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ASSESSMENT OF THE PARCIAL MODEL STABILITY OF THE QUASI-DYNAMIC COLLECTOR TEST UNDER OUTDOOR CONDITIONS EN 12975 BY THE APPLICATION OF UNCERTAINTY ANALYSIS

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ABSTRACT

Outdoor collector tests are inherently performed under variable weather conditions. Whereas ISO 9806 sets strong restrictions for the conditions of usable data sets for the steady-state collector test SST, EN12975 allows more variable ambient conditions for the quasi-dynamic collector test QDT. This results in shorter collector test times, but could have drawbacks for the uncertainties including the reproducibility of the test results, i.e. the parameters of the collector model. As the weather conditions are never the same within several tests, outdoor collector tests are not repeatable only reproducible. It is thus to be expected, that the uncertainties of the collector parameters gained by a quasi-dynamic test are higher than those from the steady-state test. In this paper we evaluate the collector parameters and their uncertainties for a covered collector using both the SST, and QDT test methods. As basis for this comparison, we apply a large data set from 2 months of operation under quasi-dynamic conditions. This set is then separated into various single data sets which either fulfill the conditions for a complete steady-state or a complete quasi-dynamic test. For the quasi-dynamic test various sets could be identified. For each of these tests, the parameters and their uncertainties are calculated. This allows for the comparison of both, the model coefficients and their uncertainties. It is tested whether the coefficients extracted from each of the 'quasi-dynamic sets' are in coherence or stable within a 95% confidence by using statistical procedures.

INTRODUCTION

The principal objective of this article is to analyze if the cost effective quasi-dynamic test according to EN12975 [1], [5] can reproduce his test results. For this, the collector coefficients obtained from several QDT testes may be regarded as identical, taking into account a 95% confidence limit.

As a second result the coefficients gained by a cost intensive steady-state test SST as described in EN12975[1], ISO9806[2], ASHRAE 93-86[3] and NBR 10184[4] are presented using the measured data of the same data set.

As prerequisite for the following discussion the models for the collector performance used in both tests are described in the next section. This is followed by a description of the method used to derive the model parameters (or collector coefficients) and their uncertainties. Finally we present a discussion of the conditions, that must be fulfilled to state that two separate QDT test results are identical within given confidence limits.

COLLECTOR TEST RIG

Aim of the collector model is to describe its efficiency for the environmental and operational conditions given by the incoming radiation, the air temperature and the inlet and outlet temperatures. To derive the parameters of the model according to different standards, the collector performance on an outdor test rig (see figure 1) is analyzed.

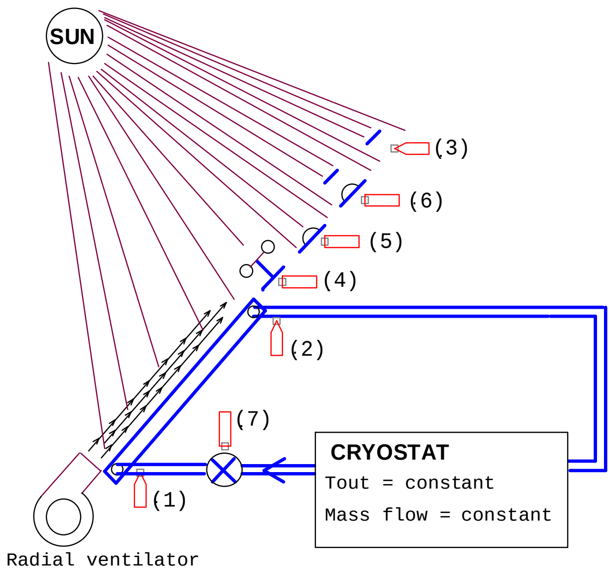

Figure 1: Schematic diagram of the test rig for the quasi-dynamic and the steady-state collector tests, where the following quantities are measured: (1) Inlet temperature: temperature of the fluid flowing into the collector, (2) Outlet temperature: temperature of the fluid leaving the collector, (3) Ambient temperature, (4) Air speed: speed of the air at the collector front cover, (5) Global radiation: Total solar radiation measured in the collector plane, (6) Diffuse radiation measured in the collector plane, (7) Flux meter: measurement of the volume flow rate through the collector.

