Towards new standards for advanced stores

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New Generation of Solar Thermal Systems

TOWARDS NEW STANDARDS FOR ADVANCED STORES – FINAL REPORT

April 2007

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SUMMARY (ARIAL 12, BOLD)

The investigations carried out at ITW, SPF and DTU on standards for advanced stores are described.

It is judged to be too early to pass on any test method to CEN/TC312 to be considered for standardisation.

1. Introduction

It is not possible to test and evaluate all kinds of new advanced designs of heat stores for solar heating systems by means of existing standards and test methods. Therefore there is a need for new/modified test methods for advanced heat stores.

Within WP4 of the NEGST (New Generation of Solar Thermal Systems) project a small group: ITW, Germany, SPF, Switzerland and DTU, Denmark in the period July, 2004 - June, 2007, carried out work related to the next generation of standards for advanced stores.

This document describes the work.

2. Background

2.1 Existing standards and test methods for heat stores

Heat stores for solar heating systems can today be tested according to ENV 12977 on custom built systems. At present, the standard is under revision. In the future the following standards must be considered:

<u>ENV 12977 - Restructured:</u>

- TS EN 12977-1: General requirements
- TS EN 12977-2: Test methods for water heaters and combisystems
- EN 12977-3: Performance test methods for solar water heater stores
- TS EN 12977-4: Performance test methods for solar combi stores
- TS EN 12977-5: Performance test methods for controllers

Only water stores can be evaluated by the standards. In the standard, the water stores are classified into five different groups. By means of test methods the following quantities can be determined for a store:

- The thermal capacity
- The operation heat loss capacity rate without pipe connections
- The stand-by heat loss capacity rate of the entire store with pipes
- The heat transfer capacity rate of immersed heat exchangers

Further, the following store parameters can be determined by means of parameter identification. Only this method will be included in the revised standard:

- The store volume
- The heat transfer capacity rate of the lowest heat exchanger and the thermal stratification during discharge
- The thermal stratification during discharge with a “high” flow rate
- The heat loss capacity rate of the entire store during stand-by
- The heat transfer capacity rate and the position of the auxiliary heat exchangers
- The position and length of the electric heating elements
- The degradation of thermal stratification during stand-by

Already today, it is not possible to evaluate all marketed heat stores by means of the above-mentioned standards.

2.2 Need for new/modified test methods for advanced stores

During the first part of the NEGST project, the following list with new/modified test methods and assignments to be considered was prepared:

- Test methods based on parameter identification inclusive verification sequences.
- Basic principles and concepts used in the test methods.
- Test method for degree of stratification for advanced water stores during charge, during discharge, during charge and discharge and during periods without charge and discharge. The test methods could be suitable for mantle tanks, tanks with inlet stratifiers, tanks with advanced DHW discharge and tanks with discharge from different levels.
- Test methods for stores with external heat exchangers for domestic water heating.
- Test methods for smart stores with variable auxiliary volume fitted to the consumption.
- Test methods for durability of tank materials and of stores suitable for low-cost water stores.
- Test methods for latent heat stores.
- Test methods for chemical stores.
- Legionella issues.

Unfortunately, due to limited resources it was not possible to carry out work on all the above-mentioned test methods/fields.

3. Work plan

It has been decided to carry out the following work within the NEGST project:

- At ITW: Work on further development of test methods based on parameter identification inclusive the aspect of verification sequences.
- At SPF: Work on performance testing of solar heat stores.
- At DTU: Work on development of simulation models and test methods for stores with external heat exchangers for domestic water heating.

The activities at ITW, SPF and DTU are described in the following.

4. Research activities

4.1 Activities at ITW

4.2 Activities at SPF

4.2.1 Introduction

The objective of testing solar heating systems and solar heat stores is to secure and improve their quality. By assessing and publishing performance figures, the confidence of installers and of end users in the solar heating technology should be increased and superior products should be preferred. The overall purpose of solar heating system testing is a higher quality and a greater quantity of solar heating systems.

There is sufficient experience in the field of solar thermal system and components testing to make a clear statement: To generate precise and reliable results, even if it is about performance only, is difficult, tedious and therefore expensive. This fact causes a severe dilemma: On the one hand, any procedure that is too expensive is useless, because it won't be applied. On the other hand, any procedure that is not sufficiently precise or reliable will not do the job. Two current boundary conditions add to the problem:

- ➢ There is much development and improvement in the field of solar thermal energy systems and components resulting in a great diversity of the technology.
- ➢ The companies which supply solar heating systems and components often (still) dispose of very limited economic strength. The most innovative and trend setting companies are (still)

rather small. They are reluctant to regularly make large expenditures for having their products tested by independent institutions.

Often, the guiding line of test procedure development was to establish test methods that are (relatively) simple and inexpensive. The reasons for this are:

- Test institutions and the manufacturers prefer easy to apply, inexpensive procedures.
- Institutions that decide about public funding and consumer organizations often base their decisions and publications on test results and test reports. However, their representatives are seldom sufficiently competent to judge the reliability of a test method.
- The ultimate and most important group of people interested in precise and reliable test methods are the potential buyers and users of solar heating systems. But they are not being asked their opinion.

As a result, the precision and reliability and therefore the use of several methods in place today must be questioned. In the following, some specific issues are outlined and general problems highlighted. Suggestions are made to generally improve the quality and reliability of test methods by including relatively inexpensive measures. Strategies are suggested for the further development of the test methods in place and the definition of new test methods. Other suggestions shall help to avoid the pitfall which lies in test methods which are too simple to reflect the true performance of the object tested.

Because the store is an important component of (nearly) any solar thermal system, any solar thermal system test is also a store test. In some cases (component test and system simulation methods) the store is tested specifically, sometimes it is even tested as an isolated component. In other cases ("black box" methods such as the procedure stipulated by the current European Standard for performance tested of "factory made systems"), the store is not tested specifically. However, any black box system test method is also a store test method. Therefore the following comments are also related to system test methods, where the store is part of the system.

4.2.2 Boundary definition

It is not always self-evident what is to be considered to be part of a store. Components often associated with stores of solar heating systems are:

- Heat exchangers for auxiliary or solar heating
- Heat exchangers for DHW preparation
- Auxiliary heaters
- Stratifiers (Devices to enhance thermal stratification in a store are here referred to as "stratifiers"). Stratifiers may include pipes, valves and heat exchangers. They are usually built into the store but may also be partially or fully external to the store.
- Valves in general and specifically thermostatic mixing valves (or "hot water mixing valves" or "tempering valves"). Thermostatic mixing valves are typically applied to limit the DHW temperature, to avoid scalding or scaling. They may also be used to enhance stratification.

Thermostatic mixing valves, are always external to the store. The other above mentioned elements may also be external, but sometimes they are built into the store. In that case they cannot be detached from the store for testing. If they are integrated, it seems logical (if not inevitable) to consider them to be part of the store. However, the service and function provided by the element is equal or nearly equal, whether it is built into the store, attached to it or if it is installed in a separate place. Anyway, the interaction with the store and the influence on the performance of the store and its associated elements may be important in either case.

