COMPARING ACCELERATED TESTING AND OUTDOOR EXPOSURE

Michael Köhl

Fraunhofer Institute for Solar Energy Systems ISE

3rd PV Rollout Conference Workshops – 2013

requirements for bankable pv modules

and pv power plants

Metro Atlanta Chamber, USA - February 25th, 2013

www.ise.fraunhofer.de

Challenges <

The durability is very good for most of the actual premium c-Si modules on the market (less than 1% loss in performance per year)

But new materials and designs have to be developed in order to decrease costs

- Accelerated service life tests are needed for optimisation of the durability and convincing investors
- The longer the desired lifetime, the higher the needed acceleration factor, the bigger the unsecurity of the tests
- The tests should be based on **real stress in the field**, because usually the materials and their degradation processes are not known

Stress-factors at operation of PV-modules

Moisture causes hydrolysis and corrosion (Acetic acid from EVA)

Electrical potentials introduce leakage currents and reduction of cell efficiency

UV – irradiation causes destruction of polymeric components: "

Photo-degradation "

Temperature cycling, static oder dynamic **mechanical loads** lead to: "

Cell-breakage, inter-connecture breakage, delamination

Salt, heat (high temperatures)

Example for development of Accelerated Life Testing < based on real stresses during operation of PV-modules <

Moisture causes hydrolysis and corrosion

Electrical potentials introduce leakage currents and reduction of cell efficiency

UV – irradiation causes destruction of polymeric components:

Photo-degradation

Temperature cycling, static oder dynamic mechanical loads lead to tensions :

Cell-breakage, inter-connecture breakage, delamination

Salt, heat (high temperatures)

1 Monitoring climatic conditions

Ambient climate and sample temperatures as 1min averaged time series

Corrosivity, salt concentration as yearly or monthly dose

City or reference: %

Freiburg Germany %

Arid

Sede Boqer

Israel

Alpine

Zugspitze

Germany

Tropical

Serpang

Indonesia

(operated by TÜV Rheinlanc

Maritime

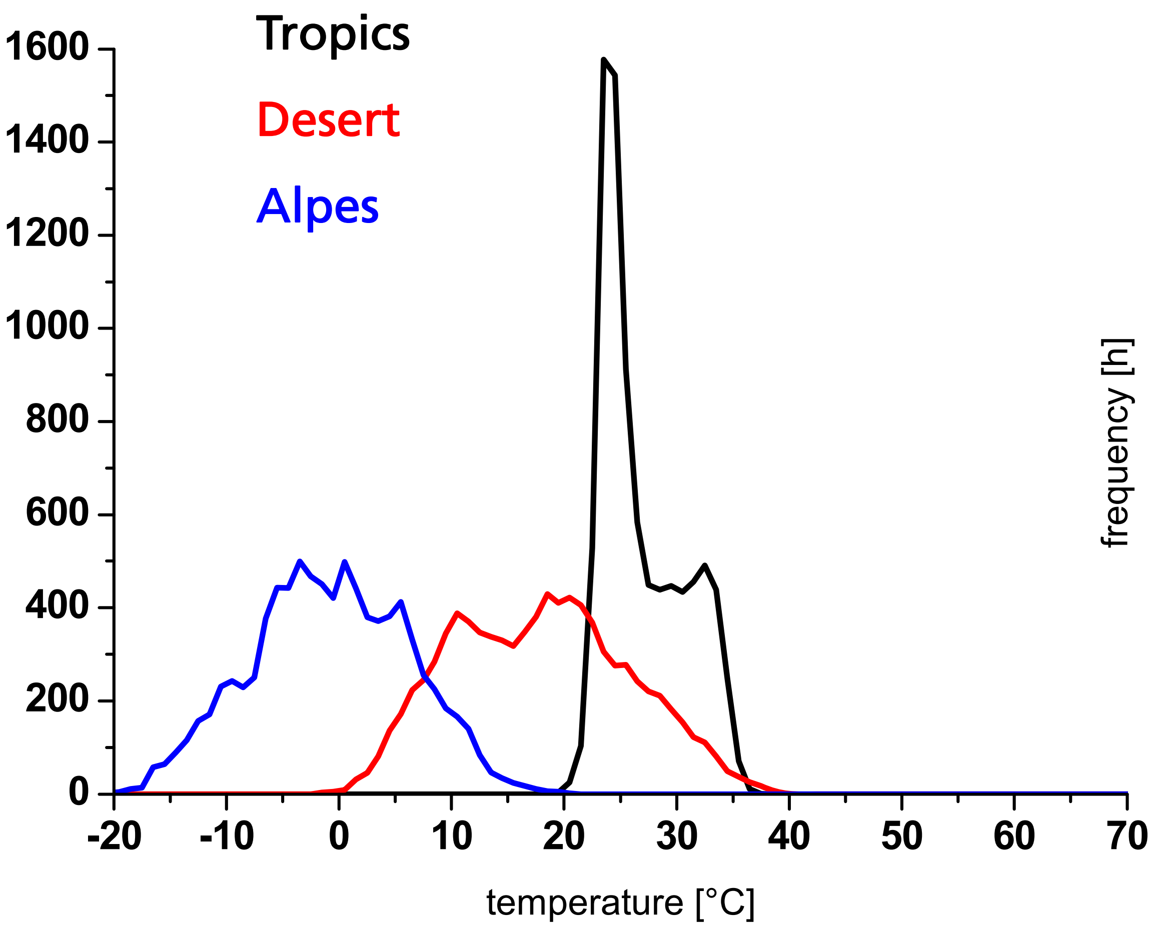
Pozo Izquierdo

Gran Canaria

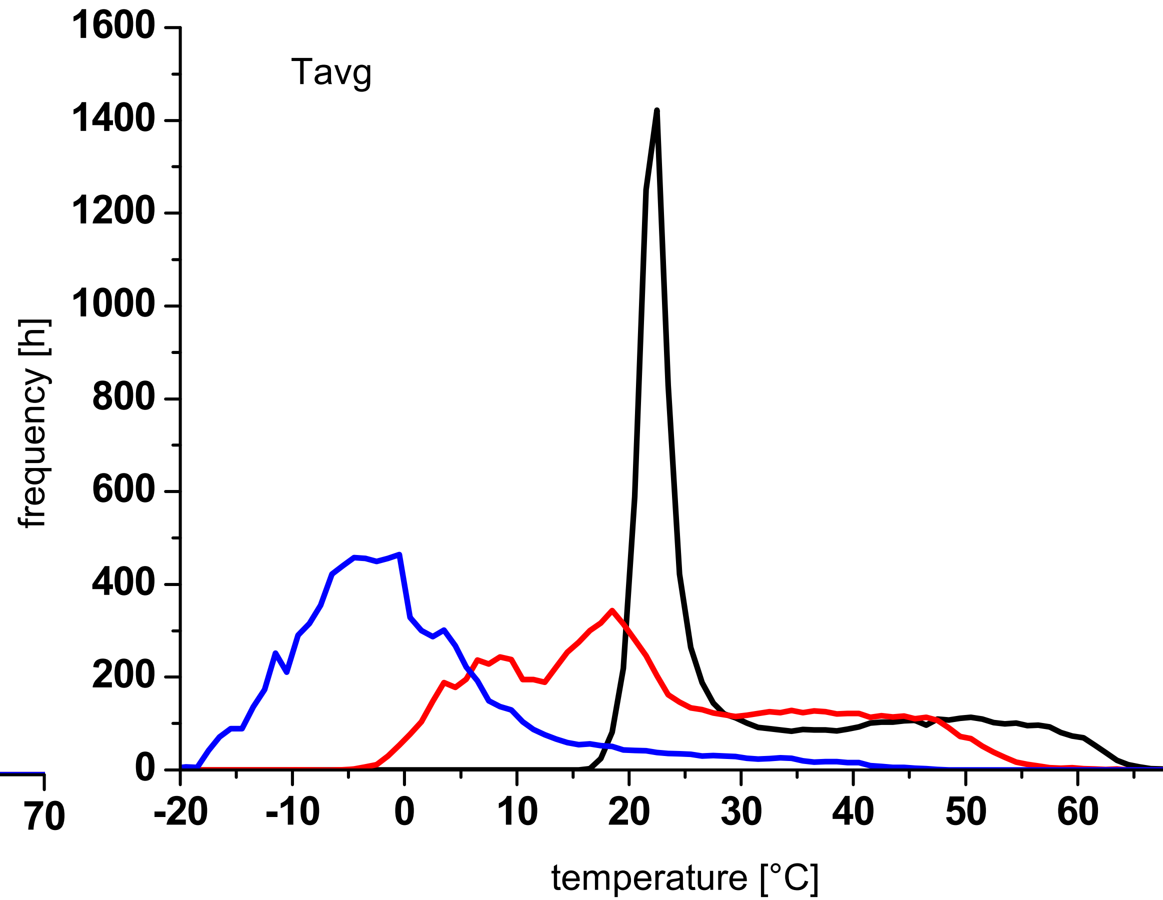
Module temperature monitoring during outdoor exposure

Macro – climate => Micro – climate

Ambient temperature



Average module temperature (c-Si)



3 Modeling micro-climatic stress factors

Physical modeling of module temperature for each of the different module types using David Faiman's approach (could be King, Fuentes……as well)

Macro – climate => Micro – climate

Irradiation, wind, ambient temperature => T_{mod}

Neglected: IR-radiation exchange and natural convection

$$T_{mod} \qquad T_{amb} + \frac{H}{U_0 + U_1 \cdot v}$$

T_{mod} module temperature

T_{amb} ambient temperature

v wind velocity

H solar radiation

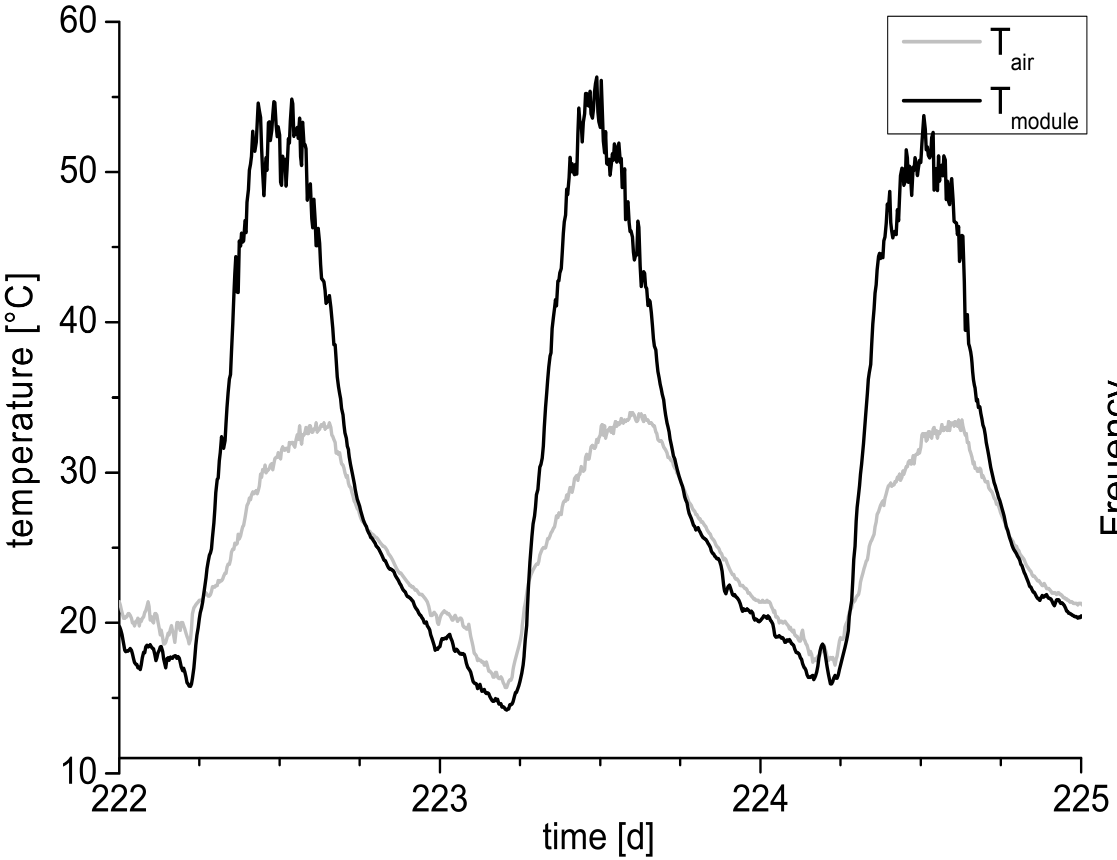
	U1	U0
a-Si 1	10,7	25,7
a-Si 3	5,8	25,8
a-Si 4	4,3	26,1
CIS 1	3,1	23,0
CIS 2	4,1	25,0
CdTe	5,4	23,4
c-Si	6,2	30,0

