BARRIERS AND POSSIBILITIES WITH DOMESTIC SOLAR HEATING – ADVANTAGES OF AN INTERDISCIPLINARY APPROACH

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1. Introduction

Research within solar energy has traditionally focused on increasing the system efficiency by developing and improving the technical components. Thermal solar collectors for hot water production have been markedly developed since the 1970s and the solar heating technology is today well-developed and has reached cost-effectiveness in many applications. Still, the implementation rate and use of solar heating remains modest.

Laboratory experiments and system simulations in advanced computer programs are frequently used methods within the present solar heating research. However, in a wider perspective, the technology should be used by people. Market actors, such as architects, installers, property developers and users, are highly influential on the implementation rate, but they are often overlooked in research and development. To achieve a state of common use of solar technology more than the purely technical aspects have to be considered.

In this paper, a socio-technical framework has been applied to solar heating to grasp the complexity of the low implementation rate and to connect technology with market actors and the social context in which the technical systems appear. The system boundaries are widened and traditional engineering methods are combined with methods usually not used within engineering research. The focus is still on technical systems, but by utilizing time-use data the user is introduced in studies of technical performance, while technology is seen in its social context by carrying out interviews. Solar heating is here regarded a socio-technical system, comprising both social and technical components. Social components may be market actors, legislation, politics or cultural aspects.

The paper is based on a doctoral thesis within Engineering Sciences, presented at Uppsala University, Sweden, in 2009 (see Lundh, 2009). The research focused on storage issues and system solutions and how social aspects may be brought into technical studies to improve the understanding of solar heating. Some of the obstacles that can appear in the planning, installation and utilization phases were identified using Sweden as a case study.

This paper presents one approach to understand the interaction between technology and people by investigating some aspects of solar heating technology in its social context. Obstacles preventing the dissemination of solar heating technology may then be identified and thereby contribute to finding solutions to the slow implementation rate.

1.1. Aim

The aim of the overall research project was to widen the system boundaries and methodology in solar heating research from pure engineering studies of materials and components to studies of solar heating technology and technical systems in a social context. The hypothesis was that both possibilities and barriers appear in the interaction between technology and people, and not only in technology itself.

This paper aims at presenting a socio-technical approach and give examples on how new methods may be used in engineering research to enrich studies of technology. It further aims at discussing advantages and problems associated with an interdisciplinary approach.

2. Methodology

Research within solar heating systems has a major focus on complex dynamic simulations of different system solutions. This is an excellent method to perform low-cost experiments on systems. The simulations, however, most often only focus on the technical components and highly simplify the social context in which the solar collector system is operated. To introduce social aspects in simulations, but also to studies of solar heating technology in general, methods from other disciplines were applied in collaboration and under supervision of a social anthropologist and a cultural geographer respectively. Those methods are described below, while the complementary engineering methods, such as experiments and simulations, are left out. The aim of this section is to explain how the different methods complement and interact with each other.

2.1. Systems approach

A systems approach characterizes all sub-projects. A system is considered comprising a set of components interacting with each other to reach a mutual goal (see also Churchman, 1973). The *performance* of the system, which often differs from that of the individual components, is the main focus in system studies. It defines what belongs to the system and what does not.

The methods or tools in system studies are not given, but should be chosen with regard to the problem to be solved, which enables interdisciplinary use of both methods and theories.

System boundaries do not need to be physical ones, such as the walls of a building. Instead, what is not influenced by the system is considered belonging to the environment, while the environment still influences the system. A broad system perspective and including values that are difficult to quantify is usually stressed in system analysis. Consequently, the social context, which is traditionally regarded as belonging to the environment, is preferably considered part of the system, added as components, and intimately interacting with the technology.

2.2. Socio-technical framework

In contrast to technical systems only comprising artifacts, technical components and appliances, or social systems in terms of the market, political or economic systems, a socio-technical system includes both artifacts (i.e. man-mad objects) and market actors (social components). The socio-technical perspective is here used as a means to relate to problems within system studies. It is used as an interdisciplinary framework to widen the system view of an artifact to also include the social context in which technology appears, and thereby allow studies on a higher system level.

The socio-technical system perspective originates from a movement towards multi-disciplinary research within the social sciences in the 1980s and 1990s (Summerton, 1998), but there is no unambiguous definition of such systems (see for example theories such as Large Technical Systems (Hughes, 1983), Social Construction of Technology (Bijker et al., 1987) and Systems of Innovation (Berner, 1999)).

