Assessment of the possibility of incorporating solar thermal cooling into EN 12977 series

Task Report 5.3.4

ITW

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

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1 Introduction

One possibility to counteract the worldwide increasing electrical energy demand for cooling and the resulting overload of electricity grids in summer months is the use of solar thermal energy to perform cooling. Within solar cooling systems a thermally driven chiller provides cooling capacity. So called SolarCombiPlus systems are capable of providing domestic hot water, space heating and space cooling. Up to now there are no standardized test procedures for solar thermal cooling systems. This may be a barrier for new products to enter the market as no testing and certification is possible. To remove market barriers and to enhance the market penetration of solar cooling systems and SolarCombiPlus systems, the availability of standardized test methods for such systems is necessary.

Due to the broad application area and the great variety of system designs of solar cooling and SolarCombiPlus systems, a component based test approach is most promising. A set of component-oriented test standards – the EN 12977 series - for testing of solar domestic hot water and solar combisystems already exists. This series consists of five standards, which are listed in Table 1.

Table 1: European solar thermal standards of the EN 12977 series

Number	**Title „Thermal solar systems and components - …“**
CEN/TS 12977-1:2010	Custom Built Systems – Part 1: General requirements for solar water heaters and combisystems
CEN/TS 12977-2:2010	Custom Built Systems – Part 2: Test methods for solar water heaters and combisystems
EN 12977-3:2008	Custom Built Systems – Part 3: Performance test methods for solar water heater stores
CEN/TS 12977-4:2010	Custom Built Systems – Part 4: Performance test methods for solar combistores
CEN/TS 12977-5:2010	Custom Built Systems – Part 5: Performance test methods for control equipment

In order to incorporate solar thermal cooling into EN 12977 series standards need to be adapted or added. In the following chapters these changes are described.

2 General requirements on solar thermal cooling and SolarCombiPlus systems

Reliability, durability and safety of solar thermal cooling and SolarCombiPlus systems are important issues to ensure customers' satisfaction and sustainable market growth. These general requirements mainly aim at the creation of initial conditions in order to reach high performance and safe operation of the system and the preservation of the system performance and safety for a long period of time.

General requirements for solar domestic hot water and solar combisystems are already defined in CEN/TS 12977-1:2010. These general requirements also cover most components and operational characteristics of a solar thermal cooling system. With regard to some components and operational characteristics unique for solar cooling systems, an extension of the requirements is needed to include solar cooling systems and SolarCombiPlus systems into the EN 12977 series. Based on the list "Requirements evaluation according to CEN/TS 12977-1:2010" given in D3.1, Table 2 lists the points to be changed or added to CEN/TS 12977-1:2010. These requirements were identified from the analysis of a questionnaire distributed to manufacturers, users and experts of solar cooling technology. The added requirements are shown in italics.

Water stores for cold water storage are normally buffer stores similar to buffer stores used for heat storage and hence should be tested according to EN 12977-3:2008.

The test methods defined in EN 12977 series are neither capable of performance testing of heat stores using phase change materials nor on cold stores using phase change materials (mostly common ice stores). Hence, a general extension of EN 12977 series on new storage concepts for storing thermal energy should be considered.

Thermal insulation for cold water circuits has to meet different requirements than thermal insulation for hot water circuits. Hence an addition to "6.4.9 Thermal insulation" is proposed which requires thermal insulation for cold water circuits to comply with EN 14114:2002 - Hygrothermal performance of building equipment and industrial installations - Calculation of water vapour diffusion - Cold pipe insulation systems.

Two main components are needed in addition to a solar thermal system in order to perform cooling - a thermal driven chiller and a heat rejection unit. Hence, requirements for these two components are added to the list of general requirements on solar domestic hot water and solar combisystems in order to extend CEN/TS 12977-1:2010 to solar thermal cooling systems. Table 2 shows the corresponding extract of this list. Especially for absorption chillers that use a dissolved salt as sorption material (e.g. lithium bromide) there is the danger of crystallization of the dissolved material. Six causes may trigger crystallization [1]:

- high ambient temperature;
- low ambient temperature with full load;
- air leak into the machine or non-condensable gases produced during corrosion;
- too much heat input to the desorber;
- failed dilution after shutdown;
- chilled water supply temperature is set too low when the weather and/or exhaust are too hot.