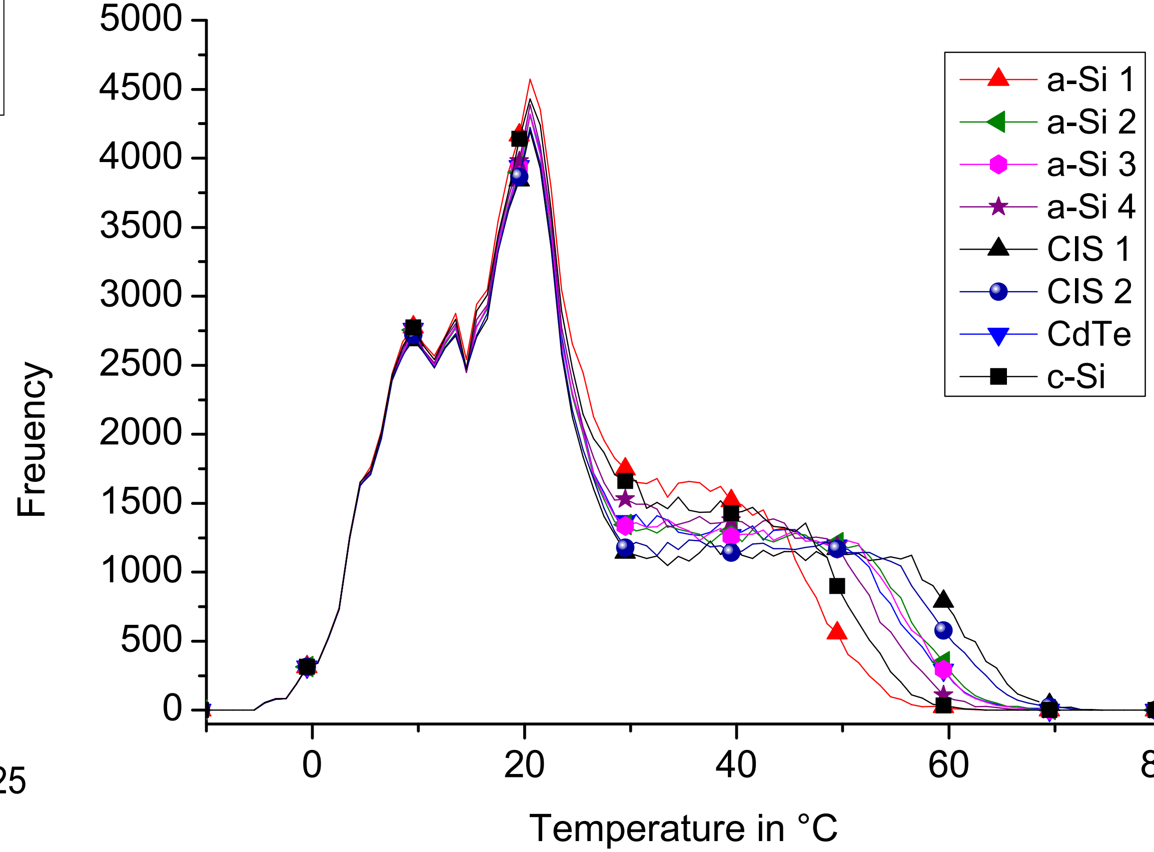
The parameters U are module-specific but location independent "

M.Koehl et.al.: Modelling of the nominal operating cell temperature based on outdoor weathering, Sol. Energy Mat. Sol. Cells (2011)

3 Modeling micro-climatic stress factors

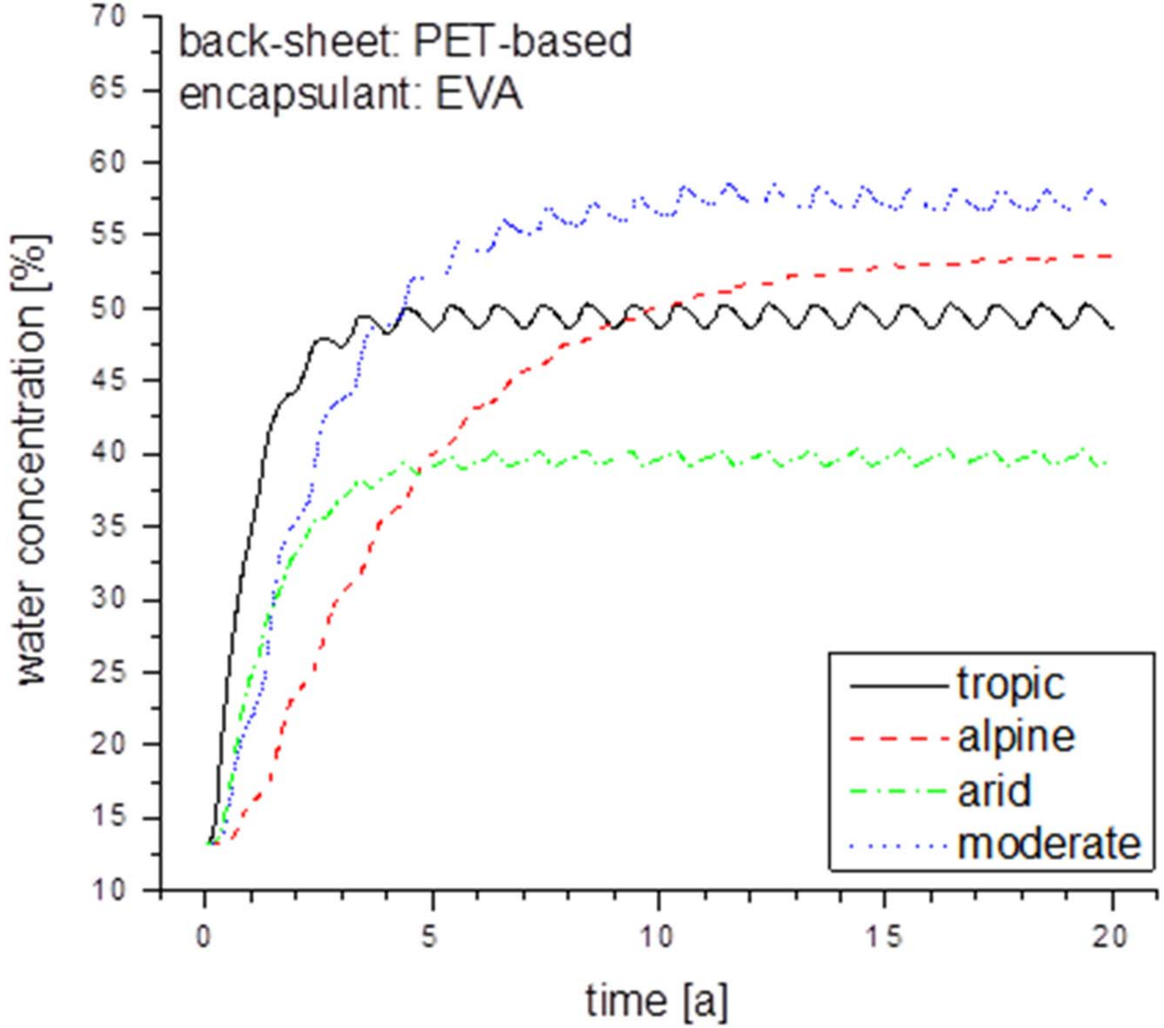
Module-temperature as time-series based on ambient climate data and as histograms (one year)

