REPORT ON TESTING PROCEDURES FOR SHP SYSTEMS

Technical Report 5.1.4

ITW – University of Stuttgart

Sebastian Bonk, Anja Loose

Fraunhofer ISE

Christian Schmidt

Centre Scientifique et Technique du Bâtiment (CSTB)

Peter Riederer

With contribution from:

SPF – Institut für Solartechnik

Robert Haberl, Michel Haller

Version: 1.4

Date: 31/05/2012

Final Document

Quality Assurance in solar thermal heating and cooling technology – keeping track with recent and upcoming developments

Contact Info

University of Stuttgart - Institute for thermodynamics and thermal engineering (ITW)

Address: Pfaffenwaldring 6, 70550 Stuttgart, Germany
Tel. : +49 711 685 63595
Fax : +49 711 685 63242
E-mail: loose@itw.uni-stuttgart.de, bonk@itw.uni-stuttgart.de

Fraunhofer Institut für Solare Energiesysteme (ISE)

Address: Heidenhofstrasse 2, 79110 Freiburg, Germany
Tel. : +49 761 45 88 – 5620
Fax : +49 761 45 88-9000
E-mail: christian.schmidt@ise.fraunhofer.de

Centre Scientifique et Technique du Bâtiment (CSTB)

Address: 290 Route des Lucioles, 06904 Sophia Antipolis Cedex, France
Tel. : +33 4 93 95 64 42
Fax : +33 4 93 95 64 31
E-mail: peter.riederer@cstb.fr

Table of contents

1 Introduction

Many manufacturers of combined solar and heat pump systems advertise their products by giving very high system performance factors, especially for such type of systems in which solar thermal part and heat pump are connected in a serial way, i.e. in which the heat pump can be provided with a higher source temperature while the solar collector might be operated at lower return temperatures, respectively. Yet, these performance factors are not very reliable and cannot be verified by the customer because no objective performance test methods and hence no quality labels (like the Solar Keymark[1] for solar thermal collectors and systems) are available for these combined systems.

Results from field tests with solar combisystems and with monovalent heat pumps [1,2] have shown that the effective thermal performance of the heating systems in real operation depends significantly on the quality of installation. Therefore, not only the performance of the solar thermal collector and the heat pump as such is important, but also the quality of the thermal insulation and the thermal stratification in the combistores. The relevance of controlling increases the more complex a combined solar and heat pump system is built up and the more important becomes the appropriate selection of the different possible modes of operation.

The thermal performance of solar thermal systems can be characterised by the reduction of the required energy for auxiliary heating or by the fractional energy savings, respectively. Test and calculation methods for the determination of these values are described e.g. in the European standards EN 12976-2 and EN 12977-2. For the thermal performance characterisation of heat pump systems the seasonal performance factor (SPF) is widely used. Assessment and calculation methods for the determination of the SPF can be found e.g. in the European standard EN 15316-4-2:2008 and in the German guideline VDI 4650.

However, these standards cannot be applied directly to combined solar thermal heat pump systems because they do not account for the interactions between the components as well as for the behaviour of the components (e.g. the heat pump) under dynamic operating conditions (varying heat source temperatures and flow temperatures in the heating system). Another complexity of combined solar and heat pump systems is the variety of different possible operating modes, like direct use of solar gains for domestic hot water preparation and space heating, use of the heat pump only in the cold season, use of solar gains as additional heat source for the heat pump, solar defrosting of air to water heat pumps etc. An efficient solar collector and a heat pump with a high coefficient of performance (COP) do not necessarily guarantee a good overall system, since an optimised sequence of operating modes depending on the outer conditions and on the minimisation of electricity consumption versus

[1] For further information see: www.solarkeymark.org

additional solar gains is very important for the overall system performance. Hence, the development of new test methods is essential in order to be able to characterise the energetic efficiency performance and the environmental impact of combined solar thermal and heat pump systems in an objective manner.

One single performance test method will not be enough to cover the variety of different possible system combinations on the market. Systems using a parallel combination of solar collectors and heat pump can be seen as solar combisystems with a heat pump as auxiliary heater, while serial combined systems are more complex. In the latter cases, additional solar gains are used as further heat source for the heat pump. This can be either directly (solar energy is been lead to the evaporator of the heat pump) or indirectly via a storage system which can be the ground, a secondary hot water storage at lower temperature level, a latent heat storage or others. Some of these systems are very compact with a high integration level while others consist of discrete components which can be separated or even exchanged. Due to this fact, different performance test methods are currently being developed by a number of institutes in Europe. At ITW there is an on-going development of a new component oriented testing procedure for SHP systems (described in Chapter 2), as well as previous work on a testing procedure based on a test of the complete system at once [3]. Regarding this approach there is an on-going work performed at Fraunhofer ISE and described in Chapter 3.

1.1 Performance factors

The thermal performance of a conventional heat pump system is characterised by the seasonal performance factor (SPF). The German VDI 4650:2003 defines the SPF as ratio of the produced heat by the heat pump in the course of one year to the electrical power used to drive the compressor and the auxiliary drives. The calculation is based on the coefficient of performance (COP) of heat pumps determined according to standardised tests (e.g. EN 14511-3:2007 or EN 255-3:1997) [4]. The performance factors to be developed for combined solar thermal and heat pump systems might look very similar to a conventional heat pump's SPF. The difference is that the energy flows of the complete system (including the solar thermal part) have to be integrated into the value, concerning both heat flow and electrical energy consumption, respectively. Besides an overall “system” or “solar” SPF, which comprises the complete heating system, many other SPF's can be defined by changing the boundaries for the energy balance. Different examples for such performance factors have been proposed within Technical Report 5.1.3, in collaboration with IEA SHC Task 44 / HPP Annex 38 [5]. In any case it is crucial to have the same definitions and boundary conditions when comparing the SPF's of different systems, since there are a variety of possibilities.

