TESTING METHODS FOR INNOVATIVE COLLECTORS AND SYSTEMS

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1. Introduction

The TestLab Solar Thermal Systems at Fraunhofer-Institute for Solar Energy Systems ISE has long term experiences with performance and quality tests for solar water and air heating collectors as well as factory made solar thermal systems. The TestLab is accredited for all relevant test standards and has the ambition to contribute a significant part to the development of new test standards, measurement methods and equipment for innovative collectors and system concepts. Therefore the TestLab Solar Thermal System is engaged in numerous projects and expert groups working on the development, enhancement and harmonization of national and international testing standards. Examples are QAiST – "Quality Assurance in Solar Heating and Cooling Technology" (funded by the EUs´ IEE program) which is working on the improvement of the European testing standards, the BMU funded project Luko-E ("Luftkollektor-Entwicklung") which is developing a standard for air heating collectors and MechTest (as well BMU funded) which deals with the development of improved mechanical load tests with the emphasis on problems related to testing of vacuum-tube collectors, factory made systems and slope forces.

Moreover extensive investments in new test facilities for performance and quality tests have been made over the last few years. The outdoor testing facility for collectors was expanded with a new high accuracy tracking device, and test facilities for mechanical load tests, storage tests and hail stone resistance tests (using real ice) have been or are being installed.

2. Solar Air Heating Collectors

Since 2002 the TestLab is operating a testing facility for solar air heating collectors which now was improved and upgraded within the project Luko-E. The main goal was to improve the accuracy of efficiency measurements which has now reached a level similar to the measurement of water heating collectors. Moreover the testing facilities now allow functional tests on air heating collectors, too, such as pressure drop and leakage rate measurements.

One goal of the revision of the testing facility was to sub-divide the permanent installation in the solar simulator into several mobile modules that can now be installed for outdoor measurements or field tests also. While outdoor measurements are mostly conducted for certification procedures, the solar simulator allows comparative measurements with a high repeat accuracy for the development of prototypes.

Fig. 1: Solar air heating collector installed on the outdoor test facility at Fraunhofer ISE

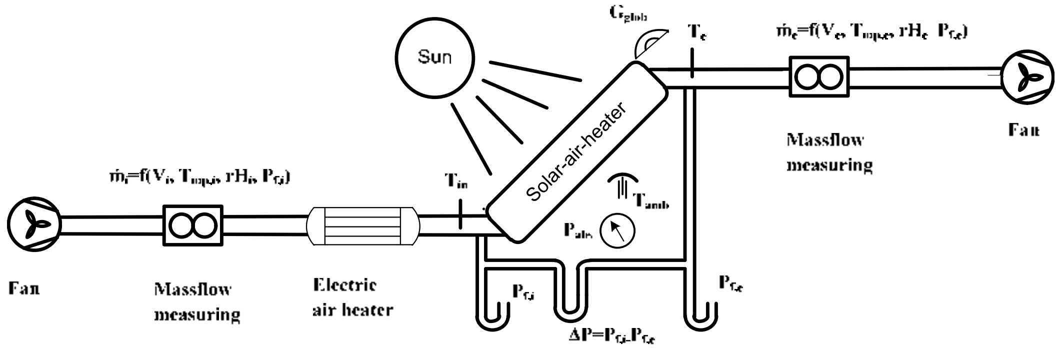

Fig. 2: Schematic of the configuration neccessary to test solar air heaters according to the proposal for revision of EN 12975, developed by Faunhofer ISE

On the outdoor tracking device it is possible to characterize solar air collectors up to sizes of 5 x 3 m under steady-state conditions. The flow rate can be varied between 0 and 2000 m^3/h depending on the collector type and it can be measured with an uncertainty of <1% of the measured value. The possible temperature range is between 0°C and 140°C for standard collectors, which can be extended up to 200°C or more for process heat collectors. Due to a new measurement concept with better sensors and calibration possibilities, the temperature rise can be measured with an uncertainty of 0,2 K.

