ANALYSIS OF THE COLLECTOR TEST PROCEDURES FOR STEADY-STATE AND QUASI-DYNAMIC TEST CONDITIONS IN VIEW OF THE COLLECTOR COEFFICIENTS UNCERTAINTIES AND MODEL STABILITY

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ABSTRACT

Outdoor collector tests are inherently performed under variable weather conditions. Whereas for the steady-state collector test SST, ISO 9806 strong restrictions are set for the weather conditions for usable data sets or samples, the ambient conditions of the quasi-dynamic collector test QDT, EN12975 are allowed to be more variable. This results in shorter collector test time, but could have drawbacks for the uncertainties caused by the reproducibility of the test results, i.e. the collector coefficients (or also called collector parameters) stability of the collector model, as well as for the estimated power and energy with this model. As the weather conditions are never the same within several tests, outdoor collector tests are not repeatable but reproducible. Like the QDT permits to use data with more variable weather conditions, it is thus may be expected, that the uncertainties of the collector parameters gained by a QDT test are superior to those from the SST test. On the other hand the model of the SST is only a reduced collector model. All optical and thermodynamic effects that appear during the application of a solar collector are not managed with that reduced model. Under this consideration it is possible, that the result of the SST collector test may estimate the produced energy with more uncertainty than the QDT. We estimate in this paper the total uncertainty and the stability of the quasi-dynamic and the steady state test methods with the objective to proof which of methods is the most reliably one. We evaluate the collector parameters and their uncertainties of a covered collector using both, the SST and QDT test methods. As basis, a large data set from 3 months of operation is applied. This set is then separated in various single data sets fulfilling either the conditions of a complete steady-state or a complete quasi-dynamic test. Hereby several sets for the case of the QDT, and one for the steady-state test one set could be identified. From each of the tests the collector parameters and their uncertainties are calculated. This allows the comparison of both, the model coefficients and their uncertainties. It is than tested with statistical methods to what extend the reduced SST model is sufficient to extract collector coefficients that are usable for the calculation of the long term energy gain of the collectors. We use as a second result statistical procedures to test whether the coefficients extracted from the QDT data sets of each of the QDT collector tests have statistical equality within 95% of confidence if we compare the same coefficients from different tests. Proofing statistical equality is in coherence with model stability of a collector model. The Energy production simulated using the SST and QDT models are compared with the measured energy during the time period of 2 month. Finally the total uncertainties for long term energy estimation of the SST and the QDT tests are quantified.

1. INTRODUCTION

The main goal of this article is to analyze with statistical methods whether the extended model of the quasi-dynamic test according to EN12975 [1], [5] is able with the same uncertainty or with lower uncertainty to estimate the collector coefficients and the energy produced by the collector using the QDT model and data set than the model and data set of a steady-state test as described in EN12975[1], ISO 9806[2], ASHRAE 93-86[3] and NBR 10184[4]. For this, the collector coefficients from a steady-state test- i.e. the basic collector coefficients η_0, k_1 and k_2 - are considered identical to those obtained form a QDT procedure. 'Identical' is defined here as identical within a 95 % confidence limit (see ISO-VIM [19]) taking into account the uncertainties of the parameter identification procedures.
The QDT and the SST data sets were selected from the amount of data set of two month. We compare the coefficient set gained by the SST data set with the coefficients extracted by the QDT data sets and explicate than how significant coefficient variations can be detected if the reduced SST model is substituted by a full QDT model. We also present the analyses whether quasi-dynamic test according to EN12975 [1], [5] yields reproducible results. This analysis is based on the coefficients and the respective uncertainties gained from several QDT tests. We present a methodology that can check which of the two test results are identical within a given confidence interval if we use two independent data sets of the QDT. We estimate the uncertainties of the collector power and energy as well as for the bias error of that energy. The methodology is applied to the models obtained from the QDT and the SST regressions. 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 collector coefficients and their uncertainties. Normalized efficiency curves with his uncertainties of the SST and QDT tests are drawn and compared.

2. COLLECTOR TEST RIG

The aim of the collector model is to describe its efficiency under the environmental and operation conditions given by the incoming solar radiation, the air temperature and the inlet and outlet collector temperatures of the solar collector. To derive the parameters of the model according to different standards, the collector performance is determined in a test rig (see figure 1). Like in that figure you can notice, the cryostat holds the mass flow and the temperature constant and the radial ventilator helps to create a constant air speed over collector window.

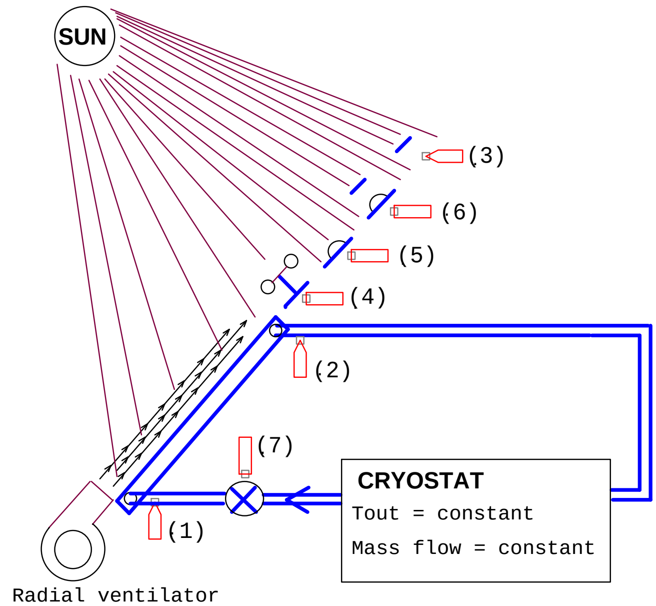

Fig. 1: Schematic diagram of the test rig for the quasi-dynamic and the steady-state collector tests, where the following quantities are measured: (1) Inlet temperature: temperature of the fluid flowing into the collector, (2) Outlet temperature: temperature of the fluid leaving the collector, (3) Ambient 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.

3. MODEL EQUATIONS

The ISO [2] and the Euro [1] standards establish the following collector models for the determination of the collector coefficients using the measured, selected, averaged and combined data of the collector test.

