Qualification of collectors and components by exposure to extreme climatic conditions

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Abstract

Solar thermal collectors and the used materials have to withstand outdoor weathering for very long periods of time; usually more than 20 years are expected. How do they cope with snow, salty ambience, desert climate, sea climate or tropical humidity? The Fraunhofer-ISE has access to 5 outdoor exposure sites where samples have to stand extreme climates: high temperatures with high daily differences in the Negev desert at Israel, snow, wind, extreme UV-irradiation and frost in the German Alps, high humidity at warm temperatures at Indonesia and high temperatures, wind and salt at Gran Canaria. The test sites are presently used for the exposure of PV-modules and will be extended for the testing of solar collectors and samples of collector components like absorbers, glazing and reflectors. The main aim is not only to collect data about the stresses on the samples, but the detection of reliability problems caused by salty atmosphere, high humidity, high wind loads and high temperature cycling, too. These activities are carried out in the next years within the German project SPEEDCOLL in a cooperation of Fraunhofer ISE with ITW (University of Stuttgart) and a number of quality-conscious companies (see list in the acknowledgements).
UV- and solar-irradiation, ambient- and sample-temperature, ambient humidity and wind speed is measured and collected at a central server in Germany. Results of the first 24 months are compared. This data is the base for the calculation of integral loads for the comparison of different climatic regions and for the development of test procedures. The load differences for the different sites and the resulting test conditions for solar collectors and their impact on accelerated service life testing are discussed. This is important because regions close to the sea are usually highly populated and therefore have high potentials for solar thermal installations and CO2 reductions.

1. Outdoor exposure

1.1. Data monitoring

Five different test-sites (see figure 1) have been equipped with instrumentation for monitoring the climate (irradiance, UV-A, UV-B, ambient temperature and humidity) and the sample temperatures. The measurement results are stored as 5 minutes averages.

1.2. Test sites

The 5 test sites (fig. 1) offer different types of climates, 4 extreme climates and one reference site at the Fraunhofer-ISE at Freiburg, Germany.

- Tropical: Serpong, Indonesia (middle right),
- Arid: Sede Boqer, Israel (upper right),
- Reference: Freiburg, Germany (upper left),
- Alpine: Zugspitze, Germany (middle left)
- Maritime: Gran Canaria, Spain (bottom)

Fig. 1: The 5 different outdoor test facilities.

2. Results

2.1 Temperature

The frequency distributions of the ambient temperature at the 4 test sites show the wide variety of climatic conditions (see figure 2).

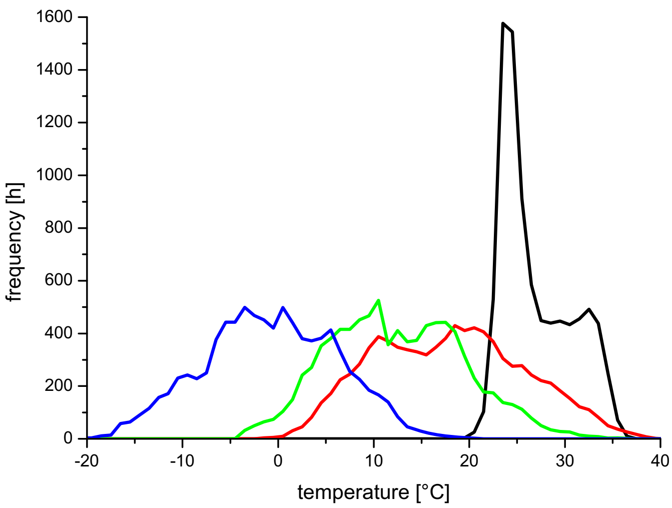

Fig. 2: Frequency distributions of the average temperatures at four different test sites for one year (black: tropical, red: arid, green: urban reference, blue: alpine).

1.2. UV-radiation

The highest irradiation was measured in the desert test site (see figure 3). The big difference in the UV-dose between the desert and the other test sites is caused by the bad calibration of the UV-A-sensors used at the test sites 1,3,4. The data must be corrected after recalibration. It is difficult to assess the irradiation dose at the alpine test site (4). The sensors were covered by snow during more than 180 days of the year.