The chiller must provide a protection against crystallization in these cases. This has to be checked. Due to safety reasons absorption chillers using ammonia as refrigerant need to comply with EN 378-1 to 4.

Table 2: Extract of general requirements for solar domestic hot water and solar combisystems listing the additional requirements for solar cooling systems (blue)

Section	Requirement	Procedure
6.4.7 Water stores	Stores of small custom built solar systems for hot water *and cold water* **<u>should</u>** be tested as described in EN 12977-3:2008. Stores of small custom built solar combisystems **<u>should</u>** be tested as described in CEN/TS 12977-4:2010 **Note:** No requirements for large systems.	Small custom built solar systems for DHW: It is recommended that tests according to EN 12977-3:2008 are performed. Small custom built solar combisystems: It is recommended that tests according to CEN/TS 12977-4:2010 are performed. In both cases the stand-by heat loss capacity rate should not exceed the value given by equation (1), section 6.4.7, CEN/TS 12977-1:2010.
6.4.9. Thermal insulation	The thermal insulation of all connecting pipes and other components of the system <u>should</u> comply with the requirements given in EN 12828. The collector loop **<u>should</u>** be insulated without any gaps between the components. Thermal bridges, e.g. incorrectly installed mounting clamps should be avoided. The thermal insulation of the pipework **<u>shall</u>** be from materials which are resistant to the maximum temperature of the circuit and deformation and which remain operative. If the insulation is installed outside, it **<u>shall</u>** be protected against (or resistant to) solar radiation, environmental conditions, ozone and any mechanical impact/deformation. Insulated pipes for underground installation **<u>shall</u>** comply with EN 253. *The thermal insulation of all connections between chiller and cold distribution system **<u>shall</u>** comply to EN 14114:2002*	Check of the system by the Laboratory: - It is recommended to comply with requirements described in EN 12828 - Thermal bridges and gaps between the components should be avoided - Material shall be able to withstand maximum temperature and deformation. - In outdoor conditions, the insulation shall be able to withstand solar radiation, environmental conditions, ozone and any impact/deformation - Insulation shall comply with EN 253 in underground pipes - *Cold insulation shall comply with requirements described in EN 14114:2002*

Section	Requirement	Procedure
6.4.10 Control equipment	Requirements for control equipment (see prEN 12977-5). *Control units **shall** withstand a power blackout during operation and restart to normal operation automatically.* *The documentation of the control unit **shall** state on the possibility of a seasonal power shut off.*	Tests and requirements according to prEN 12977-5. *Check of the system by the Laboratory:* - *Check correct operational behaviour after the control unit was disconnected from mains current during operation* - - *Check if the documentation contains information on seasonal shutdown and electrical disconnection of the system and the controller*
6.4.11. Thermal driven chillers	*Thermally driven chillers **shall** have a protection against high-temperature in the driving loop (e.g. automatic shutdown or a mixing valve).* *Absorption chillers using sorption materials that may crystallize **shall** have a protection against low-temperature in the cooling loop (e.g. mixing valve or variable speed fans of the heat rejection unit).* *Absorption chillers using sorption materials that may crystallize **shall** have a protection against high-temperature in the cooling loop (e.g. automatic shutdown).* *Absorption chillers that contain a corrosion inhibitor **shall** have a protection against the occurrence of temperatures higher than the degradation temperature of the corrosion inhibitor.*	*Check on documentation for installer:* - *Shall have reference to the existence of devices to limit the temperature of the driving loop temperature.* *Maximum temperature in the driving loop is the stagnation temperature of the collector (test according to EN 12975-2, annex C).* - *Shall have reference to the existence of devices to limit the temperature of the inlet cooling temperature.* - *Shall have reference to the existence of devices to limit the temperature of the inlet cooling temperature.* - *Shall have a reference to the corrosion inhibitor used in the chiller and its maximum allowed temperature.* - *Shall have reference to the existence of devices to limit the temperature of the fluid containing the corrosion inhibitor to a temperature 10 K below its maximum allowed temperature*

