ACCELERATED SERVICE LIFE TESTING OF PHOTOVOLTAIC MODULES

Michael Köhl

Fraunhofer Institute for Solar Energy Systems ISE

Service Life Prediction of Polymeric Materials

Monterey, March 2013

www.ise.fraunhofer.de

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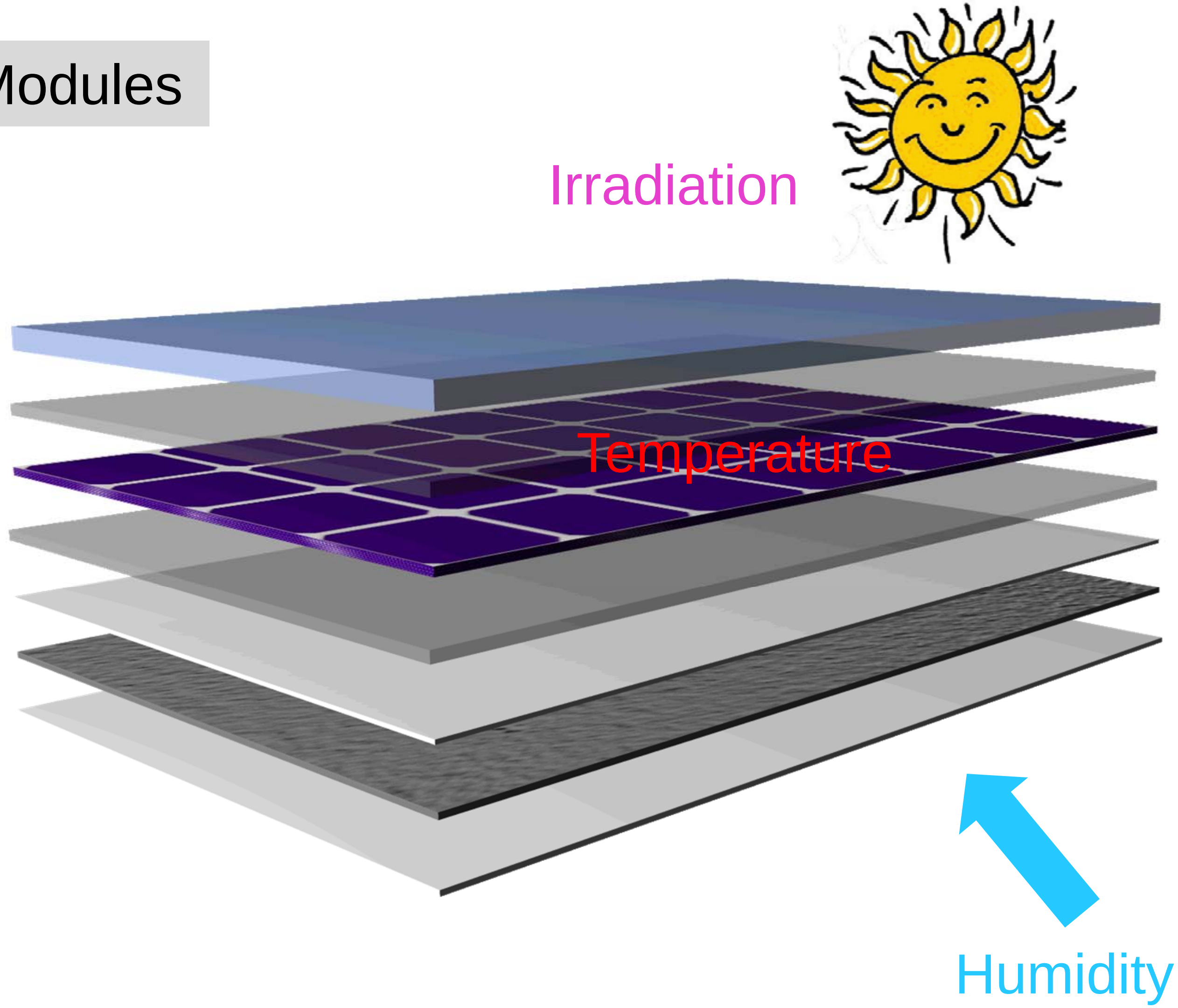
Polymers in Photovoltaic Modules



Glazing (evtl. polymeric)

Encapsulant

Silicon solar cells

Encapsulant

Back-sheet

Laminated together

Performance property is the electrical power P

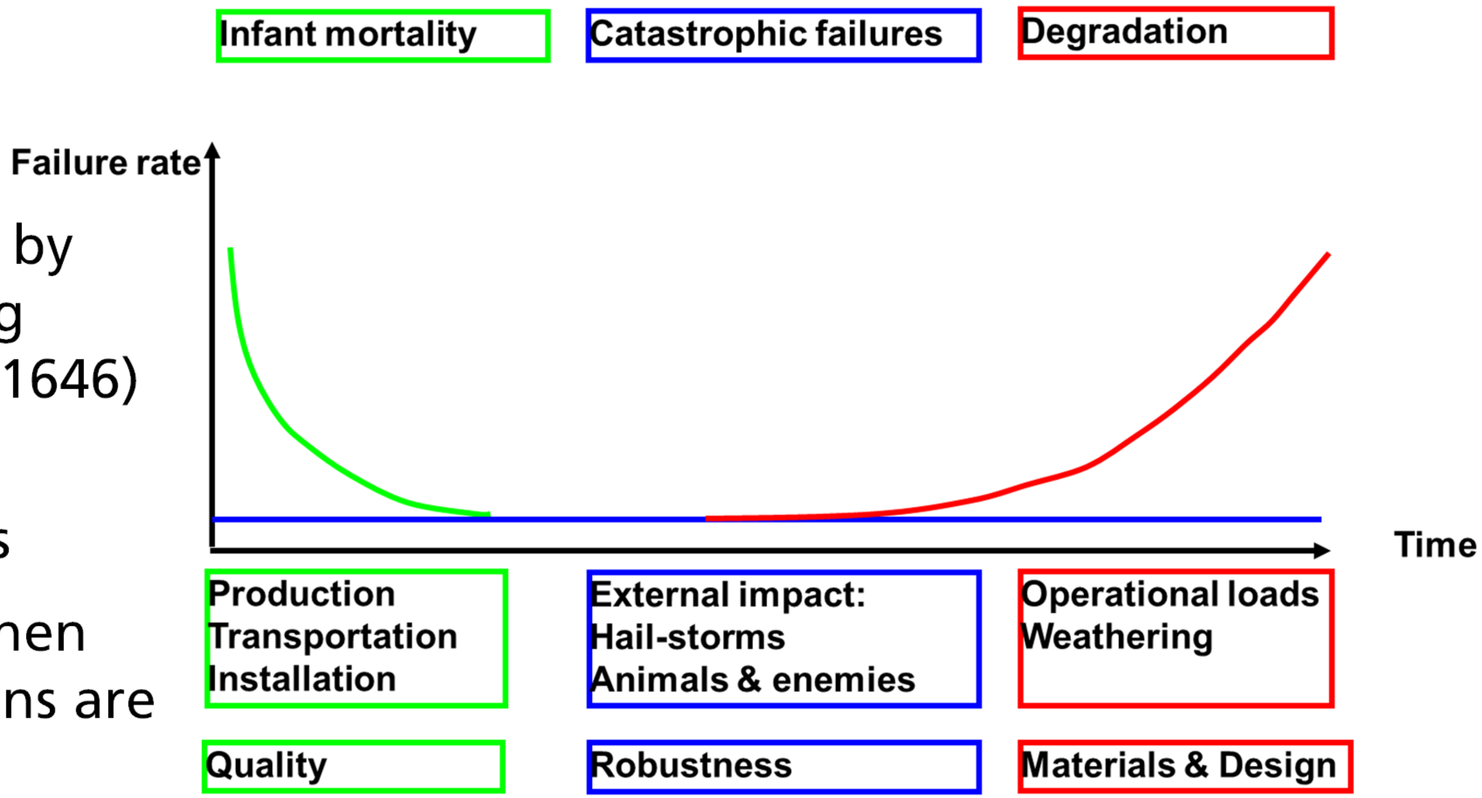
$\int P(t)\,dt$ / Costs is to be maximised for the design lifetime

25 – 30 years

Reliability

High quality is ensured by type approval testing (IEC 61215 and IEC 61646)

- Infant mortality tests
- No life tests, even when harsher test conditions are applied



Improvement of robustness is limited because of economical reasons

Long-term degradation is leading to gradual performance losses till the design service lifetime is reached

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 Rheinland)

Maritime

Pozo Izquierdo

Gran Canaria

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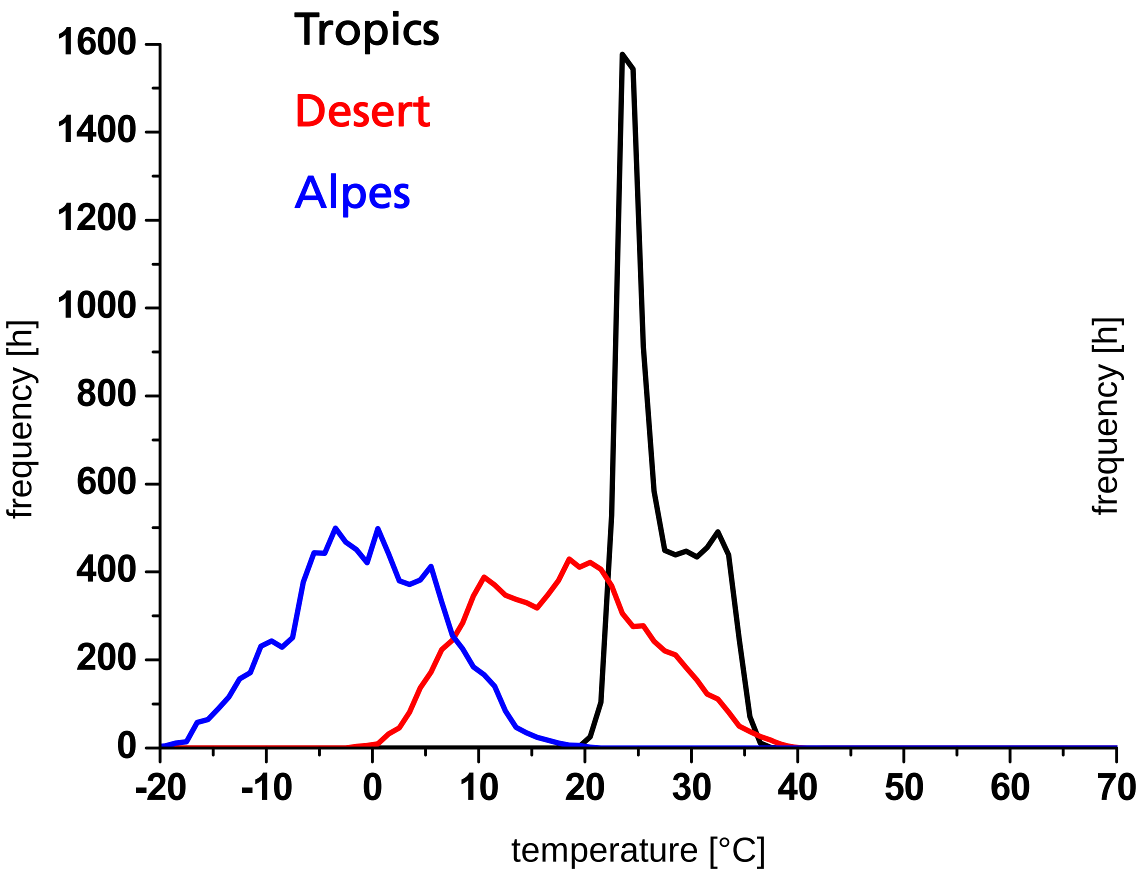
2 Monitoring micro-climatic stress factors

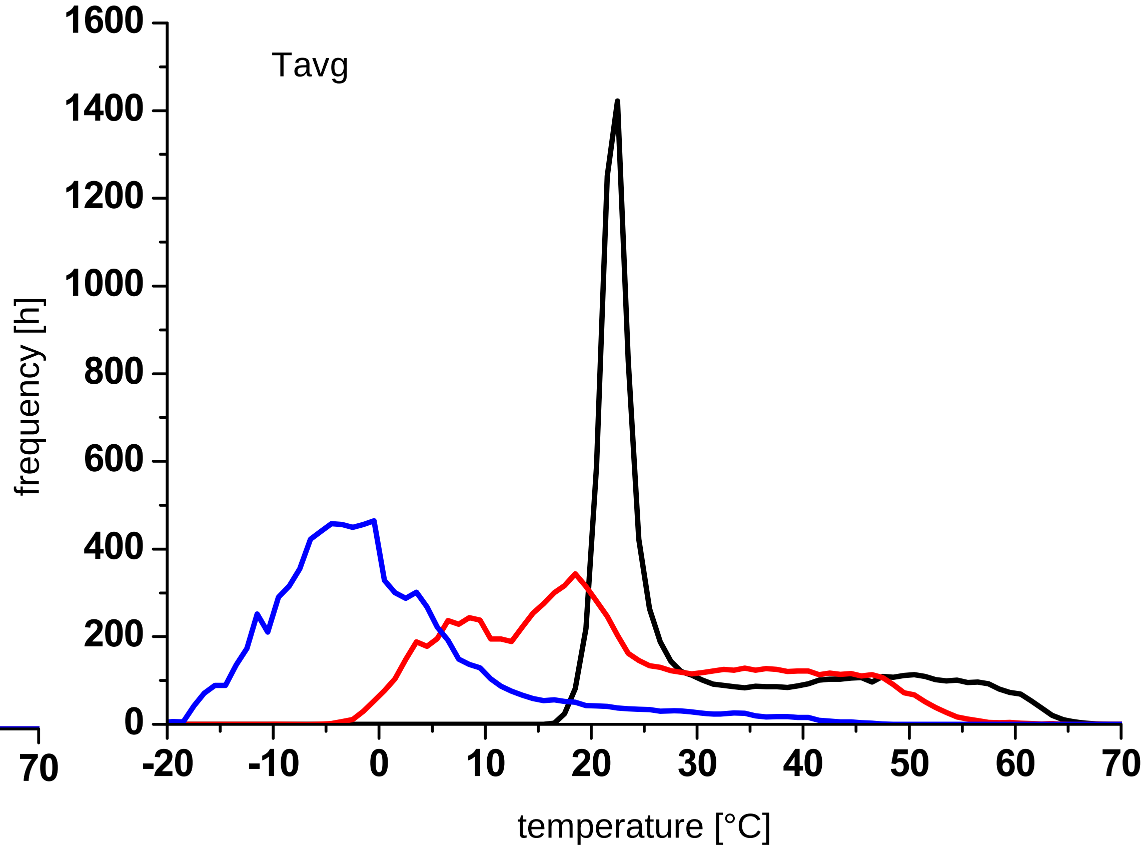
Module temperature monitoring during outdoor exposure