MODEL EQUATIONS

The ISO and the Euro-standards defines the following models to be used to extract the collector coefficients using the measured, selected and combined data.

Steady-state collector model

For the steady-state collector test model parameters and the model equation for the estimated efficiency are given as follows:

$$\eta_{mo} = \overbrace{\underbrace{\eta_0}_{a_1} \cdot \underbrace{1}_{X1}}^{\text{optical property}} + \overbrace{\underbrace{k_1}_{a_2} \cdot \underbrace{\frac{\Delta T}{G}}_{X_2} + \underbrace{k_2}_{a_3} \cdot \underbrace{\frac{(\Delta T)^2}{G}}_{X_3}}^{\text{heat loss properties}} \qquad (1)$$

In the regression with the SST we have one coefficient for the intersection η_0 and two coefficients for the slope $k_1$and k_2. We estimate the η_{mo} – values by applying the equation $\eta_{mo} = a_1 \cdot X_1 + a_2 \cdot X_2 + a_3 \cdot X_3$, but we need a set of η_{me} , X_1, X_2 and X_3 values for to obtain the regression coefficients a_1 , a_2 and a_3 by applying the multiple least square regression method.

Like η_0 defines the slope, the used regression variables are calculated by:

$$X_{i,1} = 1,$$
$$X_{i,2} = \Delta T_i / G_i,$$
$$X_{i,3} = \Delta T_i^{\,2} / G_i .$$

In the regression the measured efficiency values $\eta_{me,i}$ (mean values taken from 15 min) are set as a goal for the efficiency values estimated by the model and are calculated by $\eta_{me,i} = \dot{m}_i \cdot C_{p,i} \cdot (T_{out,i} - T_{in,i}) / G_i \cdot A$.

The measured variables used for the calculation of the regression variables are:

$\eta_{mo,i}$: modeled or estimated efficiency [-],
$G_{b,i}$: beam radiation $[W/m^2]$,
$T_{m,i}$: average collector temperature [K],
$T_{m,i} = (T_{in,i} + T_{out,i}) / 2$ [K],
$\Delta T_i = T_{m,i} - T_{a,i}$ [K],
$T_{a,i}$: ambient temperature [K].

The regression coefficients $a_1..a_3$ that have to be determined by the regression process are:

$a_1 = \eta_0$: zero loss efficiency [-],
$a_2 = k_1$: heat loss coeficient [W/(m²K)], negative,
$a_3 = k_2$: heat loss coeficient [W/(m²K²)], negative.

Quasi-dynamic collector model

To allow the use of data obtained under quasi-dynamic conditions, model parameters and model equation have to be modified accordingly:

$$\overbrace{\underbrace{\overbrace{\eta_0}^{a1} \cdot \overbrace{\frac{G_b}{G}}^{X1}}_{\text{beam model}} + \underbrace{\overbrace{\eta_0^{*} \cdot b_0}^{a2} \cdot \overbrace{\left(\frac{1}{\cos\theta} - 1\right) \cdot \frac{G_b}{G}}^{X2}}_{\text{angle of beam model}} + \underbrace{\overbrace{\eta_0^{*} \cdot K_{\theta d}}^{a3} \cdot \overbrace{\frac{G_d}{G}}^{X3}}_{\text{diffuse model}}}^{\text{optical properties}} \qquad (2)$$

beam radiation model = $K\theta b(\theta) \times \eta_0 \times Gb / G$

$$\underbrace{+ \overbrace{k_1}^{a4} \cdot \overbrace{\frac{\Delta T}{G}}^{X4} + \overbrace{k_2}^{a5} \overbrace{\frac{(\Delta T)^2}{G}}^{X5}}_{\text{heat loss properties}} + \underbrace{\overbrace{k_3}^{a6} \cdot \overbrace{\frac{dT_m}{d\tau} \cdot \frac{1}{G}}^{X6}}_{\text{thermal capacity property}} = \eta_{mo}$$

Where $K_{\theta b}(\theta)_i$ is the incident angle modifier function given by $K_{\theta b}(\theta)_i = 1 + b_0 \cdot (1/\cos(\theta_i) - 1)$.