Section	Requirement	Procedure
	*Thermal driven chillers **shall** contain a device to check and restore the vacuum in the vacuum chamber.* *Absorption chillers using sorption materials that may crystallize **shall** have a protection against crystallization caused by intruded non-condensable gases (e.g. automatic shutdown).* *Absorption chillers using sorption materials that may crystallize **shall** have a back-up system to provide electrical energy to ensure a controlled shutdown with dilution after a power blackout.* *Absorption chillers that contain ammonia **shall** comply with EN 378-1 to 4*	*Check of the system by the Laboratory:* - *Check if the chiller is fitted with a pressure gauge at a clearly visible spot. Pressure range shall be indicated.* *Check on documentation for installer:* - *Shall have reference to the existence of devices to restore the vacuum of the vacuum chamber of the chiller.* - *Shall have reference to the existence of devices to automatically shut down the chiller depending on the amount of intruded non-condensable gases.* *Check of the system by the Laboratory:* - *Check the behaviour of the chiller on simulated power blackout.* - *Absorption chillers that contain ammonia shall comply with EN 378-1 to 4*
6.4.12. Heat rejection units	*If exposed to outdoor conditions the heat rejection loop and the heat rejection unit **shall** have a protection against freezing (e.g. thermostatic bleed-off valve, thermal freeze protection).* *If a thermostatic bleed-off valve is used for freeze protection all the contained water **shall** be completely diverted from the lines and vessels* *In case of a wet heat rejection (cooling towers with open loop): A water filter to remove sediments and trash **shall** be installed.* *The filter **should** be installed in a way to allow easy periodical checks and exchange.*	*Check of the system by the Laboratory:* - *Bleed-off lines shall be laid so that any water can be accumulated in the heat rejection unit when the valve is opened.* - *All water that was filled in shall completely drain from the lines and vessels* - *A water filter shall be foreseen.* - *Water filters should easily allow a visible check and an exchange of the filter*

Apart from these requirements an accelerated ageing test procedure should be developed in order to determine the long-term durability of the chiller. The main issues related to durability of such machines are the loss of vacuum, switching valves and the degradation of corrosion inhibitor, if used.

The loss of vacuum in the evacuated chambers of the chiller happens due to leakages and diffusion effects. Hence, the vacuum has to be restored periodically. A higher rate of gas intrusion into the evacuated compartments leads to a faster decrease of the performance of the chiller. It can also accelerate corrosion due to the higher rate of intrusion of corrosive oxygen from the ambient air.

Adsorption chillers use a solid sorption material. Hence, the process is a discontinuous cycle. In order to provide a rather constant cooling performance, several adsorption-chambers are normally used in one machine. One of them is desorbed using thermal energy while the other one adsorbs the refrigerant and by this performs the cooling. After the adsorption material has reached certain saturation the functions of the chambers are switched. In common chillers switching happens every 5 to 10 minutes. Hence, the switching valves have to withstand the total number of switching cycles which happen during the total lifetime of the chiller.

In some absorption chillers corrosion inhibitors are necessary in order to decrease the corrosion effect caused by the used sorption material in combination with intruded oxygen. In general such corrosion inhibitors degrade with high temperatures. Both, high temperatures as well as leakage of air into the system have a strong impact on corrosion effects and hence on the durability of absorption chillers.

3 Performance testing of solar thermal cooling and SolarCombiPlus systems

In past decades thermally driven chillers were mostly driven by constant heat sources, e.g. gas boilers, waste heat from industrial processes and provided cooling for rather constant cooling loads, e.g. industrial processes. This made it possible to dimension the chiller for a narrow and static range of operational conditions. Hence, performance testing of gas-fired absorption chillers is focused on static operation conditions [2]. The use of a solar thermal heat source to drive a chiller and the application on space cooling result in highly dynamic operation conditions, which strongly depend on climatic and weather conditions.