3.1 Collector model of the steady-state test

For the steady-state collector test model the efficiency of the collector is expressed by:

$$\underbrace{\dot{Q}_{mo} = G\times\eta_{mo}}_{\hat{Y}=Y\ estimated} = \overbrace{\underbrace{\eta_0}_{a_1}\times\underbrace{G}_{X_1}}^{\text{optical property}} + \overbrace{\underbrace{k_1}_{a_2}\times\underbrace{\Delta T}_{X_2} + \underbrace{k_2}_{a_3}\times\underbrace{(\Delta T)^2}_{X_3}}^{\text{heat loss properties}} \tag{1}$$

Where $\dot{Q}_{mo}$ is the estimated collector power per collector aperture area *A*, estimated by the model and is given in units of W/m^2. $\dot{Q}_{mo}$ is determined as function $\hat{Y}$ of the variables X_1, X_2 and X_3 with coefficients a_1, a_2 and a_3 (see eqn. 1). The coefficients have to be determined by a regression procedure as described below, using the deviations of estimated power $\dot{Q}_{mo}$ and measured power $\dot{Q}_{me}$ – both taken per collector aperture area - as criteria. In the regression procedure $\dot{Q}_{me}$ is set as goal for the estimator $\hat{y}$. It is measured by $\dot{m} \times C_p \times (T_{out} - T_{in}) / A$, T_{in} being the inlet and T_{out} outlet temperature, $\dot{m}$ is the mass flow derived from the volume flow and the temperature of the fluid that passing the flow meter, C_p the heat capacity of the fluid (in our case water) having the units J/kg K and which depends on the mean fluid temperature of the collector T_m. The variables X_1, X_2 and X_3 are derived from measured quantities: G being the global radiation (measured in W/m^2), $\Delta T = T_m - T_a$ the difference between the average collector temperature $T_m = (T_{in} + T_{out}) / 2$, and the ambient temperature T_a. The simplified model sets the average collector temperature T_m equal to the mean fluid temperature of the collector calculated by $(T_{out} + T_{in})/2$. All measured quantities are taken from the experiment as mean values in 15 minutes intervals. With the regression variables X_1, X_2 and X_3 (see equation (1)) and the dependent variable $\dot{Q}_{me}$ all defined by the measured values, we set a linear regression problem, to find the regression coefficients a_1, a_2 and a_3. These coefficients can be identified as: η_0 which indicates the dimensionless zero loss coefficient, k_1 which is a heat loss coefficient estimated by the model having the units W/m^{2}K and k_2 which is another heat loss coefficient estimated in W/m^{2}K. The heat loss coefficients are always negative.

3.2 Quasi-dynamic collector model

To allow for the use of data taken under quasi-dynamic conditions the model parameters and the model equation have to be modified accordingly to equation (2). Where a_1 to a_6 are the regression coefficients and X_1 to X_6 are the regression variables, all together used in the multiple linear regression of the quasi-dynamic test. G_d is the diffuse radiation, G is the global radiation and G_b is the beam radiation calculated by the relation $G_b = G - G_d$, all measured in units of W/m^2.

$$\underbrace{\dot{Q}_{mo}}_{Y-estimated} = \overbrace{\underbrace{\underbrace{\overbrace{\eta_0}^{a1} \times \overbrace{G_b}^{X1}}_{\text{beam model}} + \underbrace{\overbrace{\eta_0 \times b_0}^{a2} \times \overbrace{\left(\frac{1}{\cos\theta} - 1\right) \times G_b}^{X2}}_{\text{angle of beam model}}}_{\text{beam radiation model } = \text{ K}\theta b(\theta) \times \eta_0 \times Gb} + \underbrace{\overbrace{\eta_0 \times K_{\theta d}}^{a3} \times \overbrace{G_d}^{X3}}_{\text{diffuse radiation model}}}^{\text{optical properties}} \tag{2}$$

$$\underbrace{+ \overbrace{k_1}^{a4} \times \overbrace{\Delta T}^{X4} + \overbrace{k_2}^{a5} \times \overbrace{\Delta T^2}^{X5}}_{\text{heat loss properties}} + \underbrace{\overbrace{k_3}^{a6} \times \overbrace{\frac{dT_m}{d\tau}}^{X6}}_{\text{thermal capacity p.}} = \underbrace{\text{G} \times \eta_{\text{mo}}}_{Y-estimated}$$

The average collector temperature T_m, the difference between collector mean and ambient temperature ΔT and the measured collector power per collector area $\dot{Q}_{me}$ are derived in the same way as in the steady-state collector model. Here the mean values of the measurable quantities are taken from the samples of the experiment in 5 minutes intervals. The coefficients to be determined by the regression are: a_1 that is the zero loss coefficient of the QDT given by η_0, a_2 given by $\eta_0 \times b_0$ where b_0 is the factor to scale the power losses modeled by the incident angle modifier function $1/\cos(\theta)-1$, used for scaling of that beam radiation part a^{2} x X^{2} that the collector can not transform in heating energy because of the absorption and reflection losses, where θ is the incidence angle that is the angle between the normal position of the sun to the collector and the position when the mean value of a sample is calculated, a_3 given by $\eta_0 \times K_{\theta d}$ where $K_{\theta d}$ is the mean incident angle modifier considered for diffuse radiation, $a_4 = k_1$ and $a_5 = k_2$, are the heat loss coefficients estimated respectively in units of W/m^{2}K and W/m^{2}K^2 and k_3 is the coefficient that determines the mean heat capacity of the collector together with the heat capacity of the water within the collector estimated in units of J/m^{2}K.

4. REGRESSION ANALYSIS

The sets of the collector coefficients, gained by the linear regression show uncertainty, that has to be specified. The respective procedures to analyze the uncertainties of the estimates in a linear regression gained by the classical least square method are e.g. given by ISO-GUM[20]. The regression technique, that is used to derive both, the regression coefficients and their uncertainties for the SST and the QDT tests are shown in [6]-[8] and in [9]-[11], respectively. Based on these procedures, we can also calculate the uncertainties of the estimates of the collector power and subsequently, the respective energy production of the collector.

