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ScienceDirect

Energy Procedia 48 (2014) 192 – 200

Energy Procedia

SHC 2013, International Conference on Solar Heating and Cooling for Buildings and Industry
September 23-25, 2013, Freiburg, Germany

Quality assurance for solar thermal collector production

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Abstract

The production of solar thermal collectors is already a well-established technology, although there is high potential for implementing quality assurance measures for several parts of the production procedure. Therefore, this project works on the development of methods to verify the transmission rate of the collector´s covering glass. This could be realized in a simple way, so that investment costs for the collector manufacturers can be kept as low as possible. First measurements showed satisfying results compared to reference measurements at approved testing institutes.

Selection and peer review by the scientific conference committee of SHC 2013 under responsibility of PSE AG

Keywords: Quality; production; solar; collector; transmission;

1. Introduction

The technology of solar thermal heat supply already provides a well-known form of renewable energy source and shows a steeply rising contribution to feed the world´s energy demand, especially in the low-temperature range for domestic hot water supply and space heating. The vision of the International Energy Agency [1] predicts, that in the year 2050 solar thermal energy could cover around 16% of the required final energy at low temperature, as well as nearly 17% of the energy use for cooling applications (see Figure 1). Nevertheless, the worldwide market for flat plate and evacuated tube collectors revealed a significant reduction of growth in the last years [1], also caused by a missing cost reduction of those systems [2].

Selection and peer review by the scientific conference committee of SHC 2013 under responsibility of PSE AG
doi:10.1016/j.egypro.2014.02.024

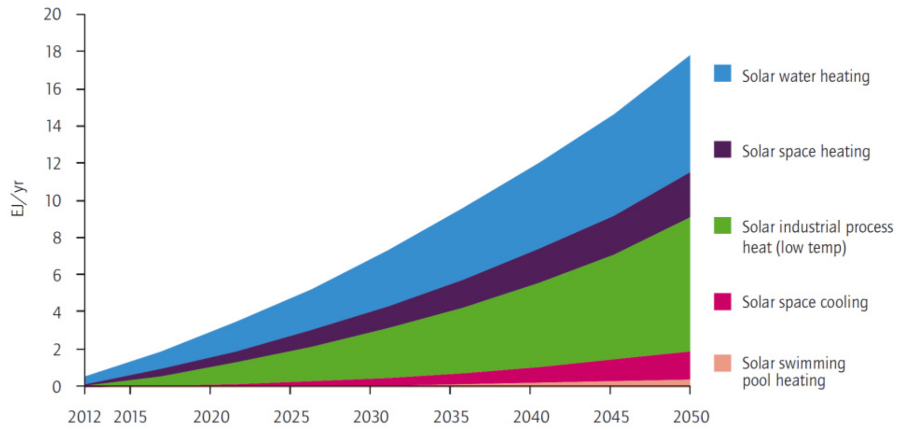


Figure 1: Vision for the growth of solar thermal energy supply [1]

One possible way to reduce the costs of solar thermal systems is seen in an increasing stability of the production processes, leading to the necessity of improved quality assurance within the entire production sequence. On the one hand, well monitored production lines can help to decrease the amount of cull and therefore save costs, and on the other hand provide the opportunity to distinguish between different levels of quality for the final product, so that the consumer can decide between low-cost and high-end systems.

As for every product, also the quality of a solar thermal collector can be defined by many different aspects. Although, the thermal performance of a collector seems to be the main characteristic value among others, because it directly influences economic and ecological calculations and affords a simple way of comparison between different products.

The thermal performance (=efficiency) of a collector depends significantly from the following parameters:

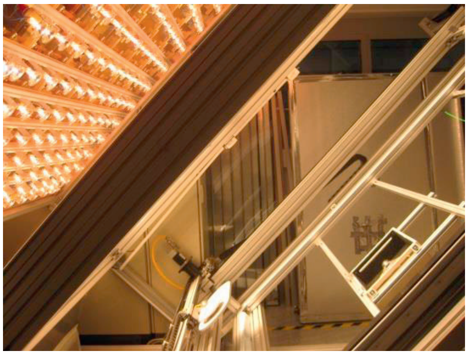
- Backside insulation
- Heat transfer rate between absorber and fluid
- Absorption and emission rates of the absorber
- Optical attributes of the covering glass

The focus of this project was defined by the investigation and the development of methods to provide a simple possibility of quality assurance for the optical attributes of the covering glass, implemented within the production line of a solar thermal collector production.