A Europe-wide survey on operational experiences with solar thermal cooling systems used for space cooling was carried out within the QAiST project. It revealed shortcomings with respect to the performance of systems in dynamic operating points, which, through an examination of static operating points, cannot be identified. Hence, a performance test method, which also takes into account dynamic operation conditions of the thermal chiller, has to be provided for a standardised performance assessment of solar thermal cooling and SolarCombiPlus systems.

Due to the fact that there is no standardised performance test method for solar thermal cooling systems available, in 2008 the project “SolTrans” was started at ITW in order to develop the required performance testing and assessment procedures for solar thermal cooling systems and SolarCombiPlus systems [3], [4]. Within this project an extension of the CTSS method (Component Testing and System Simulation) to solar thermal cooling systems and SolarCombiPlus systems is being developed. In the next chapter the performance testing of solar domestic hot water systems and solar combisystems according to the CTSS is described, as it provides the basis for the afterwards described extension of the CTSS method on solar thermal cooling and SolarCombiPlus systems.

3.1 Performance testing according to the CTSS-method

One established procedure to determine the performance of solar domestic hot water systems and solar combisystems is the CTSS method, which is already standardized in the CEN/TS 12977-2:2010. Figure 1 shows the schematic process of the testing according to the CTSS method. It is structured in two steps. The component testing containing the determination of component parameters - and the simulation of the complete system containing the implementation and calculation of the whole system in a detailed dynamic and component based system simulation program like TRNSYS.

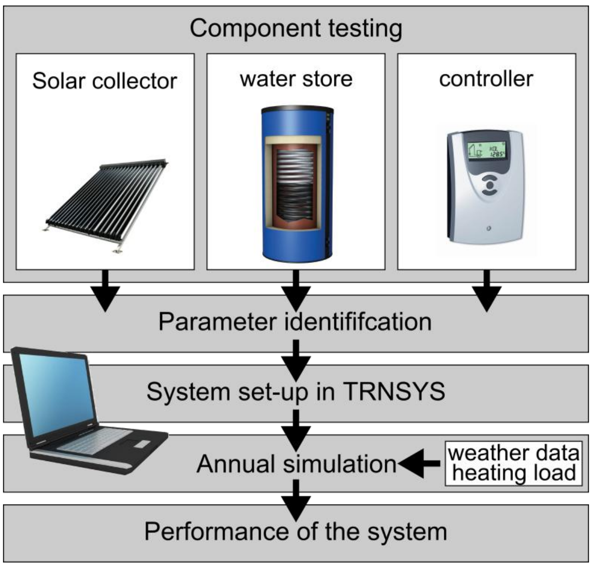

Figure 1: Process scheme of the CTSS method according to CEN/TS 12977-2:2010

The CTSS method has the advantage that the solar thermal system does not need to be installed as a whole for testing. Instead the main components of the system (collector, heat store and controller) are tested separately. The determined component parameters are used to simulate the whole system in a simulation program. By doing so, so called annual system simulations can be performed for the whole system. Table 3 contains the standards relevant for the CTSS method.

Table 3: European solar thermal standards relevant for the CTSS method

Number	**Title „Thermal solar systems and components - …“**
EN 12975-1:2006	Collectors – Part 1: General requirements
EN 12975-2:2006	Collectors – Part 2: Test methods
CEN/TS 12977-1:2010	Custom Built Systems – Part 1: General requirements for solar water heaters and combisystems
CEN/TS 12977-2:2010	Custom Built Systems – Part 2: Test methods for solar water heaters and combisystems
EN 12977-3:2008	Custom Built Systems – Part 3: Performance test methods for solar water heater stores
CEN/TS 12977-4:2010	Custom Built Systems – Part 4: Performance test methods for solar combistores
CEN/TS 12977-5:2010	Custom Built Systems – Part 5: Performance test methods for control equipment

By using a component oriented approach the method is very flexible and applicable to a great variety of system designs. Different boundary conditions regarding weather, domestic hot water tapping or heating loads can be applied because the thermal performance of the system is determined by numerical simulation.