With this view, artifacts and technology are not isolated, meaningful objects, but rather intimately embedded in a network of both social and technical factors. They are only valuable in a social context, i.e. when they interact with people and are used by people. There is no clear boundary between technical and social systems. During the development of an artifact, there are always market actors strongly influencing the technology by what they do, but also by what they refuse to do. Politics, culture and the physical surrounding influence the artifact as well.

Although socio-technical systems surround us in everyday life the focus in research is in most cases either on social or technical aspects. In this paper, both considerations are taken into account and are brought together. In practice, this means to introduce market actors in the normally strictly technological world of solar heating systems, but also to consider people's choices, political decisions and organizational structures, and how it influences the use – or lack of use – of solar heating.

2.3. Case study methodology

One method to systematically examine a phenomenon or limited system is case study. Just like the systems approach, but in contrary to many other research methods, a case study does not claim any specific method to collect and analyze information. The main advantage is the ability to manage different empirical materials.

A case study is often based on *how* and *when* questions and examines a specific occasion. It is particularly suitable when it is difficult or impossible to manipulate the relevant variables influencing the study object. It does not generalize or predict the future, but is used to understand the present situation or context. It only applies to the particular study object, but should show a general problem and may indicate what should and should not be done in similar situations. Furthermore, the case study can be used to show the complexity of a situation. It may explain why a problem occurred and give a background to a certain situation, explain why a change works or does not work, discuss and judge alternatives, as well as evaluate and summarize a situation. (Yin, 2003) A holistic view on the object is important.

Most large solar heating projects are evaluated, but very few evaluations are categorized as case studies. One exception is found in Section 3.1. Not only a technical evaluation was performed, but interviews were also carried out with residents to investigate how the technology was received. Case study was thereby used to position technology in a social context.

2.4. Time-geographic methods and time-use data

In a case study, system simulations can be seen in a context by use of several different methods, so called triangulation (see below). Still, the social context, in form of the people using the technology, is not included in the simulations. One way to introduce the household, or rather the behavior of the household members, is to use the outcome of studies on everyday life. The way people arrange their time indirectly tells how they use the technical systems that are to be simulated.

Time-geography originates from an interdisciplinary approach in geography, which connects spatial and timely perspectives, the so called time-space. A person's everyday life is the interconnected and related activities she or he performs as time flows; every person has a lifeline in the time-space. This in turn means that society is built on those everyday activities of its individual citizens (Hägerstrand, 1991).

Ellegård (1999) describes a method to empirically collect knowledge about the timely distribution of everyday activities by so called time diaries, resulting in *time-use data*. People write down all activities they perform during the day; type of activity, when and where it takes place, extension in time, accompanying persons, means of transportation and so forth. To minimize the influence from the researcher, such as communicating a notion of "important activities", the diaries are preferably open, meaning that the informants define the activities and time-steps themselves.

Time diaries have previously mainly been used within therapy and research on everyday life. A fairly new approach is to use time-use data to improve the description of human behavior in technical simulations. By translating the activities into energy use realistic load profiles may be generated. Since they are based on time diaries they do not only supply an average energy use, but are connected to an arrangement of everyday activities that makes sense to the person performing them. By letting those load profiles describe the user of the simulated system a more realistic interaction between technology and user is achieved.

2.5. Research interviews

The theoretical performance, as well as advantages and drawbacks of different systems solutions, may be studied by simulations, but those cannot explain why a particular system solution is successful or not or how users actually interact with their heating system. And there are no unambiguous answers. But there are people with experiences and perceptions. By qualitative interviews the informants get a possibility to express their thoughts about the situation, from inside the market or household. By interviews, it is possible to position technology in its social context and achieve valuable input to new important research topics.

An interview is a professional conversation aiming at the informant's experiences and opinions. It is particularly well-suited for issues that cannot be directly observed, such as the past. It is a means to understand how the interviewed person perceives a specific topic or phenomenon. In contrast to everyday conversations the research interview has specific objectives and structures and is a one-sided questioning; the interviewer defines the situation, but does not argue for her or his opinion (Kvale, 1996). The end-product depends both on the interviewer and the informant and their interpersonal interplay.

In this project qualitative semi-structured interviews were used. Topics and questions were formulated in advance, but the interview guide was not strictly followed. The principal advantage of the semi-structured interview is its openness and flexibility. There are no strict rules for how to perform it and the approach may be modified depending on the situation and the informant (for example follow-ups on new interesting topics). All interviews were recorded and partly transcribed, before being categorized and analyzed.