The thermal performance of a solar thermal system can be characterised by the fractional energy savings f_{sav} defined as the saved fuel consumption of the solar thermal system (Q_{ref} -Q_{aux}) compared with the energy consumption of a conventional reference system (Q_{ref}), where Q_{aux} is the energy load of the auxiliary boiler in a solar combisystem:

$$f_{sav} = \frac{Q_{ref} - Q_{aux}}{Q_{ref}}$$

Additional performance factors like the primary energy ratio (PER) or CO_2-emissions may be calculated if needed.

1.2 General approaches to SHP system testing

To data, there is no standard testing procedure available for the evaluation of the performance of SHP systems.

Two general approaches exist that could be used for the evaluation of SHP systems, both presenting advantages and disadvantages:

- **Component oriented approach**

  This approach has been developed for solar combisystems and could also be used for SHP systems. A technical specification (EN TS 12977-2) has been developed within the work of CEN TC 312. The performance of solar combisystems is calculated by simulation, the parameters for the numerical models of each of the system components being determined by separate component tests (solar collector, storage tank and control system). This method has the advantage of being very flexible, especially the evaluation of a whole range of products with different sizes etc. can be carried out easily. However, this method is characterised by several disadvantages:

  - The system is not even tested once in its complete assembly, there is thus as risk in the accuracy of the results;
  - The evaluation of the control system and its modelling can be a difficult task: especially for innovative controllers with more complex control algorithms, the definition of an evaluation method for the controllers and the transposition into a simulation model is tricky and can have a significant impact on the global performance of the system.

- **Global approach**

  This approach has been developed within Task 26 of the IEA solar heating and cooling programme for the evaluation of solar combisystems. In this test method, the global system is tested, integrated in a simulated environment (in the case of solar combisystems building and solar collectors – cf. Figure 1).

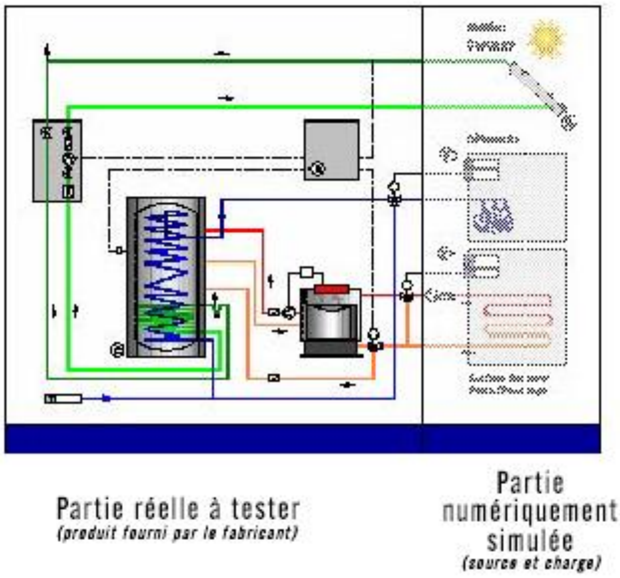

Figure 1 : Layout of the virtual test bench for solar combisystems

The left hand of the figure shows the solar combisystem being tested; the right hand shows the emulated part of the test that is the solar collector (simulated using the results of collector tests).

The advantage of this test procedure is that the global system including its control is tested. Evaluated performances are thus close to real performances. The disadvantage the extrapolation to other system sizes, climates or buildings. In this case supplementary tests for component identification are necessary. This approach will be presented in this report, applied to SHP systems.

2 The CTSS test procedure (Component Testing – System Simulation) - ITW

The development of a component oriented test method for heat pumps is one element of the project *WPSol*[2] carried out at present at ITW. Key elements of this project are extensive measurements of different heat pumps under dynamic conditions performed on a new test facility. During this process characteristic parameters for the heat pumps are determined, which in combination with corresponding numerical models allow for a detailed description of the heat pump's thermal behaviour. Furthermore, a subsequent validation of this test procedure on the basis of *in-situ* measurements of several combined solar and heat pump systems of different types installed in single-family houses will be carried out. In parallel, simulations with the software TRNSYS are performed to predict the thermal behaviour of the heating systems for a period of one year using standardised reference conditions.

In general, test methods for thermal performance testing of solar thermal systems can be distinguished into a component orientated approach (e.g. CTSS test method) and a whole system based approach (e.g. DST or CSTG method; DST: Dynamic system testing; CSTG: Complete system testing group test). The European standard EN 12976 for so-called factory made systems refers with regard to performance testing to the CSTG method standardised in ISO 9459-2 and the DST method standardised in ISO 9459-5. The CTSS method is an integral part of the standard series CEN/TS 12977. Based on these standards, two performance test methods are being developed at ITW for combined solar thermal heat pump systems. The first method is based on the *DST method* (c.f. Figure 2a), where the dynamic behaviour of the whole system is taken into account as the system is tested as a complete unit under dynamic operating conditions [3]. Within the WPSol project the main focus at ITW lies on the further development of the *CTSS test method* (Component Testing – System Simulation, c.f Figure 2b) towards combined solar thermal and heat pump systems.

The CTSS test method, developed at ITW 15 years ago, uses a component orientated approach which is based on physical tests of the key components. Today this method is standardised in the European standard series CEN/TS 12977 dedicated to so-called custom built solar domestic hot water systems and to combisystems. The heat store is tested according to EN 12977-3 (hot water stores) or CEN/TS 12977-4 (combistores) respectively, the collector according to EN 12975-2 and the controller according to CEN/TS 12977-5. The aim of the component tests is the determination of all relevant component parameters required for the detailed description of the thermal behaviour of the individual components. Therefore numerical models to describe the dynamic behaviour of the specific components are required. Parameters of these models are determined by means of parameter identification using measured data from

[2] Project WPSol: „Leistungsprüfung und ökologische Bewertung von kombinierten Solar-Wärmepumpen- anlagen" (Performance Testing and Ecological Assessment of Combined Solar Thermal and Heat Pump Systems)

several well defined test sequences of the component testing. Based on the parameters determined for the different components, the annual thermal performance of the complete system can be predicted for defined reference conditions (meteorological data, load profiles) by using a component based simulation program such as TRNSYS [3,4].