3.1.1 Component testing

In the first step of the CTSS-method the main components of the solar thermal system (collector store and controller) are being tested separately. The aim of the component test is to determine all component parameters that are relevant to describe the thermal behaviour of the respective component. The respective component is subjected to different test sequences that are defined in the standardized test procedures for every main component. Then the model parameters can be determined from the measurement data by parameter identification.

3.1.1.1 Performance test methods for solar collectors

Thermal solar collectors are tested according to EN 12975-2:2006. The determination of the characteristic parameters is essential for the prediction of the annual energy output of the collector as well as of the whole system with the collector as a component. The following data should be determined:

- Standard collector efficiency parameters;
- Heat capacity of the collector;
- Incidence angle modifier for beam and diffuse irradiance;
- Wind speed dependence of the collector heat loss coefficients (only for unglazed collectors);
- Influence of the flow rate, if relevant;

- Influence of the collector tilt angle, if relevant.

3.1.1.2 Performance test methods for stores

Solar water heater stores are tested according to EN 12977-3:2008, solar combistores according to CEN/TS 12977-4:2010. For the dynamic simulation of the thermal behaviour of the store the following data should be determined:

- Height of the store, effective volume respectively heat capacity of the store;
- Vertical positions of the connections for direct charging and discharging;
- Heat loss rate (if the thickness of the thermal insulation varies over the height of the store, the heat loss rate should be determined for different areas);
- Parameters characterizing the thermal stratification inside the store;
- Position of the temperature sensors used for controlling the system;
- Position, volume and heat transfer rate of the immersed heat exchangers;
- Position, arrangement and efficiency of electrical auxiliary heating elements.

3.1.1.3 Test methods for control equipment

Control equipment of the system is tested according to CEN/TS 12977-5:2010. By this all data necessary for implementation of the control strategy in the simulation program should be determined.

3.1.2 System simulation

The thermal behaviour of the component models can be adapted to the thermal behaviour of the real components by applying the characteristic parameters determined in the component test. By coupling the component models, a numerical model is created, which has the thermal behaviour of the whole system. For this purpose the component models are coupled in the simulation program according to the hydraulic connection scheme. The determined characteristic component parameters and the control strategy are implemented. The annual performance of the whole system can now be calculated for defined boundary and reference conditions (meteorological, tapping cycles, load profiles).

3.2 Extension of the CTSS method towards solar cooling systems and SolarCombiPlus systems

By extending the previously described performance test method, it can also be used for testing of solar thermal cooling systems and SolarCombiPlus systems. Therefore, additional components have to be included. These components are the thermally driven chiller and the heat rejection unit. Figure 2 shows the schematic process of the testing according to the proposed extended CTSS method.