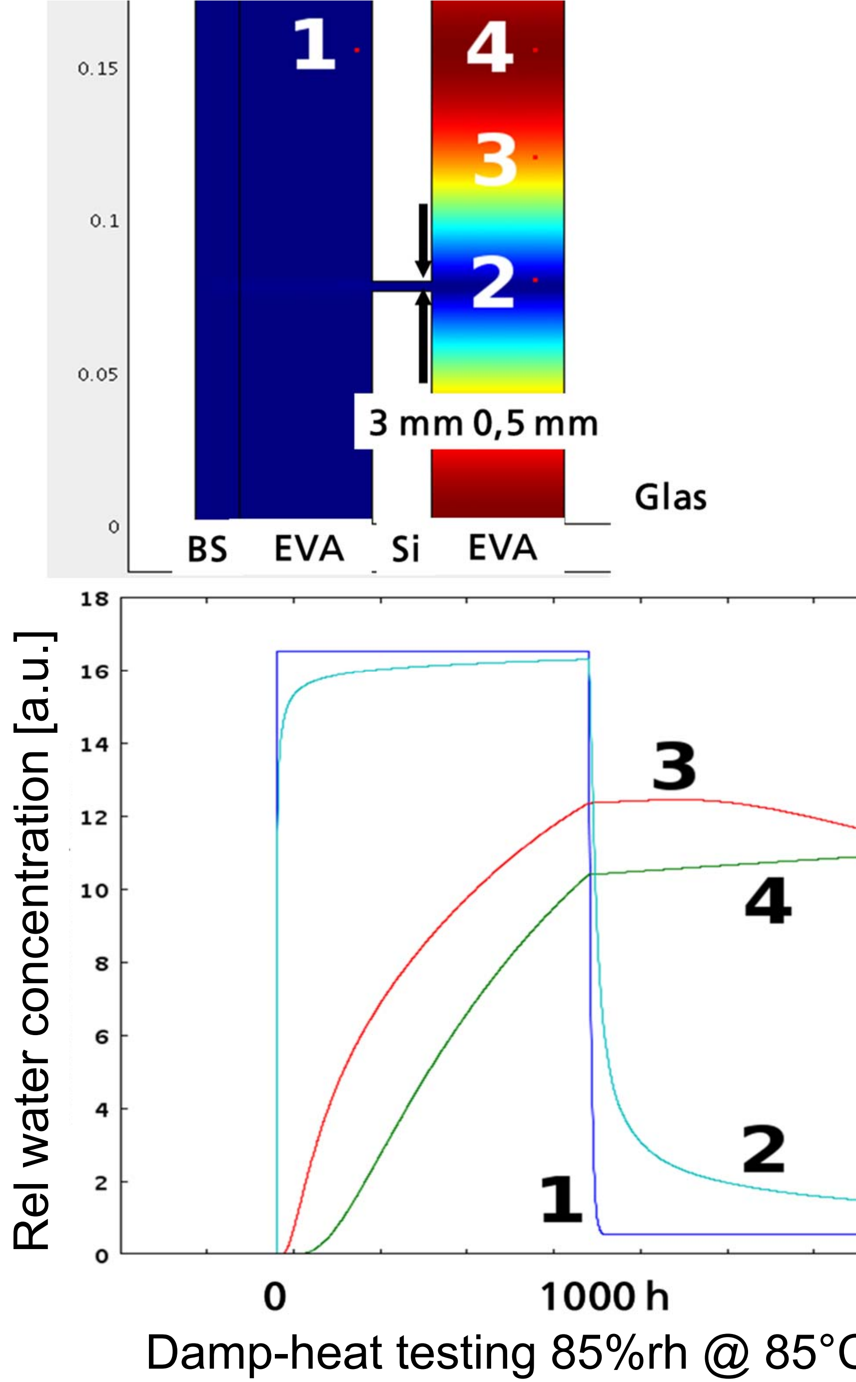




3 Modeling micro-climatic stress factors

Simulation of module humidity by FEM



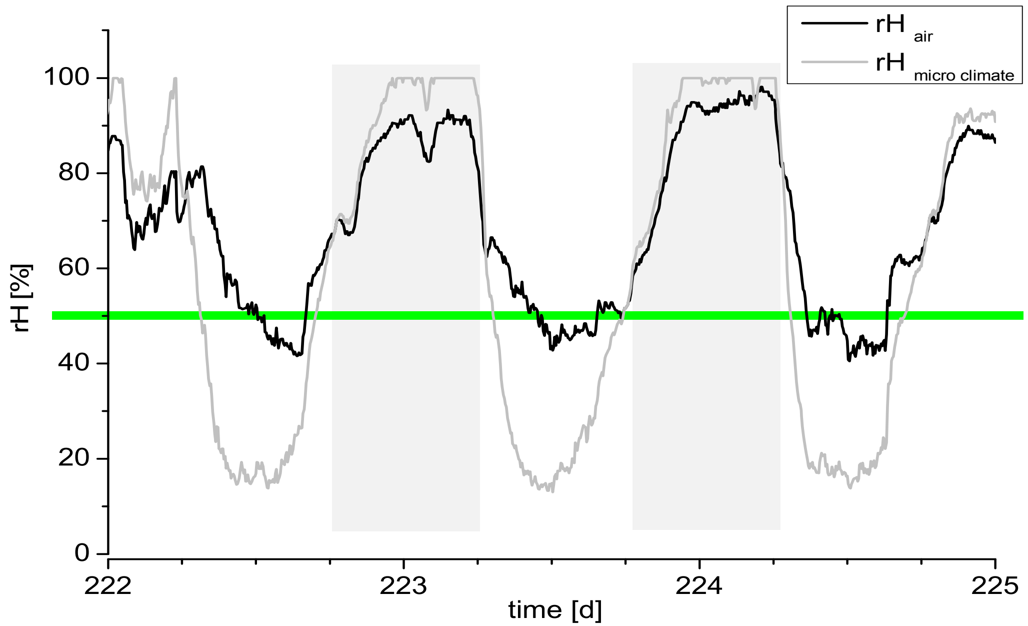


J. Wirth, Diplomarbeit. Diploma Thesis, University of Freiburg, 20

J. P. Hülsmann et al.,su bmitted to Solar Energy Materials&Solar Cells

3 Modeling micro-climatic stress factors

Phenomenological modelling of moisture impact

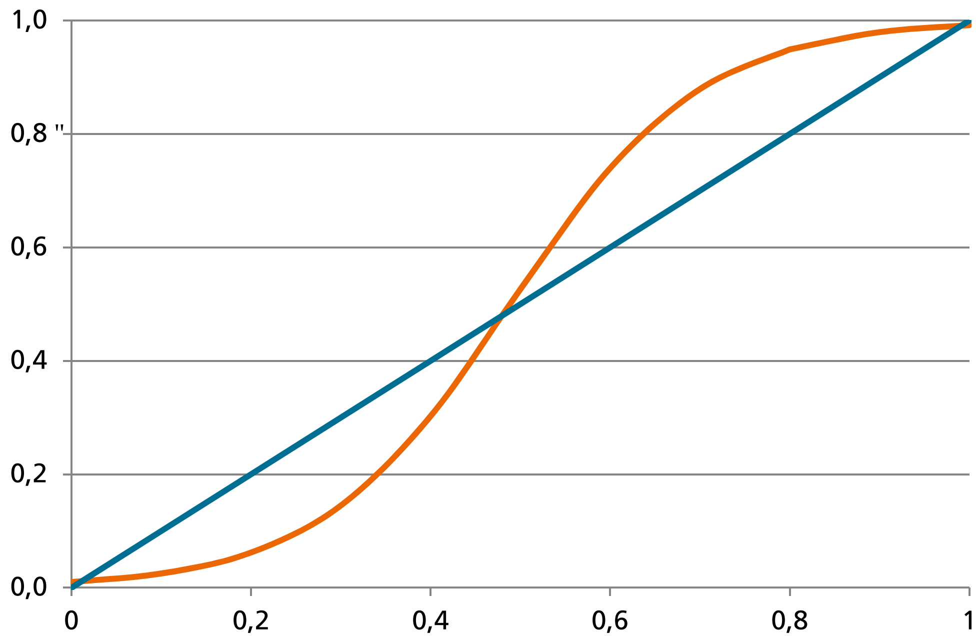


1.) Humidity at the module surface:

$$rh\,(T_{mod}) = rh\,(T_{amb}) * P_{sat}\,(T_{mod}) / P_{sat}\,(T_{amb})$$

2.) Put more weight on high moisture levels:

$$rh_{eff} = 1 / (1 + 100 \cdot \exp(-9.4 \cdot rh))$$



3.) Humidity level at test conditions (85%rh):

$$\Delta t_i = \Delta t_i \cdot rh_{eff} / 0.85$$

M. Koehl et al. / Solar Energy Materials & Solar Cells 99 (2012) 282–291

4 Time-transformation functions for major degradation processes

4.) Process kinetics depend on module temperature (Time Transformation Function):

$$t_{test} = \text{Lifetime (years)} \cdot \Sigma_i \{\Delta t_i(rh_{eff}, T_{mod,i}) \cdot \exp[-(E_a / R)\cdot(1/T_{test} - 1/T_{mod,i})]\}$$

E_a = activation energy for the rate dominating degradation process

5 Modeling corresponding ALT – conditions for micro-climatic stress factors

Testing time at 85%rh/85°C for 25 years lifetime

Example:

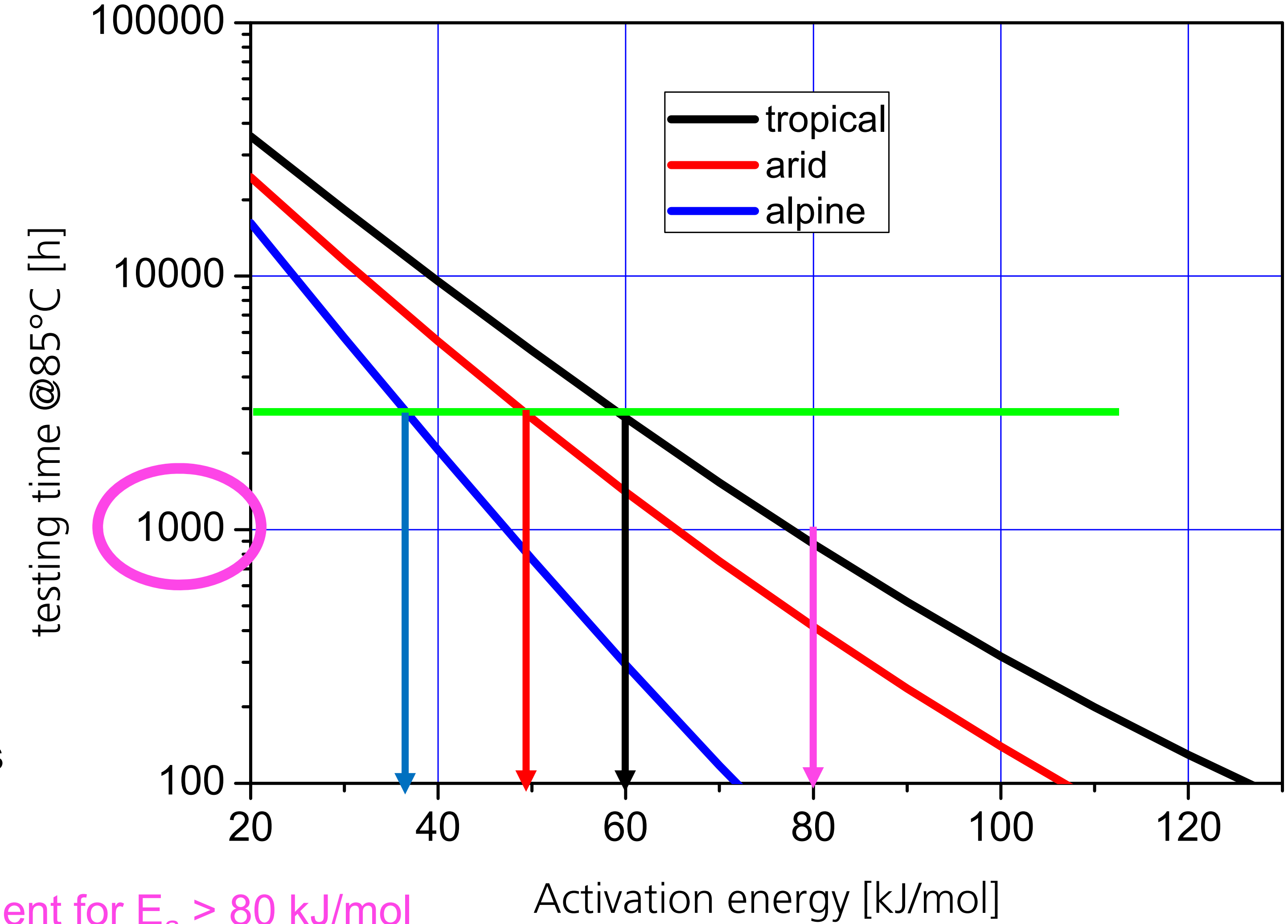
Time to failure @ 85°C/85%rh:

3000h

E_a > 35 kJ/mol for alpine climates

E_a > 50 kJ/mol for arid climates

E_a > 60 kJ/mol for tropical climates

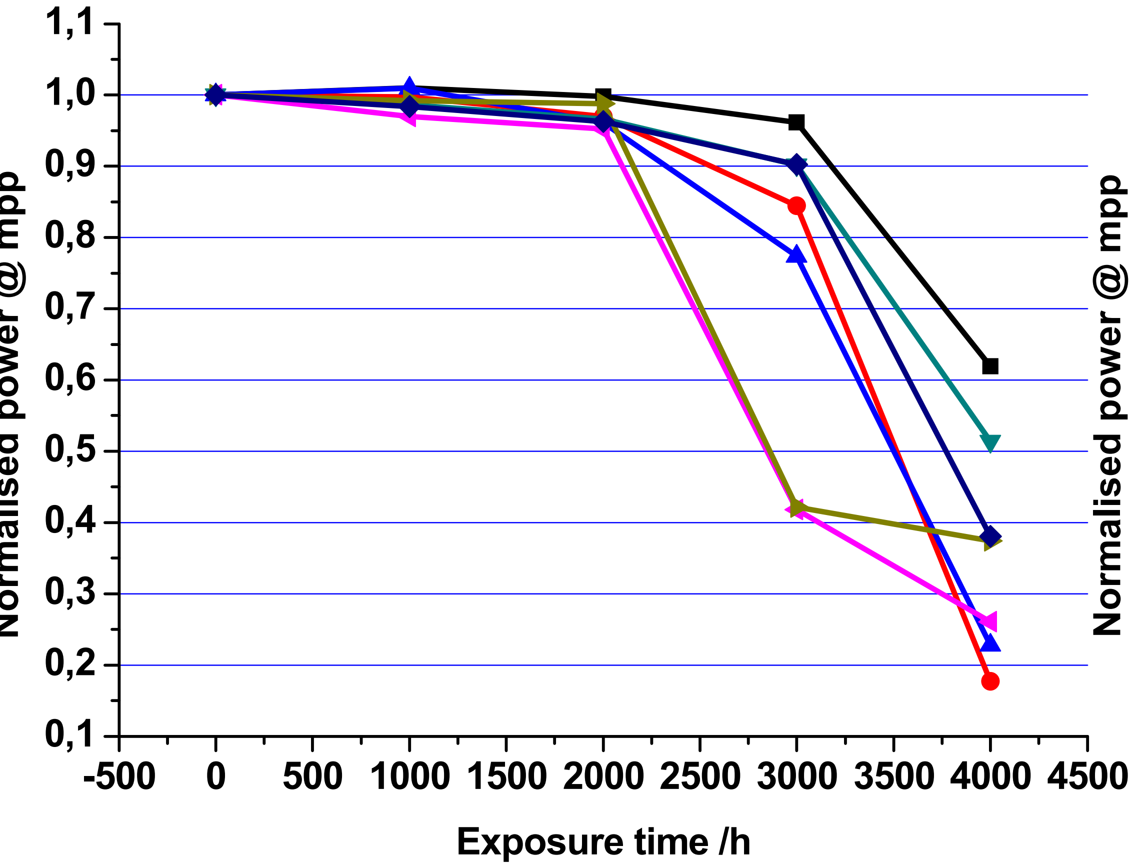


Type approval test would be sufficient for E_a > 80 kJ/mol

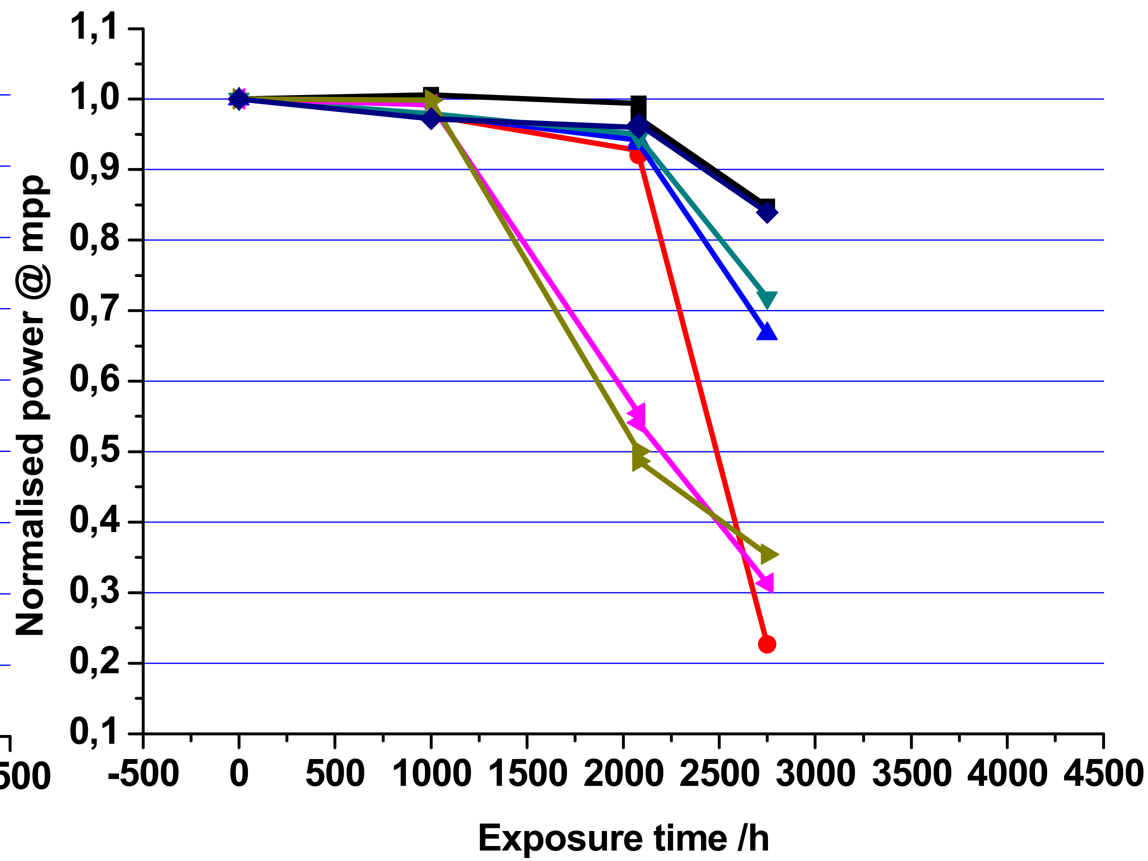
6 Evaluation of the parameters for time-transformation functions by ALT

Testing of c-Si modules from 7 different manufacturers

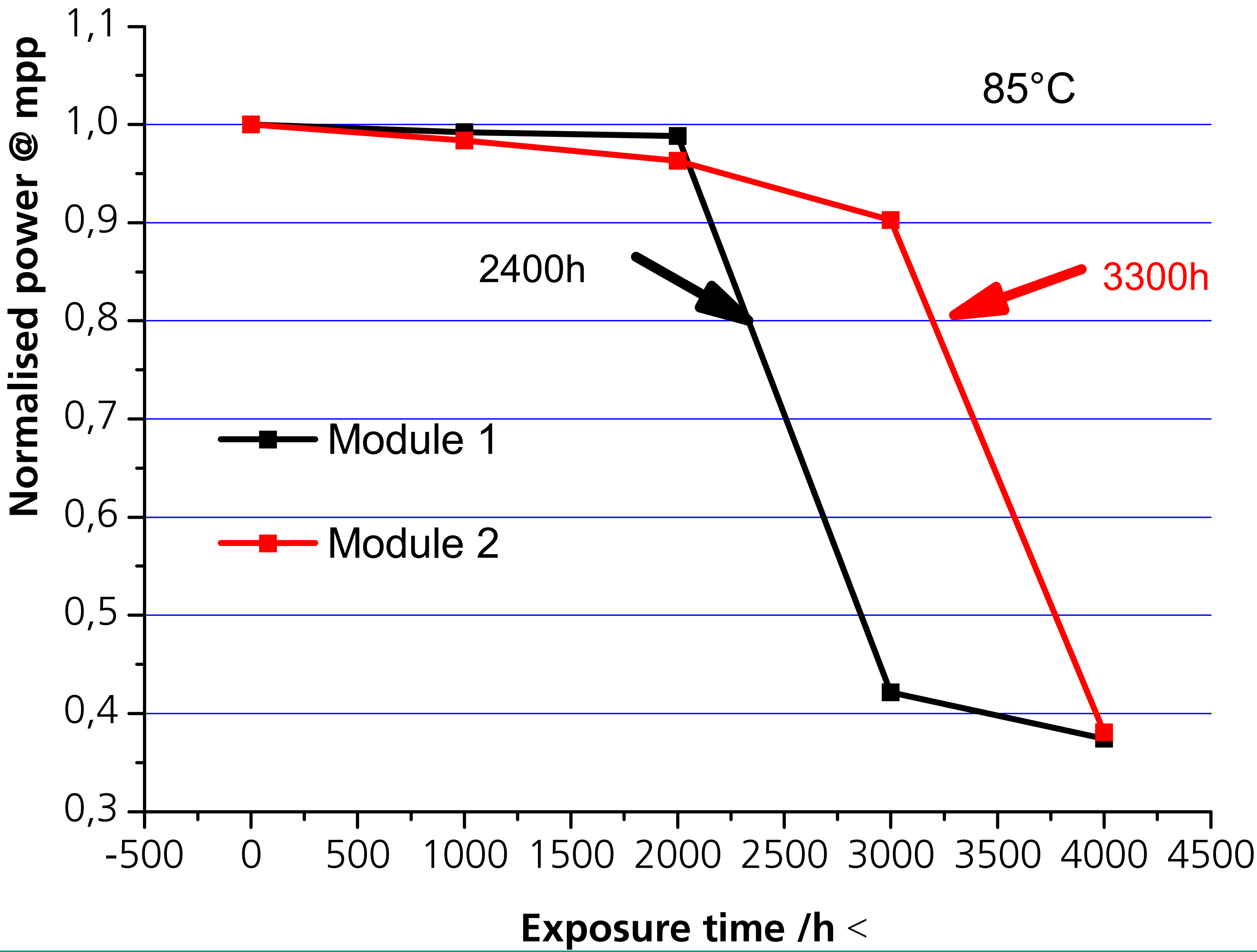
Damp-Heat at 85°C and 85% rel. humidity



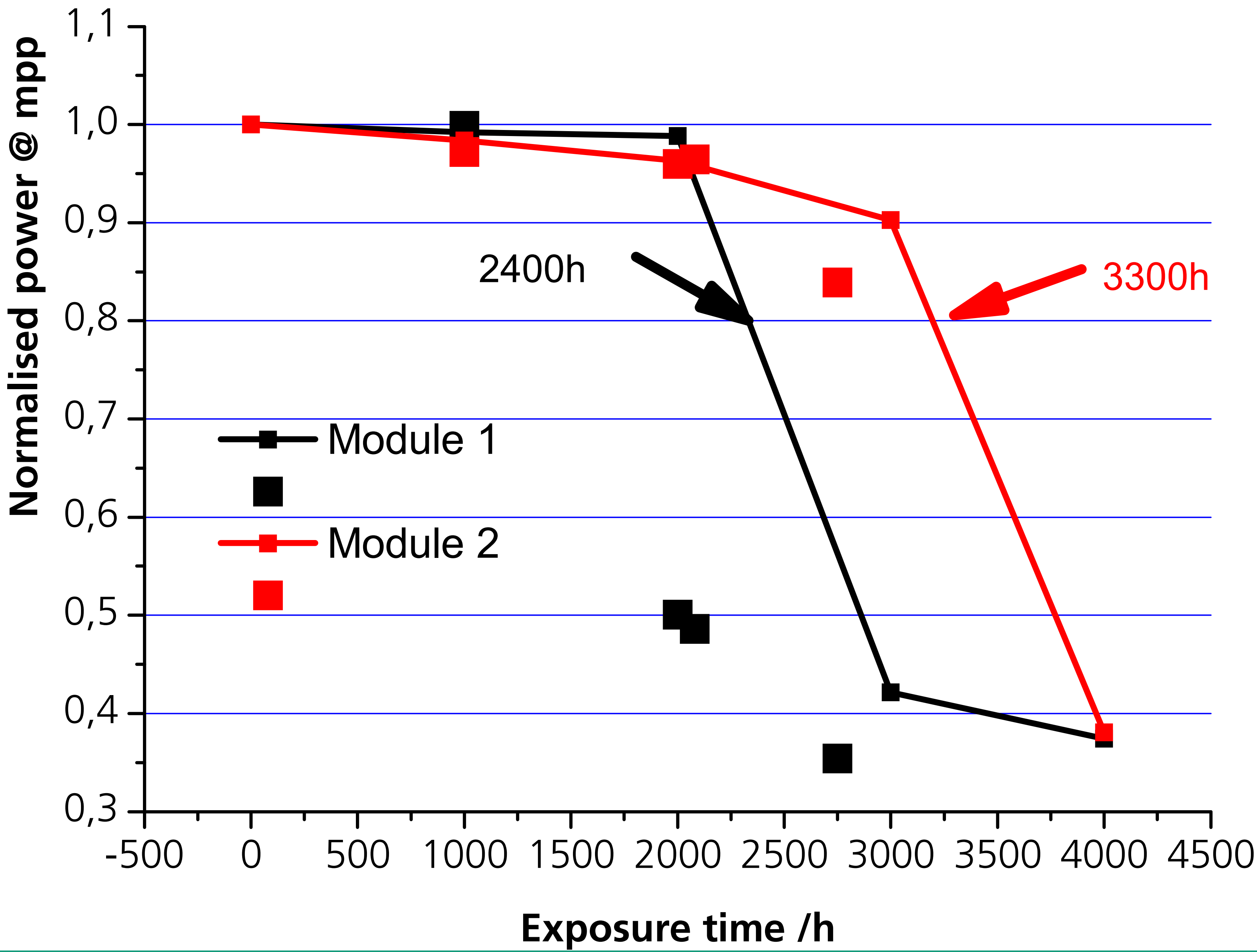
Damp-Heat at 90°C and 85% rel. humidity



Damp-heat testing at 85%rh@85°C, module 1 und module 2 "

