through windows and higher outdoor temperatures add up to reduce the heat load. This solar contribution is seldom counted, as it is passive.

Step 2. Smart control utilizing variable electricity prices can further reduce the auxiliary cost by roughly 25%, without using solar. This is compared to a traditional system for heating and hot water production.

Step 3. The addition of 10 m^2 of solar collectors + smart control can reduce the auxiliary cost by 40-50% still compared to a traditional reference system.

Step 3. A heat pump is not an ideal heat source for smart control. The maximum heating power at normal sizing rules, is relatively low. Therefore a lot of direct electricity at COP=1.0 has to be used, to utilize the short periods of low electricity prices.

Step 5. Even a double sized heat pump can't reduce the auxiliary cost significantly over a normal heat pump installation, working on the actual hour by hour electricity prices (operation without smart control).

All the % values given above are based on raw electricity cost savings without taxes or fixed electricity costs and refer to a standard reference system. The absolute savings in Euro per year will most likely be similar as in the diagrams. But the % savings can be lower when including other more or less fixed energy costs. This is a further barrier for smart systems.

A change to taxes and grid costs that are more proportional to the raw electricity price could make a large difference on the market, towards more smart use of electricity.

The differences in results between different locations in Europe are not huge when assuming the same variable electricity price pattern. But of course the solar savings will be larger at lower latitudes, especially south of the Alps, for a given solar collector area if the system is not oversized.

Note that these figures do not account for the extra savings that normally occur when the smart solar combi system replaces an old inefficient heating system. Often the savings are almost double compared to the net solar contribution as the largest savings is in summer when a traditional system can have very low efficiencies.

Subtask A cost performance inputs for small individual solar systems

As input to the subtask A for large system calculations on national level, a table with cost performance data is shown in Table 1. Exact numbers are impossible to give here as this system type is still under development and the market size is too small in most cases to allow mass production of specially adapted components like pumps, tanks pipes etc. Also the installation volumes are so small, that the present labour costs are higher than necessary.

Neither the extra energy savings, when replacing an old inefficient system, with a modern solar thermal system, or the value of smart auxiliary controls are included in Table 1. This may have a significant added economic value, both for the individual owner and on national level to reduce peak loads and better use of surplus renewable production from for example wind power. The calculations on national level in subtask A should be able to quantify this.

In a previous DTU project [5] investigating these smart solar combi systems a significant socio economic value was found already if just 10% of the potential for these systems were realized in Denmark.

Table 1: Input data to subtask A calculations, for small solar combi systems.

Technology:	**Conventional Solar Thermal Panel**					
Country:	**Denmark**					
Type:	**One-family house, existing building**					
Year	2015	2020	2030	2050	Note	Ref
Energy/technical data						
Typical size per unit (m^2)	6	6	6	6	A	1
Typical size per unit (kW)	4.2	4.2	4.2	4.2	A	
Estimated annual production (kWh/m^2/year)	500	500	500	500		
Estimated annual production (kWh/year)	3000	3000	3000	3000		
Technical lifetime (years)	20	25	30	30	B	1
Financial data						
Specific investment (1000€/m^2)	0.9	0.85	0.8	0.6	C	1-4
Specific investment (1000€/unit)	5.4	5.1	4.6	3.7		1-4
Any additional specific investment (1000€/unit)	n/a	n/a	n/a	n/a		
Fixed O&M (€/unit/year) or (€/kWh)	40	40	40	40	D	
Variable O&M (€/unit/year) or (€/kWh)	22	22	22	22	E	

Notes

A. Fixed average size but increasing efficiency is assumed. Typical range is from 3-15 m2 in one-family houses. 1 m^2 is equivalent with 0.7 kW.

B. Increase due to better materials/fluids

C. Depends on existing heating system. Savings if tank should be changed anyway. For new buildings solar heating system costs are lower.

D. Service checks, liquid etc., 40 EUR/year in average for small systems and 100 EUR/year for large systems.

Table 1 References:

1. Solvarme/faktablad, ww.altomsolvarme.dk

2. Tænk, december 2009.

3. www.batec.dk.

4. www.sonnenkraft.dk.

4 Acknowledgements

The investigations are carried out as a part of the EUDP 13-ll project: Solar Thermal & Energy Economics in Urban Environments, j.nr. 64013-0533.

The project is economically supported by the Danish Energy Agency through the energy technological development and demonstration program, EUDP program.

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[1] R. Botpaev, Y. Louvet, B. Perers, S. Furbo, K. Vajen. Drainback solar thermal systems: A review. Solar Energy (2015)

[2] B.Perers, S.Furbo, E.Andersen, J.Fan. "Solar/Electric Heating system for the future energy system". ISES Solar World Congress 2009 proceedings, Johannesburg, South Africa.

[3] Furbo, Simon; Fan, Jianhua; Andersen, Elsa; Perers, Bengt. Energy savings for solar heating systems in one family houses. ISES Solar World Congress 2011 Proceedings. 2011.

[4] NordPool Spot homepage for electricity prices: http://www.nordpoolspot.com/

[5] Simon Furbo, Mark Dannemand, Bengt Perers, Elsa Andersen, Jianhua Fan, Peder Bacher, Henrik Madsen, Rasmus Halvgaard, Henrik Aalborg Nielsen, Kristian Pagh Nielsen, Sisse Camilla Lundholm, Bent Hansen Sass, Thomas Engberg Pedersen, Jakob Nymann Rud og Kristian Harley Hansen "Solar /electric heating systems for the future energy system" DTU Civil Engineering Report R-288 (UK) May 2013