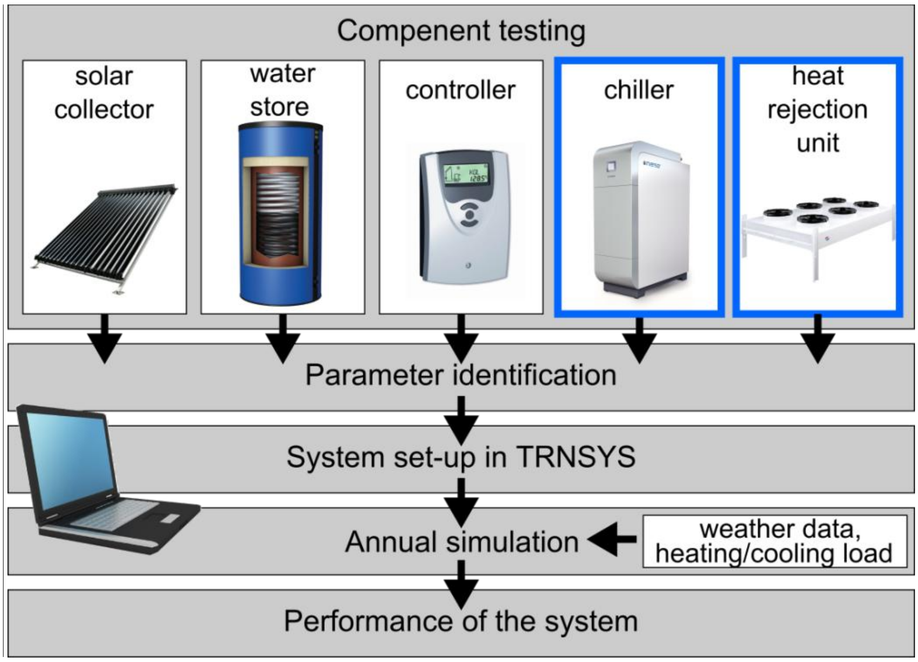

Figure 2: Process scheme of the extended CTSS method

For the additional components numerical models and performance test methods are needed which allow the determination of the characteristic parameters describing the thermal behaviour required for system simulation. As an additional boundary condition, a reference cooling load is used.

For the implementation of the extended CTSS-method into the standard within the project “SolTrans”, several work steps have to be taken. The following schedule gives a short overview of these work steps.

3.2.1 Set up of a lab test facility

In order to perform thermal performance tests of solar thermal heat transformers a lab test facility has been design and installed at ITW University of Stuttgart. It uses several controlled hydraulic heating and cooling modules to expose the test object to defined heating and cooling loads, solar energy input and heat rejection. Outlet temperatures and flow rates of the three modules can be controlled individually. Comprehensive measuring technology for all relevant temperatures and flow rates allows the determination of energy balances of the test object. Thus, the behaviour of thermally driven chillers can be investigated in detail under dynamic operation conditions. The test facility is capable of performance testing thermal heat transformers of a chilling capacity up to 20 kW. This task has already been performed completely.

3.2.2 Development of a performance test method

The main aim of the test method is the determination of characteristic parameters that describe the thermal behaviour of solar thermal heat transformers by model based parameter identification. For this purpose the solar thermal heat transformer is operated according to defined test sequences. These test sequences must be designed to stimulate physical effects that are related to the characteristic parameters to determine. These test sequences are currently under development.

3.2.3 Development of a mathematical/numerical model

Closely connected with the development of the performance test method is the development of a numerical parametric model for the system simulation program TRNSYS. Hence, the development of this model is an on-going work parallel to the development of test sequences. The validation of the developed numerical model will complete this step.

3.2.4 In-situ measurements

In order to validate the performance test method and the used numerical model, the measured performance data of solar thermal heat transformers in real operation is compared to performance data determined by lab testing. For this purpose, three different solar thermal cooling installations have been instrumented with comprehensive measurement technology. Measurement data adequate for validation is already available for two installations. During the last cooling season the functionality and the control has been optimized. Measurement data of all three installations will be available during the cooling season of 2012.

3.2.5 Ecological assessment

The environmental benefits of the use of renewable energy sources for cooling are widely known. As it is common practice this consideration usually only takes into account the driving energy source of the system. A complete and valid statement related to the environmental friendliness can only be obtained by taking into account the whole life cycle of the solar thermal cooling system. A procedure to determine the assessment criteria amortisation time, yield ratio and savings on the basis of the global warming potential (GWP) and the cumulative primary energy demand (CED) of the system during its whole lifetime has been developed [5]. This issue is not directly related to the performance or durability of solar cooling systems but is also planned to be part of the updated standard due to the fact that this assessment completes the statement on environmental friendliness of a cooling system.

3.2.6 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 solar cooling systems and SolarCombiPlus systems can be implemented into the EN 12977 series. The project SolTrans will be completed in spring of 2013. Hence, the results of the project SolTrans 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 6: Performance characterisation methods for thermally driven chillers

and in a further step on

Thermal solar systems and components – Custom built systems – Part 7: Performance characterisation methods for heat rejection units.

3.3 Assessment and classification of the extended CTSS test method

Compared to performance tests of complete solar thermal cooling systems or simple stationary performance tests of the chiller solely, the extended CTSS method has several advantages.