4.1 Estimation of the regression coefficients

$$SS_E = \sum_{i=1}^{n} (\in_i)^2 \rightarrow \min = \sum_{i=1}^{n} \left(\dot{Q}_{me,i} - \dot{Q}_{mo,i} \right)^2 = \sum_{i=1}^{n} \left(\dot{Q}_{me,i} - \sum_{j=1}^{k} \left(X_{j,i} \cdot a_j \right) \right)^2 \tag{3}$$

The basis for the regression procedure is given by the equation for the error sum of square SS_E (see eqn.(3)) of the modeled collector power $\dot{Q}_{mo}$ as compared to the measured power $\dot{Q}_{me}$, which has to be minimized, where $\in$ is the difference or error between this two power values. Here j = 1….k is the number of the used model components in the multiple linear regression and i = 1…n counts the number of the used mean values (obtained from the samples of the experiment) within a regression. For the SST k is 3, and for QDT k is 6. The regression 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.

$$\dot{Q}_{mo,i} = \hat{Y}_i = \sum_{j=1}^{k} a_j \times X_{i,j} \quad (4)$$

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). We can write this equation also as matrix expression (5):

$$\{\dot{Q}_{mo}\} = [X] \times \{a\} + \{\in\} = \begin{Bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{Bmatrix} = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1k} \\ X_{X1} & X_{22} & \cdots & X_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \cdots & X_{nk} \end{bmatrix} \times \begin{Bmatrix} a_1 \\ a_2 \\ \vdots \\ a_k \end{Bmatrix} + \begin{Bmatrix} \in_1 \\ \in_2 \\ \vdots \\ \in_k \end{Bmatrix} \quad (5)$$

4.2 Estimation of the uncertainty of the regression coefficients

The 'residual mean square error' σ^2 (also called MSE) of the regression is given by eqn. (6), using normal and the reduced matrix/vector expression where σ^2 can also be called the variance of the error term $\in$.

$$\sigma^2 = \frac{\sum_{i=1}^{n} (\in_i)^2}{n-k} = \frac{\{\in\}' \times \{\in\}}{n-k} = \frac{\overbrace{\{\{Y\} - [X] \times \{a\}\}' \times \{\{Y\} - [X] \times \{a\}\}}^{\text{Matrix expression}}}{n-k} \quad (6)$$

The residual degree of freedom is $d_f = n - k$. Using the mean square error and the data matrix *[X]*, according to references [12] and [13] the variances of the estimators for the coefficients are obtained as diagonal elements of the matrix given in eqn.(7). The matrix is formed by the regression variables X_{ij} during the whole collector test (see eqn. 5). The diagonal elements of the matrix refer to the variances $var(a_1)$ ... $var(a_k)$ and the off diagonal elements of these matrixes refer to the covariances $cov(a_1, a_2)$.... (a_1, a_k) of the estimators.

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

Where j = 1….k is the number of the used model components in the multiple linear regression**.** The standard error of the estimated regression coefficients $s_e(a_j)$ we thus obtain by the square root (see eqn. 8) of diagonal elements of this matrix given in eqn.(7).

$$s_e(a_j) = \sqrt{\mathrm{var}(a_j)} \quad (8)$$

Given the estimators of the coefficients $\hat{a}_j$, a 100(1-α) (i.e.95%) confidence interval for the regression coefficients a_j is determined by eqn.(9). Here $t_{\alpha/2,n-k}$ is the student value with the level of significance of α/2 and the degrees of freedom *n - k* (see also reference [12] and [13]). The true value of a_j is to find with selected confidence within the interval expressed by eqn.(9).

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

Respectively the expanded uncertainty of the regression coefficients we obtain by $Uc(a_j) = \pm t_{\alpha/2,n-k} \times s_e(a_j)$.

4.3 Estimation of the uncertainty of the modeled power and energy values

The uncertainty $U(Q_{mo})$ in a 100(1-α) confidence interval for the estimated collector energy Q_{mo} during a collector test is calculated with (10).

$$U(Q_{mo}) = \pm \sum_{i=1}^{n} U(\dot{Q}_{mo,i}) \times \tau = \pm \cdot \tau \cdot \sum_{i=1}^{n} t_{\alpha/2,n-k} \times s_e(\dot{Q}_{mo,i}) \quad (10)$$

Where τ_m is the time in which the mean values of the measurable quantities are taken from the samples of the experiment. The uncertainty of the estimated energy $U(Q_{mo})$ is calculated based on the uncertainties of the mean response of the estimated collector power $U(\dot{Q}_{mo,i})$ which is given by $\pm t_{\alpha/2,n-k} \times s_e(\dot{Q}_{mo,i})$, as outlined in reference [13] for linear models, where $t_{\alpha/2,n-k}$ is again the student-t value. For the following calculations we apply an α according to a confidence interval of 95% (α=0.05). $s_e(\dot{Q}_{mo,i})$ is the standard error of the i-th estimated power value obtained by the application of the collector model for a given input vector $\{ X_i \}$ that is formed by the variables $X_{i,1}$ to $X_{i,k}$; which was included in to the parameter identification procedure. It is calculated by eqn.(11).

$$s_e(\hat{Q}_i) = s_e(\dot{Q}_{mo,i}) = \sqrt{\sigma^2 \times \{X_i\}^T \times \left[[X]^T \times [X]\right]^{-1} \times \{X_0\}} \quad (11)$$

Where σ^2 is the unbiased mean square error of the estimated collector power (see also eqn. 3). $[[X]^T \times [X]]^{-1}$ defines a matrix formed by use of all the vectors $\{ X_i \}$ within a regression (see also eqn. 7 and eqn. 5). To do a estimation about the prediction of the power output for new - i.e. unused in the regression - input vectors *{ X_0 }* we have to substitute the standard error $s_e(\dot{Q}_{mo,i})$ by the expression $s_{ep}(\dot{Q}_{mo,i})$ given by eqn.(12).

$$s_{ep}(\hat{Q}_i) = s_{ep}(\dot{Q}_{mo,i}) = \sqrt{\sigma^2 \times \left(1 + \{X_0\}^T \times \left[[X]^T \times [X]\right]^{-1} \times \{X_0\}\right)} \quad (12)$$

We define the prediction interval PI_i like [13] outlines as. $PI_i = \dot{Q}_{mo} \pm t_{\alpha/2,n-k} \times s_{ep}(\dot{Q}_{mo,i})$. This prediction interval can be used to test the regression model for unknown (or unused) inputs. If we apply the prediction interval to the data used in the regression, 95% of the estimated collector power values $\dot{Q}_{mo,i}$ are expected within the interval $\dot{Q}_{me,i} - PI_i > \dot{Q}_{mo,i} > \dot{Q}_{me,i} + PI_i$.

5. STATISTICAL ANALYSIS OF THE DATA

5.1 Comparing differences of the SST and QDT parameter sets

Comparing the two models underlying the SST and the QDT procedures, one can observe that the QDT model (2) is a more complete model than the SST model (1):

- The term describing the effective transmission and absorption of the solar radiation for the QDT model is separated in two parts - one for the diffuse radiation and one for the beam radiation,
- Transmission and absorption of the beam radiation are modeled taking into account the relative incidence angle θ between the sun and the collector,
- Non-stationary operation conditions, caused by variations of the incoming radiation are accounted by a model describing the thermal inertia of the collector.