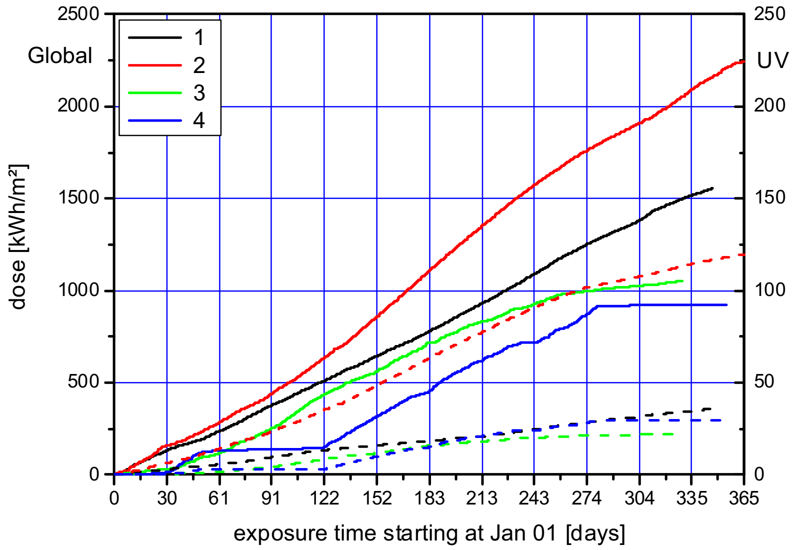

Fig. 3: Dose of the global irradiation (solid lines and left ordinate) and the total UV (dashed lines and right ordinate) at the 4 test sites during one year (black: tropical, red: arid, green: urban reference, blue: alpine). Note the periods between day 1 and 30, 50 and 120 as well as above 275 at the alpine test site (4), when snow covered the sensors.

1.3. Humidity

The third degradation factor evaluated at the test sites is the humidity. Usually, relative humidity values above 80% are considered as the so-called "time-of-wetness (TOW)". We used this definition as the starting point for our stress integration. The frequency distribution of the TOW with the respective average module temperature is shown in figure 4. The narrow peak at the tropical site shows that the high humidity is concentrated at a small temperature range, since the temperature variation is very small.

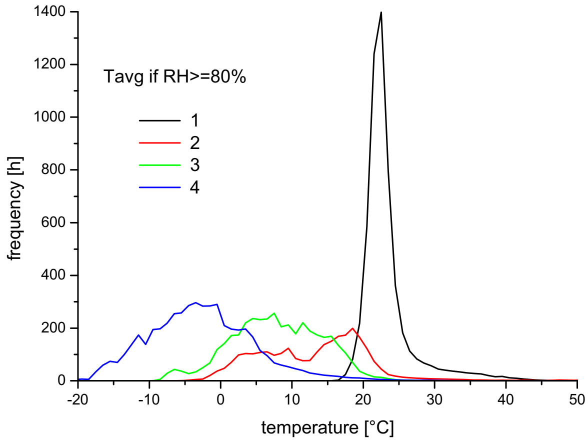

Fig. 4: Frequency distribution of the Time-of-wetness (TOW) as a function of the average PV-module surface temperature for the different test sites (black: tropical, red: arid, green: urban reference, blue: alpine).

In previous projects we investigated the micro-climate in collectors and found very different moisture impact, as shown in figure 5 [3]. We expect similar effects for the tests at the different sites.

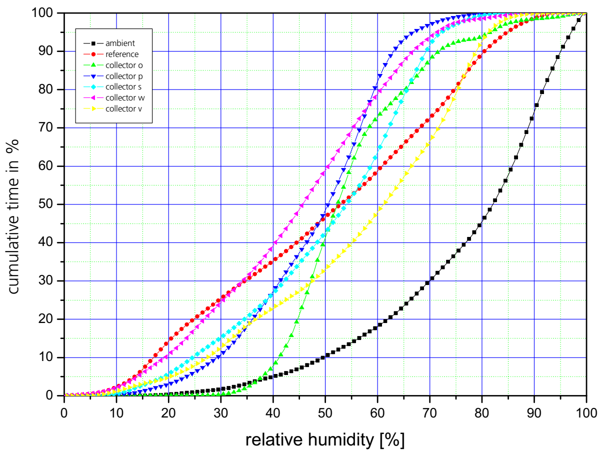

Fig.5: Cumulative frequency distribution of the rel. humidity in the air gap between absorber and glazing for different collectors in comparison with the ambient humidity (black line).

The collectors shown in yellow and red are at a higher moisture level. The blue-one, e.g., has most of the time a moderate moisture level.

3. Accelerated Testing

3.1. Data evaluation and modelling

Service life estimation needs to determine the degradation reaction kinetics of the degradation rate dominating processes and the correlation between outdoor exposure and accelerated testing. Deterministic models are usually applied for the extrapolation of the degradation data to the designed end of life time [1,2]. One of the most common models for the correlation between the weathering stresses and the degradation of materials properties is:

$$\Delta P_j = \Sigma^j_{i=1} \{\Sigma_p (A_p\ I_i^n\ \Delta t_i\ \exp[-E_p /RT_i]\ \exp[C_p *rF_i])\} \quad (1)$$

Where P is the considered performance property, p is the number and A, E, C, n are the parameters of the relevant degradation processes, Δt is a time interval, during which the Irradiation I, the temperature T and the relative humidity (or TOW) is assumed to be constant.