2. Approach

ASiC operates an accredited testing center for solar thermal collectors and is therefore able to perform various test procedures with collectors and other components. The main part of this laboratory is the “sun simulator”, where the collectors are exposed to a radiation similar to the natural sun, in terms of intensity as well as in terms of the spectral distribution, see Figure 2. This sun simulator is initially constructed to measure the thermal performance of a collector according to international test standards, but it can also be used to run transmission measurements with pieces of covering glass to check its quality. As this system is unable to be implemented in a production line, a simpler solution had to be found, basing on these experiences with transmission measurements on the sun simulator.

Collector measurement



Transmission measurement

Figure 2: Sun simulator at the ASiC testing center [3]

2.1. Concept of low-cost test rig

The spectral output of the lamps used in the simulator is already validated very well and meets the requirements of the accreditation process, so these lamps also had to be used as light source for the low-cost version of the transmission measurement. For the first step, a calibrated pyranometer from the sun simulator should serve as light detecting device. The first concept of mechanical arrangement is shown in Figure 3.

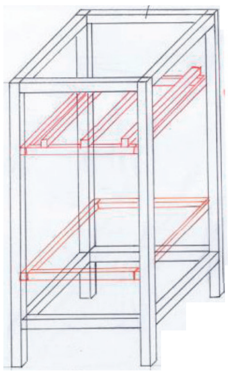


Figure 3: First concept of mechanical arrangement [4]

The construction should be made of aluminum profiles, so that a modification of the entire arrangement can be done easily and quickly. The upper level (marked in red) should host the lamps, the lower level (marked in orange) should carry the glass sample, and at the lowest level the pyranometer should be mounted.

Before starting the exact mechanical construction, a simulation of this concept arrangement had to be done to gain information about the expected radiation on the sample and the dimensions of the construction.

One of the most important goals of this project is to keep the overall costs of this concerned construction as low as possible, what has to be considered for the electrical equipment as well. The used lamps provide an appropriate spectral distribution, but they require a stable DC supply with 17 V and 8.8 A per lamp. First investigations within this concept phase pointed out, that a low number of lamps should be preferred, because otherwise the technical and the monetary effort for their power supply becomes too high.

2.2. Simulation of arrangement

Using the simulation software MATLAB, various arrangements of the test rig have been validated. The following parameters have been changed:

- Number of lamps (1…9)
- Distances between the lamps in both directions
- Distance between light source and light detector

Thereby, the aim was to find the optimal combination of all parameters, so that the homogeneity and the absolute value of the radiation in the area of the light detector are satisfying. This could be achieved with three lamps arranged in an equilateral triangle, as the radiation distribution in Figure 4 displays.

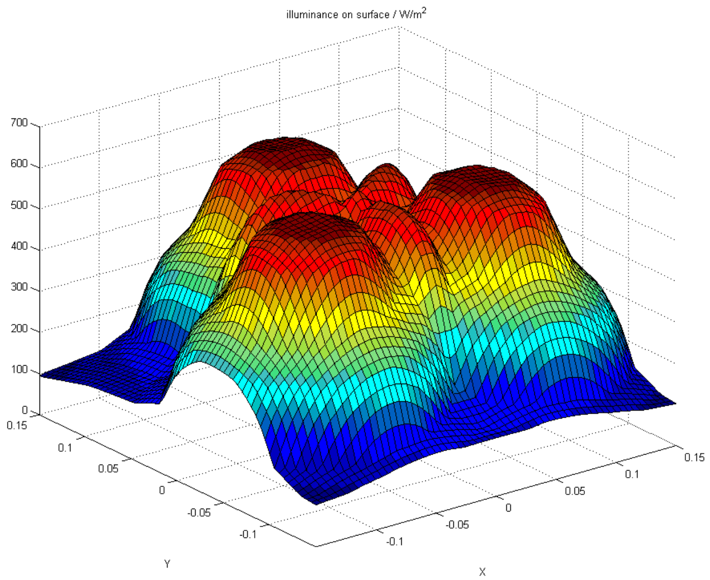


Figure 4: Distribution of radiation with three lamps; simulation in MATLAB [4]

The three maxima of radiation produced by the lamps can be observed significantly, as well as the rather steep decrease with rising beam angles.