The comparison of the SST model eqn.(1) with the QDT model eqn.(2) is possible, as the SST can be considered as a reduced and the QDT as a full model. The SST model is obtained by setting in the QDT model $\theta = 0°$, $K_{\theta d} = 1$ and $k_3 = 0$, i.e. considering that with:

- $K_{\theta d} = 1$, the coefficient that determines the transmission and the absorption of the transparent cover and the absorber is set identical to the value for the beam radiation at perpendicular incidence,
- $\theta = 0°$, the transmission absorption coefficient is not varied with the incidence angle,
- $k_3 = 0$, we are neglecting the thermal capacity i.e. without the thermal inertia of the collector he has an instantaneous response to variations of the operation conditions.

These settings define the reduced 'reduced QDT model' that can be directly compared to the SST model (compare eqn.(1) and (2)). Clifford and Clogg [14] lines out how to determine the statistical significance for the deviations of the regression coefficients of a regression analysis applied to the same data set when comparing a full model (here the QDT) to a reduced model (here the reduced QDT that is equal to the SST). If the model components added for QDT model are of importance, they will modify in a significant manner those coefficients of the QDT model (η_0, k_1 and k_2) that are equivalent to the coefficients of the SST model. Explicitly that means, if the additional model components of the QDT model are not significant, they also will not modify in a significant manner the coefficients η_0, k_1 and k_2 that are obtained from the SST or the reduced QDT model. Applying this test for the verification of variation of the collector coefficients to a data set selected under SST selection and QDT selection criteria's we obtain the information, if the reduced regression model (see the standards [1]…[4]) used for the steady-state collector tests is sufficient enough to be applied in collector tests. We have to proof for this test if the difference d_j of the two coefficients is significant in relation to the standard error $s_e(d_j)$ of that difference (see eqn. 13). The test is done comparing the coefficients η_0, k_1 and k_2 of the SST with the η_0, k_1 and k_2 coefficients of the QDT. Significant differences of these coefficients are proofed with a critical t-value. If the difference of the coefficients is too high we can pass the critical student t-value determined by eqn. (13) and proof in this manner that the coefficients are not equal within this comparison. If the t-value of a coefficient of η_0, k_1 and k_2 passes the critical t-value the coefficients of the QDT model are more representative for the energy estimations than the coefficients of the SST model.

$$\left|t_j\right| = \left|\frac{d_j}{s_e(d_j)}\right| = \left|\frac{a_j, QDT - a_j, SST}{s_e(d_j)}\right| < t_{crti} = t_{\alpha/2,df} \quad (13)$$

The critical t-value of 2.000 (eqn.13) is obtained from the student-t table using $d_f = n_1 + n_2 - (k_1 + k_2) = 146 + 48 - (3 + 6) = 87$ degrees of freedom for the significance of 95%. Where n is the number of 5 min mean values used, k the number of coefficients of the model applied and d_f are the degrees of freedom in the statistical comparison of each model.

For the comparison of the models, we have used a complete data set that was selected under steady-state test conditions and extracted the coefficients by multiple linear regression as described above. The same we accomplished for the 4 data sets selected under quasi-dynamic conditions. The quasi-dynamic regression coefficients a_j,*QDT* are than compared to the SST regression coefficients a_j,*SST*. For the better comparison we synchronize both, the QDT and the SST data sets in to 5 min mean values that are the input for the two different regressions.

Testing the significance we have to determine, as outlined in [14], the difference of the coefficients d_j - given by $d_j = a_j,QDT- a_j,SST$ and the variances of the differences $s_e(d_j)$ given by

$$s_e^{\,2}(d_j) = s_e^{\,2}(a_j, QDT) - s_e^{\,2}(a_j, SST) \times \frac{\sigma^2(QDT)}{\sigma^2(SST)} \qquad (14)$$

where $s_e(a_j,QDT)$ and $s_e(a_j,SST)$ are the standard errors of the coefficients a_j and $\sigma^2(QDT)/\sigma^2(SST)$ is a scale factor used for model comparison see paper [14], all obtained by the regression using the QDT and the SST models, respectively.With this values we can then by equation (13) calculate the student-t value to be compared with the critical t-value for each regression coefficient.

Observation: If we use the method of Clifford and Clogg [14] for the comparison of the QDT and the SST regressions, we have to remark, that although the data of the SST data set can be a part of the selected QDT data set, it never can be the same data set like Clifford and Clogg assuming for that comparison. This because of the QDT needs more data which are equal to real operation conditions (see 6.1 testing conditions). Differences of the coefficients η_0, k_1 and k_2 applied to the comparison of the QDT and the SST tests may be caused by structural instabilities of the QDT. For this, first we have to analyze if the QDT is stable by itself.

5.2 Checking the structural stability of the QDT by analyzing significance of differences in the coefficients gained from the QDT regression applied to collector tests of independent data sets

If we like to compare two independent regressions accomplished with data set from different time intervals, we can use the theorem about inferences concerning two means (see references [12] and [13]) for the comparison of the two sets of regression coefficients and their standard errors. If the number of measured variable sets and thus the number of the degrees of freedom is high, we can consider that the deviations between the measured and calculated efficiency follow a normal distribution. We can take the same consideration for the difference between two coefficients extracted by two regressions. In large samples, the significance of the difference between the coefficients, obtained from two data groups A and B can be assessed by eqn. (15) as outlined in [14]:

$$\left|z_j\right| = \left|\frac{a_{j,A} - a_{j,B}}{s_e(a_{j,A,B})}\right| = \left|\frac{a_{j,A} - a_{j,B}}{\sqrt{s_e^{\,2}(a_{j,A}) - s_e^{\,2}(a_{j,B})}}\right| \le z_{crti.} = z_{\alpha/2,df} \qquad (15)$$

Where the standard error of the coefficients of the first data group is $s_e(a_{j,A})$ and of the second data group is $s_e(a_{j,B})$. The standard error of the difference between the coefficients is $s_e(a_{j,A,B})$. The standard error of the difference between the coefficients is the square root of the sum of the two variances of the coefficients eqn.(15), assuming that we have large and independent samples [14].