The pressure drop is being metered simultaneously to the efficiency measurement and is important for the dimensioning of system components. In addition to the in-situ measurement, a pressure drop curve which describes the pressure drop as a function of the flow rate is being determined by the use of specifically designed adapters. A very precise leakage rate measurement describes the leakage as a function of the internal static pressure of the collector.

In cooperation with the project partners in Luko-E a draft version for a testing standard was developed, which at the moment has been passed to the specific normative group (CEN/TC 312 WG 1) and is in the process of commenting until 15th of October. It is expected, that this draft will be published as the first European standard for the characterization of solar air heating collectors in 2012.

Regarding the quality tests the draft is based on the existing standard for water heating collectors EN 12975-1;2. Partially it was possible to adapt existing testing methods others had to be developed completely new. The testing method for the efficiency measurement was developed on the basis of ANSI-ASHREA 93.

3. Process Heat, Large-Scale and Façade Collectors

The share of process heat in the European final energy consumption exceeds 20% of the total end-use energy needs. A third of this amount is needed at temperatures below 200°C [Aidonis et al., 2005].

These applications as well as solar driven cooling systems will use concentrating solar collectors as energy source. The increased demand for testing such collectors indicates that it is a growing market. The characterization of concentrating collectors requires a high tracking accuracy and therefore the TestLab invested in new testing equipment allowing a tracking accuracy of 0,2 degrees (angle), and, with the dimensions of 5 x 3 m and a maximum load of 700 kg, it is also capable of testing large-scale and façade collectors. The testing facility also uses a pyrheliometer which improves the determination of direct and diffuse radiation fractions.

The tracking device can be connected to modules that allow efficiency measurements up to temperatures of 210°C and pressures of 16 x 10^5 Pa.

4. Quality Tests

4.1 Hail testing facility

The Fraunhofer ISE has developed a testing facility to simulate hail impacts with ice balls with the objective to perform impact resistance tests of solar thermal collectors as well as PV-modules according to the valid national and international testing standards. This testing facility has been set-up in 2008 and gives us the possibility to perform experimental research as well as tests commissioned by the industry. A picture of the pneumatic launcher is given in Fig. 3 [Mehnert et al., 2008].

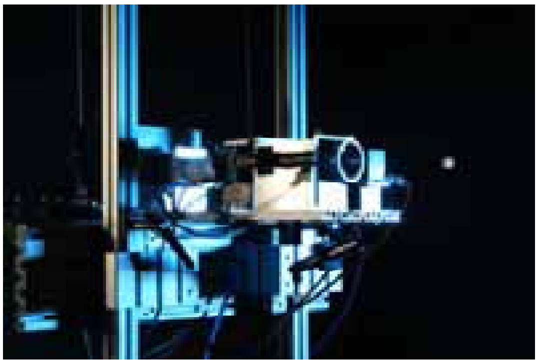

Fig. 3: Launcher of the impact resistance test facility, Fraunhofer ISE

This testing facility permits us to gain a lot of experience in testing methods and the characteristics of flat plate collectors as well as vacuum tube collectors. One of the latest results e.g. on vacuum tube collectors is that their most critical point is where the metal clamp between the inner and outer tube is in contact with the glass. Every test sample that was shot in exactly this point was damaged. Fig. 4 shows a typical vacuum tube after a hail resistance test. The point of impact was perpendicular on the surface of the glass tube as well as directly above the inner metal clamp. As a result of this, a new test procedure was proposed within the current revision of EN12975-1,2:2006. This finding makes it now possible for industry to react appropriate with technical or instructional solutions.

Furthermore we perform experimental research in hail resistance testing of new materials which are typically used in upcoming collector technologies like transparent covers made of plastics or mirrors for concentrating collector modules.