A calculation of the average value of radiation in the concerned area of the light detector in the center of the lamps´ triangle provides a result of 540 W/m². As the pyranometer planned to be used is calibrated at a radiation of 500 W/m², a high accuracy of radiation measurement can be expected with this simulated arrangement.

2.3. Mechanical and electrical construction

Basing on the results of the simulation, the mechanical construction of the low-cost test rig was done accordingly. The first prototype shown in Figure 5 is made of aluminum profiles, affording high flexibility for possibly necessary modifications and keeping the weight low. The wooden box at the bottom of the test rig will host the light detector and is therefore lined with black fabric on its inner surfaces to avoid reflections.

Figure 5: Mechanical construction of first prototype [4]

This prototype is not constructed to handle full-size glasses (normally around 2 m x 1 m), but to work with smaller samples of glass (dimension 30 cm x 30 cm) to simplify first measurements. The pyranometer hosting box is also made in the size of 30 cm x 30 cm, so that the glass samples can stably rest on it.

Material used for the mechanical construction:

- Outer frame: Al-profiles, squared cross-section, 40 mm x 40 mm, connections with M8-screws
- Lamps hosting frame: Al-profiles, squared cross-section, 30 mm x 30 mm, connections with M6-screws
- Detector box hosting frame: Al-profiles, squared cross-section, 30 mm x 30 mm, connections with M6-screws
- Wheels to enable an easy movement of the test rig

The electrical design of the low-cost test rig focuses on handling the high currents that occur within this system due to the specification of the installed lamps. As a constant voltage of exactly 17 V is required for each lamp to provide homogeneous light emission, the three lamps are connected in parallel and therefore need a total current of 3 x 8.8 A = 26.4 A. An appropriate power supply has to be chosen to cover this power demand, and the wiring has to be designed strong enough, so that the voltage drop along the lines is in an acceptable range.

Material used for the electrical construction:

- Power supply: Voltcraft HPS-13030 (max. output 30V/30A, adjustable)
- Lamps: Philips Focusline 13117, quartz halogen lamp with integral reflector, 150 W, 17 V, GX5.3
- Wiring: Copper, 10 mm²

2.4. Reference measurements with glass samples

Before starting the transmission measurements on the low-cost test rig with seven different types of covering glass for solar applications, these glass samples have been tested by three independent and renowned research institutes to get absolute reference values for the transmission rates. The following Table 1 provides an overview of the measured glass samples, whereas Figure 6 summarizes the results of the reference measurements.

Table 1: Overview of glass samples [4]

Sample number	Type of glass	Thickness [mm]
1	Albarino T	3.2
2	Diamant	4.0
3	Diamant	6.0
4	Float	2.0
5	Float	3.0
6	Float	4.0
7	Float	6.0

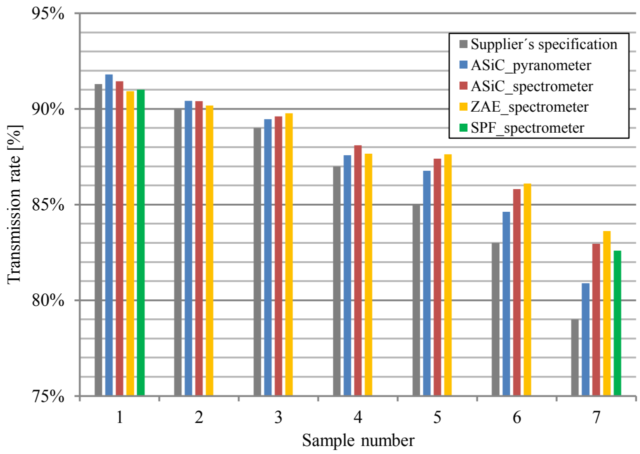


Figure 6: Reference measurement of glass samples [4]

The reference measurements have been performed by the following institutes:

- ZAE BAYERN, Abt. 3, Haberstraße 2a, D-91058 Erlangen
- SPF - Institut für Solartechnik, Oberseestrasse 10, CH-8640 Rapperswil
- ASiC – Austria Solar Innovation Center, Roseggerstraße 12, A-4600 Wels

At ZAE and SPF the transmission rates were measured with a spectrometer, whereas at ASiC a pyranometer and a spectrometer measurement were carried out. Due to logistical reasons only sample 1 and sample 7 were sent to SPF for a transmission measurement.