2.6. Triangulation

To achieve a more holistic picture of a study object several methods may be used together or in parallel, so called methodological triangulation. All the above methods may be used individually, but in this research project they were rather used complementary. As was described above, one method may fill the gap where another cannot supply a complete explanation of a phenomenon. How the methods were used in practice is described in the next section.

3. Application of a socio-technical systems approach, examples

A number of sub-projects were carried out and some examples of projects of interdisciplinary character are given in this section.

3.1. Simultaneous social and technical evaluation of a pilot plant

The residential area Anneberg, outside Stockholm, built 2000-2001, was equipped with a large solar collector area (2 400 m^2) in combination with a seasonal storage in rock (100 boreholes, 60 000 m^3 rock volume). Under design conditions solar energy should cover 70 percent of the annual heat demand. Both solar collectors and borehole storages are individually well-known technologies, but the combination was new (a similar plant was built in Neckarsulm, Germany, within the same EU project). The area comprises 50 apartments with tenant-ownership, either as semi-detached houses or terraced houses, see Fig. 1. Lundh and Dalenbäck (2008) describe the technical evaluation of the heating plant, while a more extensive description, but also a socio-technical evaluation, is found in Jonsson et al. (2005) and Lundh and Löfström (2007).

Fig. 1: Pictures of one type of semi-detached houses (left) and the terraced houses (right) in Anneberg. Photo: M. Lundh.

The initial technical evaluation of the operation period 2003 and 2004 showed that the system works as intended, charging and discharging the borehole storage, although with lower efficiency than under design conditions (Lundh and Dalenbäck, 2008).[1] The socio-technical evaluation, connecting the technical results with the residents' perceptions of the heating system performance, however, shows that technical and sociological evaluations do not always match.

First of all, the project faced several problems, both exploding pipes in the collector loop and leakages in the borehole storage. The exploding pipe in the solar collector loop, and the water leakage it caused in one of the sub-stations, were recurring issues during the interviews. Several residents communicated a very dramatic picture of the incident, although the perception varied noticeable between different informants. The damage was relatively small and the situation was handled professionally. Still, the incident seems to have caused both distrust in the heating system and in the property developer (Lundh and Löfström, 2007).

Facing new technologies (solar collectors, floor heating, "technical rooms") caused troubles as well. The informants describe an inability to affect the heating system; the floor-heating system is perceived as slow, if at all reacting, and the so called technical rooms[2] are for experts and not for laymen. Malfunctioning heating systems are often claimed. And there were problems in some solar collector sub-systems, but the experienced malfunction was rather connected to a feeling of powerlessness to control one's own heating system. (Lundh

[1] Bernestål and Nilsson (2007) showed that the solar fraction in 2006 be adjusted was still only 45 percent, and the system had not yet reached the equilibrium temperature. Some heat exchangers needed modification and the heat supply and temperature of the floor heating system were to.

[2] A small room in every apartment where the individual heating system is regulated.

and Löfström, 2007)

Furthermore, the relatively small contribution of free energy made many informants focus on the electricity bills. At the time of the study electricity was still the main heat source and the annual electricity demand corresponded to other contemporary detached houses. As communicated in the interviews most residents expected reduced electricity bills already after one year of operation, and most informants found the bills too high. They often blamed malfunctioning technology (the heating system) and although being aware of the correlation, they did not consider changing their own activities as a means to reduce the energy demand.

The electricity costs have further caused claims on financial compensation from the property developer. The residents do not consider the heating system fulfilling the expectations. The information to the residents has not been investigated, but the mismatch between the residents' expectations and well-known operational conditions show that the communication has been insufficient. By clearer information, both the dispute with the property developer and the general disappointment in the system could perhaps have been avoided.

Although the economic issues engage the informants, the lack of functionality and comfort causes the largest disappointments (Lundh and Löfström, 2007). Still, the residents have an overall positive attitude to solar heating in general and their unique heating system in particular. But one important lesson can be learnt: more effort has to be spent on informing, but also engaging, the house owners to a larger extent. The perception of the degree to which this was done differs between households, the property developer and others involved in the project, but the disappointment among the residents is a clear measure of inadequacy. Conclusively, the heating system may be considered a technical success to demonstrate new technology, while the dissatisfaction of the residents may be regarded a failure; it all comes down to the method of measurement.