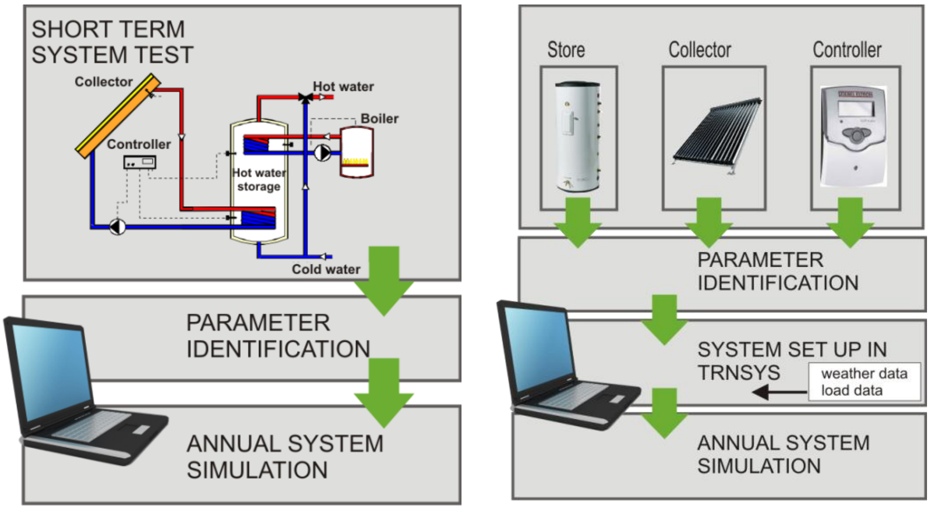

Figure 2: a) Schematic approach of the dynamic system test method for solar domestic hot water systems (left) and b) the CTSS test procedure for solar combisystems (right)

For applying the CTSS method the solar thermal system does not need to be installed as a whole for testing. Due to this, the application range of the CTSS method is very flexible because of its component-oriented approach. Hence, it is possible to apply the CTSS method on nearly every system configuration. Another important advantage of the CTSS method is that the thermal performance of the tested systems can be easily determined for any arbitrary boundary conditions such as weather and heating load since this is done by numerical system simulations only [4].

2.1 Extension of the CTSS method towards combined solar and heat pump systems

Figure 3a shows how the scheme of an extended CTSS method applicable to combined solar heat pump systems may look like in general. The difference to the scheme of the present version of the CTSS method according to CEN/TS 12977 (see Figure 2b) is that there will be one more component test for the heat pump. At present, the performance of the heat pump is derived from standardised heat pump tests which are carried out under steady-state test conditions according to already existing standards. But field tests have shown that the test results determined on this basis can differ significantly from the real dynamic behaviour of the heat pump. Hence, for a more objective assessment of the heat pump a standardised dynamic test method is required. Due to this the development of a thermal performance test method for heat pumps under dynamic conditions is an important part of the extension of the CTSS performance test method towards combined solar and heat pump systems. This includes a decision which performance parameters will be required for the dynamic operation behaviour of heat pumps, the development or modification of numerical models for heat pumps, a validation of the numerical models as well as a validation of the extended CTSS method and an integration of the extended CTSS method in a future version of the CEN/TS 12977 series.

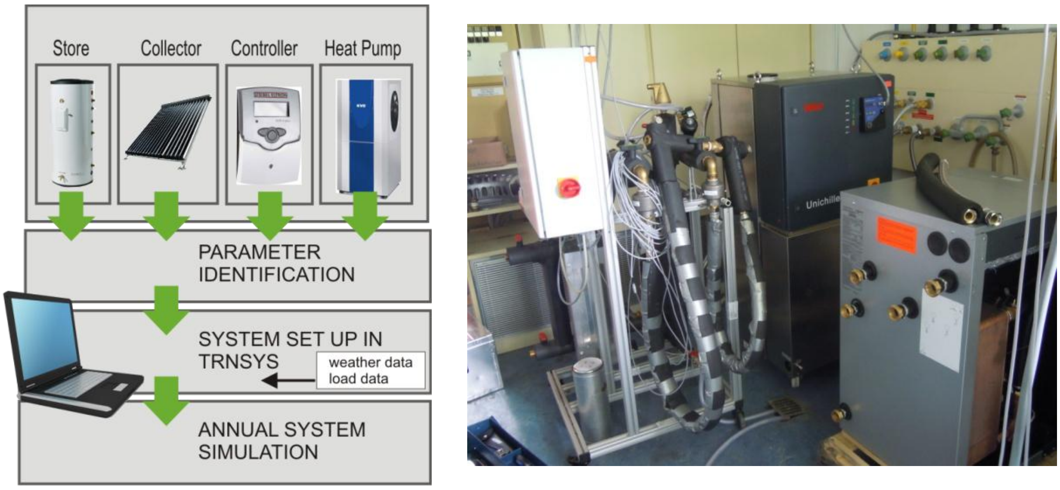

Figure 3*: a) Schematic description of the CTSS test procedure extended for solar and heat pump systems (left) and b) performance test facility for heat pumps at ITW (right)*

For that purpose, a new test facility for the examination of electrically driven compression heat pumps has been built up at ITW. The conceptual design of the test facility enables the heat pump test to be fed with temperatures from controllable heat sources and sinks. By means of this heating loads and gains of environmental heat can be simulated in a transient way.