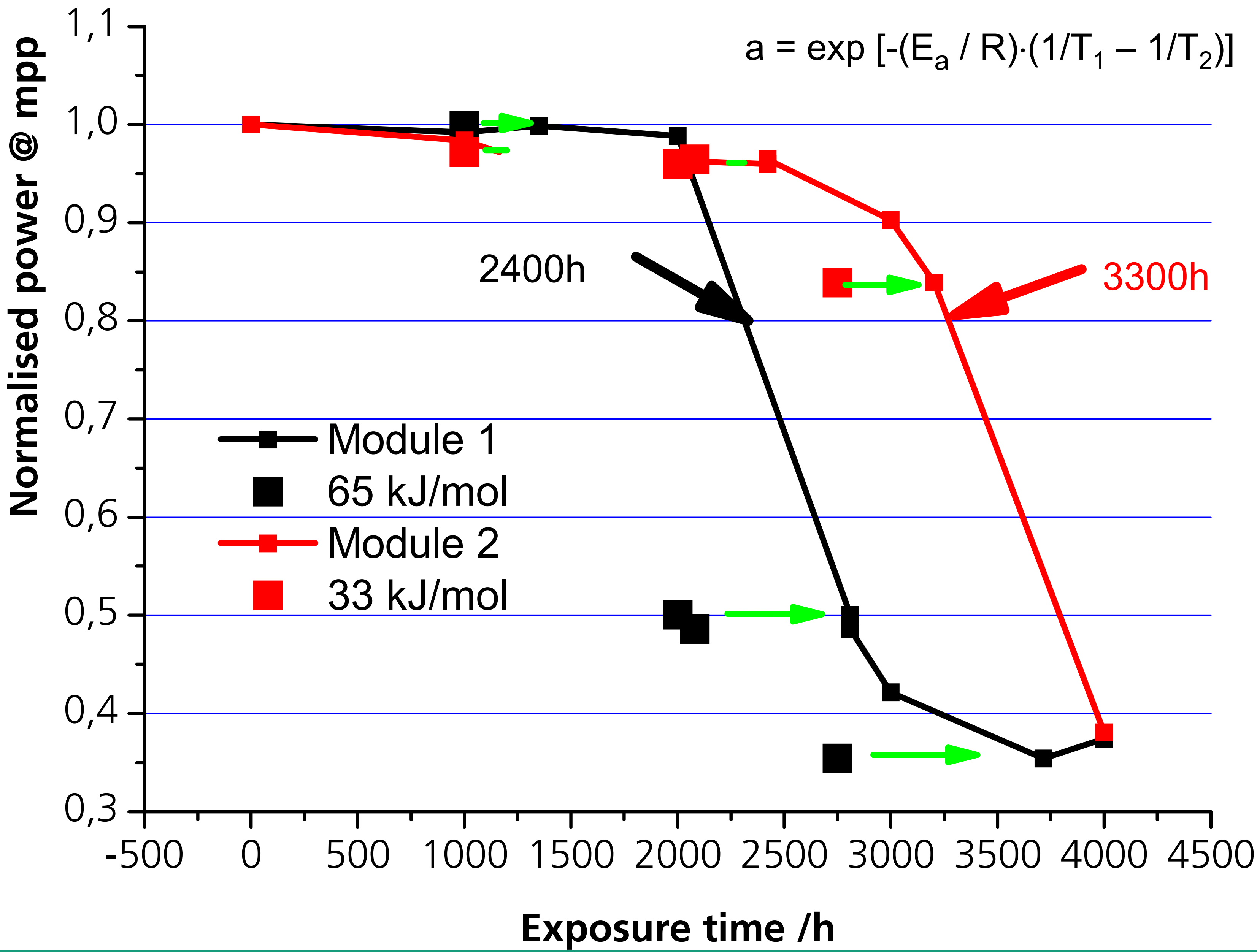


Damp-heat testing at 85%rh@85°C and @90°C, module 1 und module 2 "



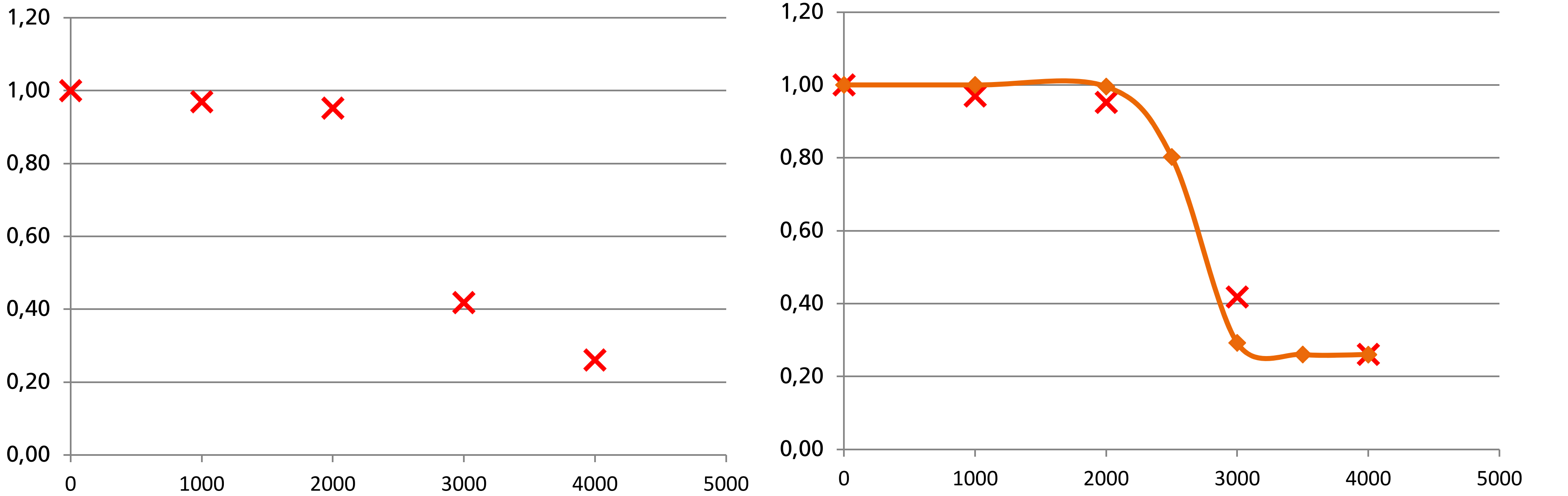
6 Evaluation of the parameters for time-transformation functions by ALT

Damp-heat testing at 85%rh@85°C and @90°C, module 1 und module 2 "