3.2. Time-use data to describe domestic hot water use in simulations

In solar heating simulations the dynamic behavior of household members is often reduced to a schematic hot water load profile, usually assuming three draw-offs per day, not distinguishing between weekdays and weekend days or taking seasonal variations into account. However, previous studies have shown that the load distribution influences the system performance and the fractional energy savings (for example Jordan and Vajen, 2000), indicating the usefulness of improved load descriptions. Measurements may be used, but they are often costly and few detailed hot water measurements have been performed so far.

An alternative approach is to model load curves. Jordan and Vajen (2000) present a model based on probability functions. Stochastic models have been developed as well. Existing models, however, seldom focus on the influence of the individual household members and their behavior. In this project, on the other hand, a model was developed to generate load profiles by translating time-use data into hot water use. Parameters describing the type of tapping (extension in time and draw-off pattern) and the required hot water volume for different activities were interconnected. The model aims at presenting the daily distribution of hot water use of individual households as well as average households, based on peoples' statements about their activities. A certain energy demand is thereby directly connected to a specific activity or user pattern (for a full model description see Widén et al., 2009).

A pilot study on time-use comprising a total of 464 persons in 179 Swedish households, from both single-family houses and apartments, constitutes the basic data set. The households were selected by Statistics Sweden and the selection is assumed to be statistically significant. All household members older than ten years wrote time diaries for one weekday and one weekend day. It should be noted that the time-use study did not focus on energy use, but on time-use in general. Therefore, the participants are assumed not to have adjusted the time statements to look better from an energy perspective.

Hot water volumes and temperatures can easily be changed in the model to suit different purposes. The model output is hot water profiles, either in volume, energy or power, for individuals, households or groups of people, separating apartments and single-family houses. The time resolution may be varied from five minutes intervals, see Fig. 2, up to one hour. The model can be applied to any time-use data organized similarly to the basic data set.

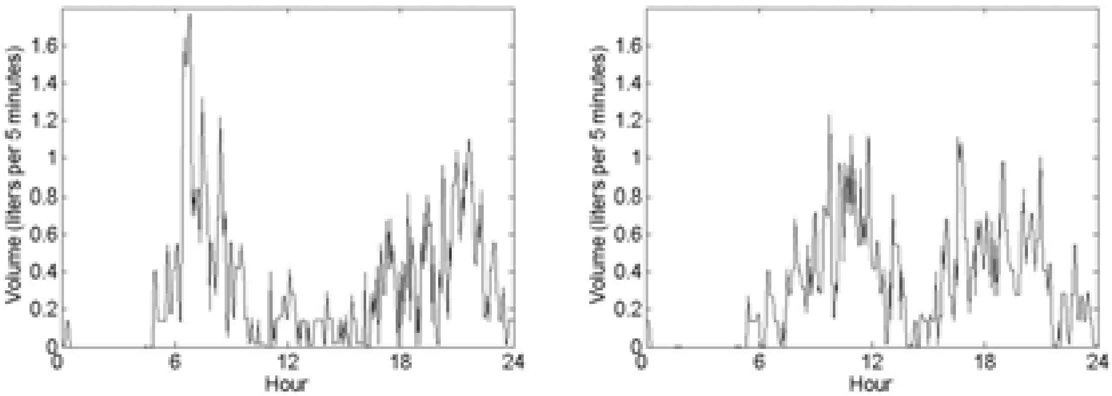

Fig. 2: Modeled hot water load for an average household member in a single-family house for weekdays (left) and weekend days (right) respectively.

To estimate the validity of the model the modeled hot water use of an average household member in an apartment was compared to measured data (see Lundh et al., 2008 and Widén et al., 2009). The modeled and measured loads follow more or less the same pattern. The magnitude of the draw-off peaks is also similar, although appearing at somewhat different times in the morning. This may be due to the two measured apartment buildings being situated in an area where most residents commute long distances to work, and therefore shower earlier than the average person in the larger time-use study. Other Swedish measurements show morning peaks that agree well in time with the modeled profiles. Overall, the model has shown to describe hot water use in apartments rather well.

The modeled profiles for ten households with characteristic patterns were used in simulations of a solar hot water system to investigate the influence from user behavior and habits on the system performance. A model was built in the dynamic simulation tool TRNSYS by modifying the standard solar combi-system from IEA-SHC Task 32 (Heimrath and Haller, 2007). The solar heating system was based on data from the low-energy buildings in Lindås Park, Göteborg, Sweden, see further in Lundh and Wäckelgård (2009).

The results show a greater impact from the load distribution on smaller systems, but that it also depends on the periods of the year and the detailed performance of the storage tank. Furthermore, the study indicates that the total hot water load has greater impact on the fractional energy savings than the daily distribution of draw-offs. The straight line in Fig. 3 represents the relation between total load and fractional energy savings while the deviation from the line shows the influence of the different profiles.