One may argue that it would be useless to consider the thermostatic mixing valves used to limit the DHW temperature being part of the solar heating system or part of the store. Because hot water mixing valves are always mounted external to the store, they are usually (but not always!) custom-added which means that they are often not supplied as a package with the store or system. As a consequence, they may (usually) be installed in different ways and positions. Thus, the argumentation to exclude the DHW-mixing valves seems to be consistent at first sight. In the following example, it will be explained that this argumentation is not without contradiction: A combistore often includes a heat exchanger for the preparation of DHW. In that case it is nearly inevitable that this heat exchanger is considered to be a part of the store. This is particularly true, if the heat exchanger is an inner tank (as is often the case), which adds substantially to the tank volume and its heat capacity. If hot water is prepared by means of a heat exchanger which is external to the combistore, it would be logical to include the heat exchanger in the test set-up and to test it just as if it was built into the tank. (Although analogue objections could be raised against this practice as those mentioned above for thermostatic mixing elements: the external heat exchanger may be a “custom-added” element.) If the DHW-preparation is accomplished by means of an external heat exchanger, the hot water temperature may be (and usually is) controlled by a variable speed pump or a mixing valve on the primary side of the heat exchanger. Therefore, there is no need for an additional thermostatic valve on the DHW outlet of the heat exchanger. Thus, to exclude the hot water mixing valve in the testing of a combistore with integrated DHW production is to arbitrarily and knowingly provide an advantage over a store with external DHW preparation. The advantage is not as marginal as it may seem to be. The pipe which connects the store’s hot water port to the mixing valve adds substantially to the store’s heat losses. If a thermostatic DHW mixing valve is not equipped with a leak-proof non return valve the heat loss rate – the most important property - of a store, may be even doubled or tripled by natural convection through the piping which bypasses the store. Additionally the behaviour of the mixing valve (just like an external heat exchanger and its controls if applicable) causes dynamic heat losses, because it may take much time for the hot water leaving the valve to reach the temperature desired by the user. To exclude the mixing valves from testing may help to render test methods simple and inexpensive. But it is arbitrary and leads to inaccurate results. If the objective was simple and easy test methods, it would be just fine. But this is not the case. The objective is: good systems! Analogue complications with the arbitrary definition of the boundary (the inclusion or exclusion of elements combined with a solar store) exist for the other components mentioned above: heat exchangers, auxiliary heaters, stratifiers. In addition to that, the way external elements are attached to the store (mixing valves, heat exchangers, etc.) may influence the system performance. To complicate the issue, depending on the system, the way external elements are positioned, is sometimes defined (e.g. by prefabrication), sometimes recommended (in an installation manual) or arbitrary (decided by the installer on site). Often this same problem occurs with the positioning of temperature sensors used for system controls which have a very high influence on the function and performance of any solar system. Often the installer is rather free to choose sensor mounting positions. Even if the position is fixed, because there is a mounting fixture, it is often easy to assess the position or temperature sensors with a ruler. But to claim that this position is the relevant one for system simulation is just pretending.

The problems drawn up above have severe implications on the applicability and reliability of any system or store test method without additional validation. Conclusions and recommendations derived from this are presented in the sections *an opinion* and *recommendations* below.

4.2.3 Installation

Two aspects regarding the installation of solar heat stores are usually not dealt with in test procedures:

- placement (property of the ground or base the store is placed upon for testing)
- pipe connections

The fist aspect (placement) is (usually, compared to the pipe connections) of minor importance. It could and should be resolved with by standardizing the material properties and geometry of the base the store is installed on during testing. The other aspect – pipe connections – is more important and more difficult to resolve. As had been pointed out by several authors (an overview of publications is given in /Vog07/) internal natural convection (counter-flow circulation) in the pipes connected a store produce considerable heat losses. The pipes connected to the store ports (or ports of heat exchangers) during testing of a store may be arranged downwards. If long (deep) enough and well insulated, such a downwards-configuration of a pipe connection acts as a heat trap and avoids said losses. This, or another standardised type of connection, is necessary if test results shall be relevant and reproducible. However, in real installations pipes are not usually installed in such a favourable way. The ports of tanks (and the pipes connected to these ports) are usually oriented in horizontal or vertical direction. Nevertheless, some tanks, dispose of ports which point downwards (vertically from the bottom of the store or at an angle from the sidewall of the store) from the hull through the insulation. This type of port also acts as a heat trap and thus avoids most of the heat losses which normally result from connecting pipes in real installations. This advantageous design of ports should be preferred, and promoted. However, advantageous port design does not deploy and is not revealed by testing if the pipes are connected in an ideal way during testing or if no pipes are attached during testing (the latter is the case if a store is fitted with both an electrical auxiliary heating element and an internal heat exchanger for auxiliary heating and if, for testing, the electrical auxiliary heater is operated only). A possible solution to this problem could be:

- For testing, pipes shall be connected to vertical or horizontal ports in the best possible way, which is a well insulated standardized heat trap siphon. For performance simulation for each of these ports an additional (penalty) heat loss rate is attributed. This additional ("penalty") heat loss rate can be a function of the dimension and orientation of the port (vertical or horizontal, port diameter).
- If the store disposes of advanced ports which act as heat traps (as described above, or ports fitted with any other element with heat trap function), the heat loss rate of these ports shall be neglected ("penalty" = 0). If there is doubt about the efficacy of the port with respect to its heat trap function, the efficacy of it shall be assessed in a separate test. This test shall yield a heat loss rate ("penalty") which is valid specifically for that type of port. In order to asses this figure, the port shall be connected to a test pipe. The test pipe shall be designed in such a way (diameter, thickness, length) that, if it was connected to a horizontal or vertical port, approximately the same penalty heat loss rate results from the connecting port/pipe as the penalties which are used for performance simulation of stores with vertical or horizontal ports. This test can be a separate heat trap test. As a measurement, it can be done independently from the other testing of the store. A basic recommendation for such a test is presented in /Lau06/ where also the heat losses of various pipe connections without heat traps and the effect of a heat trap siphon and a heat trap valve are listed.
- In the CCT procedure (Concise Cycle Test, see section modelling, test sequences, validation and conditions for performance prediction, below) and the respective tests of combisystems at SPF, the hot water outlet of the tank (or rather the outlet of the DHW mixing valve) is connected to a pipe (called draw-off pipe in the following). The "draw-off pipe" is of dimension 1". It is not insulated and has a length of about 2 m. It is installed sloping slightly (2°) upwards. The hot water consumption is controlled by measuring the temperature at the outlet of the draw-off pipe. Thus, if a system is fitted with a heat trap, standby losses (heat losses from the pipe to ambient) are low. If there is no heat trap, the non-insulated draw-off pipe is kept warm in standby periods resulting in higher heat losses. But reduced dynamic losses result whenever, at the beginning of a draw-off, the temperature in the draw-off pipe is above the specified comfort level. This set-up and procedure may inspire the standardization of a "draw-off pipe" for system testing. It is a thorough solution regarding the hot-water port of a solar thermal system. The most important advantage of this solution is that both standby losses and dynamic losses are accounted for. The most important disadvantage is that the pipe requires to be modelled with sufficient accuracy in the computer model used for system simulation.