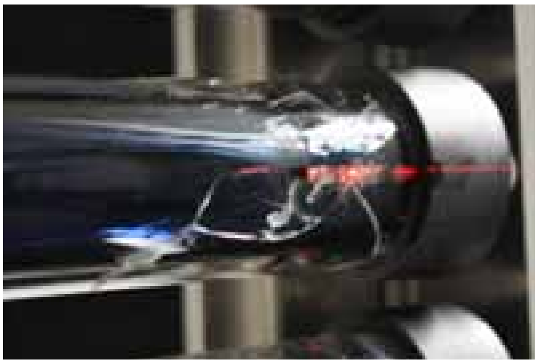

Fig. 4: Typical damage symptoms of a Sydney-pipe after shot on the clamp

4.2 Improving mechanical load tests considering realistic weather conditions

Within a growing market, quality assurance gains an increasing importance. The most important guidelines in the field of testing solar thermal collectors and systems are the European standards EN 12975-1,2:2006 and EN 12976-1,2:2006. The methods for mechanical load tests as described in EN 12975 should be updated due to the development of the market and innovations of today. Considering this challenge and the increasing number of extreme weather events, further research is needed to develop new concepts for mechanical load testing in order to meet the actual quality requirements and cover a wide range of appliances. Innovative products such as PVT and façade collectors need to be integrated in these testing methods as well as adequate mechanical testing methods for vacuum tube collectors and thermo syphon systems (def. not separable).

This led to the situation that the testing laboratories have been requested, both from assurance companies and collector manufacturers, to develop adequate testing procedures to deliver reliable and realistic data on the resilience of solar thermal collectors and systems. The mechanical load test for the collectors need to be adapted in order to meet quality assurance goals and secure further market entrance for innovative products.

Therefore the standard EN 12975 is in a phase of revision to fit the actual needs shortly. On July 2010 within the group solar thermal collectors and appliances, the project "MechTest" was started to investigate mechanical load tests, considering realistic weather conditions. The main tasks are:

- analyzing cases of overload and damage in industry requests/interviews and their reasons
- natural weather expositions on standard collectors measuring wind and mechanical loads at locations with extreme and mediterran weather conditions
- developing a new test facility ready for advanced mechanical load tests under realistic conditions in relation to the expositions
- defining new standard test procedures
- analyzing and corresponding the results to the relevant standard committees

For analyzing the different natural load scenarios characteristic test locations were chosen:

- south west of Germany in the city of Freiburg referring to mediterran weather conditions (air temperatures -5..25 °C, moderate winds and humidity)
- Atlantic island Gran Canaria in the village Pozo Izquierdo at the coast referring to a high impact on wind, humidity with maritime climate conditions (air temperatures about 15..30 °C, wind velocities 20..60 km/h, rel. humidity 60 %)
- south of Germany close to the border of Austria at the mountain Zugspitze (altimeter approx.. 3000 m) referring to a high impact on wind, snow and low temperatures for extreme weather conditions (air temperatures about -10..5 °C, wind velocities 20..40 km/h, rel. humidity 80 %)

The weather informations are given as estimated reference values for one year, this means stormy or other extreme situations are not considered in the given values. Especially at the Zugspitze and Gran Canaria extreme weather events can occur which raise the given values extremely.

During the expositions temperatures, humidity, radiation, the amount of rain and the snow situation as well as a high resolution of the wind velocity (3D) and mechanical load data of the collector fixing points will be monitored for one year. The measured values are continually analyzed to investigate more realistic testing methods which could be simulated with the new test facility.

To configure the required temperatures of different climate scenarios the test facility is enclosed in a climate chamber which can simulate temperatures from -30°C to 80°C. To test combined systems as well as customized collectors, the test facility is planned to fit sizes of collectors or systems up to 3 m x 4 m.

Collectors and systems can be mounted in orientations from horizontal up to angles of 45°. In Fig. 5 the construction and its overall dimensions are shown.