One method to describe the distribution of a random variable is using the cumulative probabilities and the controlling z_j-values are calculated with this method. The cumulative standard normal distribution has the mean value of '0' and a standard error of '1'. If the absolute value of the calculated distribution is lower than the value of the cumulative standard distribution, the two mean values can be considered equal with 95% of confidence (see references [12] and [13]). Testing the equality of two means with the different standard errors for their quality within 95% (α=1-0.95=0.05) of confidence, we have to use the value of $\alpha/2$ to calculate the controlling z-variable or get the value of z from the statistic table of the cumulative standard distribution for $\alpha = 0.025$. The regression coefficients from two data groups indicate the QDT as a stable test procedure if the test variables $|z_j|$ fulfilling the condition $|z_j| < z_{table\_\alpha/2} = 1.960 = z_{crit}$.

6. 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 selection of data sets that may be used as input for the two test procedures. The following gives a description of the test conditions and the procedure for the selection of the respective data sets.

6.1 Testing Conditions

SST and QDT using different weather conditions for calculating by regression the collector coefficients, whereby the QDT test conditions are equal to real collector operation conditions, i.e. with diffuse fraction D_f (QDT) of 0...1 instead of D_f (SST)= 0...0.3, global radiation of G(QDT) of 300...1100 W/m^2 instead G(SST)=800...1100 W/m^2, incident angle θ(QDT) of 0...60° instead of θ(SST) 0...30° and no limitation of the solar radiation variability in the quasi-dynamic-test instead of maximal variation ± 50 W/m^2 during the steady-state test. The collector test occurred over

the period of approximately 3 months using the same collector. During this period data was acquired that serves for the evaluation of both, the steady-state and the quasi-dynamic tests. The collector was first mounted in a collector tilt angle β of 45° per the ISO 9806 recommendations. In the ISO 9806 the relative angle between the sun and the collector θ has to be less than 30°±1°. With β equal to 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.
For the collector coefficient comparisons that are presented in this article we used for the data selection a diffuse fraction of $D_f = 0...1$ (that EN12975 suggests to obtain more data by the selection process). We observed that using a diffuse fraction of $D_f = 0...0.5$ (that EN12975 determines) for the data selection, we get lower stability of the coefficients obtained with the regressions. In paper [22] is showed that the collector coefficients and the normalized efficiency curves of the QDT and the SST collector tests are comparable if a diffuse fraction of $D_f = 0..0.5$ is used as data selection criteria.

6.2 Uncertainties of the used measurement transducers

We specify and calibrate our measurement system to residual measurement uncertainties of ± 0.1 K for the temperature measurements, ± 1% for the mass flow measurement, ± 0.5 m/s (for covered collectors) for the wind speed measurement and ± 40 W/m^2 for the solar radiation measurement (using calibrated secondary standard pyranometers). The time calibration is made automatically by the computer that manages the measurement system connecting the computer periodically to a time reference. With these uncertainties we are able to fulfill the conditions that are imposed by the ISO [2] and Euro [1] standards for the collector test.

6.3 Stabilities of the collector inlet fluid temperature and flow

ISO 9806 and EN 12975 define that fluid flow at the inlet of the collector has to be stable within ± 1%, the fluid inlet temperature within ± 0.1 K according to the ISO 9806, or within ±1 K according to EN 12975. With the given experimental setup, these stability criteria could not be reached for the SST but the data sets analyzed obey the stability conditions to the mass flow and to the input temperature for the QDT. Data of the test were selected under the criteria given in standards [1] and [2] for the SST and QDT. Only for the SST we had to enlarge the selection condition to ± 0.2 K for the fluid temperature. From the time period of two month with 29° tilt angle, 4 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 in the southern, subtropical part of Brazil are the clear days, this weather condition is necessary to accomplish the complete SST and the clear day condition is also necessary during one whole day for the accomplishment of a QDT.

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

EN 12975 defines that for accepting a measurement interval of 15 min all the 30 s mean values within this 15 min have to lie inside the limits of the specified 'stability conditions' (see section 6.3). That formal condition wasn't possible to reach for the fluid flow. For getting more data we enlarged the specified 30 s mean values using time intervals for the mean value calculation of 3 minutes for the steady-state test and adopted 1 minute for the quasi-dynamic test.

6.5 Operation of the tests

We observed that the system can have instability within amplitude of approximately ± 5% of the fluid flow with frequency of approximately 0.2 Hz. Closing the by pass this instability mainly disappears to ± 1%. Probably in a closed water circuit the by pass will not generate any influences.

6.6 Normalization of the zero loss efficiency

With equation (16) and (17) we can calculate the normalized zero loss efficiency for normalized conditions [1] $\eta_{0\text{-}norm}$ based on the QDT set of coefficients with $K_{\theta b}(\theta)$, b_0, $K_{\theta d}$ obtained from the regression of the QDT. The η_{0norm}-value is used to drawing the normalized efficiency curve of a solar collector.
In this way it is possible to compare the normalized efficiency curves of the QDT and the SST tests.
Standard EN 12975 [1] defines the following conditions for that normalization:

- Beam radiation: 680 W/m², (85% of the global radiation of 800 W/m²)
- Diffuse radiation: 120 W/m², (15% of the global radiation)
- Incidence angle: $\theta = 15°$.

$$\eta_{0\_norm} = \eta_0 \times \left(\frac{G_b}{G} \times K_{\theta b}(15°) + \frac{G_d}{G} \times K_{\theta d} \right) \qquad (16)$$

$$K_{\theta b}(15°) = 1 + b_0 \times \left(\frac{1}{\cos\theta} - 1 \right) \qquad (17)$$

7. RESULTS

7.1 Identification of the collector coefficients and their uncertainties

For the collector coefficients comparison we used here as example the regression results of four data sets according to the quasi-dynamic test and one regression results of the steady-state test (see Table 1 and 3). The regression coefficients a_j obtained from the SST and QDT regression, the standard errors $s_e(a_j)$ of these coefficients, the collector coefficients C_c calculated with the obtained a_j and their expanded uncertainties U_c are presented in Table 1 and 2. The highest uncertainties appears for the coefficients b_0 and k_1 (~20… 30%) of the QDT. Although the standardization of the collector test defined by the EN12975 and ISO9806 has the objective to reduce the uncertainties of the test results (that includes the reproducibility) of the collector test, both standards don't give any explicit quantitative specifications or limitations for the coefficients or estimated energy uncertainties. These uncertainties may be traced back to different causes:

a) Uncertainty of the measurement transducers or sensors
b) Problems associated with the stability of the test conditions, i.e. the stability of the inlet temperature or fluid flow, forcing to increase the tolerance band used for data selection,
c) Failing of weather conditions, which include important scales of the variables when applying the data combination process,
d) The model applied is not completely adequate to the problem e.g. it is too much reduced to cover all effects.