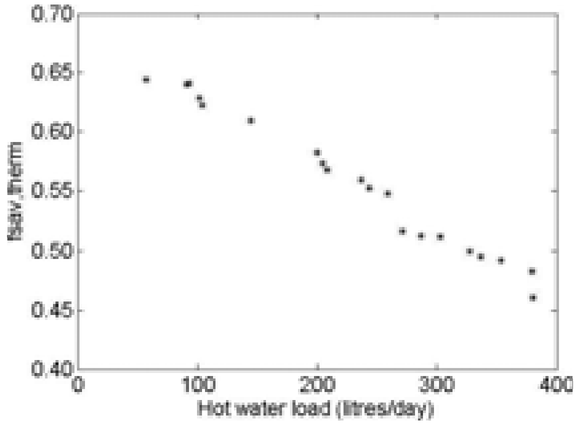

Fig. 3: The thermal fractional energy savings as a function of the domestic hot water demand for profiles with varying total hot water load (Lundh and Wäckelgård, 2009).

This study shows one possibility to incorporate the user in simulations of technical systems. Apart from load profiles for hot water and electricity, time-use data may be used to estimate occupancy and thereby heating requirements. The advantages of using time-use data to generate load profiles are many. In case of domestic hot water use, they constitute an improved description compared to the simple profiles usually applied, but above all, they connect energy use in household to the residents' behavior. They may also be used to give feedback on energy behavior. Both detailed hot water use and total demand can be studied for individuals, households and groups of people. Additionally, the method to collect data is both cheap and simple, and does not require interference in the apartment.

3.3. Interviews to examine technology dissemination

Solar collectors cannot supply all heat demanded in a building in temperate climates. In Sweden, electrical backup systems are the most common. Another system solution increasingly promoted is combined solar and wood-pellet heating. Technically, solar and wood pellet complement each other well by the increased system efficiency and sustainability. Although both solar and pellet technologies are today well-developed and several companies make effort to offer those systems, the dissemination is slow.

In this study the development towards small-scale system solutions combining solar and wood-pellet was investigated by ten qualitative interviews carried out in 2007. Among the informants were manufacturers, retailers, installers and representatives for the trade associations, all considered being involved in the process towards combined system solutions. They gave *their* view on the situation; what obstacles they experience and actions they find necessary to be taken. The interviewer's background in science and technology was considered an advantage, both in understanding the topic and conducting technical discussions with the informants. Detailed results are found in Lundh and Henning (2011).

Four main groups of market actors, perceived as preventing the development of combined systems, but possessing the power to support it, were identified in the interviews: the solar and pellet companies themselves, the customer, the installer and the government. The informants describe a close interaction between those actors, and accordingly, they claim various actions at different system levels to be necessary.

A fundamental drawback, communicated in the interviews, is the small size of both the companies and the industries. It results in poor economic assets for marketing as well as inability to compete with larger actors on the heating market. At the same time, marketing and knowledge transfer to the public is considered a prerequisite for further dissemination. The informants say that only with increased awareness, the customer will feel confident enough to exercise pressure on installers and construction companies.

Not only customers, but also the installers, are perceived as lacking in knowledge. This in turn is said to make them unwilling to argue for and install combined systems. They are considered being an important group to involve due to their major influence on the customers' choice. To change the attitude within the installer corps, it is proposed to simplify both installation and purchase, as well as making the installations more profitable. But the solar and pellet companies must also support the installer by providing proper knowledge and arguments to be used towards the customer.

Both installers and equipment supply companies need a stable market, and to create long-term stability the government must collaborate with the industries, the informants say. They demand clear political standpoints and statements. At present, customers tend to postpone their purchase due to uncertain future energy policies, according to the informants.

Although an increasing number of people show interest in combined solar and pellet systems, the technical development is considered to have too little focus on the customers' requirements. According to the informants, customers want simple and convenient, but also well-designed systems. Still, manufacturers tend to focus on improved technology. The interviewees themselves, on the other hand, focus very much on the different market actors, which they consider govern the implementation process.

The market situation is described as complex with several mutually influencing market actors that may both promote and prevent further development of this system solution. A number of obstacles that have to be overcome are identified, but solutions are also proposed. In general, the informants communicate a positive attitude. By mutual consent they claim a change towards general acceptance of solar and pellet heating and as one retailer put it: it is no longer "taboo" to mention solar collectors to a customer. The companies themselves are also perceived as respecting each other and the other technology to a greater extent, although a joint trade association is suggested to further prevent the feeling of "we" and "them". By joint effort the informants believe it is possible to reach wide implementation, and they say that combined solar and pellet systems are already close to a breakthrough, it is just a matter of time.