A comprehensive explanation of counter-flow circulation and standby-losses of pipes connected to stores is given in /Gei07/. If the quality of the heat stores shall be improved significantly, a solution of the important problem of stand-by losses of connecting pipes must be found. With time (and with the support of testing) the performance of the heat stores on the market tends to improve /Fur83/. It is deplorable, if the installation spoils much of the progress made. However, there is no hope to change the way stores are installed quickly. However, if the test standards provide the incentives necessary, port-design will improve.

4.2.4 The comfort/performance contradiction

The performance of any solar heating system, which includes the preparation of domestic hot water (DHW) depends on the level of comfort it is able to supply: The volume, temperature and flow rate of the domestic hot water. The level of comfort is sometimes called "hot water performance" which is considered a good term by the author, but is not used here to distinguish easily between the energy-performance and hot water performance ("comfort"). The level of comfort may be due to the design of the system (position of the auxiliary heat input, sizing of heat exchangers) or the controller settings (set temperature of the auxiliary heating, enable time-windows for auxiliary heating). The way this is usually dealt with is to adjust the hot water comfort at the same level for each system to be tested according to the same procedure. Typically, the problem is addressed in one of the two following ways:

- The set point of the auxiliary heater is prescribed. This concept is followed in the most important international standards for the performance testing of small (“factory made”) solar domestic hot water systems.
- A comfort test (“hot water performance test”) is carried out. This test may be used as a qualification test or it may be used to determine the controller settings necessary for the system to supply a given comfort. This method is used or considered in most test procedures for solar combisystems. Hot water performance tests are described in /Vog04/ and /Drü02/.

The first method is typically used for performance prediction of solar water heaters, the second method tends to be considered for the testing of combisystems. This choice is logical, because in combitanks the DHW is usually prepared by some sort of load-side heat exchanger, where in tanks of solar domestic hot water systems usually the DHW is heated, stored and drawn off directly, which makes it easier to anticipate and level the temperature as one important comfort criteria. However, with this approach two obvious problems are not addressed:

- the DHW volume available is not adjusted or
- solar domestic hot water systems with load side heat exchanger are not dealt with properly.

A general problem persists in any of the approaches described above: The level of comfort required is arbitrary: Some systems are designed to supply a relatively low degree of comfort, other systems are designed to supply a relatively high level of comfort. Consequently some systems will fit in nicely with the requirements defined as part of the procedure; others won’t.

- An approach to address the problem is to compensate (or penalize) the energetic performance according to the degree the set comfort level was surpassed or to penalize it according to the degree the system failed to achieve the set comfort level with the setting chosen for performance prediction. This approach was used in performance testing and rating of solar domestic hot water systems and solar combisystems by an important consumer organization in Germany (/Sti02/, /Sti03/, /Drü02-2/) and it was used in the (mostly theoretical) performance comparison carried out in Task 26 oth the Solar Heating and Cooling programme of the International Energy Agency (IEA) (/Wei03/).

Another approach is suggested here: Performance predictions could be made for various different comfort levels (different set temperatures, different time-windows for enabling the auxiliary heater). This solution is compatible with test methods which rely on detailed and accurate system modelling and simulation (the “precise modelling” approach described below, typically a method based on component test and system simulation). The level of comfort could be established through annual simulations with a stochastic load file which should be representative for a typical application (e.g. a typical draw-off pattern in a single family house): The amount or fraction of DHW energy withdrawn from the store at a temperature below a certain threshold temperature could be used as a measure for hot water comfort.

4.2.5 Modelling (test sequences, validation and conditions for performance prediction)

Computer models of solar heating systems are never perfect. In some cases a very high degree of precision and accuracy can be achieved. Much effort is necessary to achieve a precise model. This effort is usually not affordable for commercial testing. Concessions have to be made. This section describes possible strategies to avoid negative consequences incurred by these concessions. Two clear cases (strategies) can be postulated:

Rough modelling (e.g. “black box” testing, using a generic model for simulation)	**Precise modelling** (e.g. based on component testing, using specific or adapted models)
Requirements and conditions	
Typically a whole system test: the store is tested as one part of a whole system with the system tested globally (black box).	Typically the store is tested specifically as one component of even as several components (e.g. store plus heat exchangers).
Test conditions are close to conditions for performance prediction and close to the conditions in real applications.	A wide range of test conditions is used. Conditions include at least the whole range of conditions expected in real operation. They may include extreme conditions (beyond the expected range of application).
Modelling is based on a generic model. All essential parameters are adapted (parameter identification)	Modelling is based on specific or adapted computer programs.
Consequences and findings	
Moderately accurate performance prediction.	Accurate performance prediction; accuracy may be high but dependent on the quality of the model.
Limited range of boundary conditions for performance prediction admissible (in extreme cases only one reliable performance predictions for one load case and one climate).	Large range of boundary conditions for performance prediction (high variation in load and climate) admissible.
The possibility to evaluate comfort by simulation is very limited.	Normally it is possible to evaluate comfort by simulations.

Table 1: Clear strategies for performance test methods of solar thermal systems based on testing and computer simulation.

Both approaches in table 1 above may lead to reliable results. The “rough modelling” (see table 1) has the potential to be relatively inexpensive and applicable to a broad range of system designs without adaptation of the method. It will often be suitable to rate the system performance for consumer information and to allocate subsidies on a system performance basis. The “precise modelling” (see table 1) is far more complex and expensive than the “rough modelling” but leads to a broader range of results: Besides being able to encompass a large variety of boundary conditions the model also allows analysis of the system: After testing, the model allows to conduct additional studies:

- What would the performance be if one or the other system parameter were different?
- What would the performance be if the system was operated in a different way?

Replies to these answers are highly valuable information for system manufacturers and system designers. Thus “precise modelling”, even if expensive, might often be worth the cost and effort involved because it supports the goal of system testing: It helps to improve the products available.