2.5. Transmission measurements with low-cost test rig

As the above described reference measurements delivered reliable information about the transmission of the sample glasses, measurements on the low-cost test rig could be performed.

Checking the lamps´ supply voltage after activation pointed out, that the voltage drop on the connection lines is 0.15 V, which was compensated by increasing the output voltage of the power supply by this value. The following procedure of measurement was chosen:

1. Radiation measurement for a duration of 3 min without glass, calculation of average value
2. Radiation measurement for a duration of 3 min with glass, calculation of average value
3. Radiation measurement for a duration of 3 min without glass, calculation of average value

This relatively long duration of measurement was necessary to minimize measurement errors due to temperature drifting effects at the pyranometer. As such long time durations are not acceptable for a later integration into the work flow of a production line, the pyranometer was exchanged by a photovoltaic light detecting device, which can handle measurement durations of only 10 s. Moreover, the costs of this sensor are 80% lower compared to the pyranometer, so this change supports the low-cost aspect of this project.

The two average radiation values without glass were again averaged and then used to calculate the transmission rate as follows:

$$\tau = \frac{E_{glass}}{E_{100}} \tag{1}$$

τ…Transmission rate in %
E_{glass}…Radiation value with glass in W/m²
E_{100}…Radiation value without glass in W/m²

Figure 7 illustrates the measurement procedure with the low-cost test rig as described above. At the top level of the construction the power supply for the lamps and the data logging device can be seen, and the wooden box at the bottom carries the photovoltaic radiation sensor.

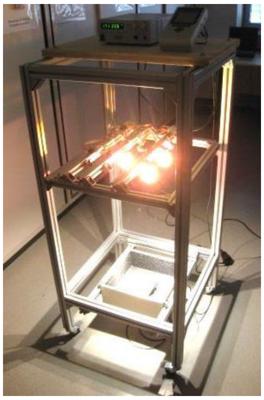


Figure 7: Transmission measurement with low-cost test rig [4]

Equipment used for the transmission measurement:

- Multimeter ISO-TECH IDM91E
- Light detector: Mencke&Tegtmeyer Silicon Radiation Sensor Si-01TC
- Data logging device: Ahlborn ALMEMO 2890-9

The data logging device is a comfortable opportunity to monitor the measurement data over a longer period or to directly calculate average values, but this described purpose such sophisticated equipment is not necessary. The radiation sensor provides an output voltage that is linearly proportional to the radiation, therefore the data logging device can be exchanged by a simple multimeter, which is normally available at every technical production site. Some of the performed measurements have been repeated with the multimeter instead of the data logging device to check the feasibility, and this could be done successfully.

3. Results

The results of the transmission measurements carried out with the constructed low-cost test rig are satisfying, compared to the data of the reference measurements. The overview of Table 2 shows for each type of glass the deviation between the transmission rates delivered by the low-cost test rig and the average value of transmission rates from the reference measurements. The systematical divergence of +1 percentage point or more is even more obvious in the graphical overview of Figure 8.

Table 2: Measurement results, raw data [4]

Sample number	Type of glass	Thickness [mm]	Av. transmission	**Abs. deviation**
1	Albarino T	3.2	91,29%	**1,16%**
2	Diamant	4.0	90,33%	**0,92%**
3	Diamant	6.0	89,61%	**1,03%**
4	Float	2.0	87,78%	**1,40%**
5	Float	3.0	87,26%	**1,27%**
6	Float	4.0	85,51%	**1,57%**
7	Float	6.0	82,52%	**1,87%**