4. Results: Barriers and possibilities

An interdisciplinary approach was used throughout this research project to identify some of the barriers that may prevent the dissemination of solar heating technology, but also to suggest solutions to those. The obstacles are summarized in Tab. 1 and are also briefly discussed below.

Low fractional energy savings

The relatively low fractional energy savings achieved with most contemporary solar heating systems result in reluctance among both installers and customers. Although there is a mismatch between high solar irradiation and high heating demand, it could be dealt with by for example development of appropriate heat stores and auxiliary heating systems, but also improved building constructions to reduce the heat demand. In practice, seasonal storages may be used for residential areas (see section 3.1 and Lundh and Dalenbäck, 2008). Economically feasible system solutions for individual buildings may be increased store sizes to allow heat to be stored for up to two weeks and increase the fractional energy savings to about 40-45 percent (see Lundh et al., 2010b). Finally, complete system solutions, where the auxiliary heat source is both technically and environmentally well-adapted to solar heating is proposed (see Lundh and Henning, 2011). As solar heating becomes the main heat source, the willingness to invest in the systems is expected to increase.

Space constraints for installations

Contemporary architecture often limits the possibility to install necessary support systems for solar heating due to lack of boiler rooms, while the dimensions of boiler rooms in existing buildings tend to limit e.g. the store size. This is an obstacle to the technology as such, but an issue that could be solved by engaging constructors and architects (see Lundh and Henning, 2011). Moreover, space constraints may be dealt with by non-optimal store dimensions without causing significant reductions in fractional energy savings, as is shown in Lundh et al. (2010b).

Investment cost and pay-back time

The relatively high investment cost is often used as an argument against solar heating: the pay-back period is considered too long (Lundh and Henning, 2011). Costs may be reduced by cheaper and more efficient components (Lundh et al., 2010a), industrialized manufacturing in large quantities and development of standardized plug-in systems. People in the solar and pellet industries suggest both lower investment costs and a refocus from economic issues to arguments on other values and advantages of solar heating to attract more customers.

Neglected user behavior

Households using domestic solar heating systems often confirm their own ability to influence the auxiliary heat demand by changed hot water use pattern. Improved descriptions of hot water loads in households, for example by modeling load profiles (such as the ones described in section 3.2 and in Widén et al., 2009) are therefore useful to better describe the dynamics and interaction between user and technology.

Engineering focus

Manufacturers tend to focus on the technical improvement of components and system and not on attracting the potential users by fulfilling their requirements or involving the installers to promote the technology (see section 3.3 and Lundh and Henning, 2011). The customer may in return be discourage when technical focus in product development result in unattractive installations. On the other hand, customers tend to choose heating systems with low investment cost, without considering operation costs or maintenance. Thus, technology alone is not decisive for whether a particular heating system is chosen or not, but different market actors play important roles.

Tab. 1: Some obstacles identified within this research project, the dissemination phase where they occur, the main actors affected by it and solutions proposed, for details see Lundh (2009).

Obstacle	Dissemination phase	Main actor(s)	Solution(s)
Low fractional energy savings	Purchase phase Research and development	Customer Researcher (academia/institute/ company)	1. Large-scale seasonal heat storages 2. Medium-sized heat stores for single-family houses 3. Adapted auxiliary heating systems with small negative environmental impact (such as CO_2)
Space constraints for installations	Planning, installation Purchase phase	Constructor Architect Customer	1. Flexible geometry of storage tanks 2. Preparation for boiler rooms in new dwellings
Investment cost	Research and development Manufacturing	Researcher Manufacturer	1. Cheap components produced in industrialized processes and large quantities 2. Plug-in systems
Neglected user behaviour	Research and development Planning	Researcher Installer Constructor	Include realistic load profiles in simulations and planning
Engineering focus	Implementation phase	Installer User Trade Government	Apply a socio-technical systems perspective to consider both market actors and technology
Complicated systems	Installation Operation Purchase	Installer User Manufacturer	Standardized plug-in systems that are profitable and easily installed and operated
Unattractive system design	Implementation phase Planning	User Architect	Demonstration projects and good examples

Complicated systems

Complex technical solutions tend to discourage installers, who make a low profit on solar heating due to time-consuming installations. They instead focus on installations that are more profitable (Lundh and Henning, 2011). Standardized systems would yield compatible components that are easily connected, and the fewer details open to the installer and user, the easier to handle, and thereby the more attractive solution. The installer would need less time to install each system and hence make a larger profit. The user, on the other hand, would not perceive the system as complicated and would easily be able to operate it.