The CCT (Concise Cycle Test) method /Vog04-2/, was developed at SPF and used for the testing of a large number of combisystems /Vog04/, /SPF/. It is an example for the case “rough modelling”. The CCT is a system test, in which a system (a large part of it: all the components including all controllers and the auxiliary heat source, excluding only the solar collectors and the building) is tested as black box using test conditions as close as possible to reality. A generic computer model is used for the simulation of the tested system and annual performance prediction. The essential procedure is the same as in the other methods covered by this document: The model parameters are identified by minimizing the difference between measurements and simulation. In the case of the CCT there is one long test cycle. A

considerable number of draw-offs (ca. 25 draw-offs per day) with various flow rates and volume, for the different draw-off occurrences. Seasonal variability of draw-off volume and mains (cold water supply) temperature is equally accounted for. Also, some of the small draw-offs are considered to be of the type “volume”, the others are of the type ”energy”. In the case of the draw-offs of type “volume” a given DHW volume is removed without considering the temperature of the hot water. In the case of energy-type draw-offs a certain energy is removed. The energy is counted only, if the temperature of the DHW is above a pre-set threshold. The temperature sensor used on the hot water side to count the energy is mounted at the end of a pipe (“draw-off pipe”, see *installation* above) which was connected to the store (or connected to the hot water mixing valve or connected to an external heat exchanger for DHW production). The draw-off pipe simulates the volume and heat losses of a hot water distribution system in single family house. Also, it induces standby losses incurred by the pipe connection (see section *installation* above). In addition, all the other boundary conditions (space heating load, weather conditions, etc.) were realistic. This is also true for the conditions used to calculate annual system performance. The duration of the test cycle is a considerable 12 days. It includes all the phases that are represented in one year. Thus the test conditions are designed to induce realistic system operation and realistic system performance.
At the Technical University of Denmark 21 marketed small SDHW systems have been tested in a laboratory test facility in the period 1992-2003. The thermal performances of the systems have been measured during a long test period with constant daily hot water consumption. Inputs for detailed simulation models for each tested system have been found in such a way that the calculated thermal performance of the system is equal to the measured thermal performance of the system, both for a summer and a winter period. The highest acceptable difference between calculated and measured net utilized solar energies for a system for a one week period is 3%. In this way the simulation models have been validated for different operation conditions. With the validated simulation models the yearly thermal performances of the tested systems were determined with weather data from the Danish Test Reference Year. Further, parameter analyses were carried out with changes in the design of the solar tank in order to determine how the design of the tank influences the thermal performance. Based on these results recommendations for improved designs of the solar tanks were given to the manufacturers.
However, most test methods do not correspond clearly to one of the two extreme cases outlined above. They are to be situated somewhere between the two cases. The most important methods supported by CEN are

- the so called DST method (CEN documents of series12976 and particularly 12976-2, which is based on ISO 9459-5) for factory made solar hot water systems and
- the so called CTSS method (CEN documents series 12977) for custom made systems.

Both of these procedures are included or are intended to be included in CEN standards. Both assume water stores as system components. They are described in more detail in the following:

The DST method (Dynamic System Test method) is a black box method. The auxiliary heater is not considered as part of the system, unless it is integrated in the store. It uses test sequences that are designed to find a set of few parameters for modelling the whole system. Thus it is a rough modelling approach. The test sequences were not selected to represent the normal operation condition. Nevertheless – according to the standard – it is permissible to predict annual system performance for a large variety of loads and climates. In the current versions, only one draw-off per day is used for annual simulation, which is very different from the real situation in an apartment or one-family house, with typically 20 to 50 draw-off occurrences per day. To derive sufficiently accurate performance predictions for a large range of systems and a large range of boundary conditions is a challenging task. A practical validation of the procedure, based on a series of comparative tests of 12 systems revealed several weaknesses and resulted in the statement that the inaccuracy is as high as 10% (/Nar99/). Because – in the current version – model validation is not part of the procedure, an inaccurate prediction won’t normally be discovered or avoided.

The CTSS method (Component Test – System Simulation) is based on testing of the essential components. Testing results in component models which are then combined in a system model for annual performance prediction. Testing of the whole system is not required. The test sequences used for store testing are selected to serve for modelling (and parameter identification) of the store and its heat exchangers. In the current version of the CEN document for CTSS store testing, the test phases which serve to take measurements are prescribed in detail. Also requirements for the quality of the test results are specified (pass/fail-citeria for the quality of each test sequence and the ability of the component models to reproduce the results of each individual test sequence). Because components are tested separately, the CTSS method is well suited for "precise modelling" with its potential to yield accurate results. High precision was not the original justification or main purpose of the CTSS method: The key advantage should be the possibility to test components individually and recombine them in different sets for annual performance calculation. With this possibility the number of tests and total effort for testing shall be reduced.

The challenge with the current CEN approaches to solar thermal system testing (current CTSS and DST methods) is to cope with the large range of different systems available: What to do, if the prescribed method is not able to model the system (or store) in question? It will be very difficult to describe a test method in detail, if it shall be applicable to the whole diversity of systems available to date. It might be impossible to prescribe a test method in detail, which is suitable for all (or most of) the systems available tomorrow.

4.2.6 An example

Consider a small solar domestic hot water system with a buffer store and an external ("load-side") heat exchanger for instantaneous domestic hot water (DHW) preparation. It is tested using the DST method (see above). Assume that the load-side heat exchanger is large, voluminous and heavy. It is not insulated. (These characteristics are typical for state-of-the-art load side heat exchangers of solar heating systems). During the test, according to the prescriptions of the standard, the system is charged with a few draw-offs per day only. Due to the fixed, prescribed model, the heat exchanger's thermal inertia and its heat losses are not modelled. Two different effects cause heat losses of the external heat exchanger and associated piping:

- normal ("static") losses by radiation and convection from the heat exchanger and its associated piping to the environment. These losses are called "static" in the following, because they occur mostly in times when no draw-off is taking place.
- Besides static losses, there are also "dynamic" losses: The domestic hot water that resides in the heat exchanger after the draw-off will mix and cool down, resulting in a temperature below the comfort level. When a draw-off occurs, the lukewarm water will seldom be used but directed to the drain.

With regards to the static losses, the simplifications will be partially accounted for by the model or rather the resulting parameters after parameter identification: The heat losses of the load-side heat exchanger will lead to an augmentation of the heat loss parameter of the store (or – less likely or to a lesser extent – to an augmentation of the collector loss parameter), because the heat losses of the store and the losses of the heat exchanger will be lumped together in the store loss parameter. However, because the number of draw-offs is considerably smaller in the test than in a real application, the total static losses will be underestimated by the model (if a real application in a family home with usually 30 to 50 draw-offs per day were considered for annual performance prediction). The heat losses of a small solar thermal system are among the most important factors that influence system performance. The static heat losses of the external heat exchanger and the associated piping may easily exceed the heat losses of the store itself. Dynamic losses may be even more important: What is the order of magnitude of the error? If the heat exchangers DHW volume is 2 litres and there are 40 draw-offs per day (in the real installation in a typical single family house), the dynamic losses alone will amount to the equivalent of 20 to 40 litres of hot water per day, thus they represent a very high fraction of the DHW load!

Therefore, it is important that either

- the heat losses of the heat exchanger are taken into account correctly (precise modelling) or

- it is made sure that both the conditions during testing and those assumed for annual performance prediction are realistic (following the guidelines postulated above for rough modelling).