The used regression variables in eqn.(2) are calculated by:

$$X_{i,1} = G_{b,i} / G_i ; \qquad X_{i,2} = (1/\cos(\theta_i) - 1) \cdot G_{b,i} / G_i ;$$
$$X_{i,3} = G_{d,i} / G_i ; \qquad X_{i,4} = \Delta T_i / G_i ;$$
$$X_{i,5} = \Delta T_i^2 / G_i ; \qquad X_{i,6} = \partial T_{m,i} / (\partial \tau_i \cdot G_i);$$

In the regression the measured efficiency values $\eta_{me,i}$ (mean values taken from 5 min) are set as a goal for the efficiency values estimated by the model and are calculated by $\eta_{me,i} = \dot{m}_i \cdot C_{p,i} \cdot (T_{out,i} - T_{in,i}) / G_i \cdot A$.

The variables used for the calculation of the regression variables are:

$C_{p,i} = f(T_{m,i})$ effective collector heat capacity of the fluid [J/(kg · K)],
$\eta_{mo,i}$: modeled or estmared efficiency,
$G_{b,i}$: beam radiation $[W/m^2]$,
$G_{d,i}$: diffuse radiation $[W/m^2]$, $G_{b,i} = G_i - G_{d,i}$ $[W/m^2]$,
$T_{m,i}$: average collector temperature [K],
$T_{m,i} = (T_{in,i} + T_{out,i}) / 2$ [°C], $\Delta T_i = T_{m,i} - T_{a,i}$ [K],
$T_{a,i}$: ambient temperature[K], θ_i : incidence angle [°].

The regression coefficients $a_1..a_6$ that have to be determined by the regression process are:

$a_1 = \eta_0$: zero loss efficiency [-],
$a_2 = \eta_0 \cdot b_0$, b_0 is a scale factor scaling the incident angle,
modifier of the beam irradiance [-], negative,
$a_3 = \eta_0 \cdot K_{\theta d}$, $K_{\theta d}$: incident angle modifier for diffuse radiation [-],
$a_4 = k_1$: heat loss coeficient [W/(m²K)], negative,
$a_5 = k_2$: heat loss coeficient [W/(m²K²)], negative,
$a_6 = k_3$: coeficient for the thermal capacity [kJ/(m²K)], negative.

REGRESSION ANALYSIS

As it is shown in [6]-[8] for the SST and in [9]-[11] for the QDT classical least square regression techniques may be used to derive both, the regression coefficients and their uncertainties. The basis for the regression procedure is given by the equation for the error sum of square SS_E (eqn.(3)) of the difference of the measured and the model efficiency, which has to be minimized.

$$SS_E = \sum_{i=1}^{n} (\in_i)^2 \to \min = \sum_{i=1}^{n} \left(\eta_{me,i} - \eta_{mo,i} \right)^2 = \sum_{i=1}^{n} \left(\eta_{me,i} - \sum_{j=1}^{k} (X_{i,j} \cdot a_j) \right)^2 \qquad (3)$$

Where j= 1...k is the quantity of model coefficients, that is 3 for the SST and 6 for the QDT, i = 1...n is the quantity of mean values of the variables used for the regression.