6 Evaluation of the parameters for time-transformation functions by ALT

$$\Delta P = G/(1+ (G/0.01-1)\ \exp(-(t-tind\ (T))*k(T))\ )$$

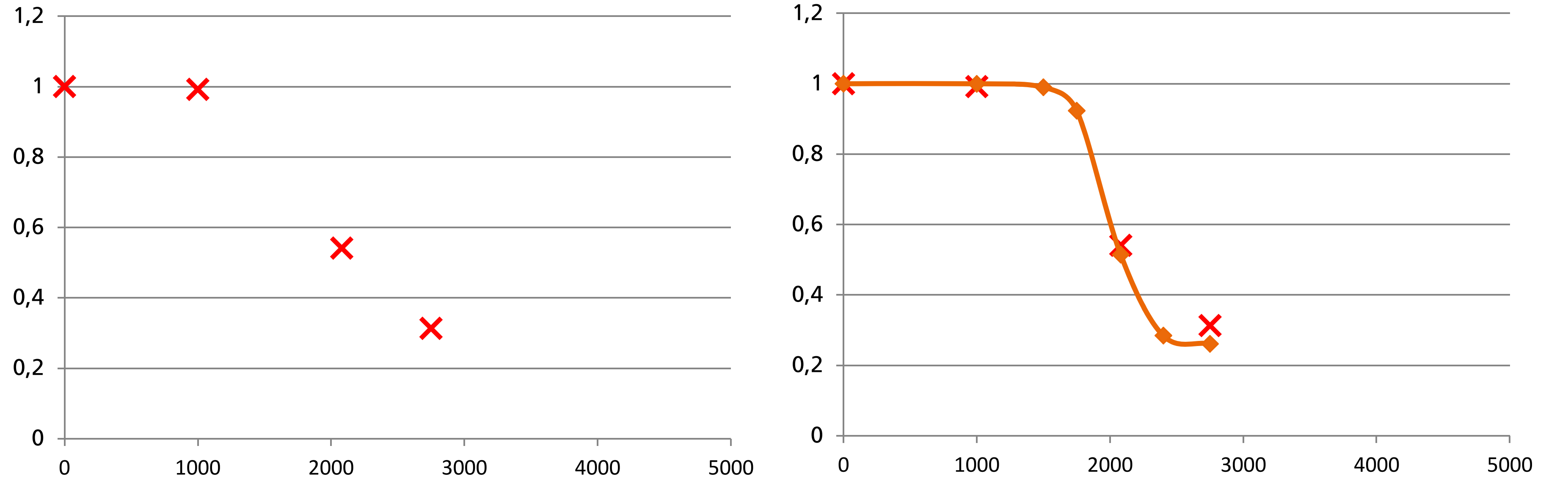


T=85°C

Tind=2100h

K=0,0082/h

G=0,26

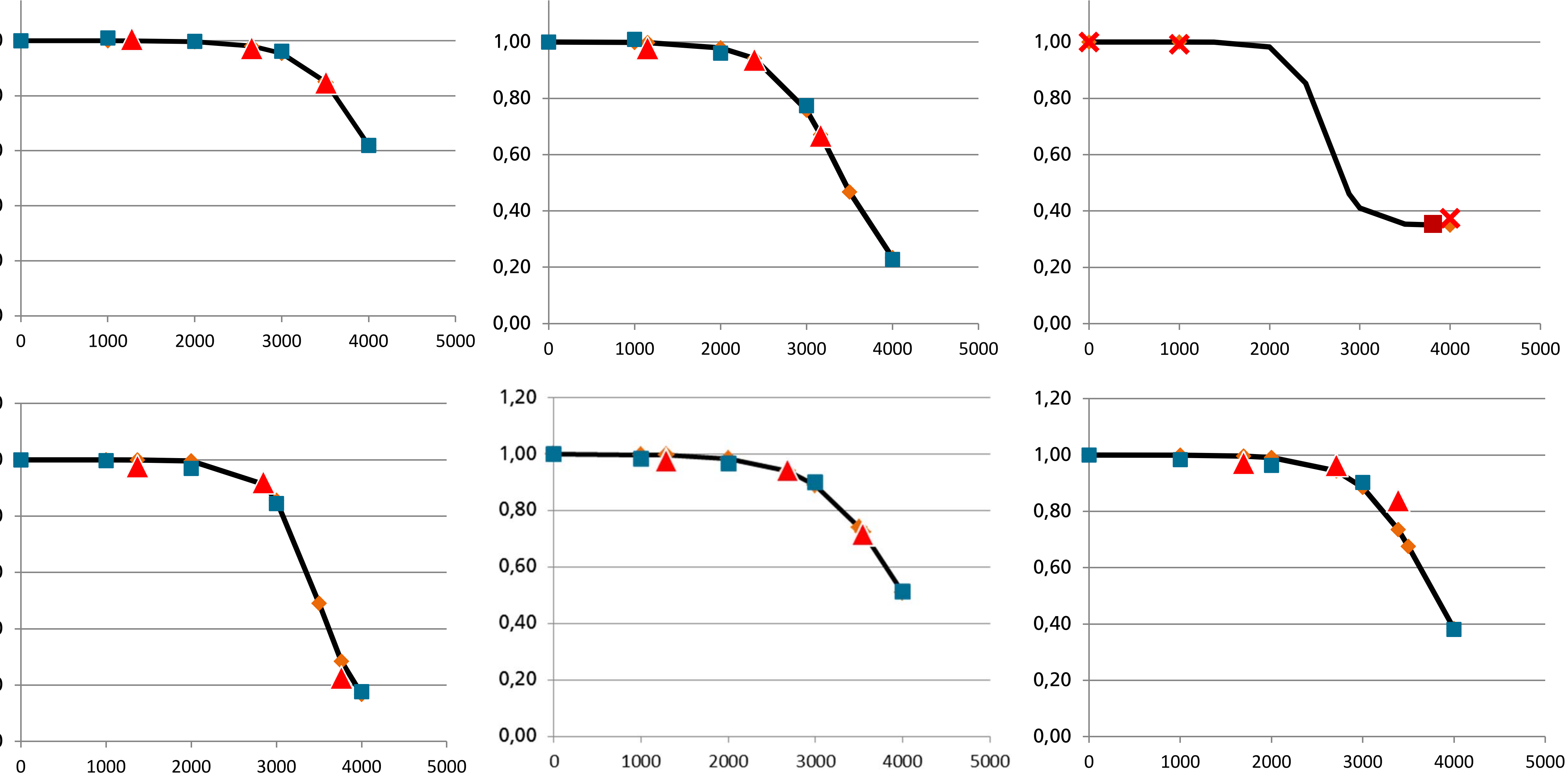


T=90°C

Tind=1500h

K=0,0115/h

G=0,26



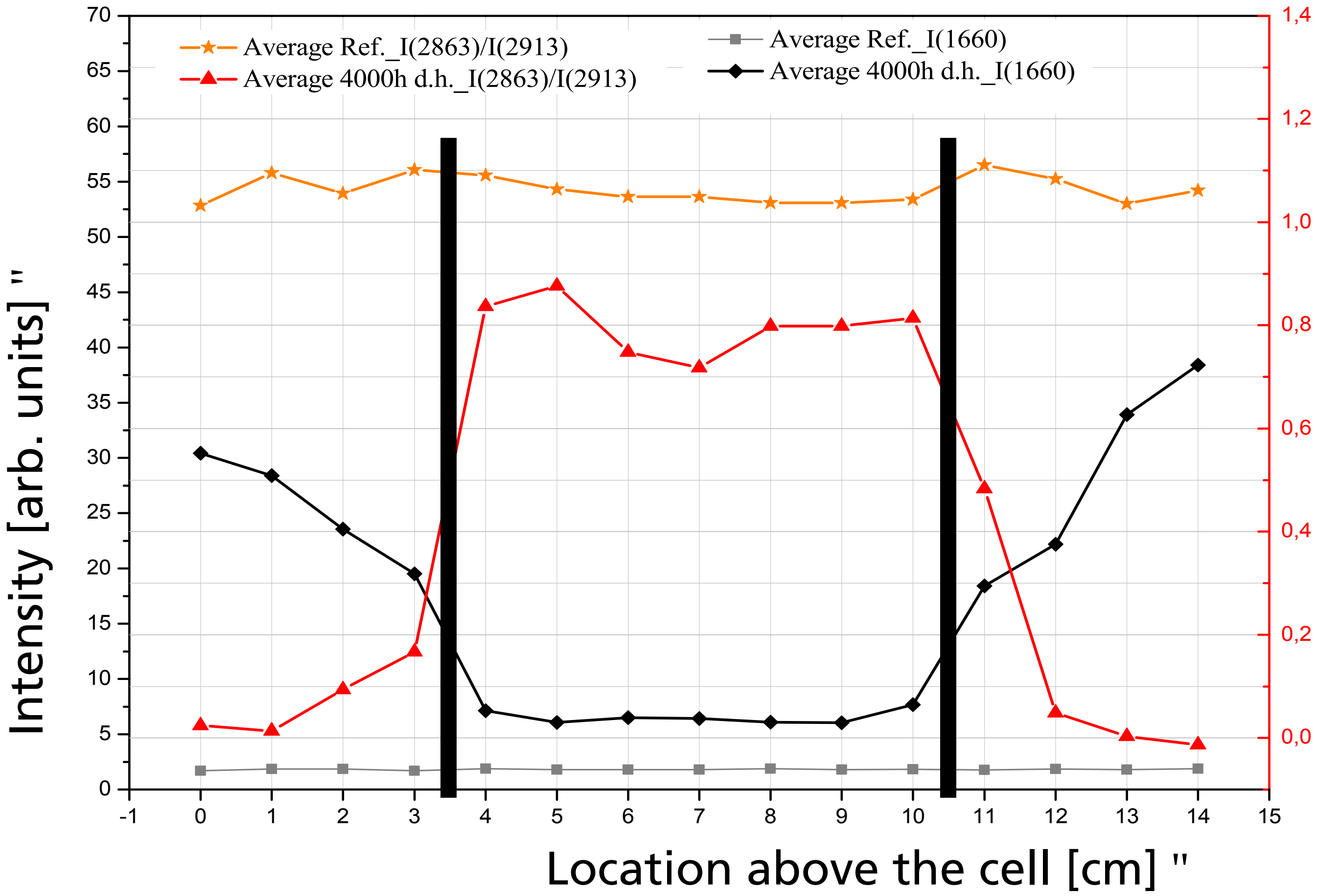
time (@85°C) [h]	2412	2576	2821	3047	3160	3227	3548
ivation energy [kJ/mol]	70	73	30	68	26	55	53
nate class	A	A	C	A	C	B	B

Qualification for different stress levels or climate zones allows diversification of PV-modules

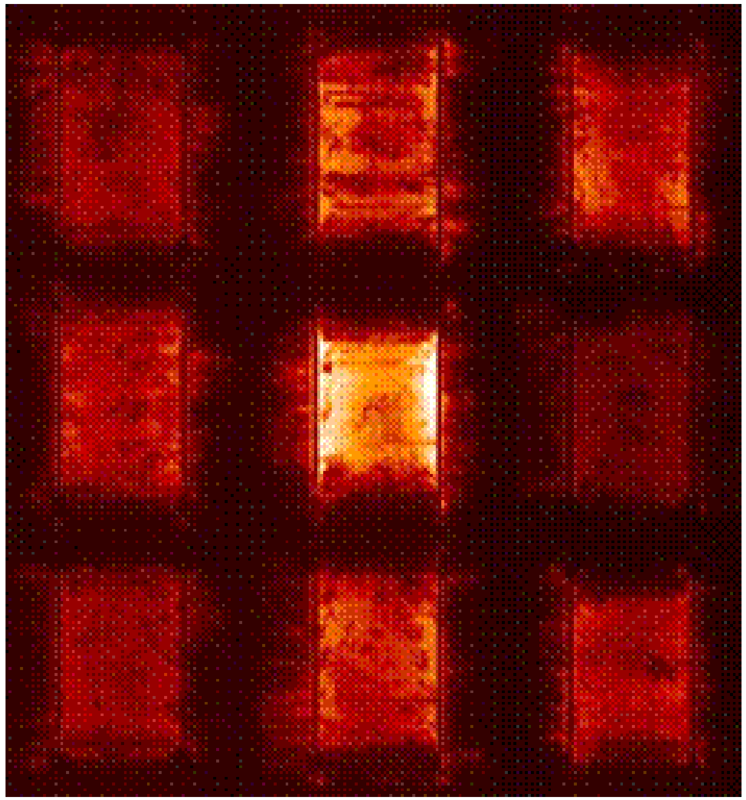
Degradation of the modules

Polymer Analysis by Raman-Spectroscopie

Comparison of the Vinyl-Band (red) and the fluorescence-background (black) unaged and after 4000h damp-heat-testing



Elektroluminescence-picture of the degraded cells



C. Peike et.al.: Non-destructive degradation analysis of encapsulants in PV modules by Raman Spectroscopy, Sol. En. Mat. Sol. Cells (2011)

6 Evaluation of the service life time for different climates

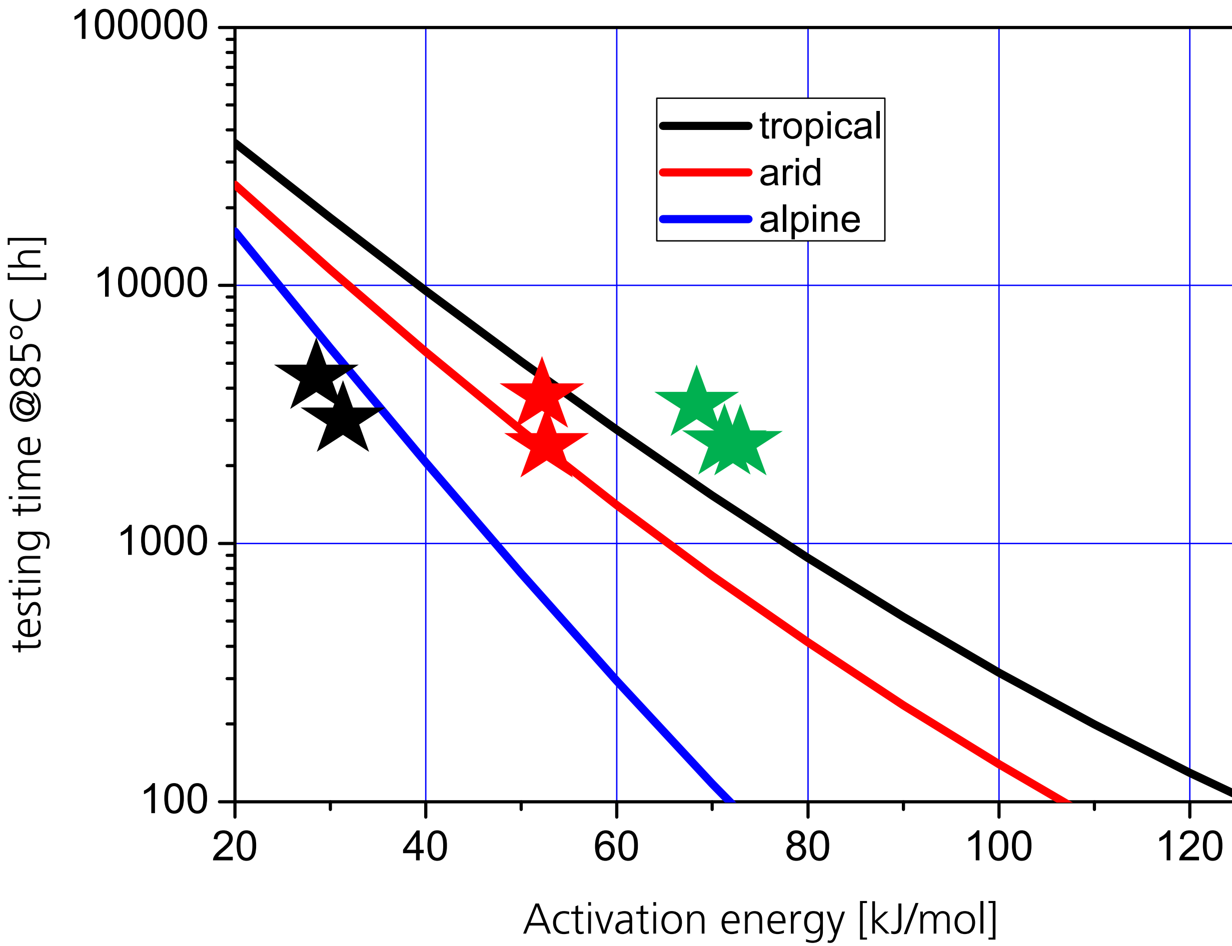
Testing time at 85%rh/85°C for 25 years lifetime

Climate classes:

A: **Most severe moisture stress**

B: **Moderate moisture stress**

C: **Low moisture stress**



Assumptions:

The measured stress levels are representative

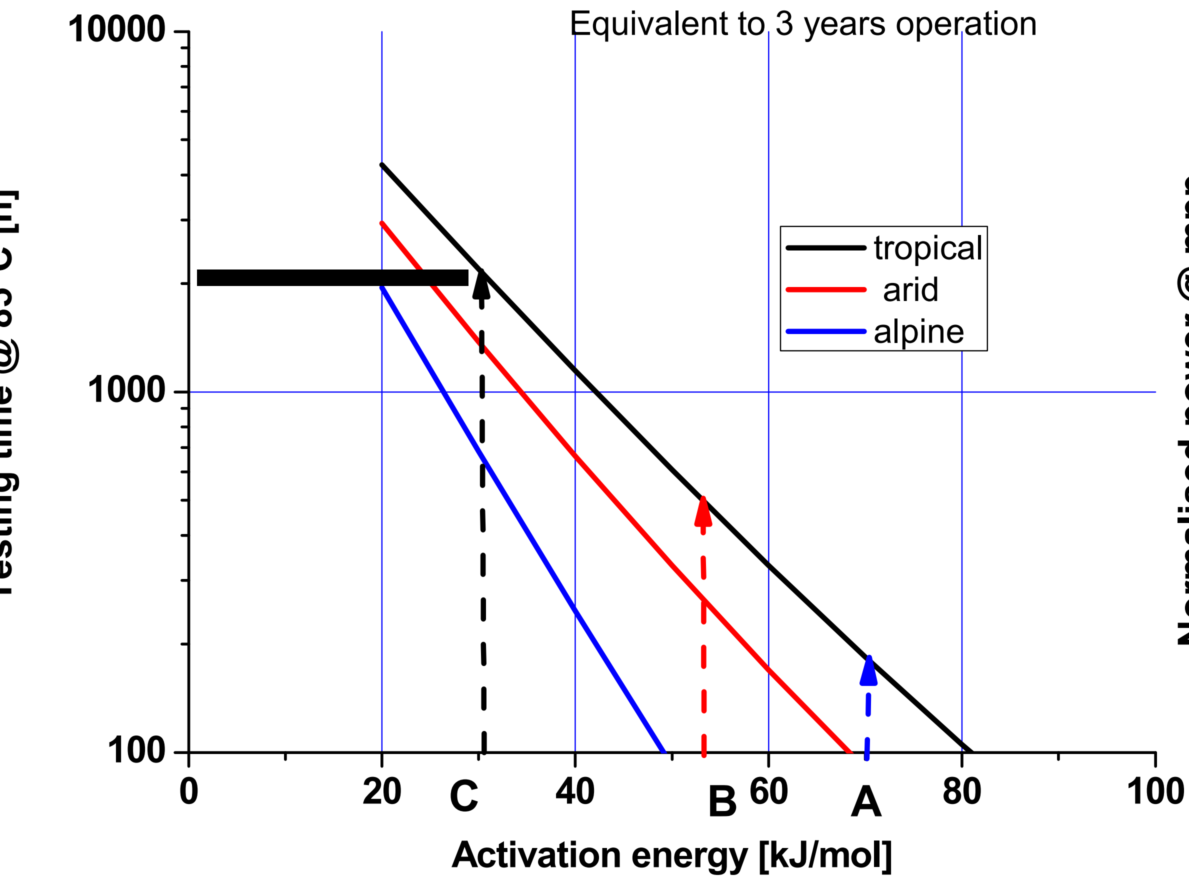
The model for the kinetics is valid

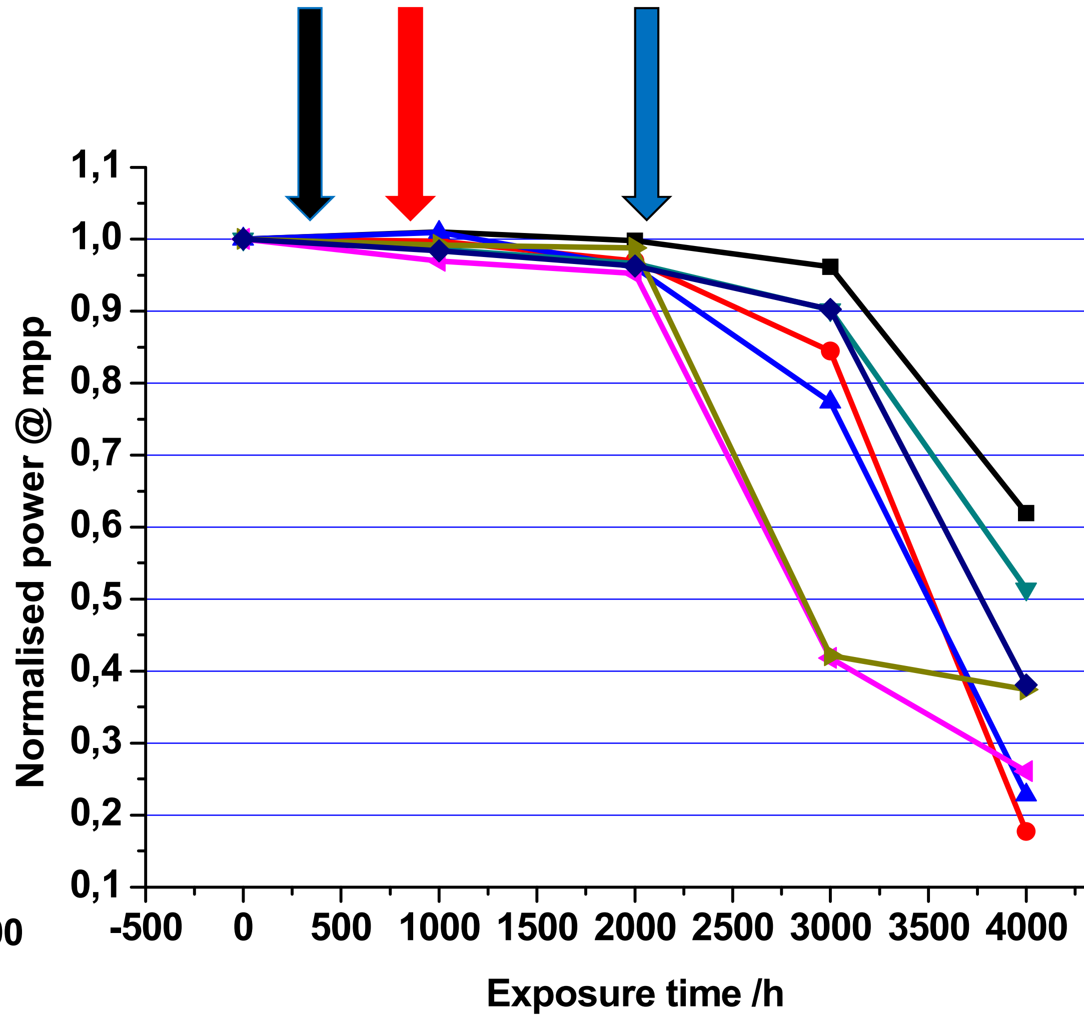
The constant load D/H test reflects reality

7 Modeling expected degradation for validation by outdoor exposure

Power reduction after 3 years outdoor exposure < 3%

Exposure time has to be doubled





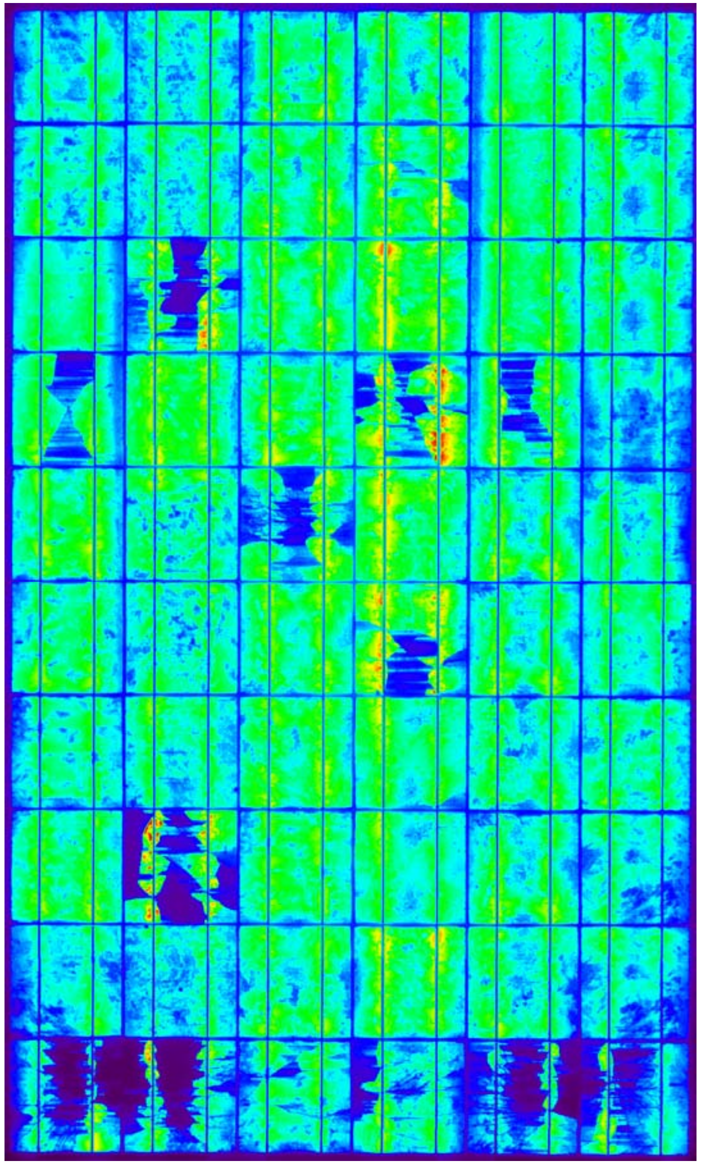
7 Degradation effects during outdoor exposure

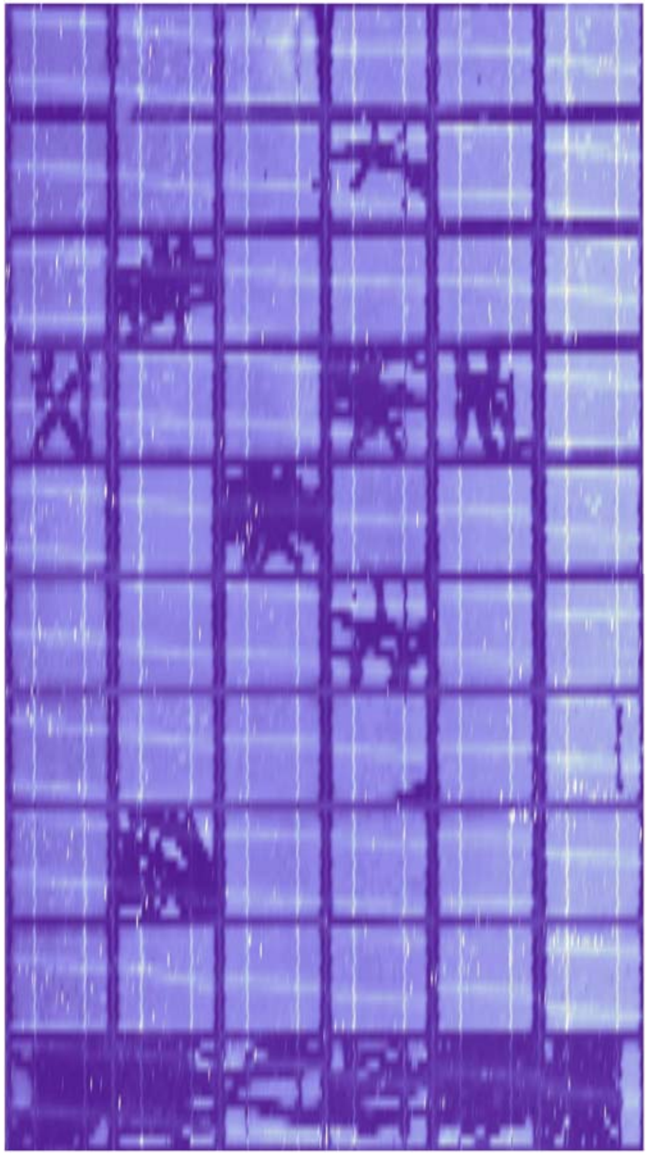
Changes of the electrical performance at the outdoor exposure site