Macro – climate => Micro – climate

Ambient temperature



Average module temperature (c-Si)



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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

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

T_{mod} module temperature

T_{amb} ambient temperature

v wind velocity

H solar radiation

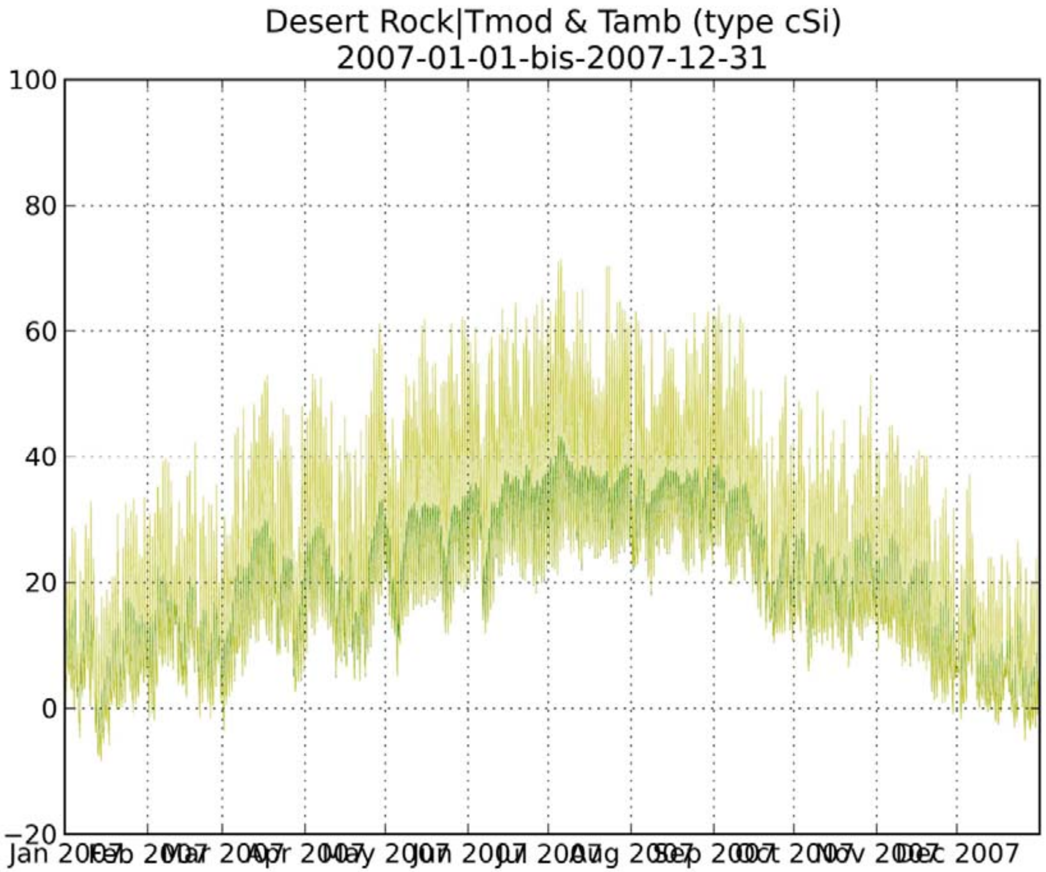
	U1	U0
a-Si 1	10,7	25,7
a-Si 3	5,8	25,8
a-Si 4	4,3	26,1
CIS 1	3,1	23,0
CIS 2	4,1	25,0
CdTe	5,4	23,4
c-Si	6,2	30,0

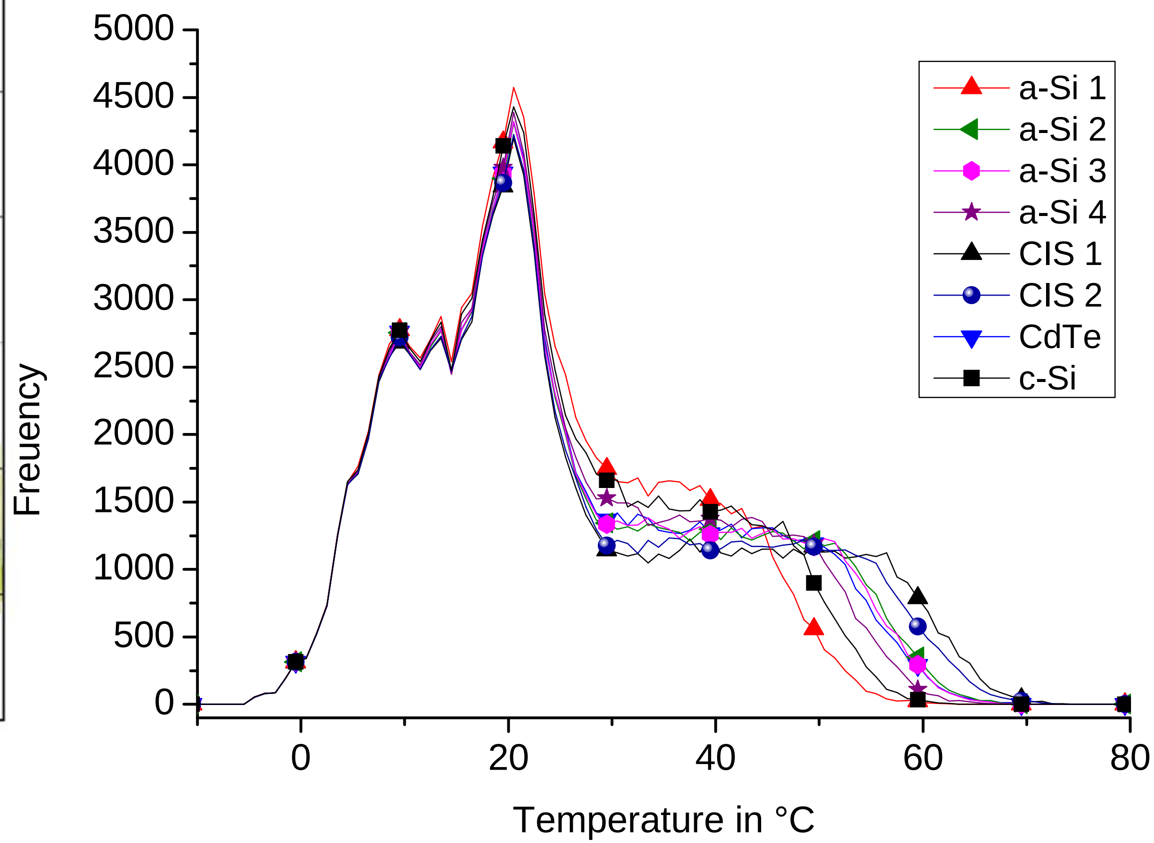
The parameters U are module-specific but location independent

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)



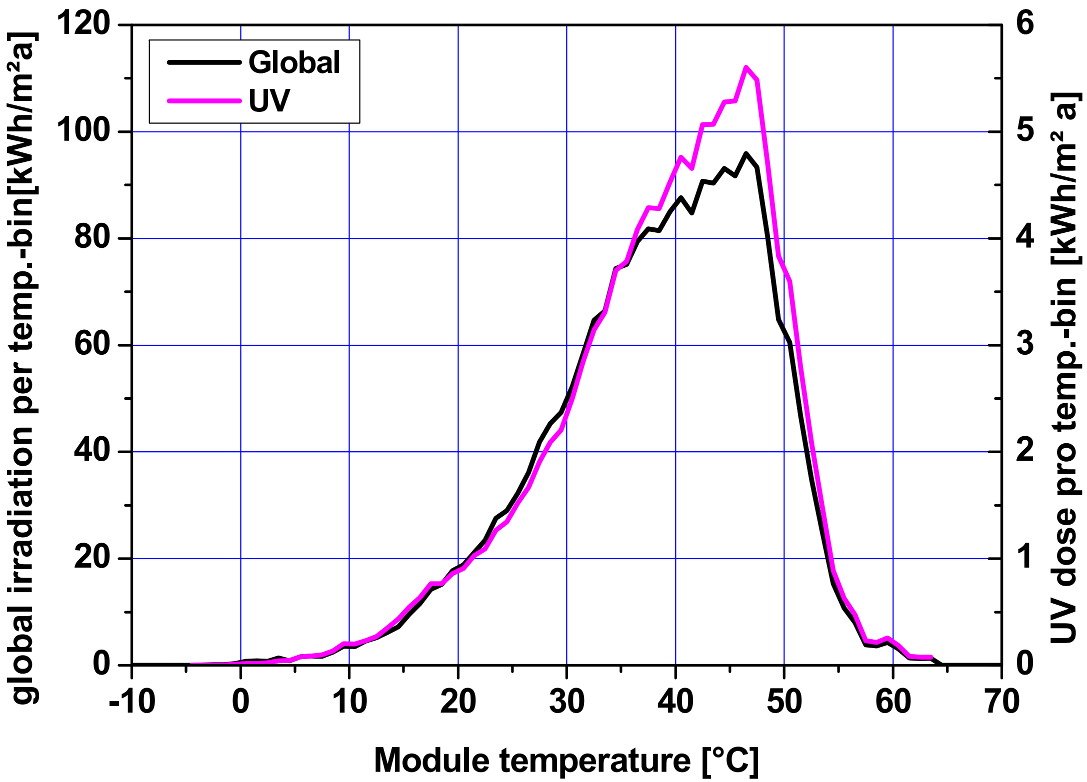


3 Modeling micro-climatic stress factors

UV intensity is strongly correlated with global irradiation:

Take 5 said Peter Trubiroha:

UV = 5.x % of global irradiation in POA



Module-temperature modeled or measured

UV - radiation modelling

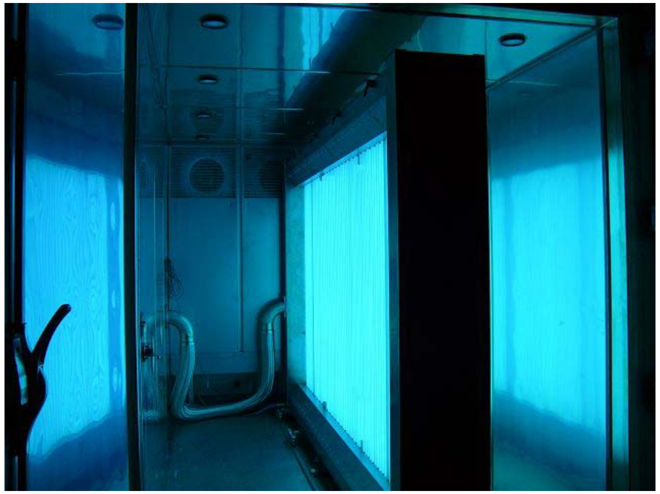
Desert Rock: 106 kWh/a m² => 2500kWh/m²

Goodwin Creek: 83 kWh/a m² => 2000kWh/m²

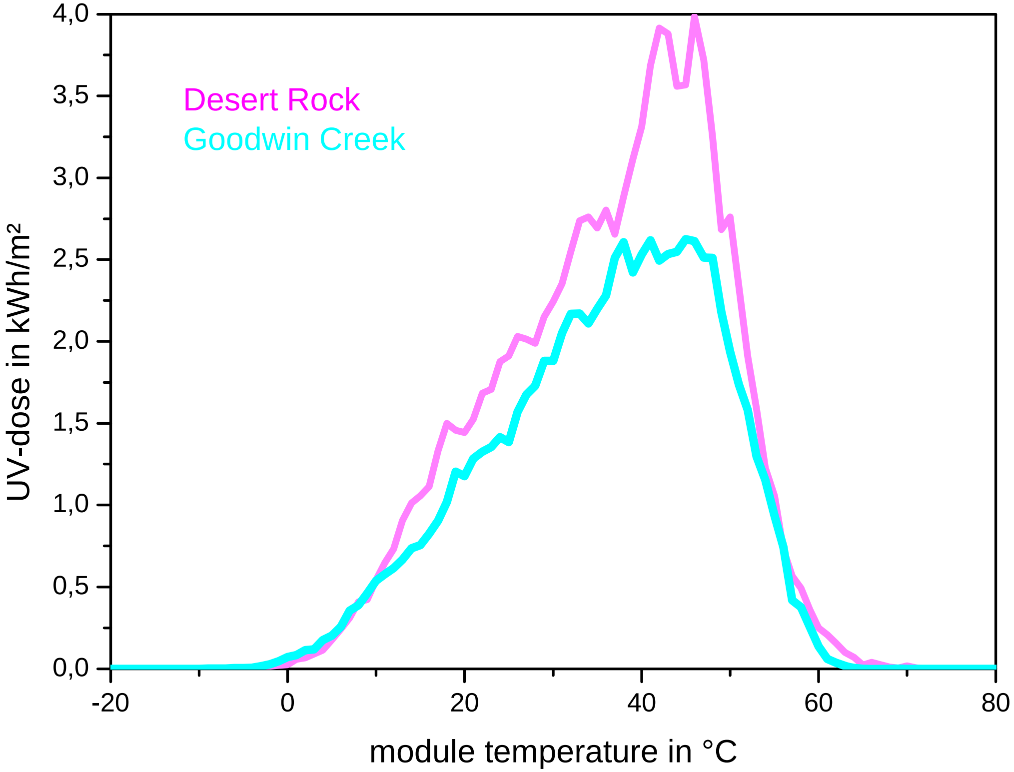
Europe => 1250kWh/m²

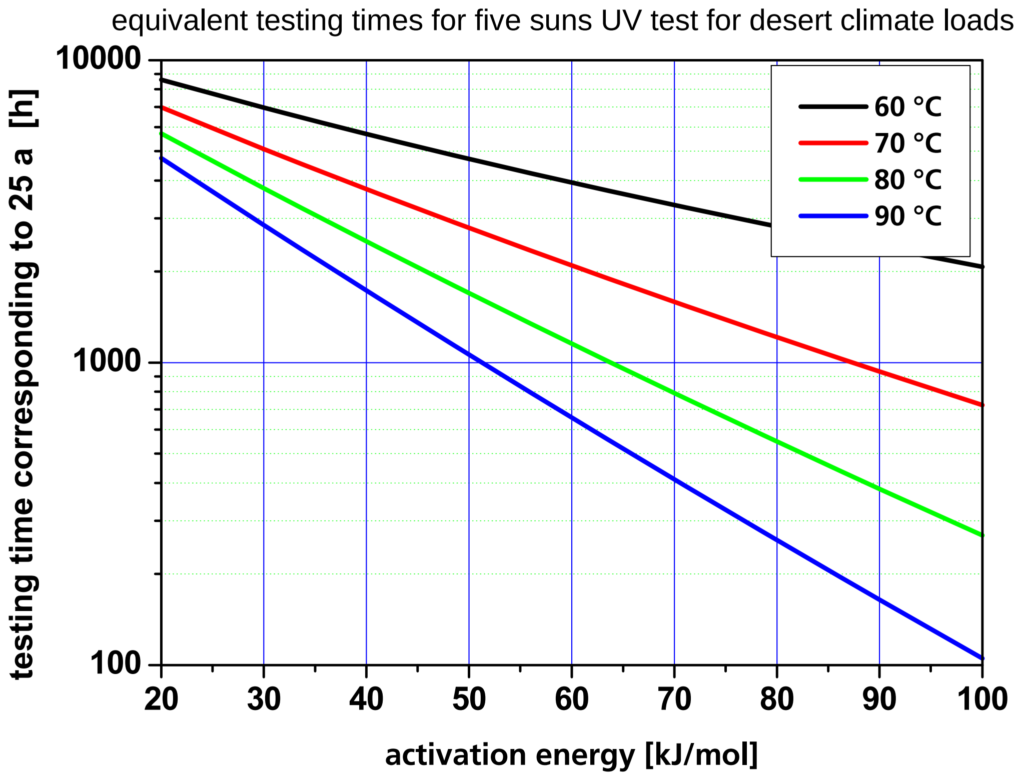
Reciprocity: p = 1

$$t_{test} = (I_i / I_{test})^p \, \Delta t_i \cdot \exp[-(E_a / R)\cdot(1/T_{test} - 1/T_i)]$$



4-5 suns and elevated temperature





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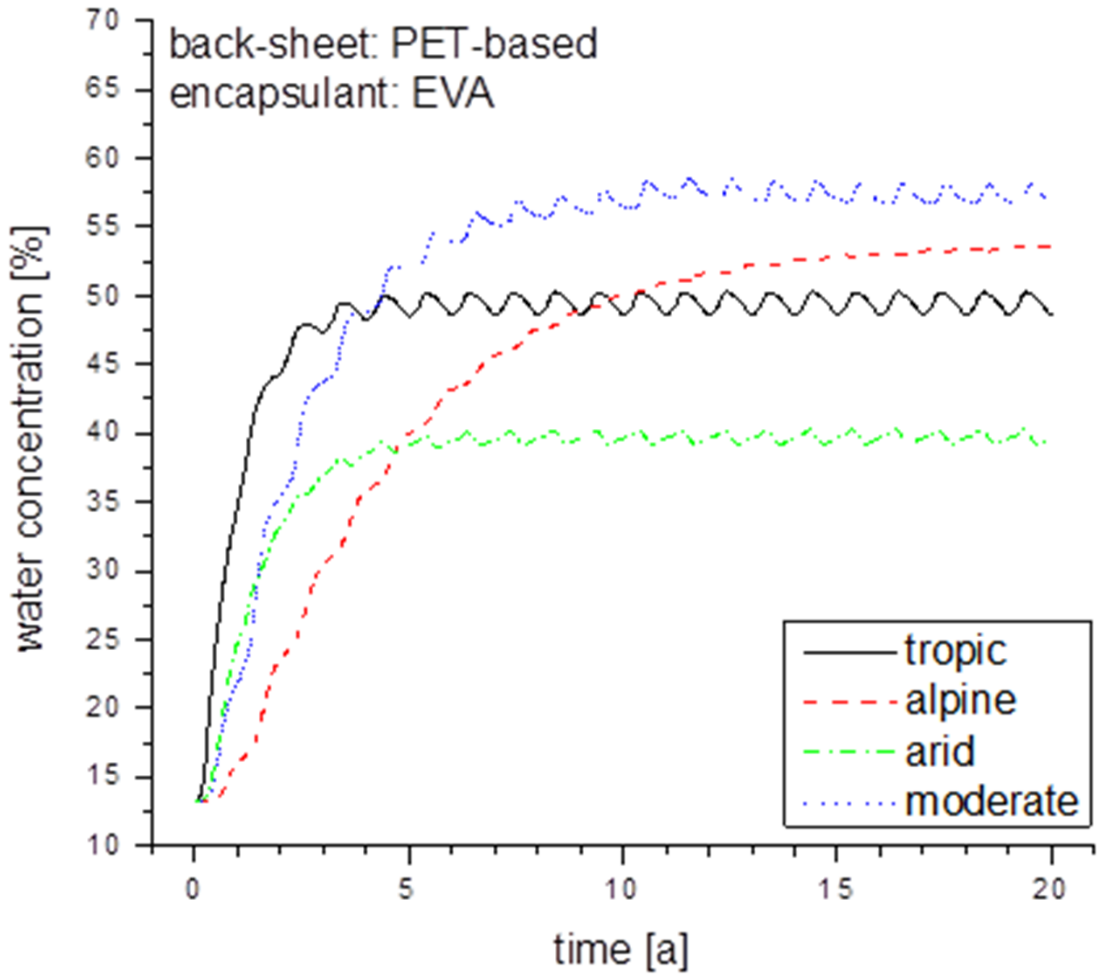
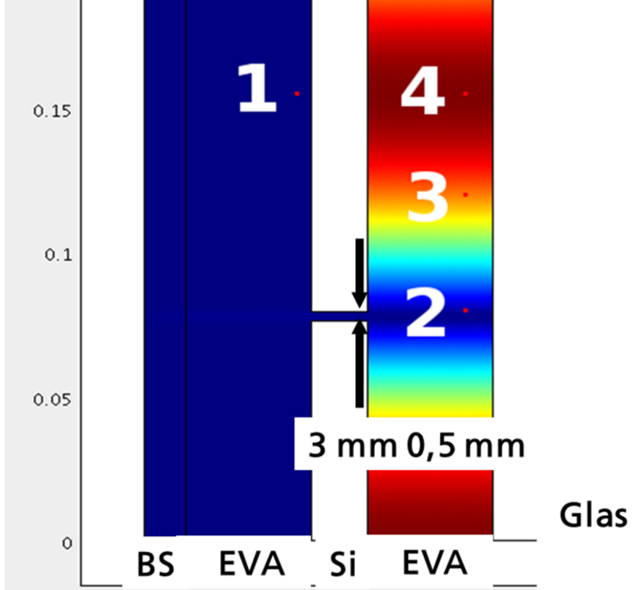
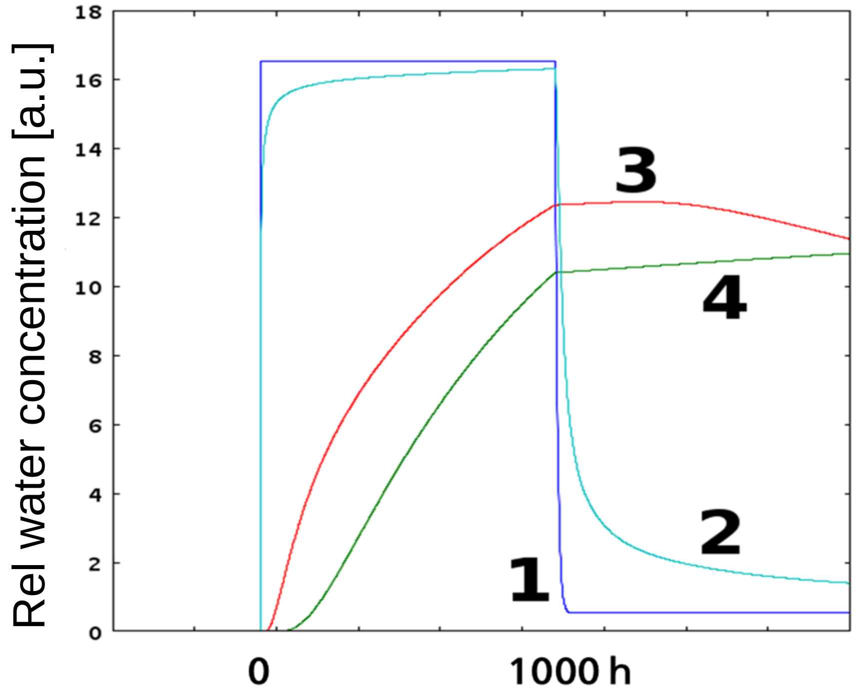
3 Modeling micro-climatic stress factors

Simulation of module humidity by FEM based on measured temperature dependent permeation/diffusion coefficients







Damp-heat testing 85%rh @ 85°C

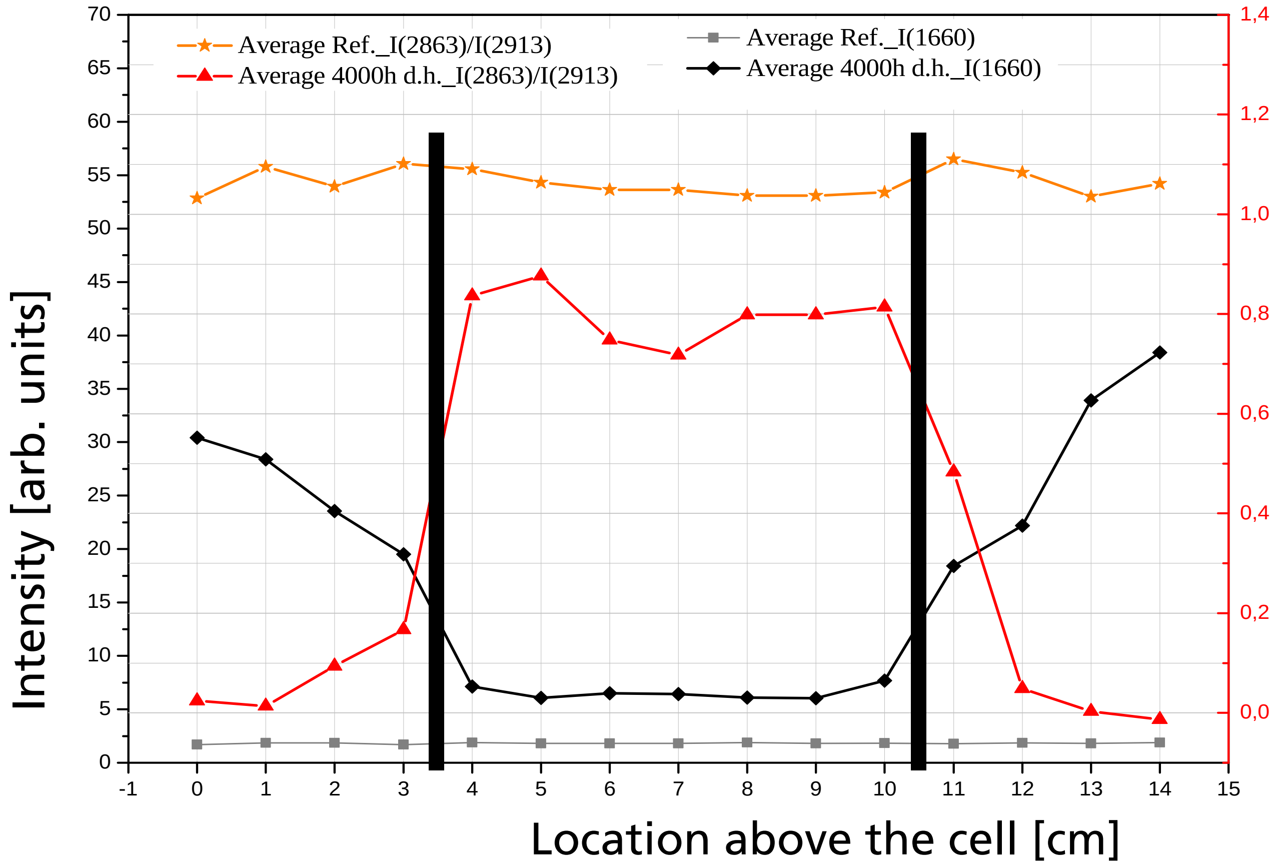
J. Wirth, Diploma Thesis, University of Freiburg, 2008.