The coefficients a_1 to a_k may be identified by solving the linear regression model (eqn. 4), which is given in eqn.(5) as matrix expression.

$$\eta_{mo,i} = \sum_{j=1}^{k} a_j \cdot X_{i,j} \qquad (4)$$

The numbers of the regression coefficients in the model are determined by a_j. The used regression variables are $X_{i,j}$ (see also eqn.1 and eqn. 2).

$$\hat{y} = \eta_{mo} = X \cdot a + \in = \begin{bmatrix} y_1 \\ y_2 \\ \\ y_n \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1k} \\ x_{21} & x_{22} & \cdots & x_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ x_{n1} & x_{n2} & \cdots & x_{nk} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_k \end{bmatrix} + \begin{bmatrix} \in_1 \\ \in_2 \\ \vdots \\ \in_n \end{bmatrix} \qquad (5)$$

Where the parameters defined as:

$y_1....y_n$: Estimated efficiency values [-],
$\in_1 .. \in_n$: : diffrence between $\eta_{mo,i}$ and $\eta_{me,i}$,
$i = 1...n$: number of the data sets,
$j = 1..k$: number of regression coefficients,
SST : $x_{11}....x_{n1} = 1$, compare also eqn.(1),
$x_{12}....x_{nk}$, measured variables,
QDT : $x_{11}....x_{nk}$, : measured variables.

The residual mean square error σ^2 (also named MSE) is given by (6), using reduced matrix/vector expression:

$$\sigma^2 = \frac{\sum_{i=1}^{n} (\in_i)^2}{n-k} = \frac{(y - X \cdot a)' \cdot (y - X \cdot a)}{n-k} \qquad (6)$$

With the regression results of two different collector tests using the same collector (the tests we named here sample A and sample B) we now proof if the regression coefficient of these two tests are statistically different with significance. By the regression of both data sets we obtain two mean square errors σ^2_A and σ^2_B. Using these mean square errors and the data matrix X, according to [12], [13] the variances of the coefficients are obtained for the data group of sample A as well as for the data group of sample B as diagonal elements of the matrix given in eqn. (7). The off diagonal elements of these matrixes refer to the covariances of the estimators.

$$\sigma^2 \cdot (X' \cdot X)^{-1} = \begin{bmatrix} \mathrm{var}(a_1) & \mathrm{cov}(a_1, a_2) & \cdots & \mathrm{cov}(a_1, a_k) \\ \mathrm{cov}(a_2, a_1) & \mathrm{var}(a_2) & \cdots & \mathrm{cov}(a_2, a_k) \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{cov}(a_k, a_1) & \mathrm{cov}(a_k, a_2) & \cdots & \mathrm{var}(a_k) \end{bmatrix} \qquad (7)$$

We thus obtain the standard error of the estimated regression coefficients $s_e(a_j)$ (that are calculated for each collector test) by the square root of diagonal elements of this matrix eqn.(8) for both data groups or samples.

$$s_e\left(a_j\right)=\sqrt{\operatorname{var}(a_j)} \qquad (8)$$

The 100(1-α) confidence interval on the regression coefficients a_j with significance α/2, for j= 1….k coefficients we obtain in the multiple linear regression by equation (9). See also reference [13].

$$\hat{a}_j - t_{\alpha/2,n-k}\cdot s_e(a_j) \le a_j \le \hat{a}_j + t_{\alpha/2,n-k}\cdot s_e(a_j) \qquad (9)$$

Where the statistic variables are defined as:

$t_{\alpha/2,n-k}$: studend value with the level of significance of $\alpha/2$
k : number of regression coefficients
n - k : residual degrees of freedom
n : numes of measured variables sets

STATISTICAL ANALYSIS OF THE DATA

Usually information on the quality of the regression and significance of the whole regression model may be gained by the F-test together with the RMS and R² values. This however does not give any information about the significant model coefficient variations resulting from different regressions, which is of importance in the evaluations of the stability of the collector test, and the partial stability of the collector model. For this kind of evaluation the uncertainties - for a given confidence - of the values for the coefficient resulting from the regression are needed. With this information, the results from different tests might be compared coefficient by coefficient and may proof whether:

1- data sets from different test runs analyzed by the same method and regression model result in the same regression coefficients,
2- different test methods (i.e. steady-state and quasi-dynamic test) yield in the same regression coefficients using the same data sets,
3- different data selection criterions yield in the same regression coefficients using the same test and the same data set.