Unattractive design

Many homeowners as well as architects lay stress on the unattractiveness of solar thermal systems and use it as an argument against installation. They often have the traditional solution with "boxes on the roof" in mind and are unaware of the possibilities: different colors, roof-integration and different architectural solutions. Well thought-out and well-functioning examples and demonstration projects are therefore highly important to show the aesthetical possibilities (such as the one in section 3.1 and Lundh and Dalenbäck, 2008, which shows that modern residential buildings with solar heating can be built for ordinary people).

5. Discussion and conclusions

After the overview in Tab. 1 an overall conclusion can be drawn: the obstacles are not isolated issues that can be tackled one by one. Instead, they all influence, interact and support, as well as suppress, each other. There is not one universal solution to reach increased use of solar heating, but various actions must be taken at different system levels and within different actor groups. It has been shown that neither the obstacles nor the solutions are simply about proper technical solutions, but rather to get the interplay between technology and market actors to work smoothly. A widened perspective in research and development therefore seems necessary.

Most researchers within engineering and technology are probably aware of social issues and problems connected to for example market forces and implementation of technology. There is, however, a great difference between awareness and concretely bringing the issues into research projects. Still, the ultimate goal of most technical research is to serve the industry and market. Two-way communication with market actors and taking social aspects into account facilitates the process towards the realization of research results.

It is not trivial to apply a socio-technical perspective to a research topic. The main struggle is the complexity of the system: to define what influences what and where the system boundaries should be drawn. Another question that cannot be neglected is how the study should be performed to generate relevant knowledge. It has to be carefully considered what makes an interdisciplinary system study more suitable than a pure disciplinary study within engineering. In the end, the choice of approach depends on the research questions to be answered.

For example, an engineering study of solar absorber coatings is very focused on a specific material. This type of study is highly important and generates knowledge about solar heating on a micro-scale system level. The system boundaries must be very narrow to allow precise results. The outcome from such a study may be how the new coatings stand up against existing commercial ones, or in a system perspective the influence on the collector efficiency or the fractional energy savings. But questions about implementation and market competition for the new coatings cannot be answered.

On the other hand, in an interdisciplinary study it is possible to move towards higher system levels to get a holistic view of solar heating. The socio-technical approach allows major obstacles and knowledge gaps to be identified on a macro-scale system level. Is it new materials or is it primarily the market situation? The potential of different actions may be evaluated and compared. Moving the system boundaries and extend the system view opens up for new research questions that cannot be formulated within strictly engineering research.

The main advantage of a socio-technical approach is that any appropriate research method can be used. Methods from other disciplines may be incorporated into studies of technology to both promote the development of technical methodology and improve the advance of technological systems. Still, dealing with new methods demands both time and effort. Without those non-engineering methods, in combination with collaboration and proper supervision, it would not have been possible to perform the studies presented in this paper. A background in science and technology (like in this case), however, strongly influences the formulation of questions, the way in which the methods are used, the reporting, but also the projects themselves.

In contrast to quantitative methods usually used within engineering, the aim of qualitative methods such as interviews is to achieve a rich and broad data set, and not necessarily a statistically significant one. The goal is rather to obtain as complete materials as possible. Interviews is an excellent method to find new technical research ideas that are highly relevant and important from a market or society point of view. In this project interviews were used as a means to capture the interplay between technology and market actors.

By applying quantitative and qualitative methods to the same object (triangulation), technical results may also be either confirmed or rejected, because success does not only come down to technically optimized solutions. In practice, this was done in Anneberg, presented above, where a purely technical evaluation would only have shown the system to work, while in this case the residents were shown to disagree with the technical results. Lessons can be learnt about how new technology should and should not be introduced to residents' daily life.

Another major advantage of an interdisciplinary approach is the new way of thinking, which also affects and is brought into other projects, also of purely engineering character. In turn, this simplifies communication and collaboration with other researchers and increases the understanding and respect for their disciplines.

This limited research project did not solve the problems of modest dissemination and implementation of solar heating. Still, it widened the system boundaries and method basis in solar heating research, which seems to be a prerequisite to understand the complexity of the dissemination process and identify barriers as well as solutions and in the end achieve a change.