J. P. Hülsmann et al., "Simulation of Water Vapor Ingress into PV-Modules under Different Climatic Conditions," Journal of Materials, vol. 2013, doi:10.1155/2013/102691

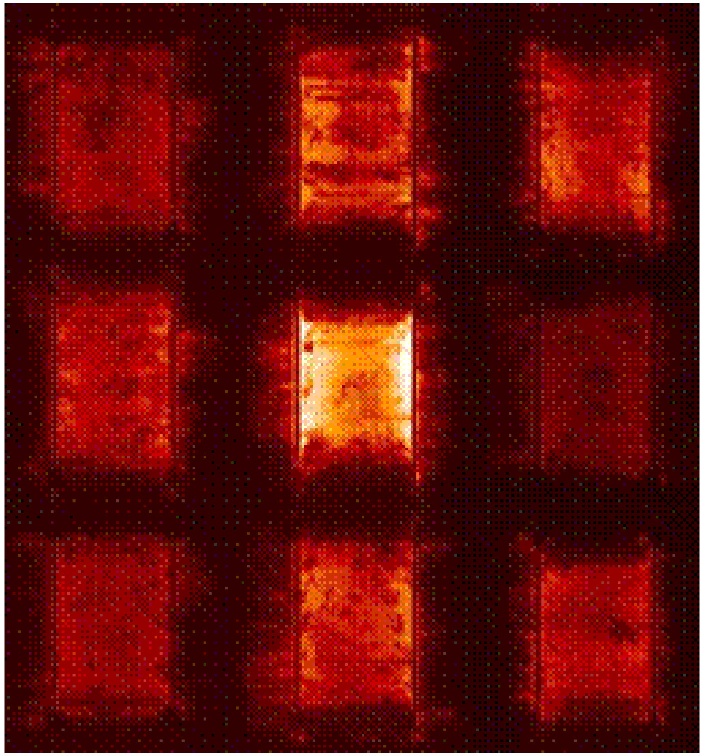
Degradation of the modules

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)

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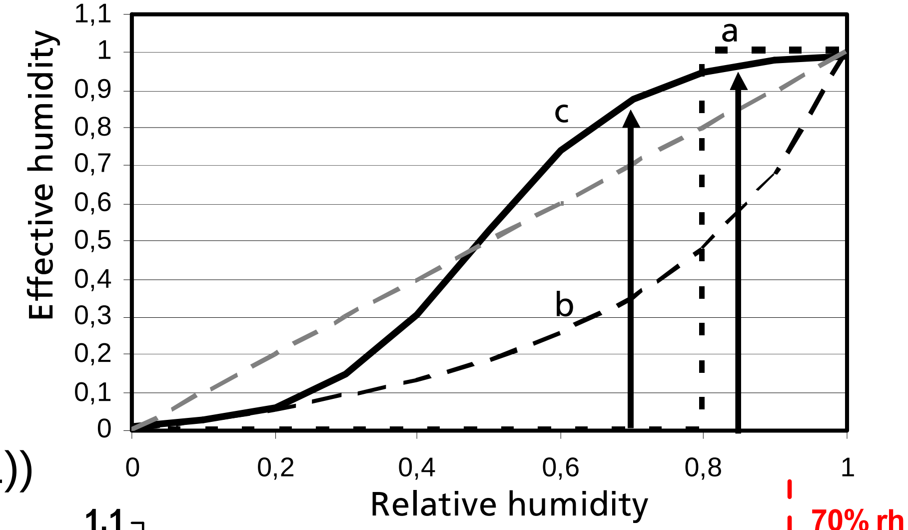
3 Evaluating micro-climatic stress factors

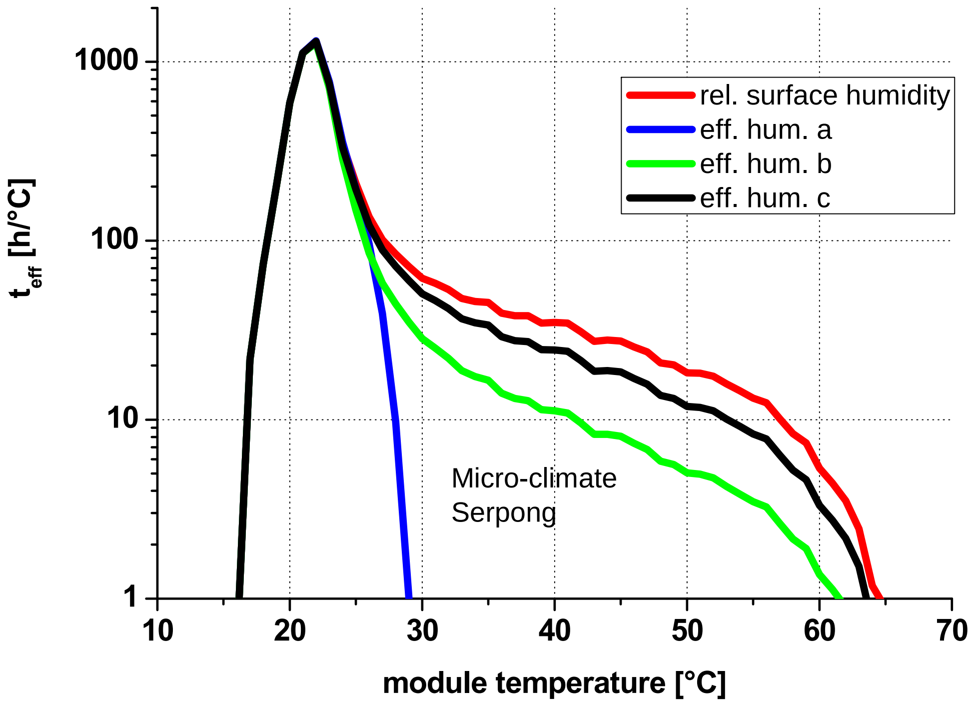
a) TOW: $rh_{eff} = 1$ for $rh > 0.8$

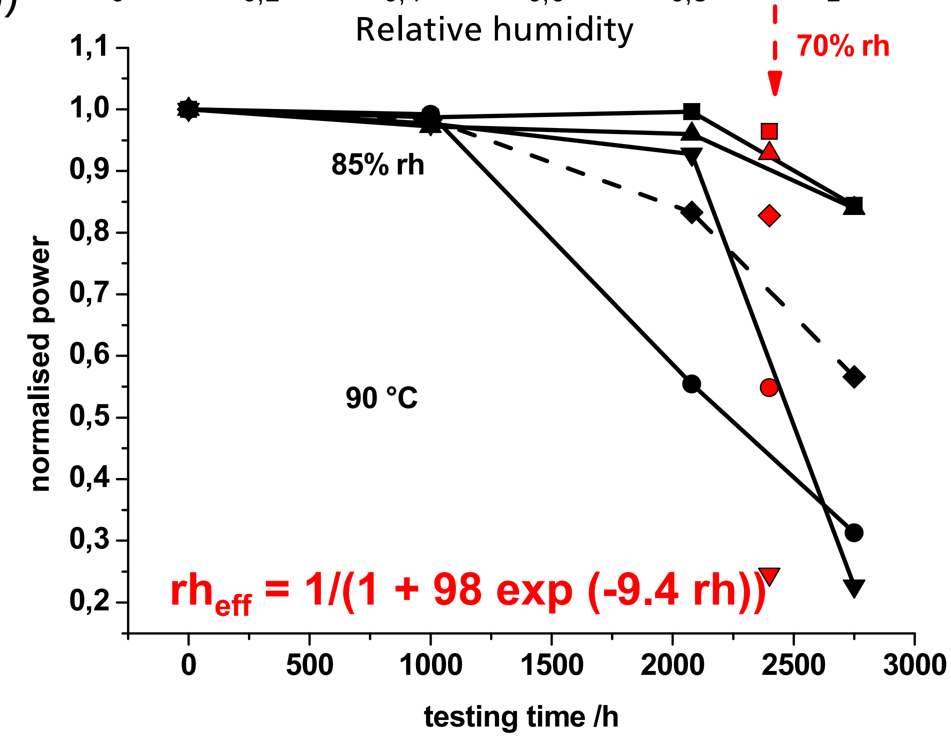
b) An effective humidity was proposed for polycarbonate: $rh_{eff} = 0.3 \cdot rh / (1.3 – rh)$

c) sigmoidal growth function

$$rh_{eff} = G/(1+ \exp(-G*rh*k) *(G/f(0)-1))$$







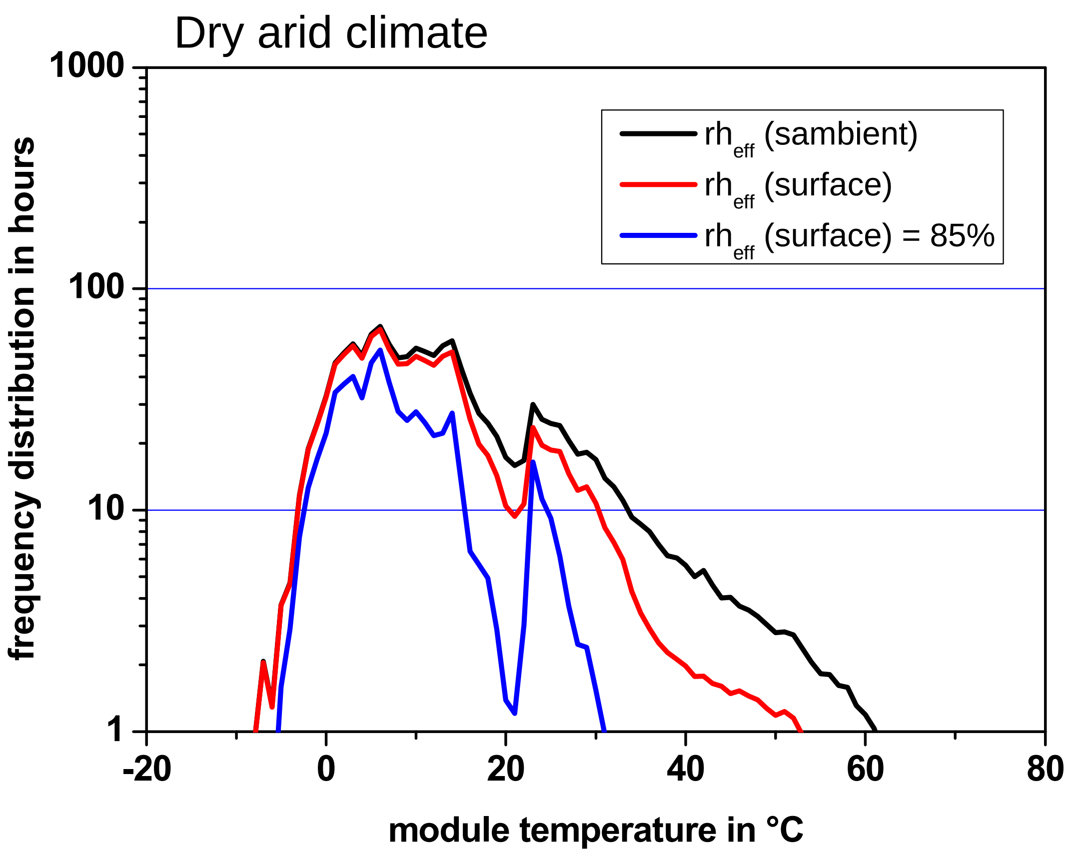
M. Koehl et al. / Solar Energy Materials & Solar Cells 99 (2012) 282–291