Test site	Tropical	Arid	Urban	Alpine	Average
Module 1	-1,5%	-0,6%	-0,9%	-1,1%	-1,0%
2	-0,1%	-1,1%	-0,8%	-4,7%	-1,7%
3	-1,0%	-0,1%	-0,5%	1,3%	-0,1%
4	-3,2%	-0,1%	1,7%	-6,6%	-2,1%
5	-0,1%	-2,2%	-1,8%	-0,8%	-1,2%
Average	-1,2%	-0,8%	-0,5%	-2,4%	-1,2%

After 3 years operation hardly out of the error bars

7 Degradation effects during outdoor exposure





After 3 years on the alpes

Degradation of module materials - UV-induced fluorescence <

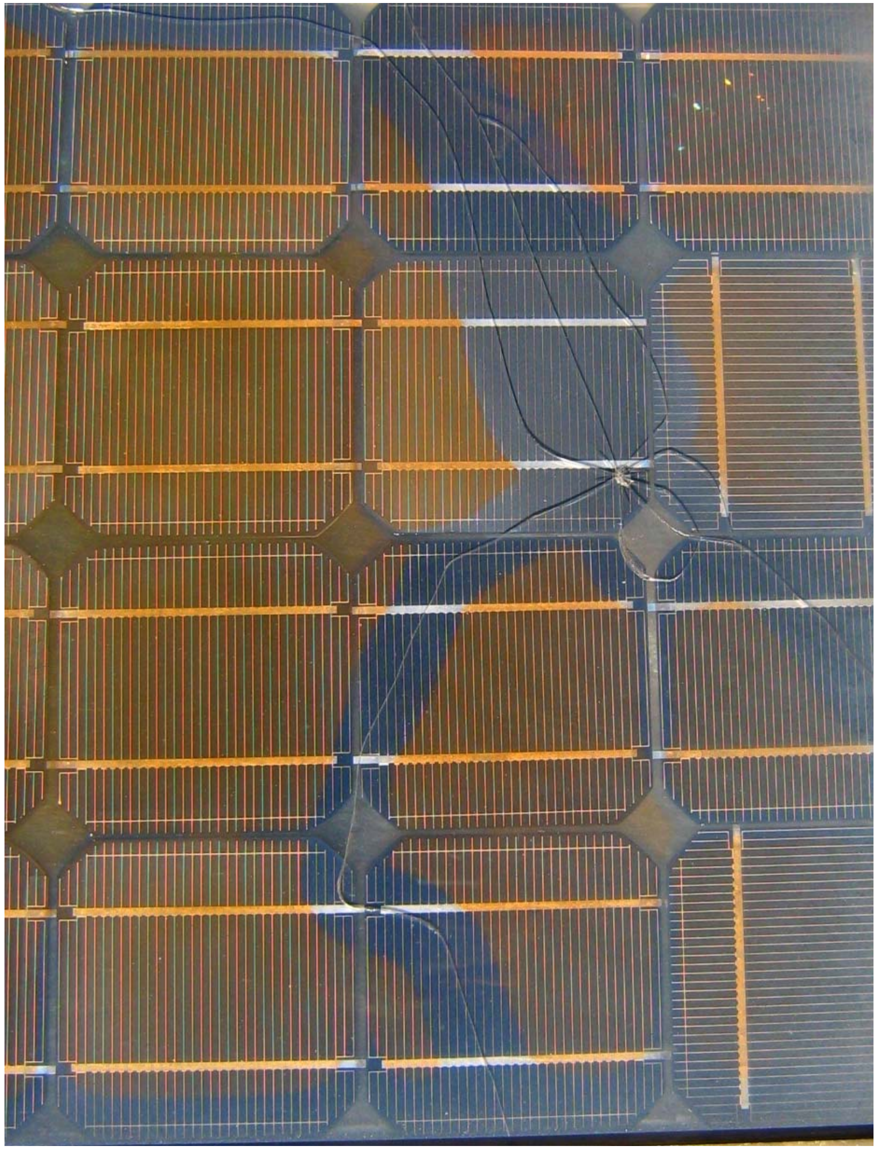
2 a alpine outdoor exposure

2 a desert outdoor exposure

Combination of electroluminescence and fluorescence

J. Schlothauer, et al., Fluorescence imaging: a powerful tool for the investigation of polymer degradation in PV modules, *Photovoltaics International* journal, November 2010

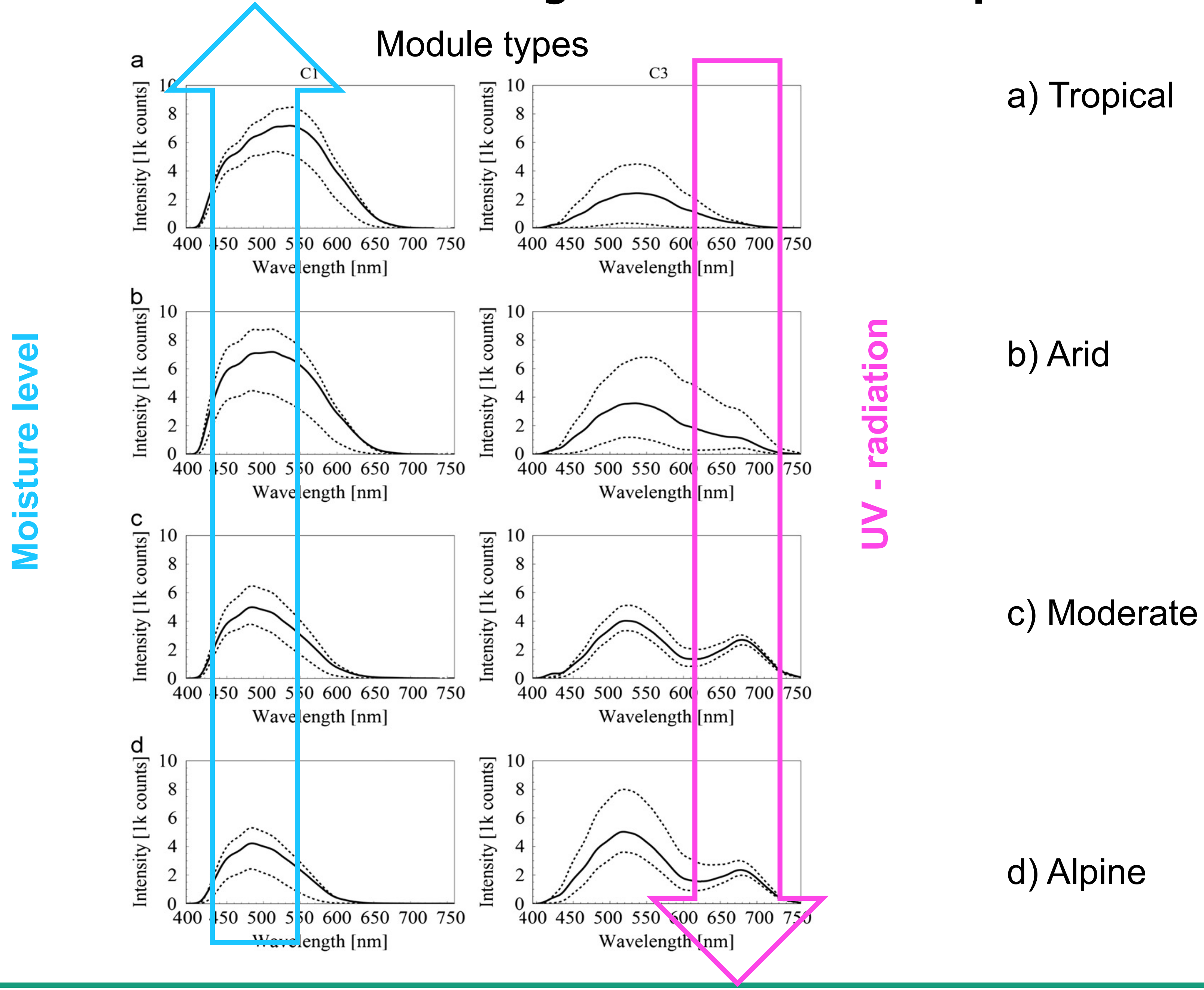
Browning and photo-bleaching - UV-induced fluorescence <



2 a desert outdoor exposure

Combination of electroluminescence and fluorescen

Effect of outdoor weathering on fluorescence spectra



J. Schlothauer, et al., Degradation of the encapsulant polymer in outdoor weathered photovoltaic modules: Spatially resolved inspection..., Solar Energy Materials&Solar Cells 102 (2012) 75–85

Methodology for design of Accelerated Service Life Testing "

1 Monitoring climatic conditions

2 Monitoring micro-climatic stress factors

3 Modeling micro-climatic stress factors

4 Time-transformation functions for major degradation processes

5 Modeling corresponding ALT – conditions for micro-climatic stress factors

6 Evaluation of sample-dependent parameters for time-transformation functions

7 Modeling of expected degradation for outdoor exposure and validation of the tests

Conclusions

Accelerated Damp-heat service life tests have been proposed

- Based on monitored climatic data
- Modelled micro-climatic stress conditions
- Modelled kinetic of the degradation processes

but final validation was not achieved yet

Conclusions and outlook

Accelerated Damp-heat service life tests have been proposed

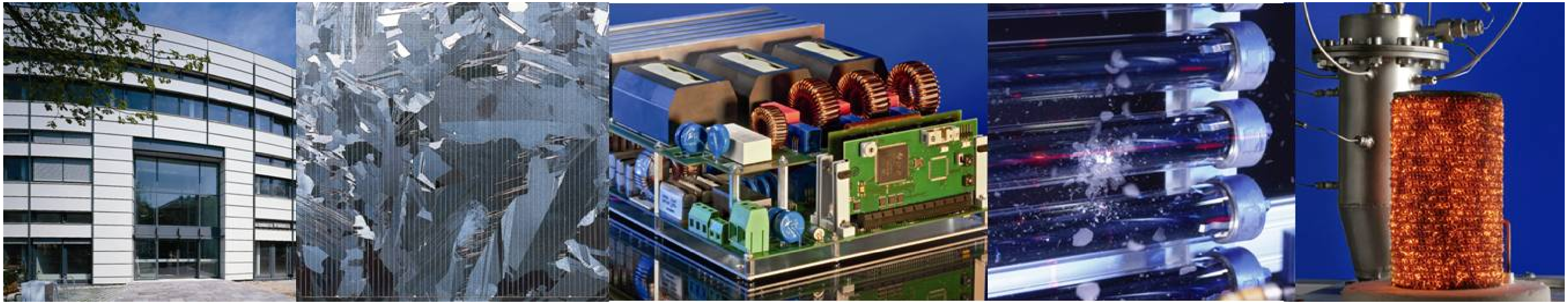
- Based on monitored climatic data
- Modelled micro-climatic stress conditions
- Modelled kinetic of the degradation processes

but final validation was not achieved yet

Tests for other stress factors (UV, temperature cycling, potential induced degradation etc) and their combinations are under development

Global stress mapping will allow qualification of diversified, specialised products for different climatic zones

Thank you for your Attention! <



Fraunhofer Institute for Solar Energy Systems ISE

Michael Köhl

www.ise.fraunhofer.de

michael.koehl@ise.fraunhofer.de