Especially sorption chillers using a solid sorption material have a highly discontinuous working mode. The main shortcoming of actual test methods related to electrically driven and gas-fired sorption chillers is the fact that they cannot account for these internal transient behaviour.

Thermal performance of a chiller according to the extended CTSS method can not only be determined for a set of stationary operational boundary conditions. The numerical model used within the performance test of the chiller describes the dynamic operational behaviour of the investigated chiller. Dynamic operational conditions are highly related to the system topology the chiller is part of.

Another important advantage of the extended CTSS test method compared to other test methods is its high flexibility. Due to its component oriented approach, performance figures of the chiller can be determined for dynamic operation in a complete solar thermal cooling system of variable component selection and topology. This also includes flexibility in the choice of boundary conditions, e.g. climate, heating and cooling loads. This allows determining the performance of the chiller in combination with different cold distribution devices like a cooling ceiling or fan coils, different heat rejection systems like dry, wet, hybrid coolers or a swimming pool, different thermal energy sources like flat plate or evacuated tube collectors. The auxiliary energy demand can be determined for different control strategies related to different comfort requirements.

A related approach was pursued by EURAC [6]. At EURAC, a test facility for solar assisted heating and cooling systems has been developed. The chiller is being installed in a complete SolarCombiPlus system. The heat source is a collector field whose performance can be boosted by electrical and gas fired heaters. The heat rejection system is a hybrid air cooler. The cooling load is provided by electrically driven thermal regulators. A performance test of the chiller can be carried out for different system configurations, climatic conditions and loads.

Compared to this, the extended CTSS test method goes one step further. Its advantage is that a numerical model is adapted to the transient thermal behaviour of the investigated chiller by parameter identification of the model parameters. During the test the conditions do not necessarily need to reproduce realistic boundary conditions. Test conditions need to initiate thermal effects that are related to the parameters of the numerical model. After the step of parameter identification the chiller performance can be determined for example in an annual system simulation for any desired system configuration under realistic climatic and load conditions independent of the test facility.

According to P. N. Melograno et al. [7, 8], stationary tests prescribed by existing standards for electrically driven or sorption based chillers are not suitable; transient test procedures and dedicated standards have to be established for a fair evaluation of the performance and the certification of discontinuous sorption chillers. Unsteady, reality-like boundary conditions that reliably simulate meteorological conditions of representative locations placed on the market addressed should be considered. The proposed extension of the CTSS method allows this.

4 Conclusion and outlook

For the development of the market for solar thermal cooling systems and SolarCombiPlus systems, the availability of standardized test methods for an overall assessment is essential. These test methods on the one hand have to assess the reliability, durability and safety of solar thermal cooling systems and on the other hand the performance and ecological benefit. Up to now, no such standard for testing solar cooling systems exists. The large application area and variety of designs of solar cooling systems suggest the usage of a component based test method. One established component based test method for solar domestic hot water systems and solar combisystems is the EN 12977 series. Hence, the possibility of an incorporation of solar cooling systems into this series has been investigated. The general requirements for solar cooling systems were determined by a Europe-wide survey on experiences of manufacturers, installers, users and experts of solar thermal cooling technology. The identified requirements extend the general requirements for domestic water heater and solar combisystems defined in CEN/TS 12977-1 to its applicability on solar cooling and SolarCombiPlus systems. Regarding performance testing, an extension of the CTSS method (Component Testing and System Simulation), already standardized in EN 12977 series, is being developed within the project “SolTrans”. For this purpose, a test stand for performance tests under dynamic operation conditions of solar thermal driven chillers with a maximum cooling capacity of 20 kW has been developed and put into operation at ITW. Using this test facility performance tests for thermally driven chillers can be developed. After a successful validation, it is planned to integrate the extended CTSS method in a revised version of EN 12977 series. It was shown that an incorporation of solar cooling systems into EN 12977 is possible and that this approach has promising properties such as high flexibility and the ability to account for the dynamic operational conditions that are characteristic for the use in combination with a solar thermal heat source.

5 Acknowledgements

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