In this article we analyze if different test runs of the QDT yields in the same collector coefficients.

ANALYSIS OF THE STABILITY OF THE MODEL COEFFICIENTS

If we like to compare two regressions executed with data set from different time intervals, we can use the theory about inferences concerning two means [12], [13] to compare the regression coefficients obtained by these two regressions. If the number of the measured variable set is high, and with this also the degree of freedoms, we can consider that the deviations between the measured and calculated efficiency obey a normal distribution. The same is true if we consider standard error of the difference between two coefficients extracted by two regressions.
In large samples (a large sample is here considered a complete QDT collector test) the significance of the difference between the coefficients, extracted from two data groups A and B can be assessed by eqn. (10) like [14] outlines:

$$z_j = \frac{a_{j,A}-a_{j,B}}{s_e(a_{j,A,B})} = \frac{a_{j,A}-a_{j,B}}{\sqrt{s_e^{\,2}(a_{j,A})+s_e^{\,2}(a_{j,B})}} \qquad (10)$$

Where $s_e(a_{j,A})$ is the standard error of the coefficients from the first data group or sample, $s_e(a_{j,B})$ is the standard error of the coefficients from the second data group and $s_e(a_{j,A,B})$ is the standard error of the coefficients difference. $s_e(a_{j,A,B})$ is the square root of the sum of the two variances of the coefficients (10), assuming that we have large samples and the samples are independent [14]. The cumulative standard normal distribution has like the standard normal distribution the mean value of zero and a standard error of 1 (see statistic table of reference [13]). Using the cumulative probabilities is a method to describing the probability of a random variable. The controlling z_j-values (Table 3) are calculated with this method. If the absolute z_j-value of the calculated distribution is lower than the value of the cumulative standard distribution z_{crit} "the two mean values can be considered equal with 95% confidence"[12], [13]. Testing the equality of two means with the different standard errors for their quality within 95% ($\alpha=1-0.95=0.05$) confidence, we have to use the value of α/2 to calculate the controlling z-value or get the value of z from the statistic table of the cumulative standard distribution for $\alpha = 0.025$ [12],[13]. The regression coefficients from two data groups indicate a stable or reproducible procedure if the test variables z fulfills the condition $|z_j| < z_{table\_\alpha/2} = 1.960$.

APPLICATION OF THE TEST METHODS

The procedures as described above are now applied to various data sets that have been taken over a longer period of time, allowing for the extraction of data sets that may be used as input for the QDT and SST test procedures. The following gives a description of the test conditions and the procedure for the extraction of the respective data sets.

TESTING CONDITIONS

The collector test occurred over the period of 3 months using the same collector. Data was acquired that serves for the evaluation of both, the steady-state and the quasi-dynamic test. The collector was first mounted in a collector tilt angle β of 45° (per the ISO 9806 recommendations for all sites for the best comparison of the results). In the ISO 9806 the relative angle between the sun and the collector θ has to be less than 30° ± 1°. With β = 45° and low relative latitudes like in Brazil (Florianópolis is 27.5°) it is not possible to get data with θ less than 30° during the summer time. For this reason we tilted the collector to 29° during the summer time.

UNCERTAINTIES OF THE USED MEASUREMENT TRANSDUCERS

We call attention that the uncertainties of the used transducers are within the range of the specified uncertainties of the ISO and Euro standards.