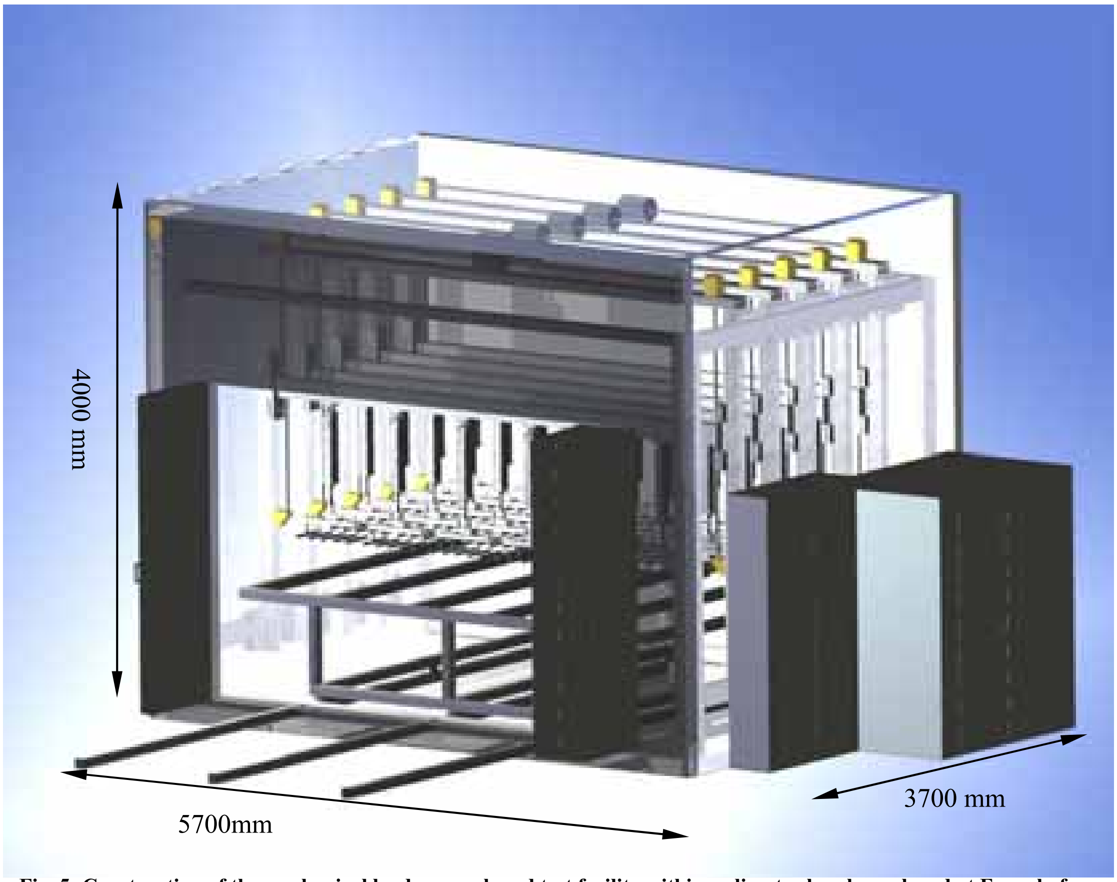

Fig. 5: Construction of the mechanical load research and test facility within a climate chamber, planed at Fraunhofer TestLab Solar Thermal Systems [Kramer et al., 2010]

A new modular loading system makes it possible to test flat plate as well as vacuum collectors with positive and negative pressure loads using different surface interfaces. The system is designed to realize positive and negative pressure loads of at least 6000 Pa (+) and 4000 Pa (-). The possible pressure loads are higher when testing absorbers with smaller sizes than the designed maximum size of 3 m x 4 m.

The mechanical test facility in combination with the climate chamber makes it possible to measure the required range for comprehensive mechanical testing. It will be an important tool finding adequate mechanical test procedures in the process of revisioning the EN 12975.

