REPORT

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Overall measurement uncertainty from the QAiST round robin test results

(1 appendix)

Summary

The project aims at identifying overall measurement uncertainty figures for solar collectors and factory made systems based on the performance figures from the QAiST round robin test results.

Results show that there is a good conformity between test labs for solar collector test results, whilst there is a slight result deviation when testing solar systems. This confirms that even though labs have different preconditions and evaluations methods, the methods used are robust and that there is a satisfactory reproducibility between lab measurements.

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Appendix

1. Result summary of the measurement uncertainty for all parameters and different collector and system types

Background

The project aims at identifying overall measurement uncertainty figures for solar collectors and factory made systems based on the performance figures from the QAiST round robin test results. These overall measurement uncertainty figures shall make it easier for manufacturers and end users to understand measurement uncertainties related to performance tests of solar collectors and factory made systems according to EN 12975[1, 2] and ISO 9459-5[3].

With a general measurement uncertainty for all test laboratories less questions need to be raised in this issue from manufacturers and end users regarding the final test results. Further on the test laboratories can use the general measurement uncertainty in the test reports that are the basis for the Solar Keymark certification. This will lead to an increased understanding of the uncertainty of the performance figures presented in the Solar Keymark certificate.

Theoretical framework for mathematical statistics and measurement uncertainty estimation

The overall measurement uncertainty for all test labs that were involved in the QAiST project consists of two parameters; an overall lab uncertainty, u_{lab} that is constant between measurements, and uncertainty of repeatability within each lab, u_{rep}. These two then form an equation for the overall uncertainty of all test labs[4], see Equation (1)

$$u_{tot} = \sqrt{u_{lab}^2 + u_{rep}^2} \quad (1)$$

The repeatability is a function of the number of repeated measurements for each lab,

$$u_{rep,i} = \frac{u'_{rep,i}}{\sqrt{n}} \quad (2)$$

where $u'_{rep,i}$ is the repeatability for a single measurement in lab i, and n is the number of repeated measurements in the final average result. Since this number is either unknown or varies between labs, Equation (2) can be simplified by assuming that n is large enough to make the repeatability contribution negligible. Equation 2 is then broken down to,

$$u_{tot} > u_{lab} \quad (3)$$

Thus, neglecting the uncertainty derived from repeated measurements, the total measurement uncertainty is slightly higher (as $u_{rep}^2 \rightarrow 0$) than the overall lab uncertainty.

An estimation of an overall measurement uncertainty for all test laboratories and parameters is done by calculating the standard deviation of all labs. It is valid under the following conditions:

- all test labs that participated in the round robin project represents the whole population of test labs
- reported data were measured/calculated under normal circumstances, i.e. with a representative selection of people performing the test

The standard deviation is estimated by the observed deviations or dispersion from the average value. The standard deviation, s, of a data set is given by the square root of its variance, see Equation (4),

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (4)$$

As the measurement uncertainty is given by the standard deviations under the stated assumptions, Equation (5) illustrates the relation between the standard deviation and the overall measurement uncertainty derived from Equation (3) and (4),

$$s = u_{lab} < u_{tot} \Rightarrow \boldsymbol{s} < \boldsymbol{u_{tot}} \quad (5)$$

The standard deviation is then given in absolute terms as the deviation from the expected value for the data set of each measured parameter. Transforming this to relative terms is done by using Equation (6) and the mean value, $\bar{x}$ of each respective parameter,

$$\mathrm{v} = \frac{\mathrm{s}}{\bar{x}} \quad (6)$$

Measurement uncertainties for each parameter in the round robin test of solar collectors and systems are given in Appendix 1, Table 1-4 and presented in relative terms to the mean value of the parameter.

Discussion and conclusion

Twelve different flat plate and vacuum tube collectors (FPCs and ETCs respectively) from Buderus and Ritter were measured and evaluated based on different climates and methods by thirteen different test laboratories. The results showed good conformity for all parameters. This is a good confirmation that even though all accredited test labs have different preconditions, they all end up with similar results when evaluating these parameters for solar collectors; confirming that the evaluation methods[1] are robust and the reproducibility is satisfactory. Even for a variable such as the power output at different temperature differences that are dependent on other measured values, the measurement uncertainty is still within a reasonable range.

As of the solar systems from Solahart (*thermosyphon system*) and Vaillant (*forced circulation system*) there is a slight increase in the overall measurement uncertainty from these evaluations. This owing to that a number of measured parameters has to be considered in the calculation process; adding multiple uncertainties into the evaluation. The repeatability within each lab though, u_{rep}, shows a good conformity for measurements performed at different occasions, (*e.g.* 2010 and 2011) for most labs. Comparing test results from one year to another shows that for both solar systems the uncertainty is lower in 2011. Furthermore test labs that where different from the others in 2010 managed to perform results closer to the mean value in 2011; giving a lower standard deviation.