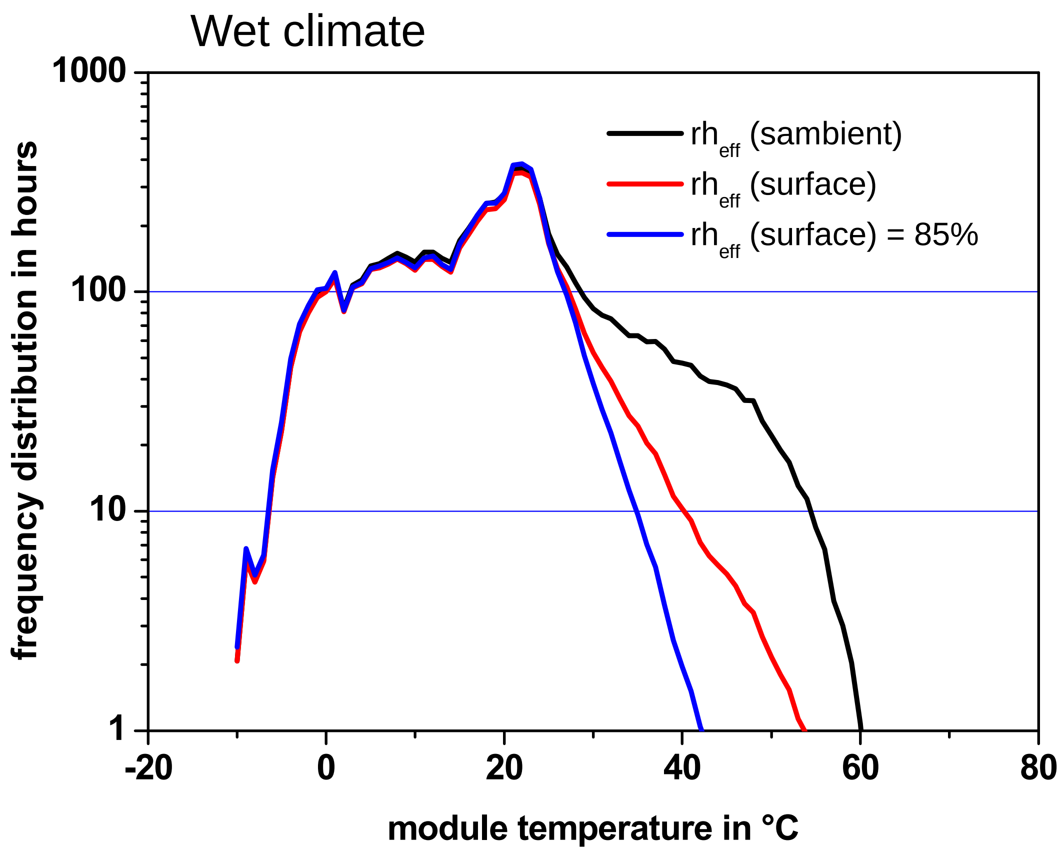
3 Modeling micro-climatic stress factors for given climate

1.) $rh_{eff} = 1/(1+ \exp(-9{,}4rh) \cdot (1/0{,}01-1))$ effective humidity gives more weight to periods with high rh

2.) $rh(T_{of}) = rh(T_{amb}) * P_{sat}(T_{of}) / P_{sat}(T_{amb})$ takes into account the higher module temperature

3.) $\Delta t_{85} = \Delta t * rh_{eff} / 0{,}85$ relates to the moisture level during testing





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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:

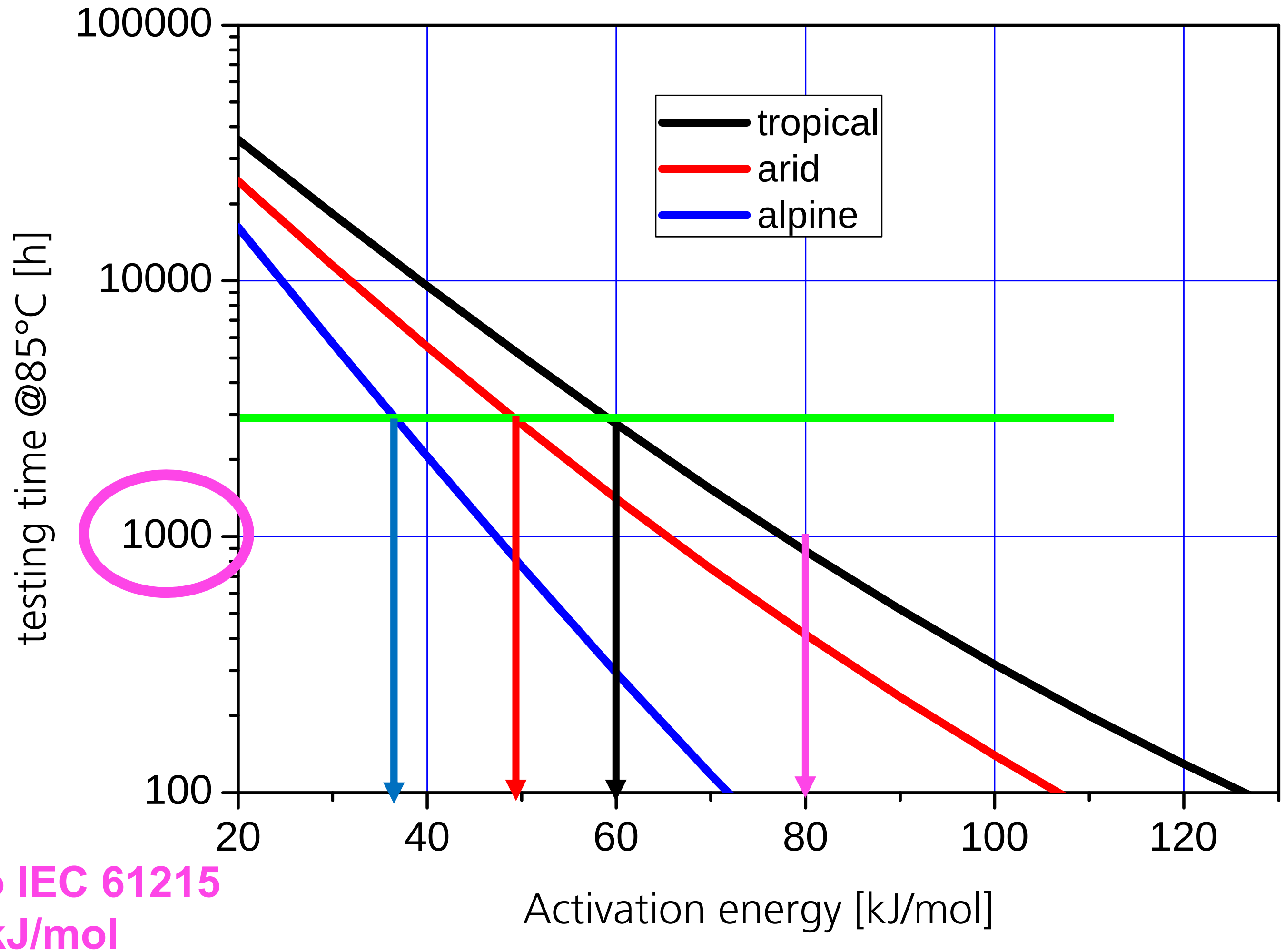
Time to failure @ 85°C/85%rh:

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 according to IEC 61215 would be sufficient for E_a > 80 kJ/mol

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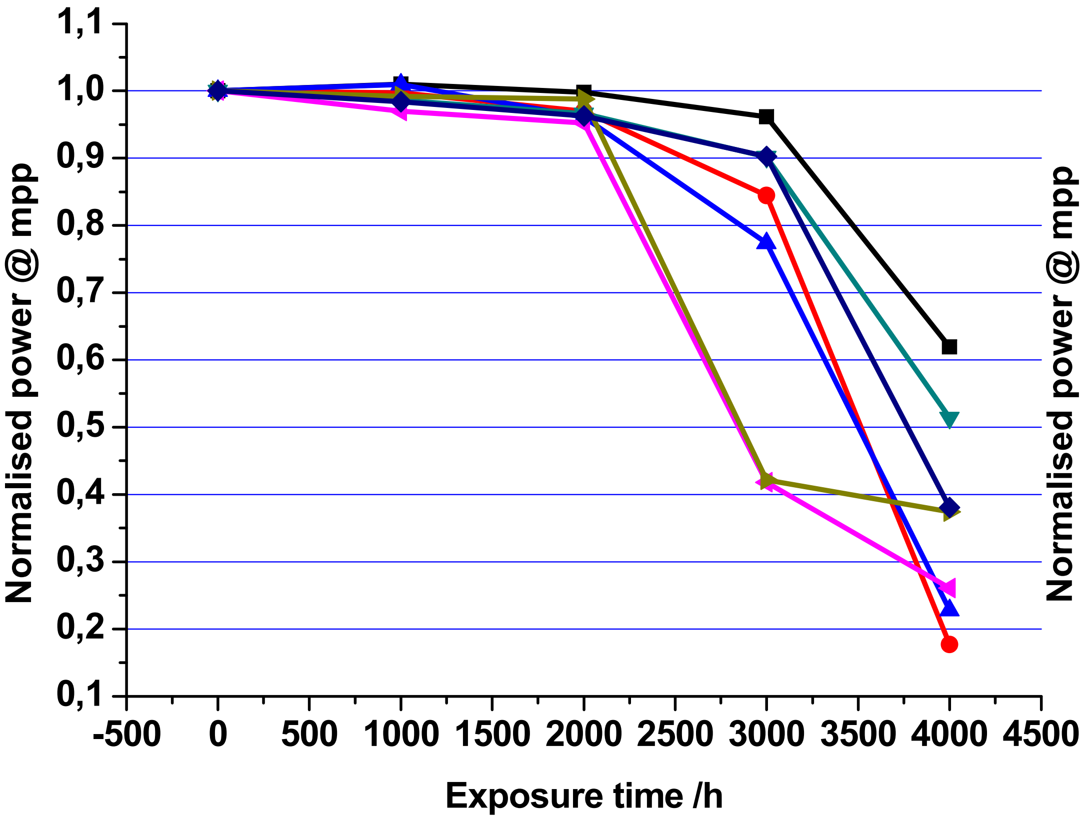
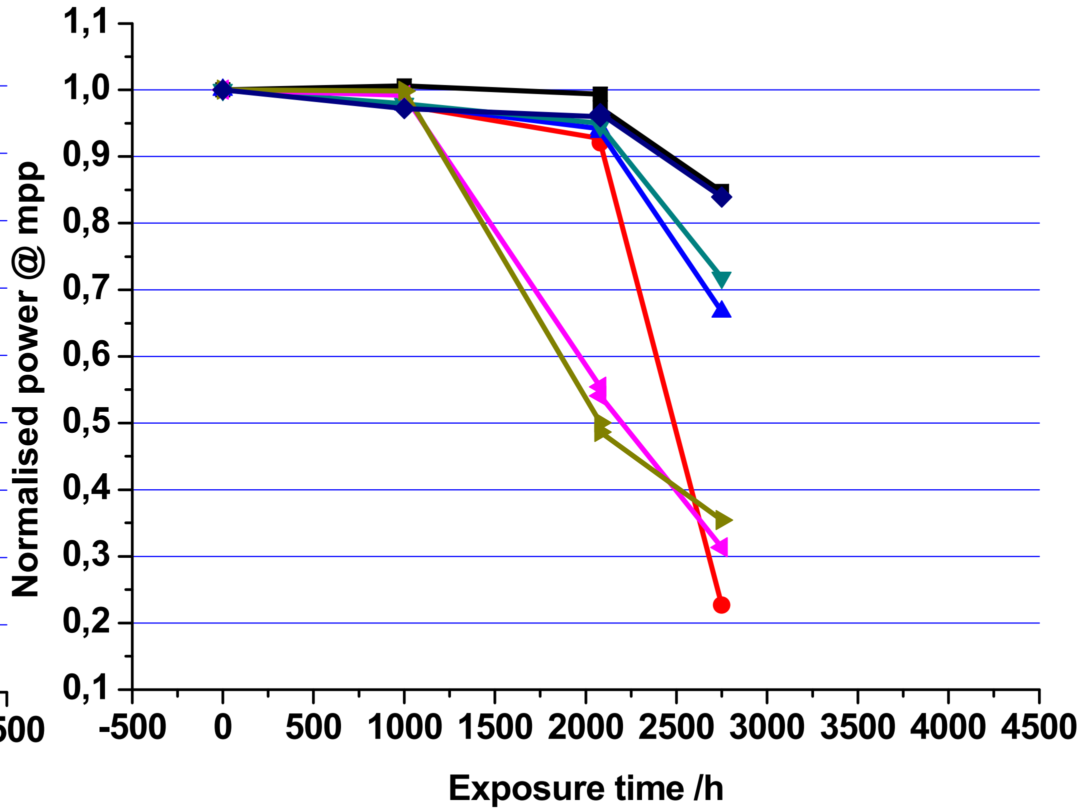
6 Evaluation of the parameters for time-transformation functions by ALT