If annual performance predictions are carried out in the case described above, neither of the two heat loss effects associated with the special design will be accounted for correctly and wrong results will be generated. If tested according to the DST procedure, the performance will be strongly overestimated. A wrong signal will be provided to end-users and system developers.

4.2.7 An option (validation of the model, rather than precise prescription of the method)

Both test methods supported by CEN today risk to lead into a dead end. Accuracy, reliability, applicability and cost of the methods might not suit the requirements of the future. New ways should be explored. To bridge the gap between the existing methods and new methods and to ascertain the applicability of the existing methods, a method for model validation should be defined. The validation sequence(s) should be as close as possible to the expected real operation of the system or component. Validation shall serve to determine the range of boundary conditions which the model shall be considered to be valid for and for which annual performance predictions shall be published. (If the model matches very well with the measurements, the range of boundary conditions shall be large; if the agreement is poor the model shall be valid for a very restricted range of boundary conditions; if the agreement is insufficient, the model must be rejected.) The validation procedure may be used for any systems size suitable for (indoor or outdoor) laboratory testing.

4.2.8 Recommendations (free choice of method with some general rules)

A comparative round robin test on a solar heat store conducted by three independent institutions has yielded very good agreement of results. Thereby each institution had used its own specific method. The three methods were very different. The outcome of the study (/And98/, /Nie99/) indicates that comparable results can be generated by a variety of methods. There is no need to pinpoint the details of the method. Test institutions should be given their own choice of the method for performance assessment of solar thermal systems and stores.

As a guiding line for test method development it should be adhered clearly either to the “rough modelling” or clearly to the “precise modelling” as described in the section *modelling* above. If some essential general rules and procedures are postulated by standards and followed by test institutions, the methods do not need to be described in detail. The rules may cover the following themes:

- The boundary conditions (test conditions) for validation (see section *an opinion* above),
- the pass/fail criteria for model validation and
- the boundary conditions for annual performance prediction as well as – to a reasonable extent –
- the details of the presentations of test results and
- the system boundary (of the whole system) shall be clearly defined.

The system should always include the auxiliary heater(s). However, a standard auxiliary heater (or several) should be defined and used in case no auxiliary heater is supplied with the system. This standard auxiliary heater could be defined as

- a simulated component or as a
- a real component (an emulated auxiliary) or
- an emulated auxiliary as well as a simulation model. In this case the simulation model and the emulated auxiliary heater should be designed to have quasi-equal characteristics and performance.

A few rules regarding the method and tools used should be prescribed. E.g.:

- It should be set as a general rule that all the essentials (parameters, settings and executable program) of the computer model used, must be identical for validation and long term prediction.
- The simulation program with all its essential program components should be validated by means of a standardized benchmark test.

- It should be required that any modification of (or interference with) the system or component tested shall be such that the performance is not altered. Any such modification or interference (the mounting of extra temperature sensors, the blocking of valve positions, etc.) should be reported in the test report.

Also some rules should be set up to assure that testing yields comparable results:

- It should be prescribed, how systems and components have to be installed for testing.
- It should be prescribed how pipe connections are to be made and rated. Some recommendations on this subject can be found in the section *installation* above.
- Rules could be defined to qualify or disqualify a system for testing: E.g. it could be stipulated that, for the system to qualify, all the system's sensors must be installed in mounting fixtures and that each sensor has its unambiguous fixture (that it is mechanically impossible to place a sensor in the wrong fixture).
- Rules should be established to solve the problem of the comfort/performance dilemma by equalizing the comfort level or by specifying the rating of the performance as a function of the comfort level. (See also suggestion in the respective section above.)

Through mandatory validation of the whole system, the approaches and methods to characterize (model) the various components of the system (or the system as a whole) are liberalized. This will be an impediment for the philosophy of component testing and system simulation: E.g. if an institution is free to choose the method to characterize a heat stores, the results of that test might not be used (by the same or different institution) for further processing and synthesizing system test results for different combinations of components. However, unless the computer program is standardised, this restriction practically applies to any component test method anyway. Surely, the necessity to verify the whole system performance through validation is in contradiction with the original idea of component testing and system simulation. However, if a simulation model which is based on precise modelling is validated for one combination of components (in practice one specific collector area) the results are certainly, within reasonable accuracy, extendable to different collector areas (or a different type of collector). To assure or extend the use of a store model gained trough a store test, a validation sequence for the store could be defined (which resembles the validation sequence for a corresponding whole system). Through this validation the original idea and benefits of separate component tests can be maintained. Just like with the standard auxiliary heater component (as a simulation model or an emulated component), a standard collector model could be defined to conduct a virtual system test. In Denmark a standard SDHW system with a reference solar tank was defined and used in connection with state subsidies for SDHW systems with different solar tanks. Based on tests of the solar tanks a tank factor was determined for each solar tank on the market. The reference tank had a factor of 1. The better the tank the higher the tank factor and the higher the state subsidy will be for the SDHW system /Nie91/ and /Nie93/. Typical tank factors varied in the interval from 0.9 to 1.1. In analogy, a validation sequence could be defined for solar collectors (the validation might be used or required for special solar collectors only).

For clear rough modelling methods testing and validation could be combined. A sequence (a validation-and-test-sequence which could be identical or similar to the validation sequence(s) used for other methods) could be defined to be used as the only boundary conditions for testing and ("quasi-") validation. In that case there would be no additional specific validation. According to the idea of "rough modelling", the boundary conditions for annual performance prediction would have to be as close as possible to the conditions of the "validation-and-test-sequence". This makes rough modelling methods simpler (and less expensive) but reduces reliability. The usefulness and feasibility of this approach has been demonstrated successfully by the testing of a large number of solar combisystems according to the CCT test method.

Liberalization of the method used to assess solar thermal system performance offers several important advantages:

- Through case designed or case adapted methods the diversity of the system technology present can be covered.
- A variety of different methods will allow to deal appropriately with the diversity of purposes of system testing and rating (e.g.: consumer information; rating for the allocation of subsidies;

supplying a precise model and useful information for system development and improvement to a manufacturer)

➢ Scientists will be encouraged to develop new and better test methods.

The author reckons that gaining all the above advantages is indispensable. The future of performance testing and rating of solar systems will depend on the acceptance of a free-choice-of-method philosophy. Future work in the field of solar thermal system testing should concentrate on the establishment of essential guidelines and rules necessary for the successful implementation of a variety of methods.

4.3 Activities at DTU

4.3.1 Laboratory tests

Measurements have shown that the heat loss coefficient of a heat storage with an external heat exchanger for domestic hot water heating built into a side-arm can be high due to a high heat loss from the side-arm.

Measurements of the heat loss coefficient of the side-arm have been carried out for a 655 l heat storage from SOLVIS GmbH & Co KG, see figure 1. The domestic hot water heating takes place in a heat exchanger (11) built into a side-arm going from the top to the bottom of the heat storage.