DATA SELECTION

Stabilities of the collector inlet fluid temperature and flow

ISO 9806 and EN 12975 define that fluid flow through the collector has to be stable within ± 1%. The fluid temperature has to be stable within ± 0.1K according to the ISO 9806, and within ±1K according to EN12975. With the given experimental setup, these stability criteria could not be reached. The data sets analyzed obeyed the stability conditions for the mass flow and for the input temperature for the QDT. Only for the SST we enlarged the selection condition to ± 0.2 K for the fluid inlet temperature. From the time period of two months with 29° tilt angle, four QDT and one SST data sets could be gained by data selection and combination. It has to be remarked that the most critical weather condition to be obtained in Santa Catarina/Brazil is the clear day condition. Clear day weather conditions are necessary for executing the complete SST and also necessary during one whole day for the QDT.

Time intervals used for the identification of periods with stable operation conditions

EN12975 defines that for accepting a measurement interval of 15 min all the 30 s mean values have to lie inside the limits of the specified stability conditions. That formal condition wasn't possible to reach for the fluid flow condition. For getting more data we enlarged the 30s mean values by using mean values of 3 minutes for the steady-state test and adopted 1 minute for the quasi-dynamic test.

OPERATION OF THE TESTS

We observed that the system has instability within amplitude of approximately ± 5 % of the fluid flow with frequency of approximately 0.2 Hz. If we closed the bypass this instability mainly disappears to ± 1 %. In a closed water circuit the bypass will probably not generate any influences.

NORMALIZATION OF THE ZERO LOSS EFFICIENCY

With equation (11) we can calculate the normalized zero loss efficiency η_{0_norm} of the QDT, that is used for to drawing the typical efficiency curve of a solar collector that is comparable to the efficiency curve of a SST.
EN12975 [1] defines the following conditions for that normalization:

- beam radiation: 680 W/m² (85% of the global radiation),
- diffuse radiation: 120 W/m² (15% of the global radiation),
- global radiation: 800 W/m²,
- Incidence angle: 15°.

$$\eta_{0\_norm} = \eta_0 \cdot \left(\frac{G_b}{G} \cdot IAM_{dir\_15} + \frac{G_d}{G} \cdot M_{Gd} \right) ,$$

$$K_{\theta b}(\theta) = 1 + b_0 \cdot \left(\frac{1}{\cos\theta} - 1 \right) \tag{11}$$

For the statistical comparison of the collector coefficients we used four data sets according to the quasi-dynamic test (see Table 2 and Table 3). The regression coefficients obtained from the QDT-regression a_j, the standard error $s_e(a_j)$ of these coefficients, the collector coefficients Cc calculated with the obtained a_j and their uncertainties *Uc* (see reference [18]) are presented in table 1.

QDT N° 1				
regression coefficients	a_j	$s_e(a_j)$	$Uc(a_k)$	units
a_1	0.655	0.003	0.006	[-]
a_2	-0.092	0.012	0.024	[-]
a_3	0.624	0.004	0.008	[-]
a_4	-5.236	0.180	0.355	[W / m² K]
a_5	-0.042	0.003	0.007	[W / m² K²]
a_6	-12.367	0.496	0.978	[kJ / m² K]
QDT N° 1				
collector coefficients	Cc	U(Cc)	units	U(Cc) %
η_{0_norm}	0.647	0.006	[-]	0.99
b_0	-0.140	0.037	[-]	-26.55
$K_{\theta d}$	0.953	0.016	[-]	1.66
k_1	-5.236	0.355	[W / m² K]	6.79
k_2	-0.042	0.007	[W / m² K²]	16.07
k_3	-12.367	0.978	[kJ / m² K]	7.91

Table 1: Regression results of the quasi-dynamic collector test no 1.