Testing of c-Si modules from 7 different manufacturers

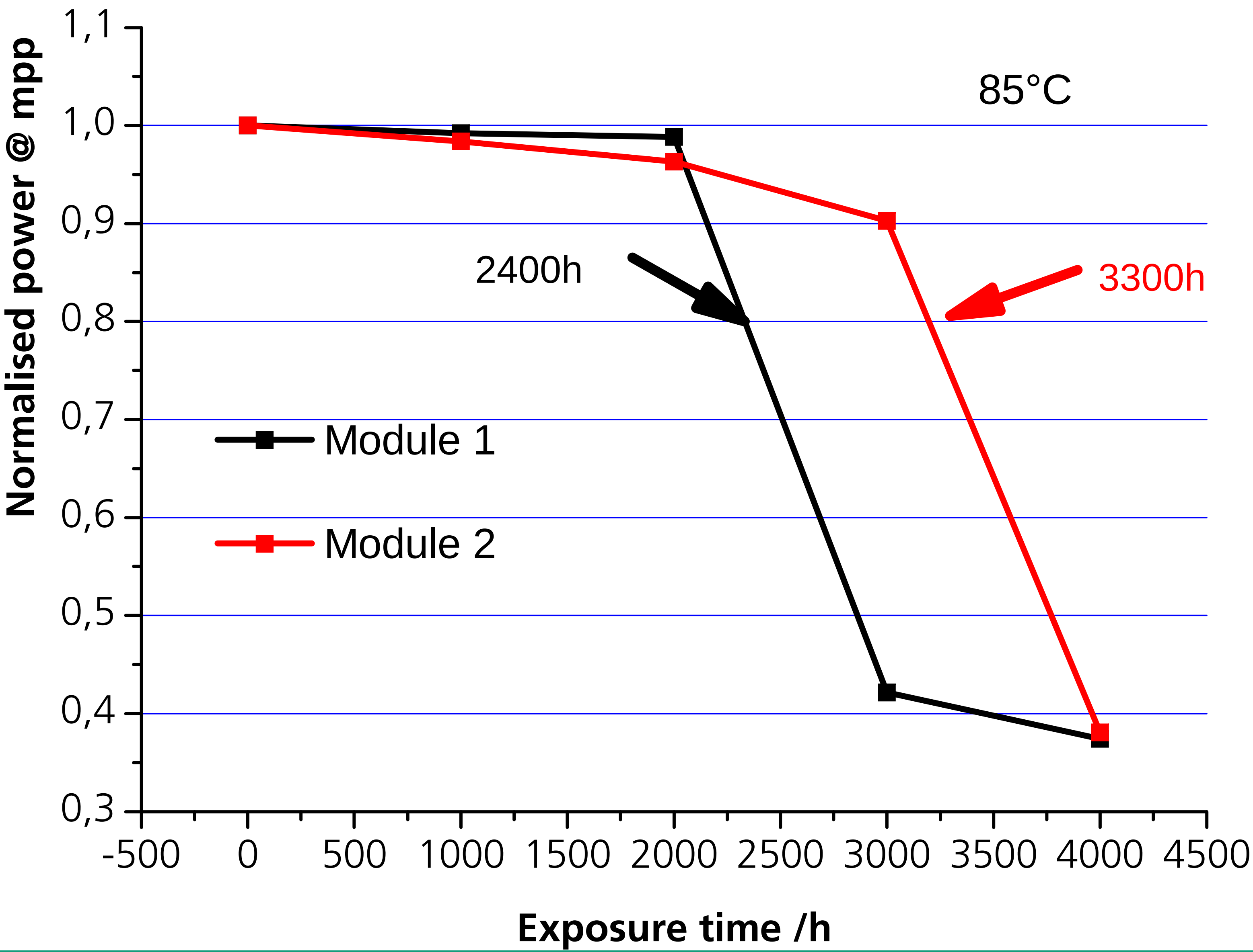
Damp-Heat at **85°C** and 85% rel. humidity



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

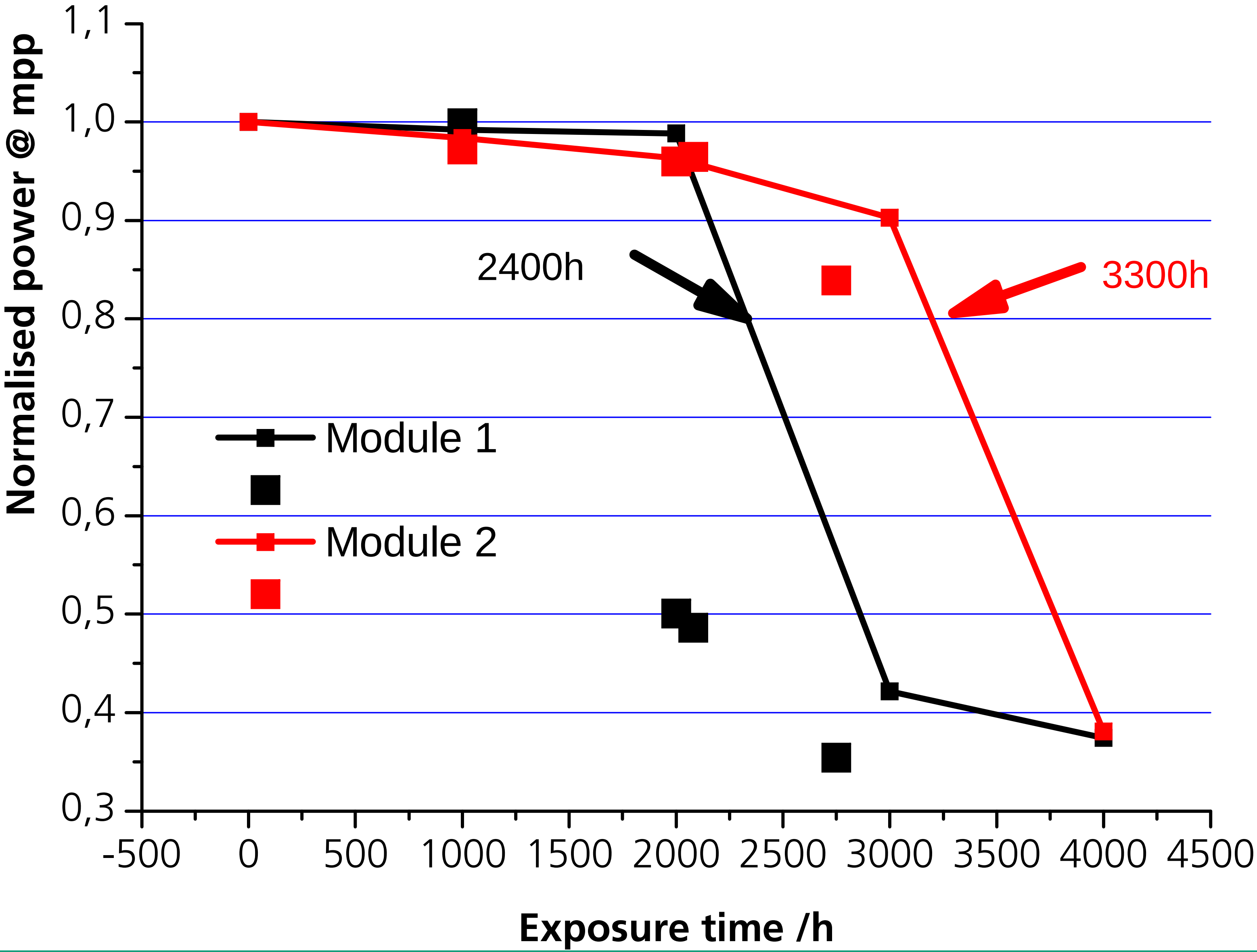


Damp-heat testing at 85%rh@85°C, module 1 und module 2



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



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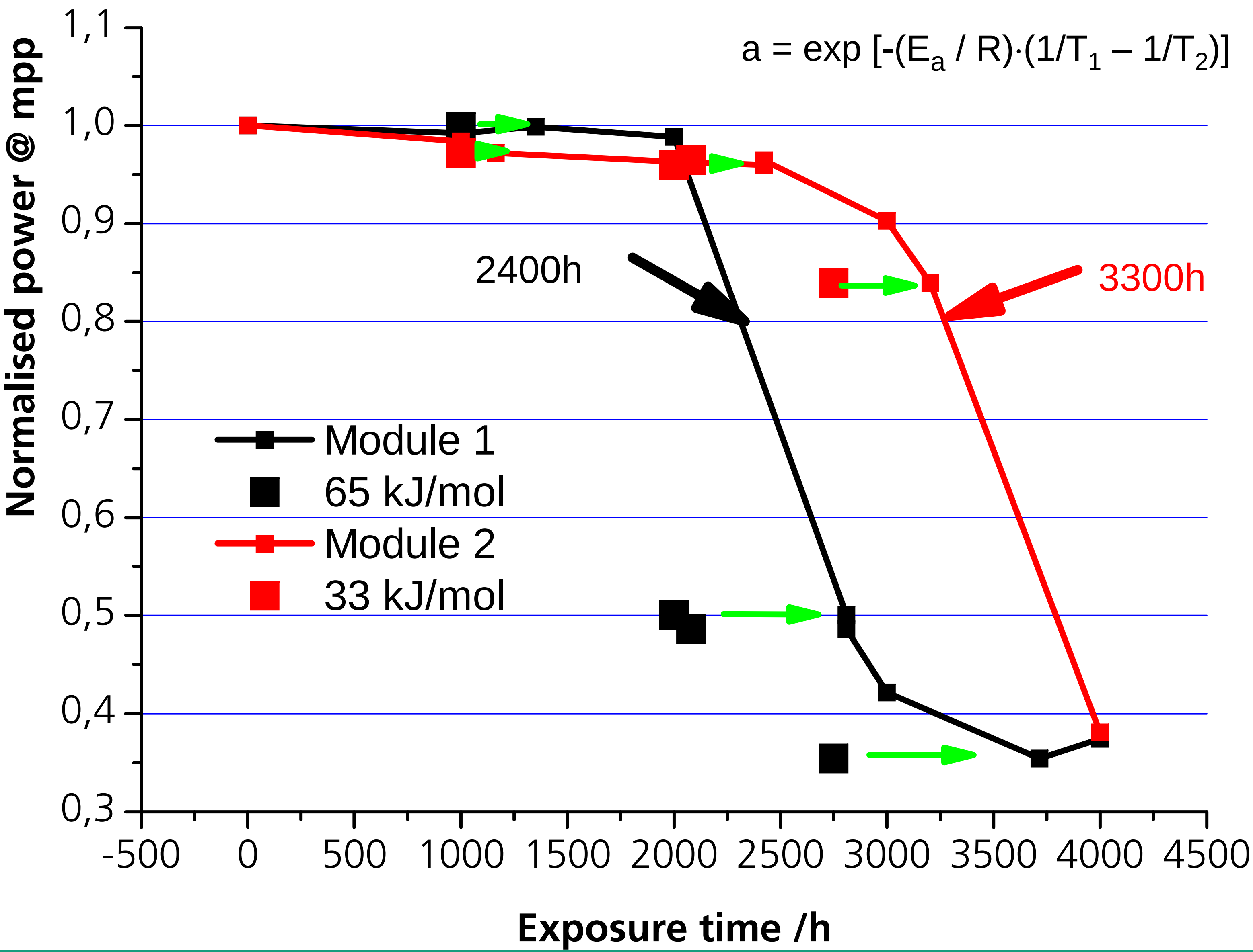
Damp-heat testing at 85%rh@85°C and @90°C, module 1 und module 2