The test facility is equipped with extensive measuring instrumentation for the monitoring of all relevant temperatures, volume flow rates and electric power consumption of the heat pump and auxiliary systems. Therefore a complete energy balance is feasible and the specific values of the heat pump can be determined. The controlling of the test facility and the acquisition of measured data is carried out with a *Labview* program, which has been developed for this application. The data recorded during the dynamic test of the heat pump are processed in such a way that they can be used directly for the determination of the parameters required by the numerical heat pump model for a detailed characterisation of the thermal behaviour of the heat pump. So far brine to water and water to water heat pumps up to 25 kW heating capacity can be tested. An extension to air to water heat pumps is planned for the near future.

2.2 Standardisation

It is important that the procedures established under the project to determine the thermal performance and to assess the environmental impact in the long term be included in the European (CEN) and international (ISO) standards. An employee in the appropriate standards bodies is therefore provided.

On the basis of the previous steps the extension of the CTSS method towards combined solar and heat pump systems can be implemented into the EN 12977 series. The project WPSol will be completed in autumn of 2013. Hence, the results of the project WPSol shall be implemented by the European Committee for Standardization TC 312 in a revision or extension of the European standard EN 12977. A new work item shall be established in TC 312 in order to extend EN 12977 in a first step on

"Thermal solar systems and components – Custom built systems – Part 8: Performance characterisation methods for electrically driven heat pumps."

2.3 Acknowledgement

The work described in this paper is part of the project "Performance Testing and Ecological Assessment of Combined Solar Thermal and Heat Pump Systems" (WPSol) funded by the German ministry BMU (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit / Federal Ministry for the Environment, Nature Conservation and Nuclear Safety) under the grant number 0325967A and managed by PtJ (Projektträger Jülich / Project Management Jülich). The authors gratefully thank for the support and carry the full responsibility of the content of this publication.

3 Characterisation of SHP systems with a modified DST method – Fraunhofer ISE

The DST method, as described in Technical Report 5.1.2, part of the QAiST Deliverable5.1 [6], is a very efficient outdoor testing method for the characterisation of compact solar thermal systems for domestic hot water production. Similar to the CTSS method, the test sequences are designed to investigate the system behaviour under extreme operating conditions. The goal is to determine the characteristic system parameters using a computer model and an optimisation tool for data processing after the measurements. Unlike for the CTSS method, the system is tested as a whole.

The proprietary, MS-DOS based DST software does not seem to be suitable for building a new system model including a heat pump model. In the past, efforts have been undertaken to use different software, such as TRNSYS [7].

The performance relevant parameters of the new set up system have to be identified. Additionally, the present test sequences used for solar thermal systems would have to be adapted.

In order to develop the modified DST method, a new system model needs to be set up in TRNSYS. During development, the effectiveness of selected test sequences to identify selected performance parameters can be carried out using synthetic "measurement" data which have been previously generated by simulation, similar to the approach described in [8]. Validation of data needs to be carried out using experimental data, which should be preferably done using monitoring data; alternatively also data from a fully installed system on the test rig could be used.

Depending on availability of existing TRNSYS models and a system to be tested for developing the method, first results can be expected by the end of 2012.

Expected advantages of the modified DST method are:

- the whole system is tested, unlike e.g. within the CTSS method (single components) or the CCT [9] method (system without collector[3]):
  - "proper" validation procedure of the whole system is possible;
  - allows testing for the determination of the stagnation behaviour of the whole system;
  - considering compact SHP systems with a HP attached [9], integrated into the collector or systems with other extraordinary collector designs which cannot be characterized according to collector test standard EN 12975, neither CCT nor CTSS could be applied
- as for the CCT method, it requires less detailed component modelling than the CTSS method which allows the method to be used for a greater variety of system configurations. The effort for system adaptions is lower;
- compared to the CCT method, the requirements regarding the infrastructure (test rig) are less demanding. The same applies for the test sequences.

Expected disadvantages of the modified DST method are:

- less detailed (accurate) modelling is a challenge regarding the requirement for an accurate yearly performance simulation or regarding a higher effort for the validation;
- testing of complex system configurations strategies can result in insufficient accuracy to properly predict system performance;
- there are currently no test methods available which fully account for sophisticated system control algorithms.

[3] Exception: AC/DC method (Direct Characterisation – Annual Characterization)

4 CCT Concise Cycle Test – SPF - Institut für Solartechnik SPF

The “Concise Cycle Test” method (CCT) is a special dynamic method developed at the Institut für Solartechnik SPF in Rapperswil to test solar combisystems. The method is based on previous and parallel research and experience gathered from other research institutes and was developed within IEA’s solar heating and cooling programme in Task 26 [10].

Test setup

The entire system, inclusive of auxiliary heating, hydraulics and controllers, is installed on SPF’s indoor test rig. The test building and the collectors included in the solar loop are emulated in real-time using controlled heat sources and sinks.

Test cycle

A special 12-day test cycle was developed to test a complete, solar combined heating system in dynamic operation under the boundary conditions that typically occur over the year. Over this period of time the system should operate realistically, with no external interference, to cover the imposed space heating and domestic hot water heating requirements.

Heat Pumps

When a heat pump is used as an auxiliary heater the source of the heat pump is emulated in real-time to achieve realistic operation behaviour. In the case of air source heat pumps a climatic chamber is used that is conditioned to the 12-day test cycle climatic data. The air-source heat pump is placed in this chamber. In the case of a ground source heat pump the response of the ground heat exchangers is simulated and the test rig is used to emulate this heat source.

Annual simulations

After completion of the 12-day test sequence a complete simulation model is set up and parameterized by comparing its results with the measured data. With this calibrated model, annual performance data is calculated. The model provides also the opportunity to calculate the effect of variations in system design and control without any further practical tests and thus to identify any potentials for improvement.