TABLE 1: REGRESSION RESULTS OF THE STEADY-STATE COLLECTOR TEST

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
σ^2=	16.65 [W/m²]²			

The absence of the collector coefficients stability and the resulting failure of the model stability may also be caused by these effects as they may affect each collector test set differently. On the other hand the t_j-values or z_j-values are reduced by higher standard errors $s_e(a_j)$ of the coefficients, like you can notice in equation (13) or (15). That means that a higher uncertainty in the coefficients leads to more stability of the tests. From this we can conclude that for testing the stability of a model the uncertainty has to be specified.

7.2 Inferences

Table 3 presents the 95% confidence limits for the coefficients of all executed tests that are mentioned in this article. The mean square error σ^2 of each regression that gives general information about the quality of the executed regression is also presented in this table. From Table 3 and Table 5 you can notice that the η_0 coefficients are stable for all the QDT but the η_0 values are different if compared to the SST.

TABLE 2: REGRESSION RESULTS OF THE QUASI-DYNAMIC COLLECTOR TEST No 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
σ^2=	183.9 [W/m²]²			

TABLE 3: REGRESSION COEFFICIENTS OF THE QDT AND SST COLLECTOR TESTS

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.
ηo [-]	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
σ^2 [W/m²]²	16.65		183.89		132.27		190.46		160.09	

7.3 Comparison of the QDT and SST test results based on the significance of the variations of the regression coefficients

Comparing the normalized zero loss efficiency $\eta_{0\text{-}norm}$ of the 4 QDT with the η_0 value SST one can observe that the SST underestimates the zero loss efficiency by 2.6% (notice also in fig.2). In Table 4 we compare the critical student value with the student value of each coefficients comparison.

TABLE 4: STATISTIC TEST OF THE EQUALITY OF THE NORMALIZED QDT AND THE SST COLLECTOR COEFFICIENTS

Studend t-values	QDT 1 compared to the SST		QDT 2 compared to the SST		QDT 3 compared to the SST		QDT 4 compared to the SST	
	$\|t_j\|$	test	$\|t_j\|$	test	$\|t_j\|$	test	$\|t_j\|$	test
$t(\eta o)$	0.92	eq.	1.18	eq.	2.17	uneq.	1.05	eq.
$t(k_1)$	1.72	eq.	2.56	uneq.	4.69	uneq.	1.93	eq.
$t(k_2)$	1.95	eq.	2.87	uneq.	5.66	uneq.	2.18	uneq.

If the student t value of an individual coefficient (taken from both, the QDT and the SST tests) is higher than the critical student-t value that is 2.000, the coefficients can be considered as unequal. If we apply the statistic test for the collector coefficient's comparison for the two different test methods (SST and QDT) as described in 5.1 you can notice, that the η_{0norm} coefficient is only in 1 of the 4 comparisons different to the η_0 coefficient of the SST (see table 4). In that case the inequality was determined by the low mean square error σ^2 (notice in Table 3) obtained by the regression of the QDT n° 3. The values are compared to the critical t-value of $t_{crit} = 2.00$. The heat loss coefficient k_1 is stable in 2 of 4 comparisons and the k_2 in only 1 of 4 comparisons.

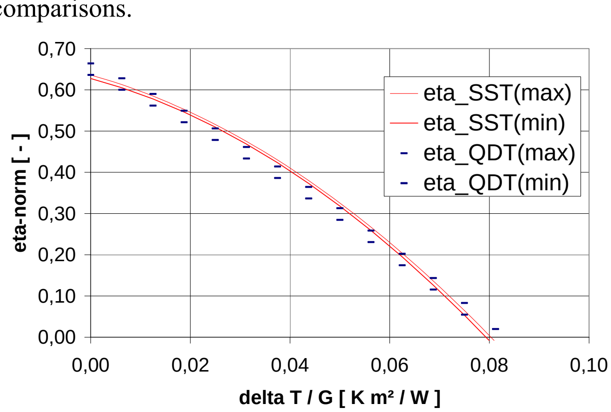

Fig. 2: Normalized efficiency curve with its uncertainties interval (95% of confidence) of the SST and the QDT collector tests using the same collector

Drawing the normalized efficiency curve for both test methods with its uncertainties (see figure 2) is another method to compare two different test methods. Like you can notice in that figure - giving the uncertainty range for the normalized efficiency curves of a QDT and the SST tests- they do not coincide for the complete range of $\Delta T/G$. Here it is to be remarked, that these differences exist, even so the normalizations according to EN12975 (see eqn. 16 and 17) mimics the zero loss coefficient of the STT test.

7.4 Analysis of the structural stability of the quasi-dynamic tests by testing the equality of two collector coefficients together with the owned standard error or uncertainty

The structural stability of the QDT is checked by applying the method described in section 5.2 for the comparison of the collector coefficients within the several QDT tests.
We obtain from the QDT data sets the minimum of $n_1 + n_2 - (2 \times k) = 196 + 146 - 12 = 330$ degrees of freedom d_f, and thus consider a normal distribution of the standard errors $s(a_{j,A,B})$. Considering a large and normal distributed population, we obtain the tests controlling variable $z = 1.96$ from the table of the 'cumulative standard normal distribution'. In Table 5 we can observe the z-variables obtained from the inter-comparison of the QDT tests. The values are compared to the critical z-value of $z_{crit} = 1.96$. By combining the coefficients sets of the 4 QDT we get 6 different combinations of test comparisons.

TABLE 5: STATISTIC TEST OF THE STRUCTURAL STABILITY OF THE QDT

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	
	$\|z_j\|$	test	$\|z_j\|$	test	$\|z_j\|$	test	$\|z_j\|$	test	$\|z_j\|$	test	$\|z_j\|$	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.

As given in Table 5, the coefficients that determine the optical model of the collector η_0, b_0 and $K_{\theta d}$ in the table represented by the regression coefficients a_1, a_2 and a_3, as well as the coefficient that determine the thermal capacity k_3, here presented as a_6 are stable in that 6 combinations of the comparison. The quadratic heat loss coefficient, in the table presented by the regression coefficient a_5 is failing one time with the z-value of 3.28, and the linear heat loss coefficient here presented by the regression coefficient a_4 is failing 2 times with the z-values 2.57 and 3.63.