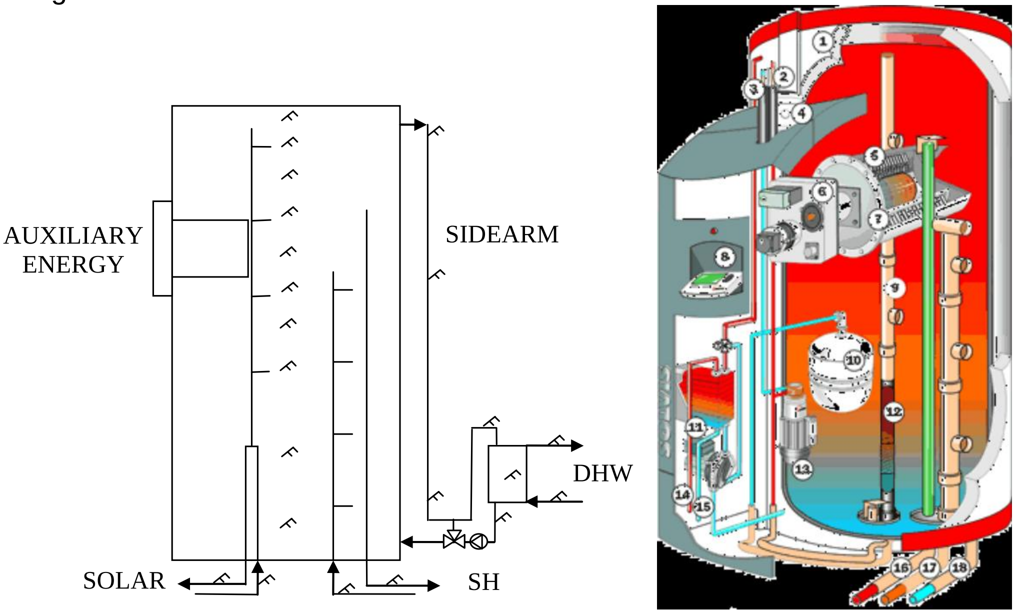

Figure 1. Heat storage investigated in laboratory experiments.

Temperature sensors were placed at different locations of the side-arm and heat exchanger in good thermal contact with the pipe/heat exchanger material. The temperature sensors were placed beneath the insulation material of the pipe/heat exchanger. The locations of the temperature sensors are shown in figure 2. Temperature sensors were also placed inside the heat storage.

The heat storage inclusive the side-arm was heated to a high constant temperature by means of the solar heat exchanger. The heat storage was left in a stand-by period without any charge or discharge of the heat storage. Based on measurements of the temperatures in the side-arm, of the ambient air temperature and on knowledge of the heat capacity of the side-arm and the heat exchanger the heat loss coefficients of the different parts of the side-arm were determined by equation 1:

$$Ki = -(Ci/t) \times \ln((Tie - Ta)/(Tis - Ta)) \qquad (1)$$

where Ki is the heat loss coefficient of part i of the side-arm, W/K

Ci is the heat capacity of part i of the side-arm, J/K

t is the time of the stand-by period, s
Tis is the temperature of part i of the side-arm at the start of the stand-by period, °C
Tie is the temperature of part i of the side-arm at the end of the stand-by period, °C
Ta is the average ambient air temperature during the stand-by period, °C

The heat capacities of the different parts of the side-arm are determined by means of knowledge of the water volumes and pipe/heat exchanger material and dimensions of the side-arm.

Figure 3 shows measured temperatures during a number of stand-by periods. The first stand-by period is used to determine the heat loss coefficients.

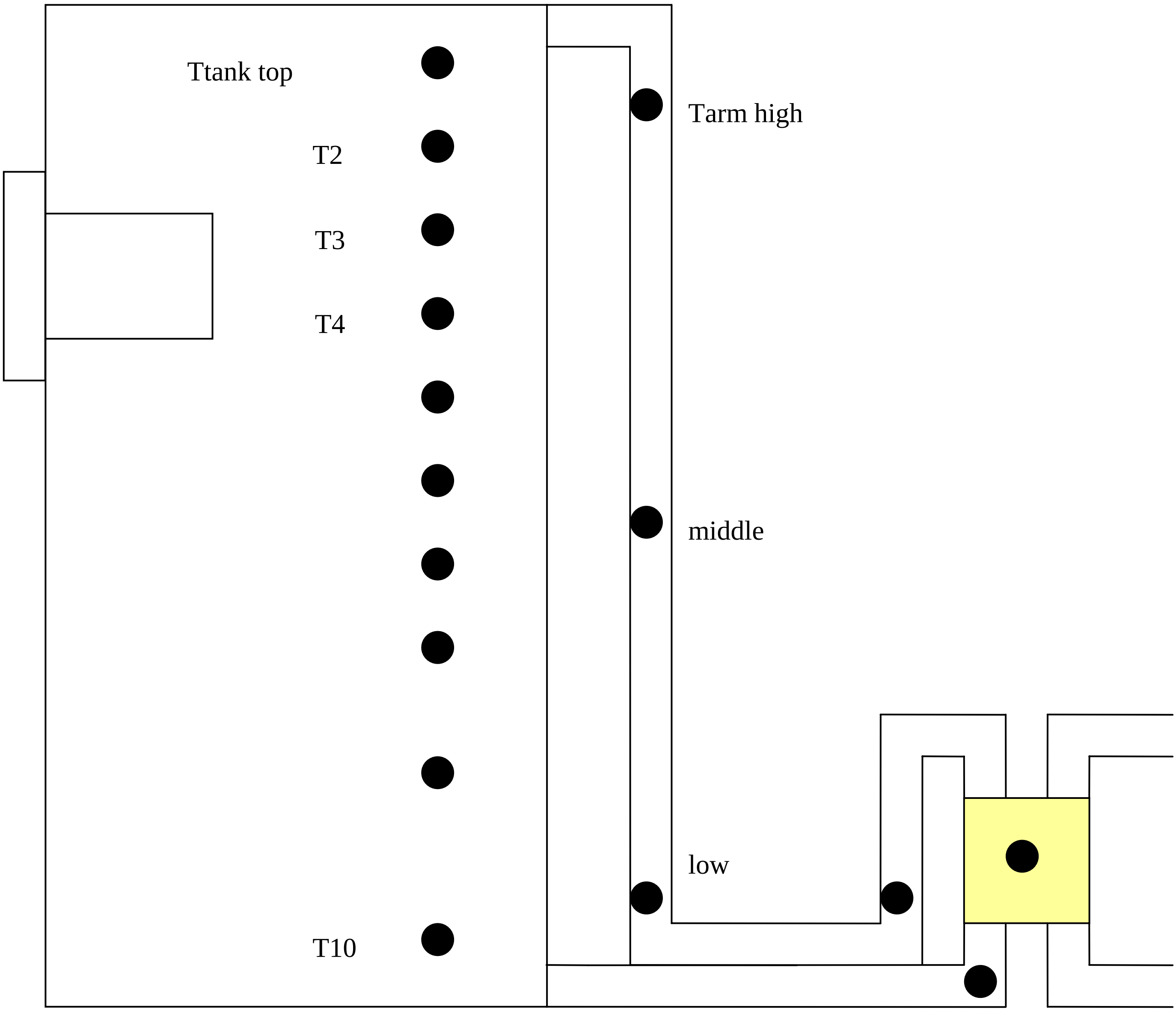

Figure 2. Locations of temperature sensors on the side-arm of the tested heat storage.