Research and development

The combination of different heat sources within a single system sets high standards for the design of hydraulics and controllers. Dynamic whole system test methods are well suitable and an efficient tool to support the development of (new) systems and components with accurate and efficient measurements.

Harmonization

Other institutes that apply whole system test procedures for solar combisystems are the research institutes SERC and SP form Sweden and INES from France [11] These other whole system test methods use direct extrapolation instead of modeling and simulation to obtain annual performance figures. Within the project MacSheep that receives funding from the EU FP7, a further development and harmonization of these different test methods is aimed for.

5 Global Testing Procedure - CSTB

5.1 The approach

More and more innovations appear on the market to provide multi-energy systems for space heating, cooling and domestic hot water supply. These systems can be based on solar thermal, heat pumps, biomass boilers etc. or any combination of the previous.

The necessity of innovation on this field imposes on the industry to develop faster and faster new products or product assemblies while managing perfectly the quality of the products. Prototypes and later the finalized product have to be developed and tested. Once the product on the market, standard tests exist in some cases of systems, but in most cases annual performances of the systems have to be estimated from simplified standardized test results.

In order to accelerate this process, a dynamic emulation test method has been developed on the example of a geothermal heat pump system [12]. The aim is to prepare a testing method for heat pumps allowing the evaluation of their performances close to real, annual performances as obtained in field tests. The method, initially developed for heat pump systems, can also be used for SHP systems.

Emulation technique is used for control systems since the early 90’s [13]. Similar approaches have already been investigated and validated for renewable energy systems for solar combisystems [10,14,15]. These approaches are based on system emulation: the solar combisystem is emulated in a virtual building and simulated solar collectors.

The advantage of this approach is, that the test is carried out under “quasi”-realistic, dynamic conditions: dynamic weather conditions and occupancy profiles are used as well as a simulated building and heating/cooling system. This approach opens a large variety of possible test schedules since the simulated building, the heating system, weather conditions and occupancy can be changed freely.

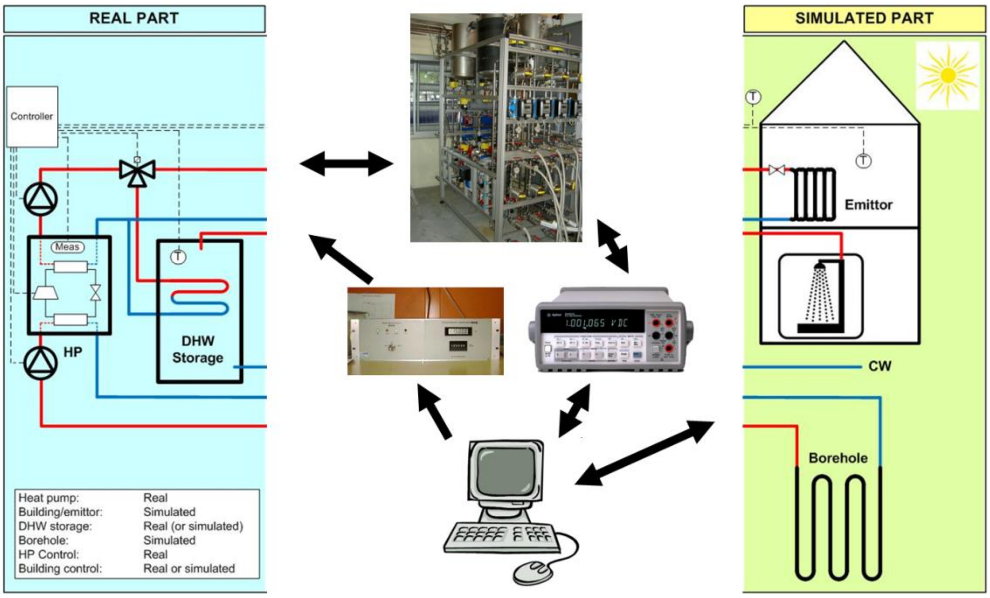

Figure 4 : Principle of the virtual test bench for a heat pump system

A methodology for the definition of a reference test scenario is described in this report for the application of a geothermal heat pump for heating, cooling and hot water preparation.

The test method is developed by parametric, numerical study: A typical GSHP system is modelled in Matlab/Simulink.

The development of the whole methodology follows the steps listed hereunder:

- Step 1: annual simulation of a geothermal heat pump for different climates, ground types etc.;
- Step 2: development of a first test sequences by calculation of average days representing each the average of one month;
- Step 3: adjustment of the average days in order to fit the extrapolated, annual consumption by the 12 day-test method with those calculated by annual simulation (optimisation of the test sequence);

One particular problem of such a method for the geothermal heat pump is the inertia of the parts of the system (in this case the inertia of the ground). The methodology shows how to deal with this issue and to obtain a representative test methodology.

5.2 The testing facility

The real system is installed on a semi-virtual test bench. Figure 5 shows an example of such a test bench.

Figure 5 : Test bench facilities with charge and discharge modules

These test benches allows the emulation of almost any water-flowed energy-system using different charge and discharge circuits. The test bench control allows the outlet temperature and flow rate being controlled following building or system simulation. Matlab/Simulink or TRNSYS is used for the numerical part of the test bench. Simulation is therefore slowed down to real time and the simulation environment enables at the same time the test bench control, system simulation (emulator) and online monitoring of the test. Outlet and zone temperature sensors are replaced by programmable resistances, also controlled by simulation.

The test facilities shown in Figure 5 are only for water flowed systems. The same approach is currently being developed for air based systems which will allow also the test of SHP systems using air/air or air/water heat pumps.

The graphical user interface for test bench control and visualisation is shown in Figure 6.