coefficients and unbiased mean square error	SST coefficients		QDT 1 coefficients		QDT 2 coefficients		QDT 3 coefficients		QDT 4 coefficients	
	min.	max.	min.	max.	min.	max.	min.	max.	min.	max.
η0 [-]	0.63	0.64	0.65	0.66	0.65	0.67	0.65	0.66	0.65	0.67
k_1 [W / m² K]	-3.45	-3.04	-5.59	-4.88	-6.49	-5.53	-6.38	-5.79	-5.90	-5.27
k_2 [W / m² K²]	-0.08	-0.07	-0.05	-0.04	-0.04	-0.02	-0.03	-0.02	-0.04	-0.03
bo [-]	-		-0.18	-0.10	-0.16	-0.10	-0.15	-0.11	-0.19	-0.10
$K_{\theta d}$ [-]	-		0.94	0.97	0.92	0.95	0.93	0.95	0.91	0.95
k_3 [kJ / m² K]	-		-13.3	-11.4	-14.4	-12.7	-14.1	-12.7	-14.9	-13.4

Table 2: Collector coefficients of four quasi-dynamic and one steady-state collector tests.

ANALYSIS OF THE STRUCTURAL STABILITY OF THE QUASI-DYNAMIC TEST BY TESTING THE EQUALITY OF TWO MEAN VALUES WITH THE OWNED STANDARD ERROR

Applying the method described above for the comparison of the collector coefficients, we get the result that the heat loss coefficients are not full stable comparing these four quasi-dynamic tests (Table 3). If we evaluate the QDT with $d_f = n_1 + n_2 - (2 \cdot k) = 196 + 146 - 12 = 330$ degrees of freedom, we can consider a normal distribution of the standard errors $s(a_{j,A,B})$ with the test controlling z-variable $z = 1.96$.

The uncertainty (Table 1) obtained by the regression can be caused by the following effects within the data set:

- Uncertainty of the measurement transducers or sensors,
- Failing of the stability of the inlet temperature or fluid flow,
- Failing of weather conditions which include important scales of the variables when applying the data validation process,

- Selection criterions applied to the data set with to much tolerance band for the variables that change during the test,
- Failing of a physical test condition for the test (collector test rig),
- Application of a model that is to much reduced,
- Disturbances that appears during the outdoor test which are not possible to describe with a sub model.

Normal z - values	QDT 1 compared to the QDT 2		QDT 1 compared to the QDT 3		QDT 1 compared to the QDT 4		QDT 2 compared to the QDT 3		QDT 2 compared to the QDT 4		QDT 3 compared to the QDT 4	
	$\lvert z_j \rvert$	test	$\lvert z_j \rvert$	test	$\lvert z_j \rvert$	test	$\lvert z_j \rvert$	test	$\lvert z_j \rvert$	test	$\lvert z_j \rvert$	test
$z(a_1)$	0.95	eq.	1.09	eq.	0.33	eq.	0.06	eq.	0.47	eq.	0.49	eq.
$z(a_2)$	0.35	eq.	0.51	eq.	0.03	eq.	0.11	eq.	0.27	eq.	0.38	eq.
$z(a_3)$	1.43	eq.	1.17	eq.	0.42	eq.	0.55	eq.	0.79	eq.	0.39	eq.
$z(a_4)$	2.57	uneq.	3.63	uneq.	1.48	eq.	0.26	eq.	0.99	eq.	1.65	eq.
$z(a_5)$	1.86	eq.	3.28	uneq.	1.25	eq.	0.66	eq.	0.49	eq.	1.51	eq.
$z(a_6)$	1.84	eq.	1.75	eq.	1.30	eq.	0.26	eq.	0.60	eq.	0.39	eq.

Table 3: statistic test of the structural stability of the qdt with z-variables obtained from the above comparison and test together with the critical z-value.

Absence of the collector coefficients reproducibility or failing of model stability can be caused by the same effects if they appear in a different manner between the data set of two separate tests.

RESULTS

All the optical and thermodynamic characteristics can be reproduced statistically. The sub-models of the heat loss coefficients show are different comparing the QDT1 to QDT2 and the QDT1 to the QDT3 (see Table 3). Also the heat loss coefficients that results from the SST- test method (Table 4 and Table 2) are different to that obtained with the QDT.