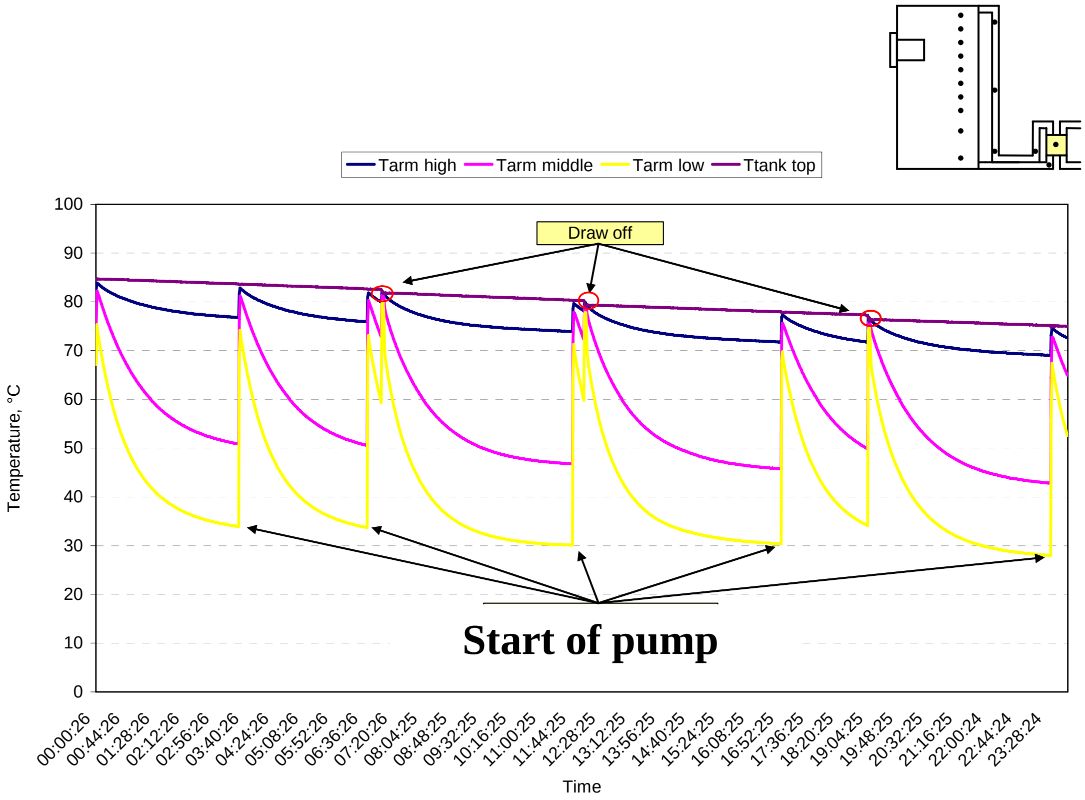

Figure 3. Measured temperatures during a number of stand-by periods.

The determined heat loss coefficients for the side-arm appear from table 1.

Part of side-arm	Heat loss coefficient
Pipes (22/20 mm copper)	0.39 W/K
Heat exchanger	0.37 W/K
Side-arm total	0.76 W/K

Table 1. Measured heat loss coefficients of the side-arm.

Further, measurements for periods of normal operation of the SOLVIS solar heating system showed that the temperatures of the side arm always are relatively high, see figure 3. This is caused by the fact that the control system of the system automatically starts the circulation pump in the side-arm in short periods if the temperature of the side-arm is too low.

If the circulation pump is not activated the tank/side-arm loop will be a loop in which thermosyphoning will occur due to the relative fast cooling of the water in the side-arm unless a closed valve prevents it. The thermosyphoning will keep the side-arm temperature warm, even in periods without hot water draw-offs. Consequently, the heat loss of the side-arm will in most systems be high.

Calculations have shown that the yearly thermal performance of solar combisystems based on heat storages with side-arms is relatively low, first of all due to the high heat loss from the side-arm, /And07/. It is therefore important that test methods are able with a reasonable accuracy to determine the heat loss coefficient of the side-arm.

Furthermore, the distribution of the heat loss coefficient on the different parts of the heat storage will influence the thermal performance of the solar heating system. Calculations are carried out for a solar heating system with a 20 m² south facing, 65° tilted solar collector and a 1000 l heat storage with three different distributions of the heat loss coefficient:

- The heat loss coefficient of the tank is 4.58 W/K, and the heat loss coefficient of the side arm is 0.76 W/K, as it appears from table 1.
- The heat loss coefficient of the tank is 5.34 W/K inclusive a thermal bridge at the top of the tank of 0.76 W/K. The heat loss coefficient of the side arm is not considered.
- The heat loss coefficient of the tank is 5.34 W/K inclusive a thermal bridge at the bottom of the tank of 0.76 W/K. The heat loss coefficient of the side arm is not considered.

The solar heating system is installed in a one family house in Denmark with a yearly space heating demand of 15000 kWh and a daily hot water consumption of 200 l. Calculations are carried out with the hot water consumption drawn once a day and three and eight times a day. The calculated net utilized solar energy of the solar heating system is shown in figure 4. It is seen that the thermal performance is decreasing for increasing number of daily hot water draw offs. It is also clear that the thermal performance is influenced by the distribution of the heat loss coefficient. Especially the thermal performance will decrease for increasing heat loss coefficient at the top of the tank. It is therefore also important that test methods are able to determine the distribution of the heat loss coefficient of heat stores with a reasonable accuracy.