[1] For the solar collectors (FPC & ETC), three different evaluation methods were used; steady-state outdoors, steady-state indoors and quasi dynamic (outdoors)

References

[1] EN12975-1:2006+A1, *Thermal solar systems and components - Solar Collectors - Part 1: General requirements* 2010, ^European Committee for Standardization. October 2010

[2] EN 12975-2:2006, *Thermal solar systems and components - Solar Collectors - Part 2: Test methods* 2006, ^European Committee for Standardization. March 2006

[3] ISO 9459-5, *Part 5: System performance characterization by means of whole-system tests and computer simulation*. 2007, ^International Organization for Standardization (ISO). First edition 2007-05-15

[4] Svensson, T., *Nio tumregler och två kungsvägar för att behärska mätosäkerhet*, 2009. ”Nine rules of thumb and two highways to master measurement uncertainty" [In Swedish] ISBN 978-91-85529-86-6. SP Technical Research Institute of Sweden, SP Structural and Solid Mechanics. SP-report 2009:09

Appendix 1

Result summary of the measurement uncertainty for all parameters and different collector and system types

Solar collectors

Table 1 Estimation of measurement uncertainty for parameters and calculated power outputs for Buderus, FPC ***(Labs w/o data points: not stated)***

Data selected	Aperture area	η_0	IAM 50°	Power output at 1000 W/m² for ΔT = 0 K	Power output at 1000 W/m² for ΔT = 10 K	Power output at 1000 W/m² for ΔT = 30 K	Power output at 1000 W/m² for ΔT = 50 K
2010	0.2%	1.3%	4.4%	1.3%	1.4%	2.0%	2.9%
2011	0.2%	1.1%	4.0%	1.2%	1.4%	2.2%	3.3%
2010-2011	0.2%	1.3%	4.2%	1.3%	1.4%	2.1%	3.1%

Table 2 Estimation of measurement uncertainty for parameters and calculated power outputs for Ritter, ETC ***(Labs w/o data points: not stated)***

Data selected	Aperture area	η_0	IAM_L 50°	IAM_T 30°	IAM_T 40°	IAM_T 50°	IAM_T 60°	Power output at 1000 W/m² for ΔT = 0 K	Power output at 1000 W/m² for ΔT = 10 K	Power output at 1000 W/m² for ΔT = 30 K	Power output at 1000 W/m² for ΔT = 50 K
2010	0.4%	2.0%	4.8%	1.9%	0.7%	1.8%	5.5%	1.7%	1.8%	2.4%	3.2%
2011	0.3%	2.0%	3.4%	0.8%	1.7%	2.2%	3.0%	1.8%	1.8%	2.0%	2.6%
2010-2011	0.4%	2.0%	4.1%	1.5%	1.4%	2.1%	4.4%	1.8%	1.9%	2.2%	2.9%

Appendix 1

Solar systems

Table 3 Estimation of measurement uncertainty for all parameters and System Solahart *(Labs w/o data points: not stated)*

Data selected	Stockholm, f-sol 170 l/day	Wurzburg, f-sol 170 l/day	Davos, f-sol 170 l/day	Athens, f-sol 170 l/day
2010	6.6%	5.4%	8.1%	4.7%
2011	6.8%	4.7%	5.5%	3.6%
2010-2011	7.0%	5.3%	7.2%	4.2%

Table 4 Estimation of measurement uncertainty for all parameters and System Viallant *(Labs w/o data points: not stated)*

Data selected	Stockholm, f-sol for 400 l/day, SOS[2]	Stockholm, f-sol for 400 l/day, SPSS[3]	Wurzburg, f-sol 400 l/day, SOS	Wurzburg, f-sol 400 l/day, SPSS	Davos, f-sol 400 l/day, SOS	Davos, f-sol 400 l/day, SPSS	Athens, f-sol 400 l/day, SOS	Athens, f-sol 400 l/day, SPSS
2010	17.5%	12.9%	13.8%	10.4%	15.3%	10.4%	9.1%	6.7%
2011	5.4%	10.1%	3.7%	9.2%	4.2%	8.2%	2.7%	5.5%
2010-2011	12.7%	12.5%	10.4%	10.6%	11.5%	10.0%	7.0%	6.6%

[2] Solar-only systems (*SOS*)
[3] Solar-plus-supplementary systems (*SPSS*)