Their parameters (A, n, E, C ; indicated in red) have to be evaluated from the results of lab tests under well defined and well-controlled conditions, usually called “screening testing”.

3.2 Temperature

The temperature loads depend on the climatic conditions, as could be seen in figure 2. One way to get an idea about the different stresses at different locations is the calculation of the effective temperature load (see equation 2) according to the deterministic degradation model shown in equation 1.

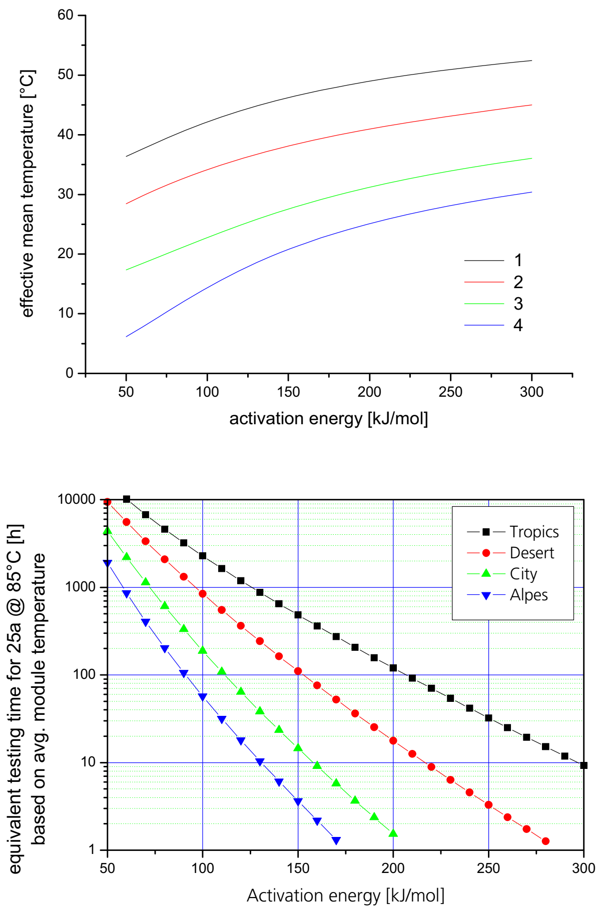

Fig. 6: Effective mean temperature load as function of the activation energy of the rate dominating degradation process for the different test sites (top) and the corresponding testing times at 85°C for 25 years lifetime (bottom).

The integration of the measured sample temperature for a given time period (one year, e.g.) is assumed to result the same changes of the performance as a constant temperature load Teff during the same time period, if the simple Arrhenius model can be applied.

$$\exp[-E_p / RT_{eff}] = 1/(t_{max}-t_{min}) \Sigma^{tmax}_{tmin} \exp[-E_p / RT(t)]\Delta t \quad (2)$$

The activation energy as the remaining parameter determines, how much a degradation process could be accelerated by temperature increase.

The effective temperature can be used as characterisation of climatic locations with respect to the thermal stress. It is the base for further time and temperature transformations for the design of appropriate conditions for service life testing [2,3].

3.3. UV- radiation

The maximum observed UV-load was 120 kWh/m²a in the desert. It sums up to 3000 kWh/m² for a lifetime of 25 years. Enhancing the temperature helps accelerating. Therefore the temperature-depending UV-load is the base for evaluating accelerated tests (see figure 7) by means of eq. 1. A higher sample temperature can shorten the testing times drastically, as can be clearly seen in figure 8 and allow service life testing in less than 1 year or even less than some weeks, depending on the activation energy of the photo-degradation process.

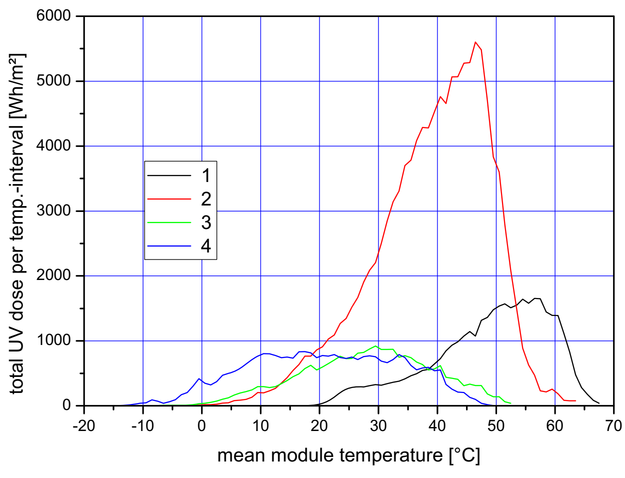

Fig. 7: Frequency distribution of the UV dose as a function of the average sample temperature for the different test sites (note that the UV-sensors at site 1, 3, 4 have to be recalibrated).