The project "MechTest" is funded by the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety in Germany.

5. Systems, Storages and Combinations with Heat Pumps

The solar thermal system and store test facility of the TestLab has been operated since 1997. Measurements of prefabricated solar thermal systems have been carried out according to EN 12976 for awarding the Solar Keymark label. In order to meet the increasing demand for system tests, the test facility had been expanded to test up to four systems at a time in 2008 [Striewe et al., 2008]. During the expansion the infrastructural fundamentals were established for domestic hot water store testing according to EN 12977-3. The new store test facility was realised in 2010. This year the test stand has been upgraded for the measurement of combi-stores according to TS 12977-4, which is expected to become an official standard within this year.

Fig. 6: Roof of the system facility at TestLab Solar Thermal

Fig. 7: Store test integrated into the system test facility

The hydraulic system of the test facility is designed as a closed loop in order to avoid air bubbles, sudden pressure drops and uneven temperatures from the water supply network. Stores can be tested by accessing the measurement infrastructure of one of the four system test stands (not shown). A common cooling loop with pre-cooler and a 20kW cooling aggregate combined with a large buffer store assure constant temperatures also for very large tapping volumes. The heating loop is a mobile unit equipped with a 20kW heating rod. In order to carry out test sequences according to EN 12977 part three and four, the mobile heating unit has been equipped with a controller to assure constant temperature or constant power for various mass flow rates. Entire store test sequences can perform autonomously without the need of further user interaction.

In order to extract the store parameters from the measurement data, an evaluation procedure is performed using parameter identification with TRNSYS and GenOpt [Schmidt et al., 2011]. This step requires data processing which has been realized using a script based on data processing software developed at Fraunhofer ISE. The software permits automatic preparation of these test sequences upon basic user inputs (e.g. date and time, filename) and reduces manual steps to a minimum, thus allowing more efficient data processing.

The system test stand was designed with the major objective of achieving a high degree of flexibility to meet requirements beyond today's standard system tests. Therefore apart from data preparation also the test stand control and the data logging software are proprietary Fraunhofer ISE developments which allow custom modifications anytime if necessary. An example for a non-standard system test – the measurement of solar thermal system combined with heat pump – can be seen in fig. 8.