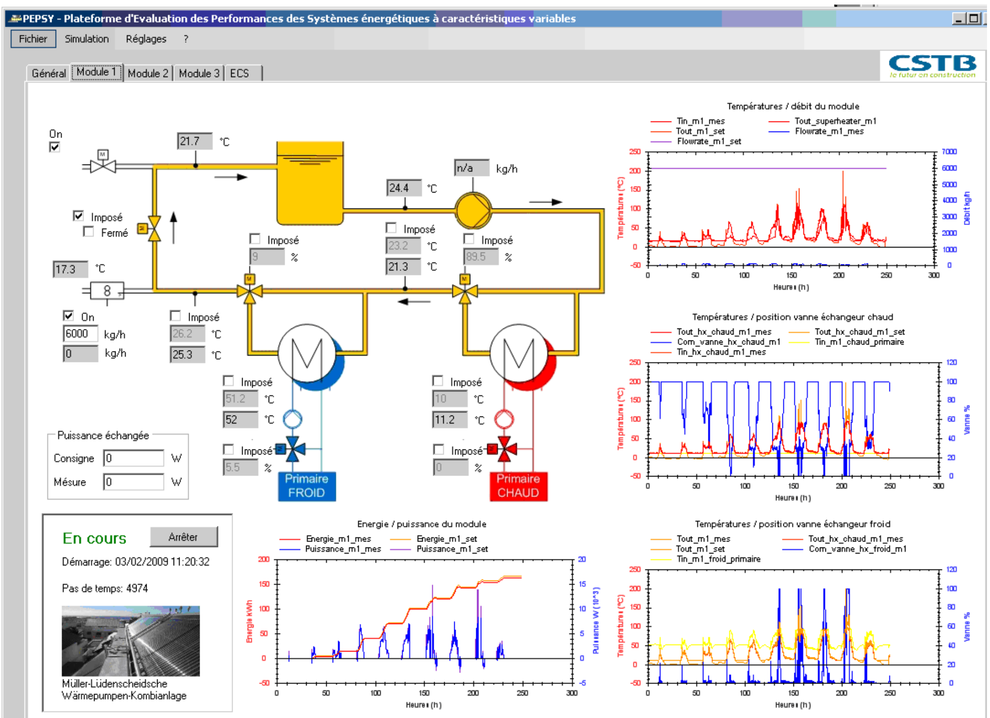

Figure 6 : GUI for the test bench

5.3 Development of the test procedure

The test procedure consists in a 12-day test scenario with each day representing a typical day of one month. The test scenario consists in a file with the following data of a time step of one hour:

- Weather data: outdoor temperature, solar direct and diffuse radiation;
- Occupant and equipment data: tap water profiles and internal gains.

The approach chosen is a mixture between annual simulation and a 12-day test in real time: the whole system including a model of the heat pump (based on identification) is simulated over one year. Each month one day (e.g. 15th day), the simulation is slowed down to real time and the numerical model of the heat pump (based on identification) is replaced by the system to be tested on the test bench, Figure 7.

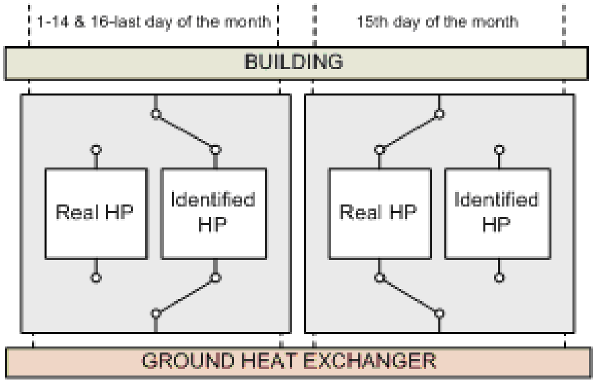

Figure 7 : Integration of real and simulated heat pump in the testing method

The particular problem when developing a reduced test scenario for SHP systems is the high inertia of the ground part of the system (geothermal HP) and the building.

5.3.1 Average test days

Each real-time day (one per month) of the testing sequence requires the use of specific weather data that have to be as representative as possible for the month concerned. Two methods for calculating the averages are applied:

- Method 1: the weather data of that day of the month (and the day before) where the average energy demand of the whole month has been reached has been replaced with the averaged hourly values of all days of the month with energy demand. Depending on the season, either heating or cooling demand is chosen as the reference (weighted momentum approach - WMA).
- Method 2: if one day of the month matches with the average energy demand of the building in this month and the average solar radiation this day is chosen as the real test day.

If the test in method 2 is positive, this method is applied for the specific month; if not method 1 is chosen.

In method 1, the typical day, with hourly data, is determined as follows:

$$\overline{X} = \left(\overline{x}_1 \ldots \overline{x}_{24}\right) = \frac{1}{n_d} \times \sum_{i=1}^{n_d} X(i)$$

where $\overline{X} = \left(\overline{x}_1 \ldots \overline{x}_{24}\right)$ are the 24 (hourly) values of the typical day, $X(i)$ are the 24 values of the ith day of the month and n_d is the number of days of this month to be considered (either all days or all days with energy demand, depending on the method).

This operation is realised on the weather data required by the simulation model, such as air dry bulb temperature, direct normal radiation, diffuse horizontal radiation. Figure 8 shows the results for the outdoor air temperature for the case of the climate of Trappes, France.

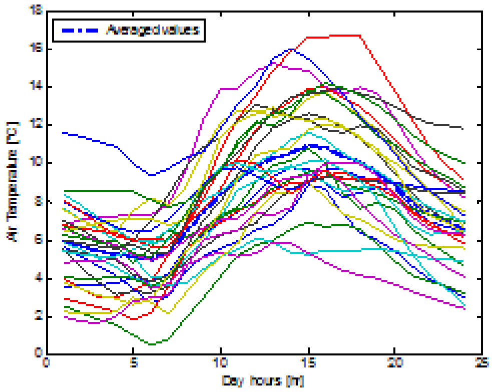

Figure 8 : Daily air temperatures of the original weather file (April, Trappes)

5.3.2 Mixture between annual simulation and real test days

Since the test is in fact an annual simulation with only 12 days in real time, the main part of the simulation has to be carried out using a model of the SHP system. This allows geothermal heat exchangers (if existing) as well as the building to be kept, in-between the real tests, at a temperature level that is as close as possible to that in real conditions.