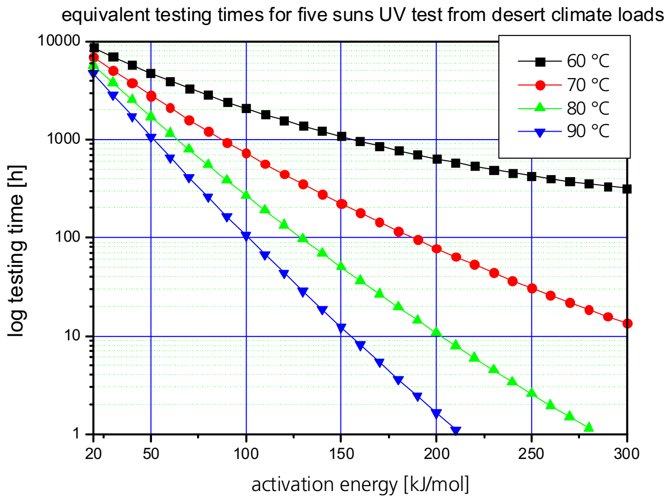

Fig. 8: Estimated testing times as a function of the activation energy for 5X UV-intensity and different sample temperature for 25 years exposure at the desert site.

3.4. Humidity

A similar approach for the evaluation of the test procedures as for the temperature only was used for the TOW (only data with rH > 80% had been counted). Here we made a complete time-transformation to the damp-heat-conditions (85%RH @85°C) for which figure 9 shows the testing times corresponding to the fluctuation of temperature and humidity at the real test sites. A 1000h damp-heat test might be appropriate for 25 years lifetime at a dry mountain climate for degradation processes with activation energies down to 50 kJ/mol, but for tropical humid climates the limit is 70 kJ/mol.

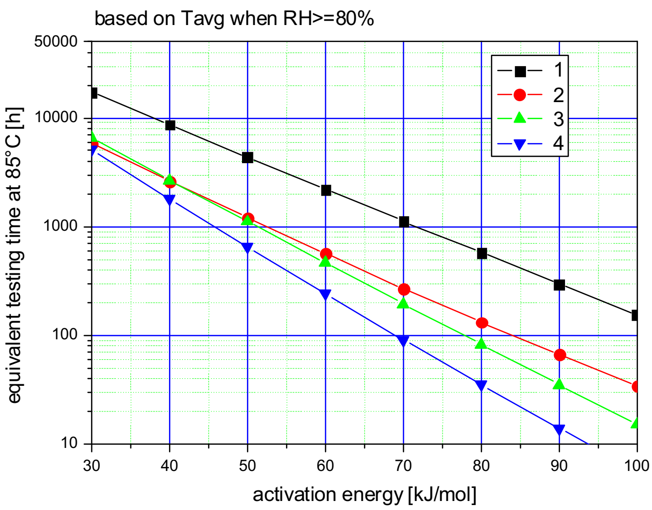

Fig. 9: Equivalent constant testing times for a damp-heat test (85%RH @ 85°C) for a service life of 25 years as function of the activation energy for the monitored one-year exposure data at the 4 different test sites.

4. Conclusion

The different test sites with a comprehensive climate and load monitoring provide a good basis for the evaluation of the stress levels for accelerated service life tests of solar collectors and their components.

Better climatic cabinets and UV-sources are needed for accelerated testing, providing a higher intensity and being operated at higher temperature levels and in combination with the other important stress factor: the humidity.

5. Acknowledgements

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References

[1] Martin J.W.; Time transformation functions commonly used in life testing analysis; Durability of Building Materials, 1 (1982) 175.

[2] Köhl, M.; Carlsson, B.; Jorgensen, G.; Czanderna A.W., Performance and Durability Assessment of Optical Materials for Solar Thermal Systems, ELSEVIER 2004, ISBN 0-08-044401-6.

[3] Köhl, M.; Volker Kuebler, Markus Heck, Optimisation of the micro-climate in solar collectors, Solar Energy Materials & Solar Cells 91 (2007) 721–726.