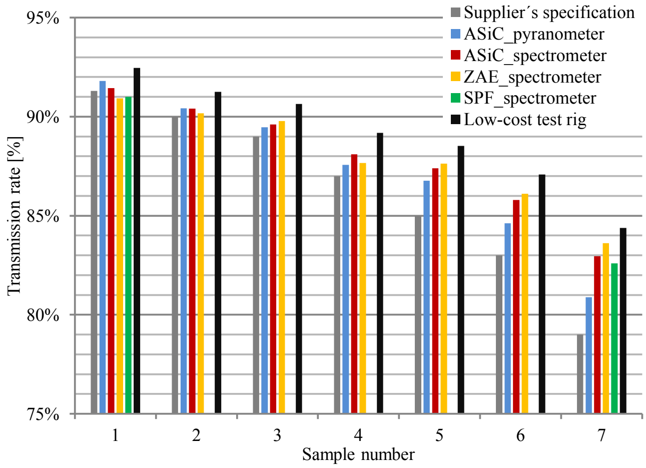


Figure 8: Measurement results, raw data, detailed comparison [4]

Although these transmission measurements already show a sufficient accuracy of the low-cost test rig, the systematical deviation can be corrected mathematically by subtracting 1 percentage point for all types of glass. The adapted data are displayed in the following Table 3 and Figure 9.

Table 3: Measurement results, corrected [4]

Sample number	Type of glass	Thickness [mm]	Av. transmission	**Abs. deviation, corrected**
1	Albarino T	3.2	91,29%	**0,16%**
2	Diamant	4.0	90,33%	**-0,08%**
3	Diamant	6.0	89,61%	**0,03%**
4	Float	2.0	87,78%	**0,40%**
5	Float	3.0	87,26%	**0,27%**
6	Float	4.0	85,51%	**0,57%**
7	Float	6.0	82,52%	**0,87%**

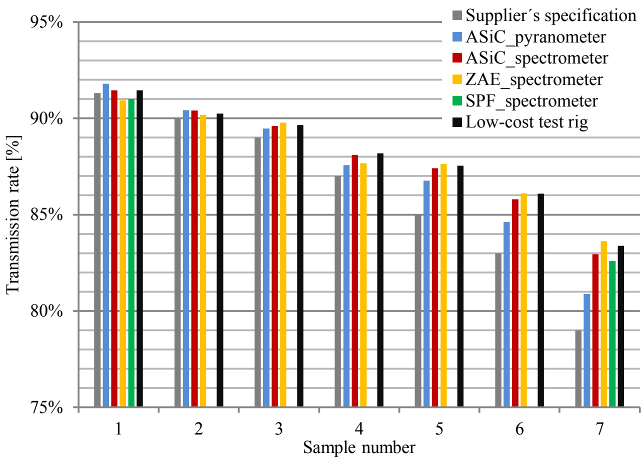


Figure 9: Measurement results, data corrected, detailed comparison [4]

With correction of the systematical deviation, the results of the transmission measurements with the low-cost test rig are highly satisfying, because transmission rates of all concerned types of covering glass can be detected with an accuracy of +0.9/-0.1 percentage points, even compared to the variation of the results of the reference measurements, which is between 0.9 and 2.7 percentage points.

The total material costs of this entire measurement system can be summarized to around € 1200,- (excl. tax), providing some potential for further reduction within the mechanical construction.

4. Conclusions and Forecast

The developed system for transmission measurement of sample glasses for solar applications fulfills the requirements in all significant aspects. The accuracy of the transmission rates determined by this low-cost test rig is within the scale of the variation of the reference measurement results performed by renowned and partly accredited institutes. The measurement procedure itself is suitable for a full integration into the process of a solar thermal collector production, because it only takes 20 seconds per glass, the results are reliable and reproducible and the installed components are durable for industrial applications. Furthermore, the costs for setting up this first prototype could be kept at the low level of about € 1200,- and still afford potential for reduction.

Further work on this topic of quality assurance in terms of the covering glass will include the following steps:

- Investigation on the systematically positive deviation of the transmission rate, compared to the average value of the reference measurements
- Modification of the mechanical construction to become capable of handling full-size glasses
- Modification of the mechanical construction to reduce costs

Acknowledgements

This work is embedded in the research project “InSolTec – Inspection Tools for Solar Technology”, which is financially supported by the program “Research Studios Austria”, provided by the “Bundesministerium für Wirtschaft, Familie und Jugend (BMWFJ)”. The coordination of this program is done by the “Forschungsförderungsgesellschaft (FFG)”.

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