SST				
regression coefficients	a_j	$s_e(a_j)$	$Uc(a_j)$	units
a_1	0.632	0.001	0.003	[-]
a_4	-3.411	0.137	0.276	[W / m² K]
a_5	-0.071	0.002	0.004	[W / m² K²]
SST				
collector coefficients	Cc	U(Cc)	units	U(Cc) [%]
η_0	0.632	0.003	[-]	0.47
k_1	-3.411	0.276	[W / m² K]	8.09
k_2	-0.071	0.004	[W / m² K²]	5.85

Table 4: Collector coefficients obtained by a SST test analysis.

OUTLOOK AND CONCLUSIONS

It has to be remarked that it wasn't possible to realize all stability conditions in the actual system configuration (see the section of data selection). Better coefficients stability may be reached by maintaining the inlet conditions of the fluid flow and the input temperature which are recommended by the ISO- and EURO-standards. It has to be analyzed whether the application of a regression procedure which takes the influence of wind conditions into account (like recommended by EN12975) may help in this topic. In the used test rig allows the back and the sides of the collector were exposed to the natural variations of the ambient wind. This influence can be reduced if the collector is fixed on a roof during the collector test. It has to be confirmed if variations of wind speed at the back sides of the collector have any influence on the uncertainty and the coefficients stability of the test results, with further tests using a roof installation. The collector coefficients may be used to calculate the expected energy gain for a given system configuration, hot water consumption and weather data (e.g. a typical meteorological year TMY [16],[17]) for the site of interest. In [5] is outlined that the uncertainty of the yearly energy production can be ~ 2 % by Tm = 40 °C and 7% by Tm = 60 °C in a simulation with the uncertainties obtained by a QDT for the same collector that is used in this article. Although the stability of the collector coefficients are important, for the collector development and production as well as for the optimization of the collector test procedures itself, the most important number for the application of a solar collector is the stability of his energy production. To control whether the energy production estimated using a specific set of regression coefficients obtained with the regression is representative, a method that gives an empirical error limit of 2% for the data sequence of validation is shown in [15]. With these limits it is possible to analyze if a data set of a collector test can be accepted or rejected by comparing the measured and modeled energy during the test time and a separated reference time period.

NOMENCLATURE

η_0	zero loss efficiency at normal incidence [-]
η_{0_norm}	η_0 of the QDT normalized to the SST conditions [-]
$K_{\theta b}(\theta)$	incidence angle modifier for direct radiation [-]
$K_{\theta d}$	incidence angle modifier for diffuse radiation [-]
k_1	heat loss coefficient at $(T_m - T_a) = 0$ [W/(m² x K)]
k_2	temperature dependence of k_1 [W/(m² K²)]
k_3	effective thermal collector capacitance [J/(m² x K)]
G	global solar irradiance [W/m²]
G_d	diffuse solar irradiance [W/m²]
G_b	beam irradiance [W/m²]
D_f	diffuse fraction [-]
θ	incident angle of the beam irradiance [°]
b_0	incident angle modifier coefficient [-]
T_{in}	inlet fluid temperature [K]
T_{out}	outlet fluid temperature [K]
T_m	mean collector temperature [K]
T_a	surrounding air temperature [K]
ΔT	difference between T_a and T_m [K]
$\dot{Q}$	power output of the collector [W/m²]
$\in$	measured minus modeled collector power [W/m²]
$\dot{m}$	Mass flow [kg/s]
s_e	standard error of 'a_j' or a 'modeled energy Q'
σ^2	residual mean square error $[W/m^2]^2$
a_j	regression coefficient
$X_{i,j}$	regression variable
j = 1..k	number of the used model components
i = 1..n	number of the mean values used for the regression
τ	time interval for calculating each mean value
t	student value used for significance test
z	normal distribution value for significance test
$(1-\alpha)$	significance for the statistical tests

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