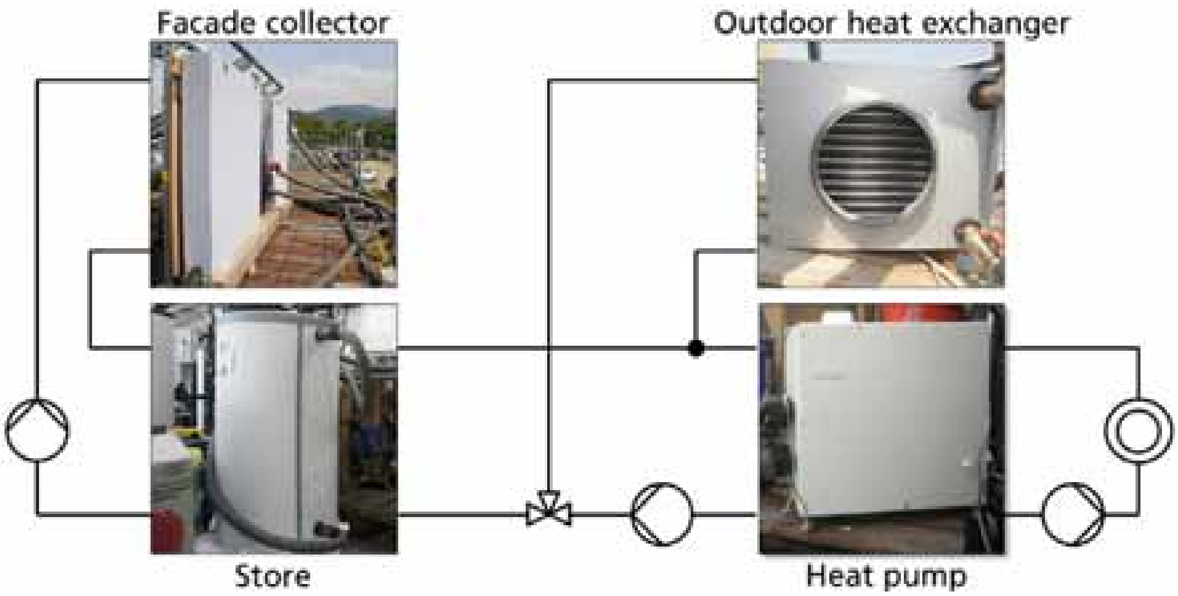

Fig. 8: Experimental set-up of an innovative heat pump system.

A number of system concepts for space heating and/or domestic hot water applying the combination of solar thermal systems with heat pumps have been developed and introduced to the market during the recent years. Within such concepts, solar collectors can, for example, heat a combi-store as does a heat pump in parallel. In the investigated system presented above, however, unglazed absorber energy is used indirectly on the source side of the heat pump to increase the heat pump source temperature and therefore its efficiency. Further information on this system can be found in [Ruschenburg et al., 2011].

The heat pump itself was first characterized at the respective test facility of Fraunhofer ISE based on DIN EN 14511. A comparison between the heat pump rating under stationary conditions and the results obtained during the dynamic system tests shows a considerable discrepancy. For example, the heat pump efficiency averaged within the first 30 minutes of running is determined as about 10 % lower than the value measured under stationary conditions. Further efforts will therefore concentrate on improved test methods for heating systems with multiple heat sources.

To achieve an overview on available solar heat pump systems and their market, to establish performance figures and corresponding methods for testing, monitoring and simulating, a joint project within the Solar Heating and Cooling Programme and the Heat Pump Programme of the IEA, known as Task 44 / Annex 38 was started in 2010 [Hadorn, 2010]. Fraunhofer ISE is closely involved in all working groups of this project, and first results are expected for this year.

6. References

Aidonis, A. et al.: PROCESOL II: Solarthermische Anlagen in Industriebetrieben, Planungs- und Wartungsrichtlinien. Garching (Germany), 2005.

Hadorn J.-Ch.: Solar and heat pump systems. A new IEA SHC Task 44 & HPP Annex and analysis of several combinations for low energy houses. In: Proceedings of the EuroSun International Conference on Solar Heating, Cooling and Buildings, Graz (Austria), 2010.

Kramer K. et al.: MECHTEST – DEVELOPING A METHODOLOGY FOR TESTING THE MECHANICAL SNOW AND WIND LOAD ON SOLAR THERMAL COLLECTORS. In: Proceedings of the EuroSun International Conference on Solar Heating, Cooling and Buildings, Graz (Austria), 2010.

Mehnert S. et al.: Quantification of the impact resistance of solar thermal collectors and photovoltaic-modules against severe hailstorms. In: Proceedings of the EuroSun International Conference on Solar Heating, Cooling and Buildings, Lissabon (Portugal), 2008.

Ruschenburg et al.: Experimental and simulation results on a solar-assisted heat pump prototype for decentral applications. In: Proceedings of the 10^{th} IEA Heat Pump Conference, Tokyo (Japan), 2011.

Schmidt C. et al.: Evaluation procedure for storage tank tests using the combination of TRNSYS with GenOpt and new proposal for holistic error estimation. In: Proceedings of ISES Solar World Congress 2011, Kassel (Germany), 2011.

Striewe W. et al.: Leistungs- und Qualitätsprüfung von vorgefertigten Solaranlagen und Speichern. In: Proceedings of the OTTI 18. Symposium Thermische Solarenergie, Bad Staffelstein (Germany), 2008.