7.5 Uncertainties and mean bias errors for the estimation of the produced collector energy and collector power

Applying the equations (10)…(12) for the calculation of the uncertainties and the prediction intervals to the whole variables ranges of data occurring in collector tests, it can be noticed that both the QDT and the SST collector models can estimate the produced power with the small uncertainty of the mean response of 5 W/m^2, on the other hand the prediction interval of the SST is lower than in the QDT (notice the results presented in figure 3 and figure 4).

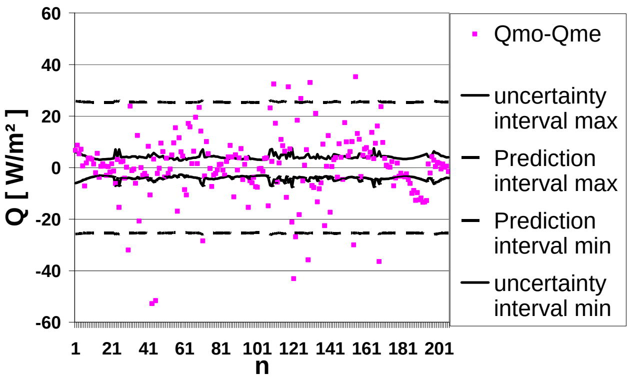

Fig. 3: Differences between the modeled and the measured powers (5 min mean values) per collector area ∈ of the QDT Data set n° 4 together with the uncertainty interval and the prediction interval using 95% of confidence, both calculated for the individual measured points.

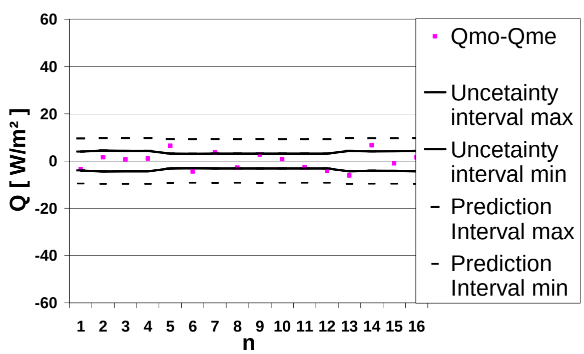

Fig. 4: Differences between the modeled and the measured powers per collector area ∈ of the SST data set (15 min mean values) together with the uncertainty interval and the prediction interval using 95% of confidence both calculated for the individual measured points.

95% of the estimated collector power points $\dot{Q}_{mo,i}$ are expected within the interval $\dot{Q}_{me,i} - PI_i > \dot{Q}_{mo,i} > \dot{Q}_{me,i} + PI_i$ where PI_i is the prediction interval and $\dot{Q}_{me,i}$ is the measured collector power. By subtraction of $\dot{Q}_{me,i}$ from this inequality we obtain the uncertainty limit of the power difference, $-PI_i > \dot{Q}_{mo,i} - \dot{Q}_{me,i} > PI_i$ that is shown in figure 3 and figure 4. Analyzing the total energy output of a complete QDT test sequence (that presents the typical application conditions for the solar collector) an uncertainty (see eqn. 10) of ± 1.2% can be identified (figure 3). Doing the same with the SST (figure 4) we obtain a lower uncertainty for the energy estimation of ± 0.9%. It has to be noted that these uncertainties are only based on a single test; they don't give any information about the reproducibility of the collector test if performing several test.

7.6 Test stability and reliability of the models to estimate the produced energy

As we dispose of several complete test sequences, we can use different model coefficients sets and apply them to the data of the different tests (see Table 6). In the rows of this table you can notice the differences of the energy obtained with the model in relation to the total measured energy in a data set of the collector test.

TABLE 6: ENERGY BIASES OR DIFFERENCES OF THE MODELED ENERGY ESTIMATIONS TO THE MEASURED ENERGY USING DIFFERENT TEST RESULTS

		Diffrences to the measured energy [%]			
		$QDT1_{model}$	$QDT2_{model}$	$QDT3_{model}$	$QDT4_{model}$
Used dataset:	$QDT1_{set}$	-0.02	-0.83	-0.16	-0.31
	$QDT2_{set}$	1.06	-0.08	0.66	0.47
	$QDT3_{set}$	0.49	-0.49	-0.02	-0.11
	$QDT4_{set}$	0.81	-0.97	0.07	-0.01

Combining the results of each 'row' of Table 6 and applying a z-test as described in 5.2 to the energy differences obtained by the different combinations of models using the same data set, we get 6 combinations of each row, where eqn.(15) is substituted by $z_i = (Q_A - Q_B) / s_e(Q_{A,B})$. We observed that within 24 analyzed combinations only in one combination ($QDT4_{set}$; estimated energy of $QDT1_{model}$ is statistically different to the $QDT2_{model}$ with a z-value of 2.07) the models with different coefficients sets gives statistically different energy results. From this test we infer that our energy estimation results do not show a high sensitivity to significant variations in the model coefficients. Only in 1 of 24 combinations the model estimation is significantly unequal to the measured energy. Thus, based on these combinations, within > 95% of confidence the measured energy is estimated by the model. Combining the results of each 'column' of Table 6 and applying the z-test as described in 5.2 to the energy differences obtained by the different combinations of data sets using the same model, we get 6 combinations of each row. We observed that within 24 analyzed combinations all the z-values are lower than the critical z-values. From this test we infer that our model estimations are not subject to significant variations in the data sets. That means that when estimating the collector energy by one collector model using data sets from different collector tests no statistical variations occur. The standard errors $s_e(Q_{mo})$ of 0.51…0.61% of the total estimated energy used for the statistical comparisons above we obtained by summing up the individual standard errors $\tau \cdot s_e(\dot{Q}_{mo,i})$ (see also eqn. (10)).

7.7 Long term energy estimations

During the whole collector test time of 2 month, 2250 mean values (each mean value represents the mean of 5 min data) could be selected using the QDT selection criteria. To compare the different parameter sets and models we apply all parameter sets to estimate the energy gain for the data set of the 2250 measured mean values. The measured overall energy gain during this time period is 58 kWh. The mean biases (given in percent of the overall gain) of the estimated energy's are:

a) 0.5% for the model of QDT1,
b) -1.64% for the model of QDT2,
c) -0.5% for the model of QDT3,
d) -0.5% for the model of QDT4,
e) -0.08% for a model of QDT derived by applying the 2250 mean values the regression,
f) 6.6% by not taking into account the incident angle modifiers and diffuse model component of the QDT, (using the η_{norm} coefficient)
g) 6.2% for the model of the SST.