6 Evaluation of the service life time in different climates

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

Time to failure 3300h

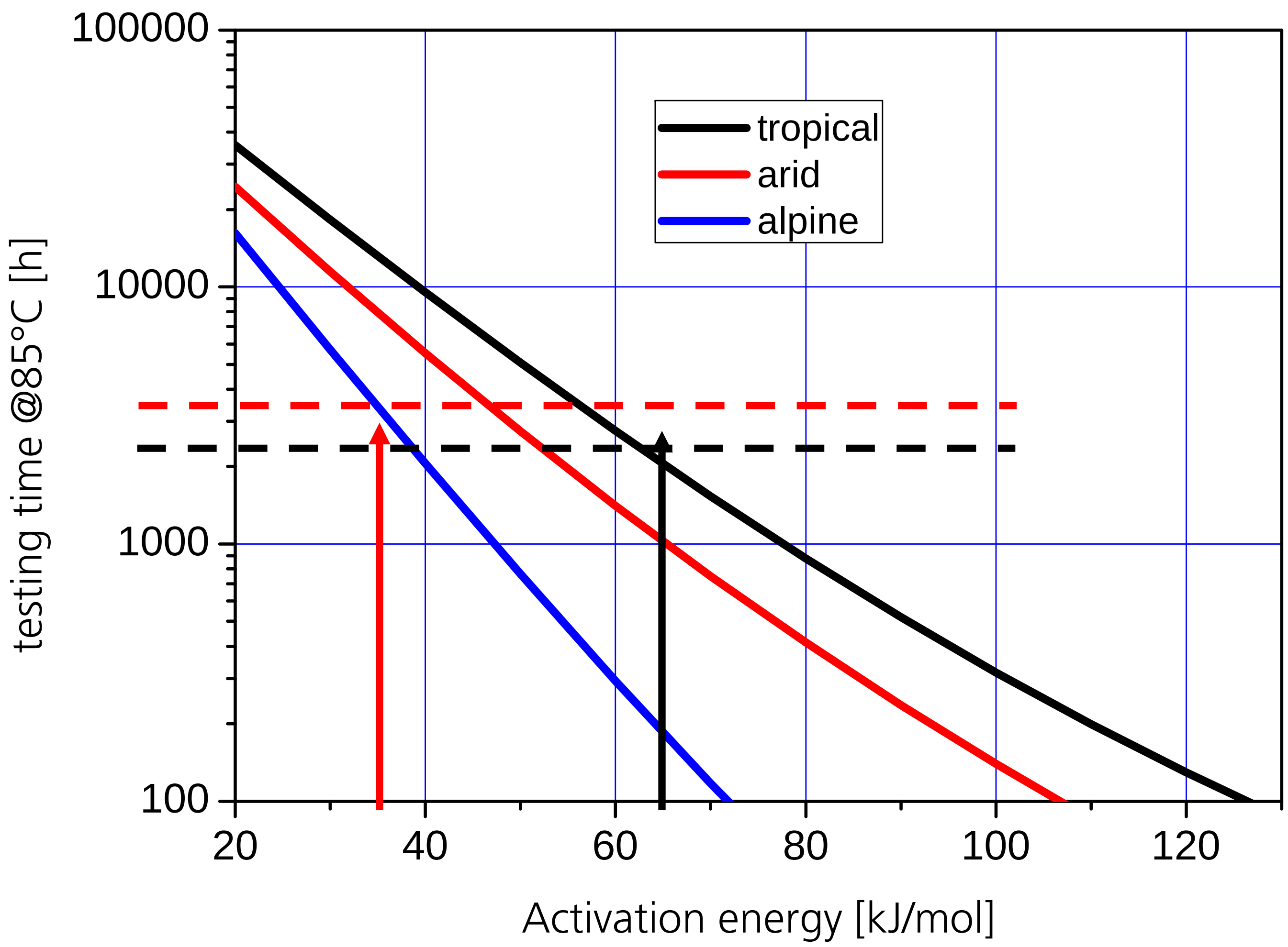
E_a > 35 kJ/mol

=> for alpine climates

Time to failure 2400h

E_a > 65 kJ/mol

=> for tropical climates



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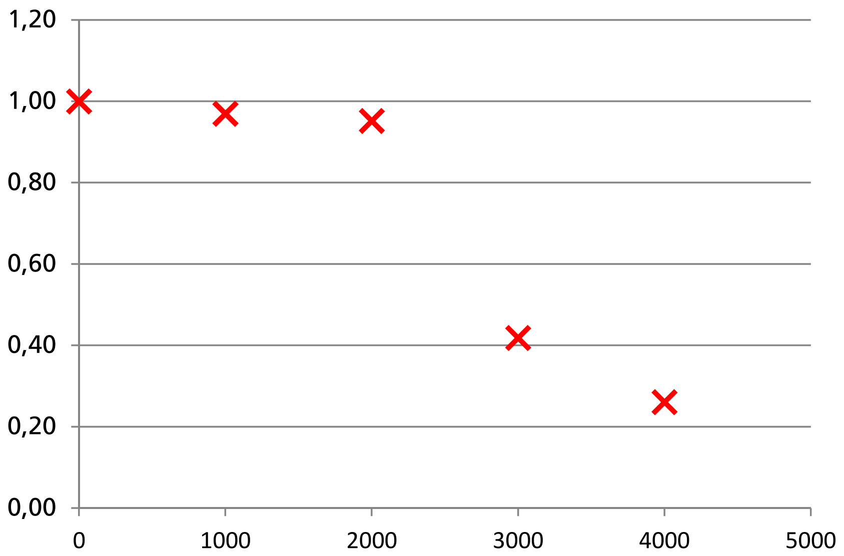
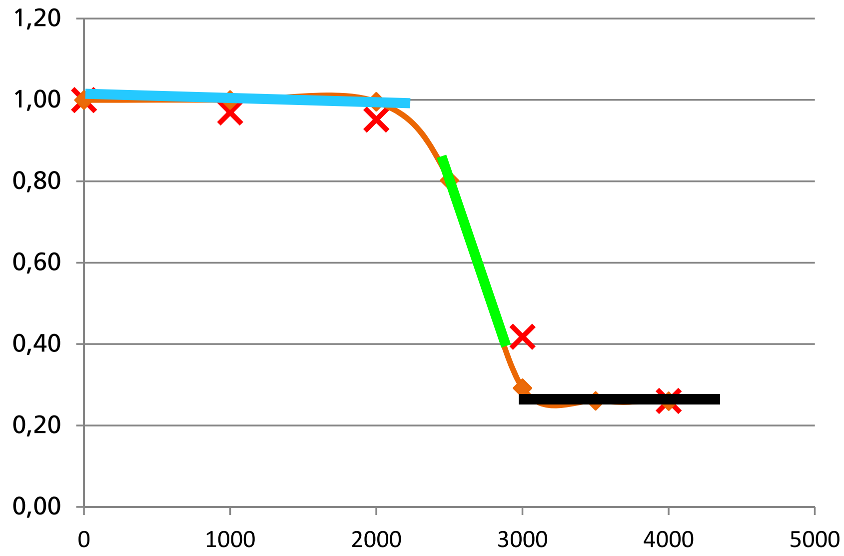
6 Evaluation of the parameters for time-transformation functions by ALT

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



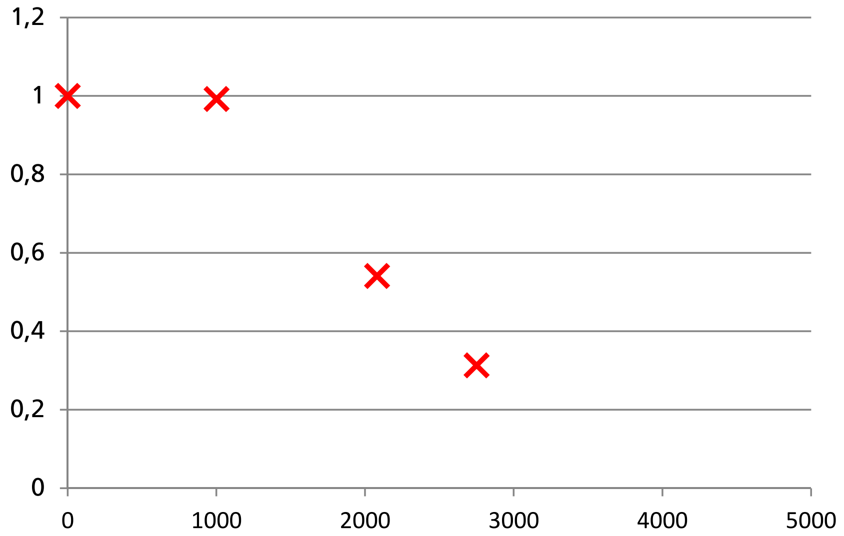


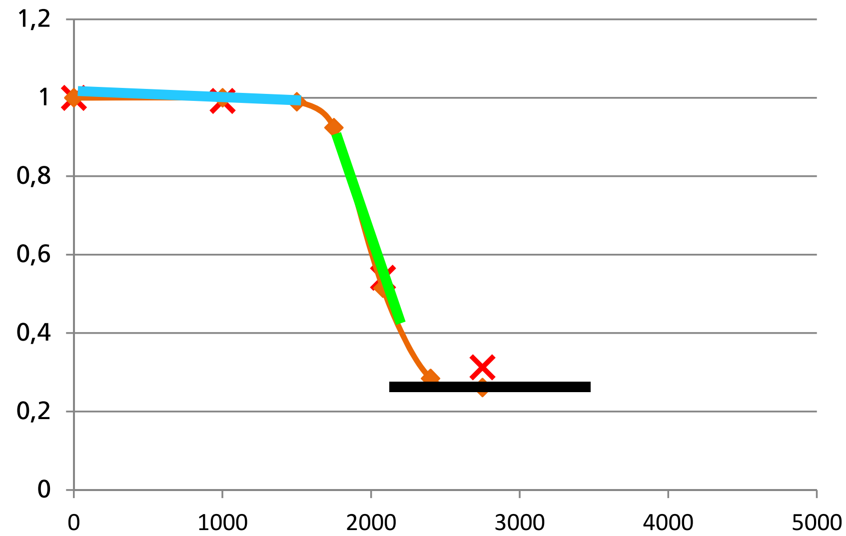
T=85°C

Tind=2100h

K=0,0082/h

G=0,26





T=90°C

Tind=1500h

K=0,0115/h

G=0,26

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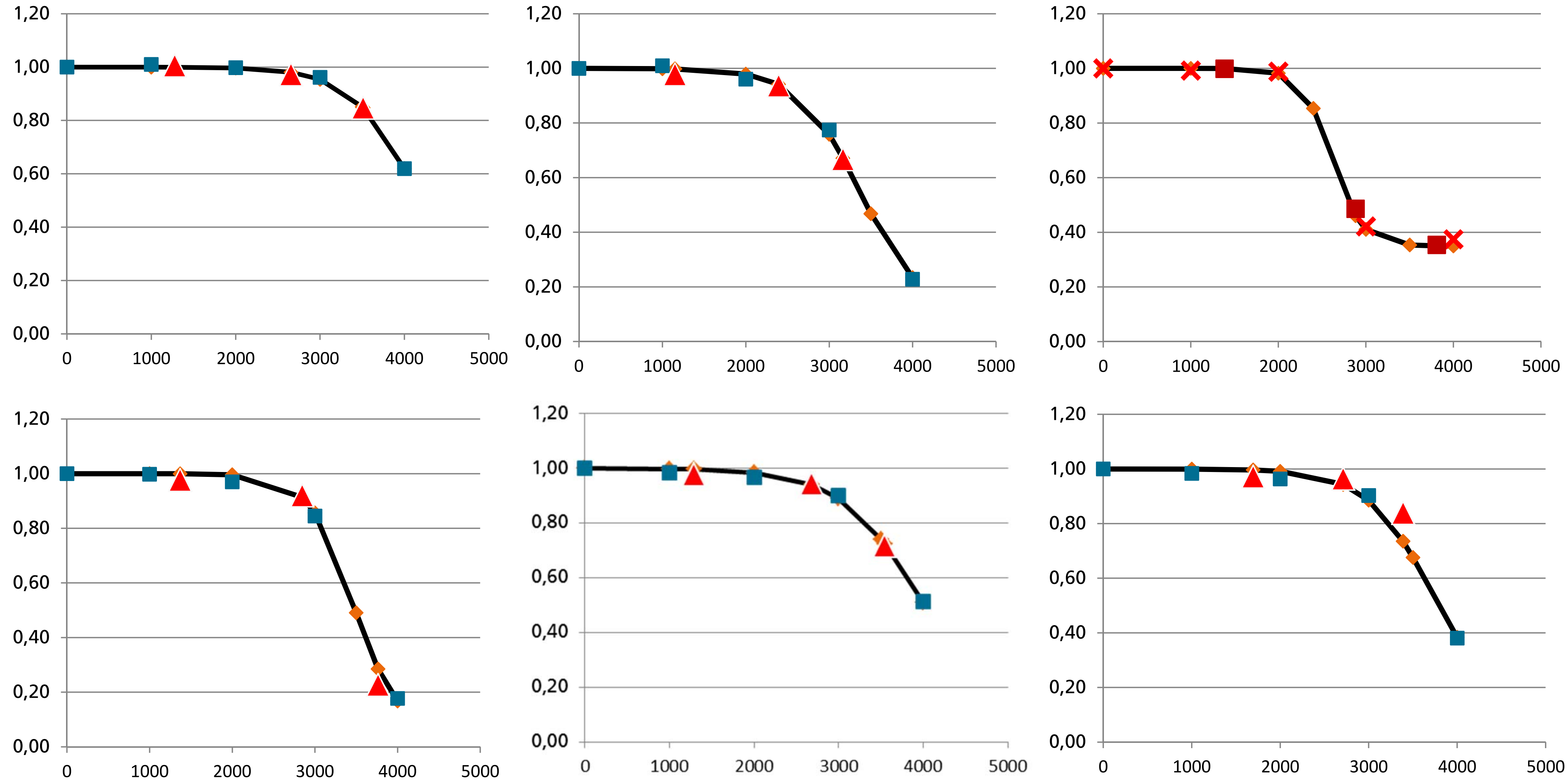


Lifetime (@85°C) [h]	2412	2576	2821	3047	3160	3227	3548
Activation energy [kJ/mol]	70	73	30	68	26	55	53
Climate class	A	A	C	A	C	B	B

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

6 Evaluation of the service life time for different climates

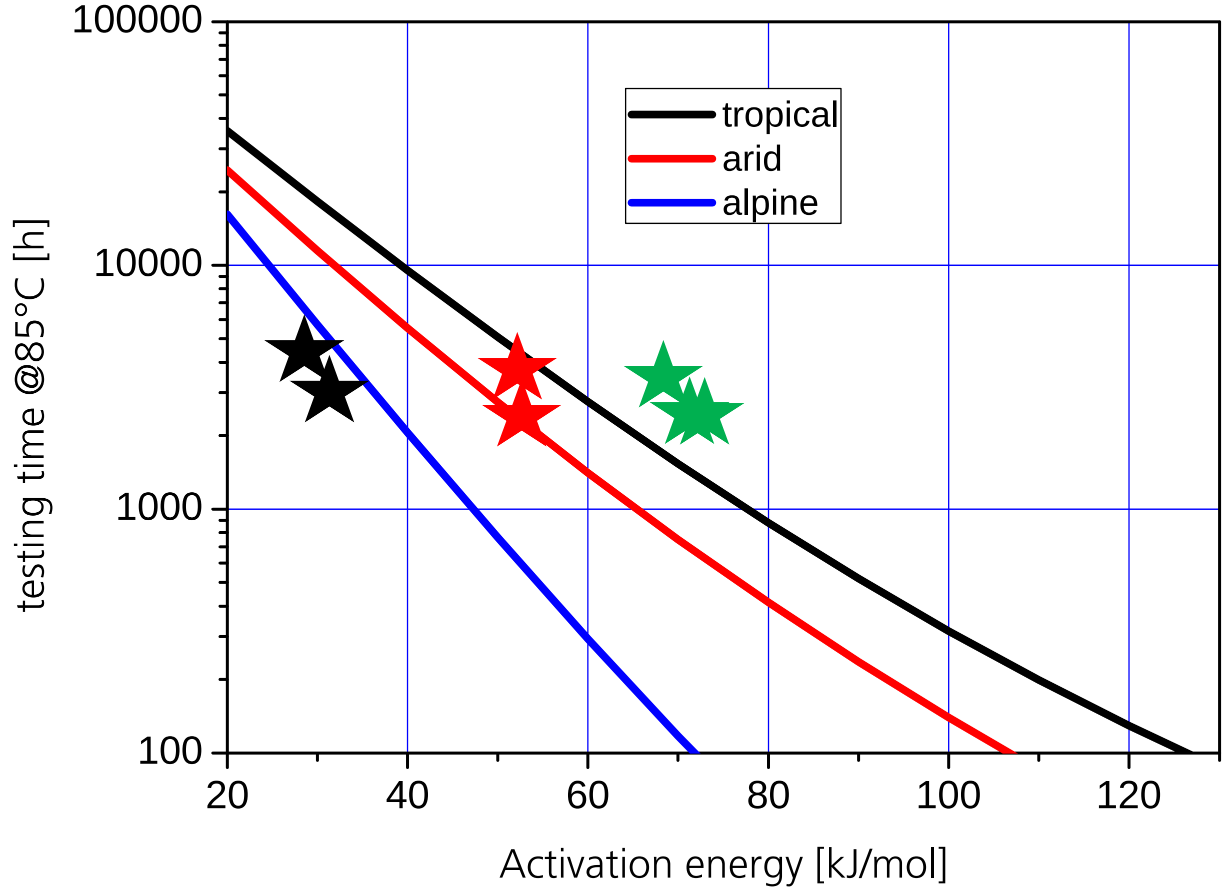
Testing time at 85%rh/85°C for 25 years lifetime