All components of the SHP system have then to be identified based on measurement results, except the first month (not data available, catalogue data is used in this period). This is done after each real test day with all measurement data available (e.g. in month 12 using data from month 1-11).

It has been chosen to use an identification approach. The steps of the method are explained hereunder for the case where the 15th day is carried out in real time:

- in the first 14 days of the year the model parameters are those taken from manufacturer data or from a preliminary test;
- during the 15th day, the real heat pump is used;
- after each real time day where test data is available, new component models are identified representing the "real" performance data of the components (mainly heat pump, storage tank and controller).

The approach is illustrated in Figure 9 for the component of the heat pump.

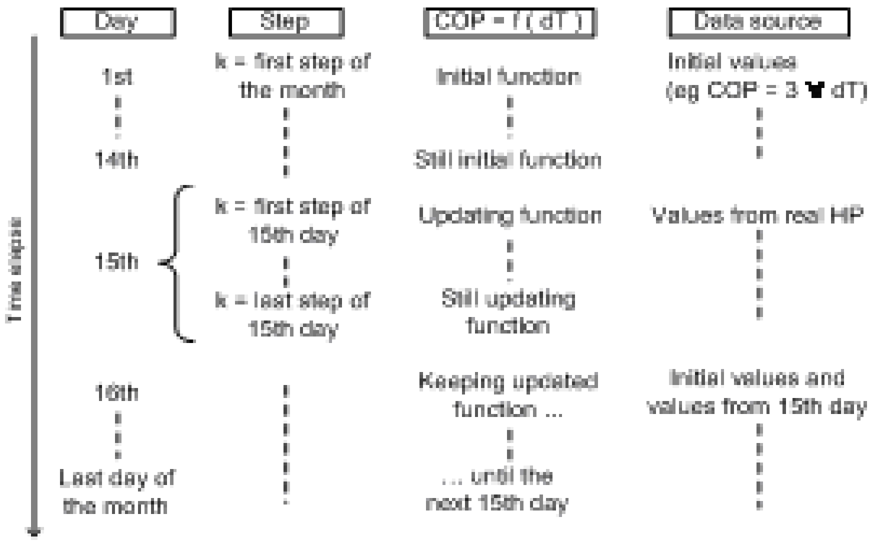

Figure 9 : Identification procedure for the example of the heat pump

In this way, it is possible to simulate the whole as close as possible to the real case and, at the end of the test, to dispose of component models based on the total available testing data of the real SHP system.

5.3.3 Modelling of the SHP system

The whole system model is based on Matlab/Simulink. The system includes the following components:

- Building part (building, floor heating system, domestic hot water tank, zones control, occupants, ventilation and equipment, hydronic network);
- SHP part (Heat pump, storage tank, controller(s)), real or identified;
- Heat pump source part

Only the SHP part is concerned by the identification procedure since all other components represent the “boundary conditions” of the system and do not change during the test.

5.3.4 Validation of the approach

The approach presented in this paragraph has been validated for the case of a geothermal heat pump system.

The results showed acceptable agreement between the annual results and the test of the heat pump in a 12 day test sequence in terms of energy extrapolation to yearly results and the evaluation of seasonal performances.

5.3.5 Application to the SHP system

Figure 10 shows the application of this emulation method to a SHP system.

The water storage tank(s) and heat pump source (in this case geothermal) can be either real or simulated; the building including emitters and solar collectors are simulated.