Based on the energy production we see that applying the SST test and model as used for the parameter identification overestimates the energy by 6.2% as the model does e.g. not account for increased reflection losses at high incidence angles. If we use the reduced QDT test model (using only the coefficients η_0, k_1 and k_2), we get a similar overestimation of the energy of 6.6%.

7.8 Long term stability and reliability of the models to estimate the produced energy

It is also possible to verify whether the estimated energy during this time period is stable or not. For this we compare the energy values obtained with the 4 QDT models. Applying the data and the respective standard errors of the coefficients gained in the 2250 mean value set to eqn. (15), we observed that in 5 of the 6 combinations the estimated energy's are statistical equal. Only the estimated energy's of QDT n°1 and n°2 are statistical unequal, compare a) and b) in section 7.7.

7.9 Total uncertainties in long term energy estimations

Considering the large data set of 2250 mean values as a reference, and applying it as a basis to verify the energy estimation for different applied models, we can do the following inference: For both, the QDT and the SST models we have to add the resulting bias errors to the total uncertainties as we do not have any information on the stability of these bias errors. In this way we obtain the following total uncertainties with our collector:
In the steady-state test the energy is estimated with a bias error of +6.2% (see section 7.7). Adding this bias error to the inherent aleatory uncertainty of ± 0.9% we obtain a total uncertainty of ± 7.1% for the long term energy estimation.
In the quasi-dynamic test the energy is estimated with a maximal bias error of + 1.64% (see section 7.7). Adding this bias error to the inherent aleatory uncertainty of ± 1.3% we obtain a total uncertainty of ± 3% for the long term energy estimation.

7.10 Confidence limit of the power estimations

The prediction interval for the predicted power of unknown inputs is broader than the confidence interval for the power modeled for known (used) inputs(see figure 2 and figure 3). This is caused by taking into account the inherent variability of the system and transducer response for a certain input. Using the prediction interval we are able to validate the applied model and regression. Within the e.g. QDT test n°4 we observed that 6.8% of the $\in$-values are lower than the prediction interval. Expecting the α-value of 5% (by 95% of confidence), the model losses only 1.8% of confidence (notice also figure 3) within the QDT regression.

8. CONCLUSIONS

We recommend substituting the SST with QDT for outdoor collector tests with fixed mounted collectors for three reasons:

- The QDT collector test is more cost effective as it can be accomplished in less time,
- Due to the increased completeness of its underlying model, the QDT collector coefficients can estimate the energy production of the collector with lower uncertainties than the SST estimate based on a limited model (see section 7.9).
- Although we cannot find full model stability of the estimated collector coefficients within different QDT tests, energy estimations using the different test data sets and combing these data sets with

different QDT coefficients sets have high model stability or statistical equality, (i.e. 95%, see section 7.6). Instability of the collector coefficients not affects the stability for energy estimations,
- Diffuse fractions of D_f = 0…1 (instead of 0…0.5) can be used in QDT to get reliable energy estimations.

It has to be remarked that our actual system configuration not fulfills the complete stability conditions (see 6.3) of the test system that are recommended by CEN standard 12975-2[1] and ISO9806-1[2]. Although the deviations to the standard conditions are very small (i.e. 0.2 K instead of 0.1 K for the inlet temperature of the SST), improved stability may be reached by maintain the conditions of the fluid flow and the temperature at the collector inlet that are recommended by the ISO- and EURO-standards. The test rig in which the collector was mounted allows that the back and the sides of the collector are exposed to the natural variations of the ambient wind. As the used collector doesn't have any isolation at the sides, the model stability can be reduced by the variation of wind on this part. This influence may be reduced if the collector will be installed to a roof during the collector test. With further tests using the roof installation and a good isolated collector, it has to be confirmed if less wind speed at the back and the sides of the collector improve the results of the uncertainty and stability of the heat loss coefficients.

9. OUTLOOK

The collector coefficients can be used to calculate the expected yearly energy gain for a given system configuration. Weather data for this calculation are used in the form of a typical meteorological year TMY [16], [17] for the site of interest. Collector test reports are accompanied with such calculations using a reference system with different collector areas applied to the estimated collector model [18]. These calculations are accomplished for sites with different climatic conditions. The results of performance prediction are important for the selection of the most efficient collector for each determined solar system. In [5] is outlined that the uncertainty of the yearly energy production in a simulation with the uncertainties obtained by a QDT for the same collector that is used in this article can be ~ 2% by T_m = 40°C and 7% by Tm = 60°C. The result has to be checked by quantifying and including the reproducibility of the QDT collector test. The partial model components that determine the heat losses have to be checked accomplishing e.g. the 'extended multiple regression' as described in reference [21]. Although the 'stability of the collector coefficients' may be important for the collector development and production, as well as for the optimization of the collector test procedures itself, most important for the application of a solar collector is the uncertainty including the reproducibility of the estimated energy that the collector will produce in his application. To control whether the energy production estimated using a specific set of regression coefficients obtained with the QDT is representative, a method that that gives an empirical error limit of 2% for a data sequence of validation is shown in [15]. With these limits it may be 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.

10. ACKNOWLEDGEMENTS

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11. 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 [-]
b_0	incident angle modifier coefficient [-]
k_1	heat loss coefficient at $(T_m - T_a) = 0$ [W/(m^2 x K)]
k_2	temperature dependence of k_1 [W/(m^2 K^2)]
k_3	effective thermal collector capacitance [J/(m^2 x K)]
G	global solar irradiance [W/m^2]
G_d	diffuse solar irradiance [W/m^2]
G_b	beam irradiance [W/m^2]
D_f	diffuse fraction [-]
θ	incident angle of the beam irradiance [°]
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]
$\dot{Q}_{me}$	measured power output of the collector [W/m^2]
$\dot{Q}_{mo}$	modeled power output of the collector [W/m^2]
$\in$	measured minus modeled collector power [W/m^2]
$\dot{m}$	mass flow [kg/s]
d_j	difference between two coefficients or energy's
a_j	regression coefficients
$X_{j,i}$	regression variable
s_e	standard error of 'a_j' or a 'modeled energy Q'
U	expanded uncertainty of 'a_j' or a 'modeled energy'
σ^2	mean square error [W/m^2]^2
j = 1..k	number of the used model components
i = 1..n	number of the mean values used for the regression
d_f	degrees of freedom
τ	time interval for calculating each mean value
t	student value used for significance test
z	normal distribution value for significance test

12. REFERENCES

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