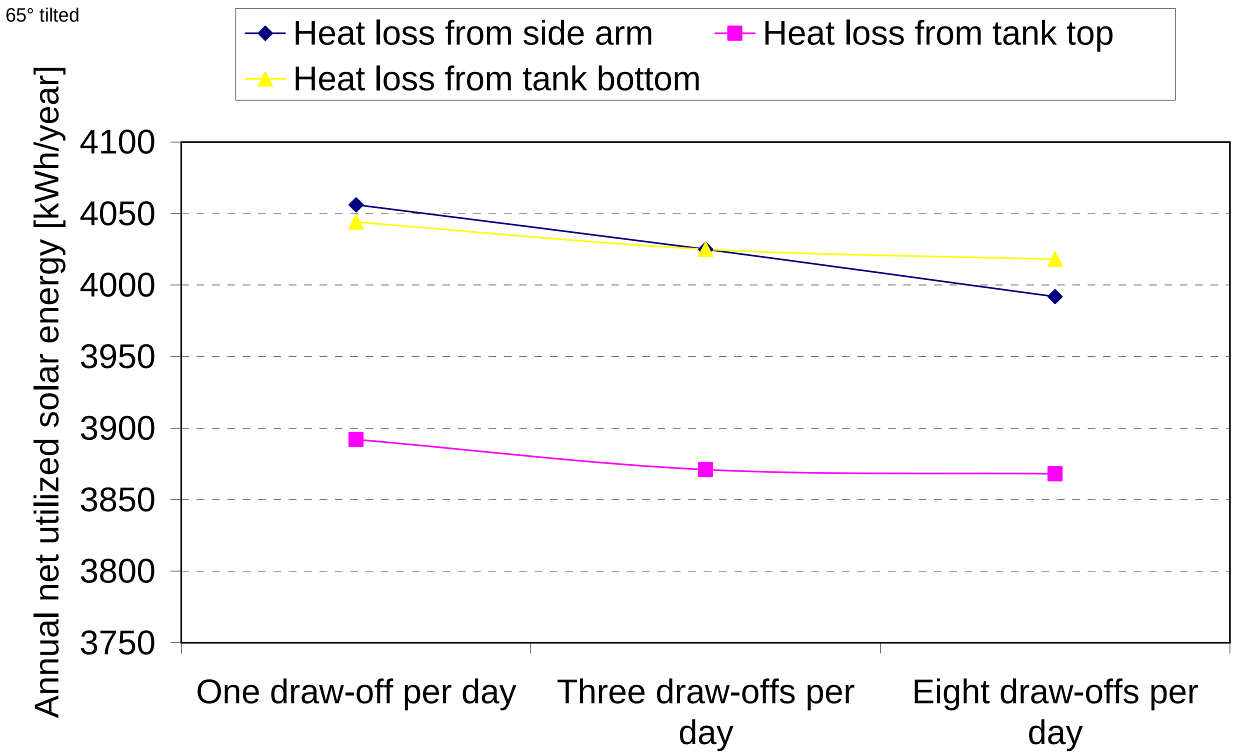

Figure 4. Yearly net utilized solar energy for a solar heating system with different distributions of the heat loss coefficient.

Finally, heat storages with side-arms with heat exchangers for domestic hot water heating require a higher temperature in the top of the heat storage than the required hot water temperature. The required tank top temperature depends first of all by the heat exchange capacity rate of the heat exchanger. The heat exchange capacity rate is a function of the flow rates used on both sides of the heat exchanger.

The auxiliary energy supply system will in normal systems heat the top of the tank to a required high temperature to met the domestic hot water comfort requirements in periods without sufficiently solar energy. The thermal performance of solar combisystems is strongly influenced by this tank top temperature. It is therefore important that test methods can determine the required tank top temperature.

In the following proposals for different test methods to determine the heat loss coefficients of side-arms and for a test method to determine the needed temperature at the top of the heat storage are described.

4.3.2 Test methods to determine the heat loss coefficient of a side-arm with built in heat exchanger for domestic hot water heating

PROPOSAL 1

The total heat loss coefficient of the heat storage inclusive the side-arm at finite flow rate through the solar heat exchanger is measured in a steady state period with a constant solar collector fluid inlet temperature of 70°C.

A valve is built into the side-arm, if a valve is not already integrated in the side-arm, and temperature sensors are located in good thermal contact to the side-arm at different parts of the side-arm and heat exchanger beneath the thermal insulation. The heat storage inclusive the side-arm is heated to 75°C and left alone for a 3 h stand-by period. Based on equation (1) the heat loss coefficients for the pipe connecting the top of the store to the heat exchanger, for the heat exchanger and for the pipe connecting the heat exchanger to the lower part of the store are determined by means of temperature measurements during the stand-by period.

The heat loss coefficient of the store without the side-arm is found as the difference between the total heat loss coefficient of the heat storage and the total heat loss coefficient of the side-arm.

PROPOSAL 2

The heat loss coefficient of the heat storage inclusive the side-arm at a finite flow rate through the solar heat exchanger is measured in a steady state period with a constant solar collector fluid inlet temperature of 70°C.

The side-arm is disconnected from the heat storage. The pipe connections at the tank surface are carefully insulated. Hereafter the measurement of the heat loss coefficient is repeated using the same method as mentioned above.

In this way the heat loss coefficients of the heat storage and the side-arm can be found.

PROPOSAL 3

The heat loss coefficient of the heat storage inclusive the side-arm at a finite flow rate through the solar heat exchanger is measured in a steady state period with a constant solar collector fluid inlet temperature of 70°C.

The measured heat loss coefficient is compared to the theoretical heat loss coefficient calculated based on information of the heat storage geometry inclusive the geometry of the side-arm, the insulation material and the insulation thickness.

In this way the distribution of the heat loss coefficient on the different parts of the heat storage can be determined if there is a good agreement between measured and calculated heat loss coefficients.

If the measured heat loss coefficient is lower than a certain quantity the heat storage has a reasonable low heat loss and no further tests should be carried out. An estimate of the distribution of the heat loss coefficients on the different parts of the heat storage will be made. The errors introduced in this way will be reasonable small.

If the heat loss coefficient is higher than a certain quantity the heat storage should be further investigated. Proposal 1 or 2 can in this case be used to determine the heat loss coefficient of the side-arm.

4.3.3 Test method to determine the needed temperature at the top of the store

The heat storage is heated to 55°C, 60°C, 65°C and 70°C. When steady state has been reached 50 l of domestic hot water is drawn from the heat storage with a flow rate of 2, 5, 10 and 15 l/min. In this way 16 draw-off tests are carried out. The hot water temperature is measured during the draw-offs. A figure and a table showing the average hot water temperature during the draw-off as functions of the tank top temperature and flow rate can be worked out based on the tests. By means of the figure and table the needed top tank temperature can be determined.

4.3.4 Conclusion

It is recommended test institutes to make use of the above mentioned methods in order to gain experience with the methods. It is judged to be too early to pass on any test method to CEN/TC312 to be considered for standardisation.

5. Conclusions

The activities on standards for advanced stores have been described. It is judged to be too early to pass on any specific test method to CEN/TC312 to be considered for standardisation. Instead it is suggested that test methods may be adapted or developed to suit specific store designs or specific utilization of the findings gained through testing. Rules and guidelines to be followed in general and validation procedures shall ensure that the outcome of testing is generally comparable and reliable. The recommended liberalization of the method used to assess solar thermal system and storage tank performance offers several important advantages:

- Through case designed or case adapted methods the diversity of the system technology present can be covered.
- A variety of different methods will allow to deal appropriately with the diversity of purposes of system testing and rating (e.g.: consumer information; rating for the allocation of subsidies; supplying a precise model and useful information for system development and improvement to a manufacturer)
- Scientists will be encouraged to develop new and better test methods.

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