6. References

Berner, B., 1999. Perpetuum Mobile? Teknikens utmaningar och historiens gång, Arkiv förlag, Lund. In Swedish.

Bernestål, A., Nilsson, J., 2007. Brf Anneberg: Kv Vindkraften, Kv Solvärmen, Kv Solfångaren – Utvärdering av energianvändning, Ingenjörsbyrån Andersspn & Hultmark AB, Göteborg. In Swedish.

Bijker, E.W., Hughes, T.P., Pinch, T.J. (Eds.), 1987. The social construction of technological systems: newdirections in the sociology and history of technology, MIT Press, Cambridge, Massachusetts.

Churchman, C.W., 1973. Systemanalys, Rabén & Sjögren, Stockholm. In Swedish. Original title: The Systems Approach, 1968.

Ellegård, K., 1999. A time-geographical approach to the study of everyday life of individuals – a challenge of complexity. GeoJournal 48, 167-175.

Heimrath, R., Haller, M., 2007. Project Report A2 of Subtask A: The Reference Heating System, the Template Solar System, Solar Heating and Cooling Programme, International Energy Agency.

Hughes, T. P., 1983. Networks of Power: electrification in Western society, 1880-1930, John Hopkins University Press, Baltimore.

Hägerstrand, T., 1991. Om tidens vidd och tingens ordning: Texter av Torsten Hägerstrand, Byggforskningsrådet. In Swedish.

Jonsson, A., Lundh, M., Löfström, E., 2005. Hushåll med solvärme – ett svenskt pilotprojekt i Anneberg. Arbetsnotat Nr 30, Program Energisystem, Linköping. In Swedish.

Jordan, U., Vajen, K., 2000. Influence of the DHW load profile on the fractional energy savings: a case study of a solar combi-system with TRNSYS simulations. Solar Energy 69, 197-208.

Kvale, S., 1996. InterViews: An Introduction to Qualitative Research Interviewing, Sage Publications, Inc.

Lundh, M., Löfström, E., 2007. Large scale pilot project with solar heating for a residential area – success and disaster, in: Proceedings of ECEEE 2007 Summer Study, Côte d'Azur, France.

Lundh, M., Dalenbäck, J-O., 2008. Swedish solar heated residential area with seasonal storage in rock: Initial evaluation. Renewable Energy 33, 703-711.

Lundh, M., Vassileva, I., Dahlquist, E., Wäckelgård, E., 2008. Comparison between hot water measurements and modelled profiles for Swedish households, in: Proceedings of Eurosun 2008, Lisbon, Portugal.

Lundh, M., 2009. Domestic Heating with Solar Thermal. Studies of Technology in a Social Context and Social Components in Technical Studies, doctoral thesis, Dep. of Engineering Sciences, Uppsala University, Sweden.

(http://uu.diva-portal.org/smash/record.jsf?pid=diva2:212624)

Lundh, M., Wäckelgård, E., 2009. Influence of different load profiles on the performance of a solar hot water system, in: Proceedings of ISES Solar World Congress 2009, Johannesburg, South Africa.

Lundh, M., Blom, T., Wäckelgård, E., 2010a. Antireflection treatment of Thickness Sensitive Spectrally Selective (TSSS) paints for thermal solar absorbers. Solar Energy 84, 124-129.

Lundh, M., Zass, K., Wilhelms, C., Vajen, K., Jordan, U, 2010b. Influence of store dimensions and auxiliary volume configuration on the performance of medium-sized solar combisystems. Solar Energy 84, 1095-1102.

Lundh, M., Henning, A., 2011. Challenges of merging two markets: Views from the Swedish solar and wood-pellet industries. Submitted to Energy Policy.

Löfström, E., 2008. Visualisera energi i hushåll: Avdomesticeringen av sociotekniska system och individ-respektive artefaktbunden energianvändning, doctoral thesis, Dep. of Technology and Social Change, Linköping University, Sweden.

Summerton, J., 1998. Den konstruerade världen, in: Blomkvist, P., Kaijser, A. (Eds.), Stora tekniska system: En introduktion till forskningsfältet. Brutus Östlings Bokförlag Symposion, Eslöv, pp. 19-43.

Widén, J., Lundh, M., Vassileva, I., Dahlquist, E., Ellegård, K., Wäckelgård, E., 2009. Constructing load profiles for household electricity and hot water from time-use data – modelling approach and validation. Energy & Buildings 41, 753-768.

Yin, R.K., 2003. Case Study Research: Design and Methods, third ed. Thousand Oaks: Sage Publications, Inc.