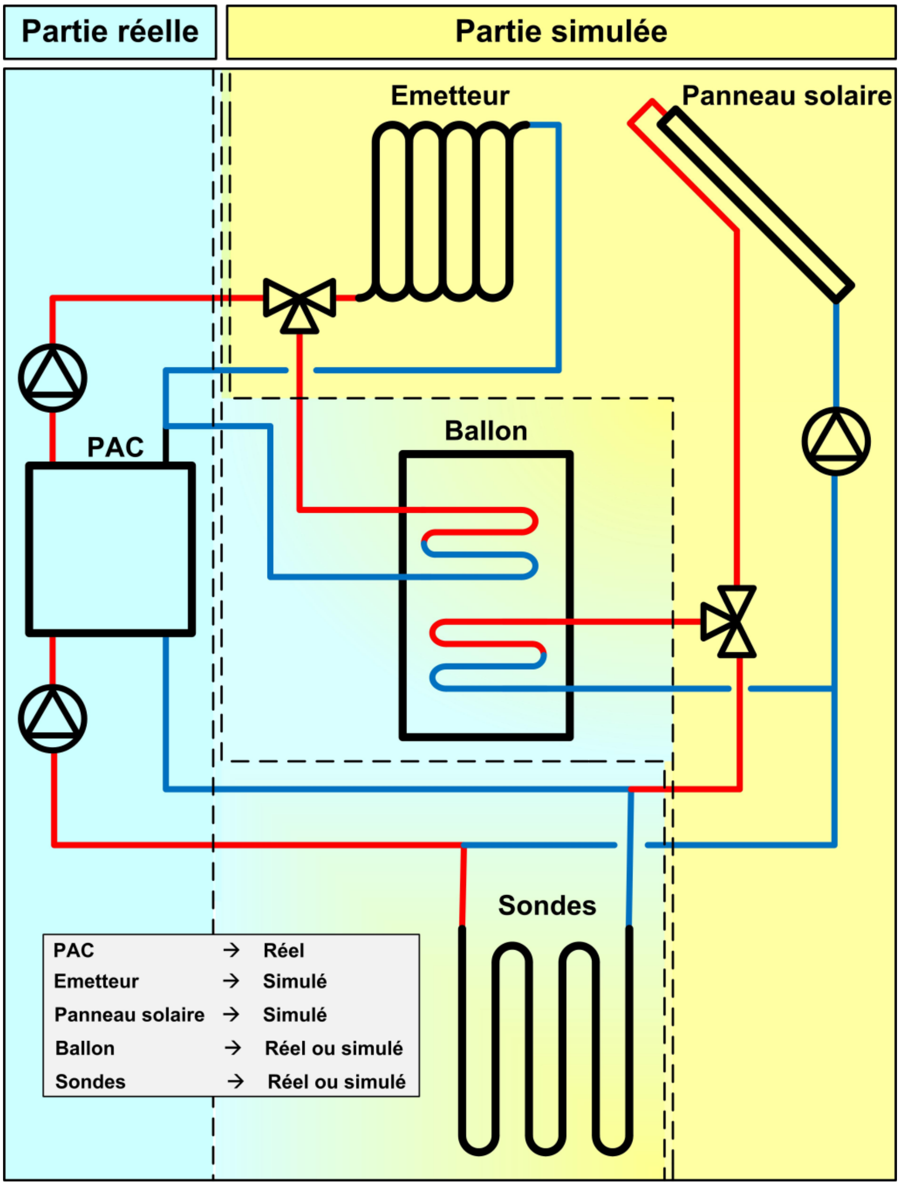

Figure 10 : Application of the global method to a SHP system

6 Conclusion

A number of test methods for performance evaluation of SHP systems is currently under development or has recently been developed and are under evaluation.

Besides the approaches described in the document, there are reports of further methods developed by different European institutes. For example, within the EU FP7 project “macsheep[4]”, four European research institutes are harmonising their test methods and work jointly with other partners on common guidelines for current and future dynamic system test methods. Reports on tested SHP systems is expected also from the on-going IEA SHC Task 44 / HPP Annex 38.

Even though there have been some publications about the method comparisons, no comprehensive and validated work on that topic has been performed and published yet.

[4] http://www.macsheep.spf.ch

References

[1] Combisol Project, 2010, Standardization and Promotion of Solar Combi Systems. Final report. Internet: http://www.combisol.eu

[2] Miara, M., Günther, D., Kramer, T., Oltersdorf, T., Wapler, J., 2011, Wärmepumpeneffizienz – Messtechnische Untersuchung von Wärmepumpenanlagen zur Analyse und Bewertung der Effizienz im realen Betrieb – Kurzfassung des Abschlussberichtes. Fraunhofer ISE, Freiburg, Germany

[3] Mette, B., Drück, H., Bachmann, S., Müller-Steinhagen, H., 2009, Performance testing of solar thermal systems combined with heat pumps. ISES Solar World Congress 2009, Johannesburg, South Africa

[4] Frey, P., Drück, H., Müller-Steinhagen, H., 2010, Extension of the CTSS test method toward solar cooling systems. EuroSun 2010 – Graz, Austria

[5] Malenković, I., 2012, Definition of performance figures for solar thermal and heat pump systems. Technical Report 5.1.3, part of Deliverable 5.1 of the project QAiST – Quality Assurance in Solar Heating and Cooling Technology (Contract No. IEE/08/593/SI2.529236)

[6] Malenković, I., 2012, Review on testing and rating procedures for solar thermal and heat pump systems and components. Technical Report 5.1.2, part of Deliverable 5.1 of the project QAiST – Quality Assurance in Solar Heating and Cooling Technology (Contract No. IEE/08/593/SI2.529236)

[7] Sol, A.N., Mexa, N., Facão, J., Gomes, J. D., Carvalho, M. J., 2010. Factory Made Solar Thermal Systems - Dynamic System Testing and development of parameter identification tool and LTPP validation. In Eurosun 2010 - 2nd international congress on Heating, Cooling and Buildings, Graz, Austria

[8] Spirkl, W., 1990, Dynamische Vermessung von Solaranlagen zur Warmwasserbereitung. Thesis at TU München, VDI-Verlag, Düsseldorf.

[9] Haberl, R., Frank., E., Vogelsanger, P., 2009, Holistic system testing – 10 years of concise cycle testing. ISES Solar World Congress 2009, Johannesburg, South Africa

[10] Vogelsanger, P., 2002, The Concise Cycle Test Method – A Twelve Day System Test, IEA SH&C Task 26 Technical Report

[11] Papillon, P., Albaric, M., Haller, M., Haberl, R., Persson, T., Pettersson, U., Frank, E. & Bales, C., 2011, Whole system testing: the efficient way to test and improve solar combisystems performance and quality. In: ESTEC 2011 - 5th European Solar Thermal Energy Conference, 20-21 October, Marseille, France.

[12] Riederer, P., Partenay, V., 2010, Dynamic test method for the determination of the global seasonal performance factor of heat pumps used for heating, cooling and domestic hot water preparation, World geothermal congress, WGC2010, Bali, Indonesia

[13] Haves P., Dexter A.L., Jorgensen DR., 1991, Use of a building emulator to evaluate techniques for improved commissioning and control of HVAC systems, ASHRAE trans.1991, vol.97.

[14] Visser, H., Naron, D. ; Direct Characterisation test method for solar combisystems – 5th draft. Technical report of Task 26 « Solar combisystems » of IEA Heating and Cooling Programme. Publications, Task 26, March 2003.

[15] Bales, C. : Thermal store testing, Evaluation of test methods. Chalmers University, Dep. of Building Services Engineering, Göteborg, Sweden, 2002.