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

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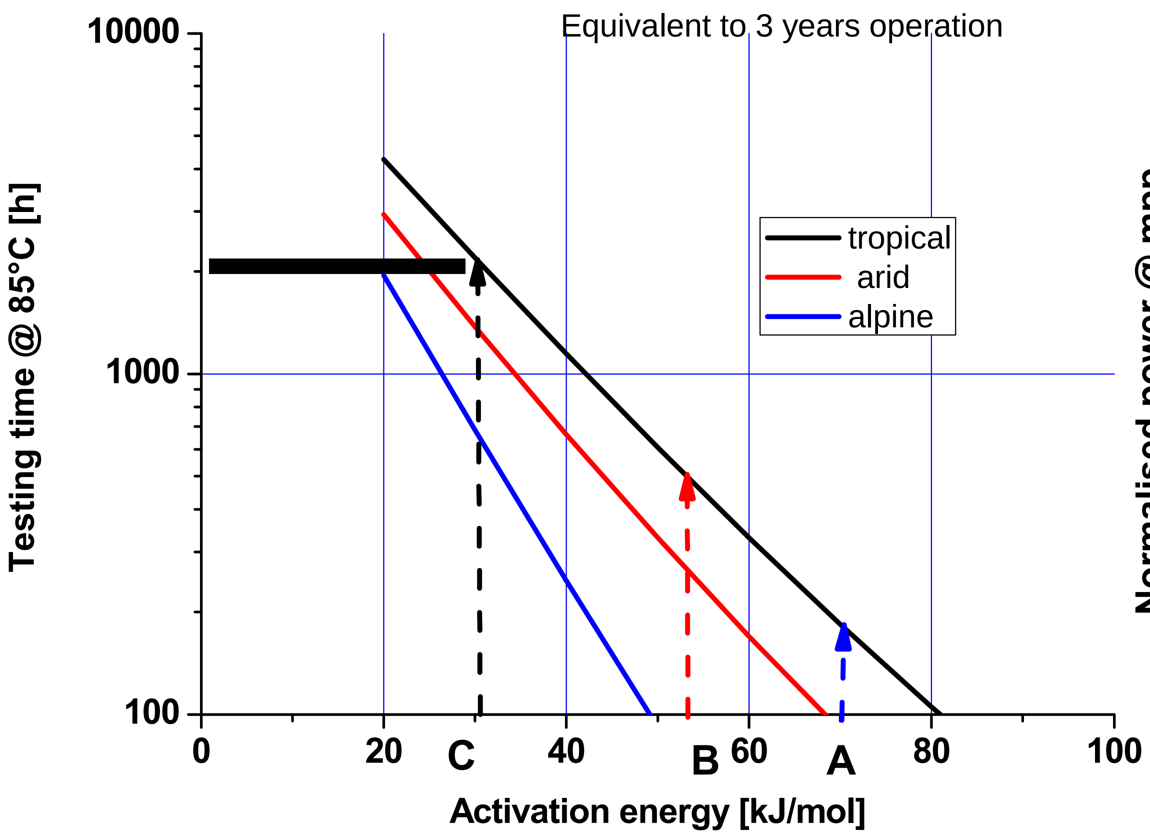
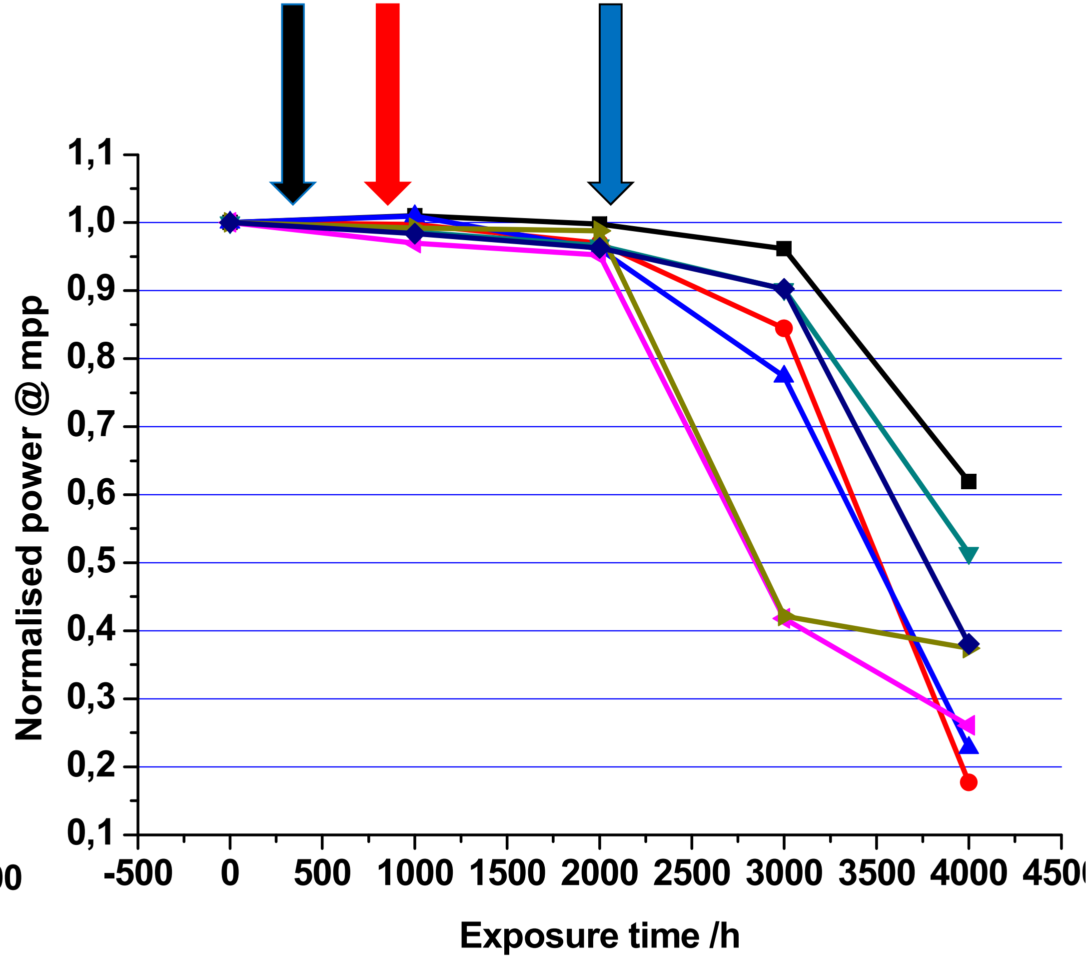
7 Modeling expected degradation for validation by outdoor exposure

Power reduction after 3 years outdoor exposure < 3%

Exposure time has to be doubled





7 Degradation effects during outdoor exposure

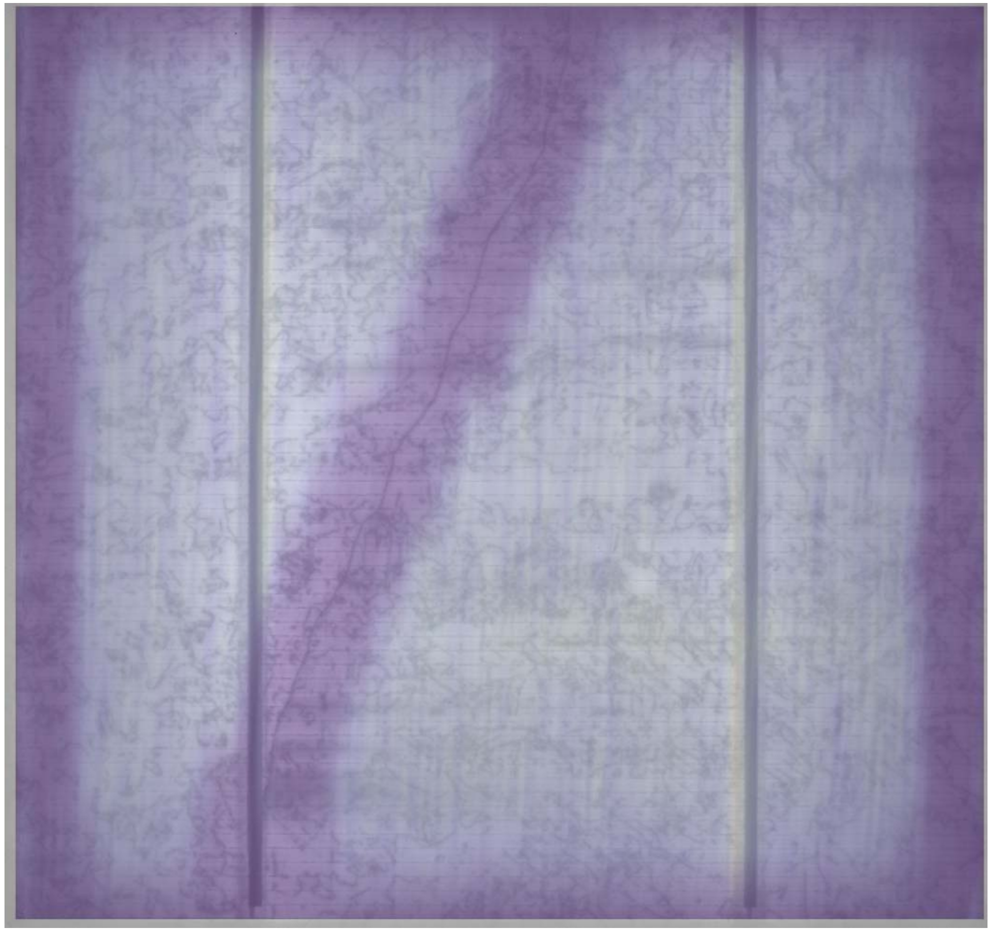
Changes of the electrical performance at the outdoor exposure site

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

Degradation of module materials - UV-induced fluorescence

2 a alpine outdoor exposure

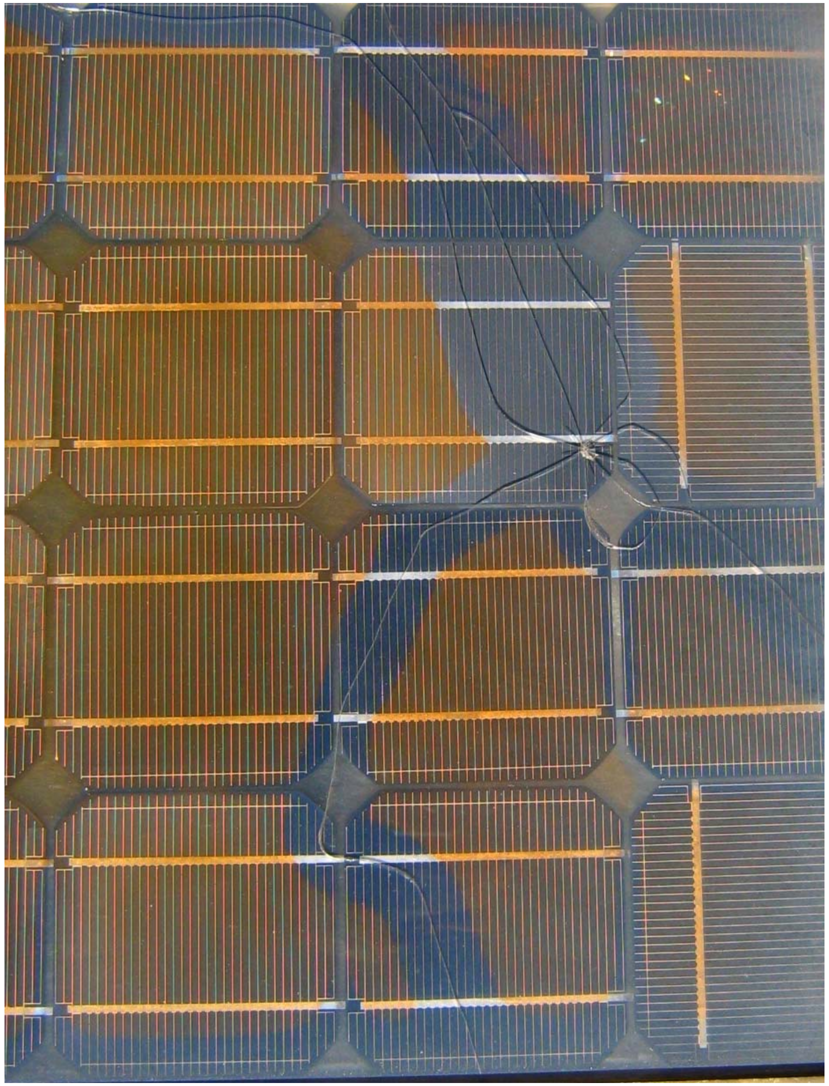


2 a desert outdoor exposure

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

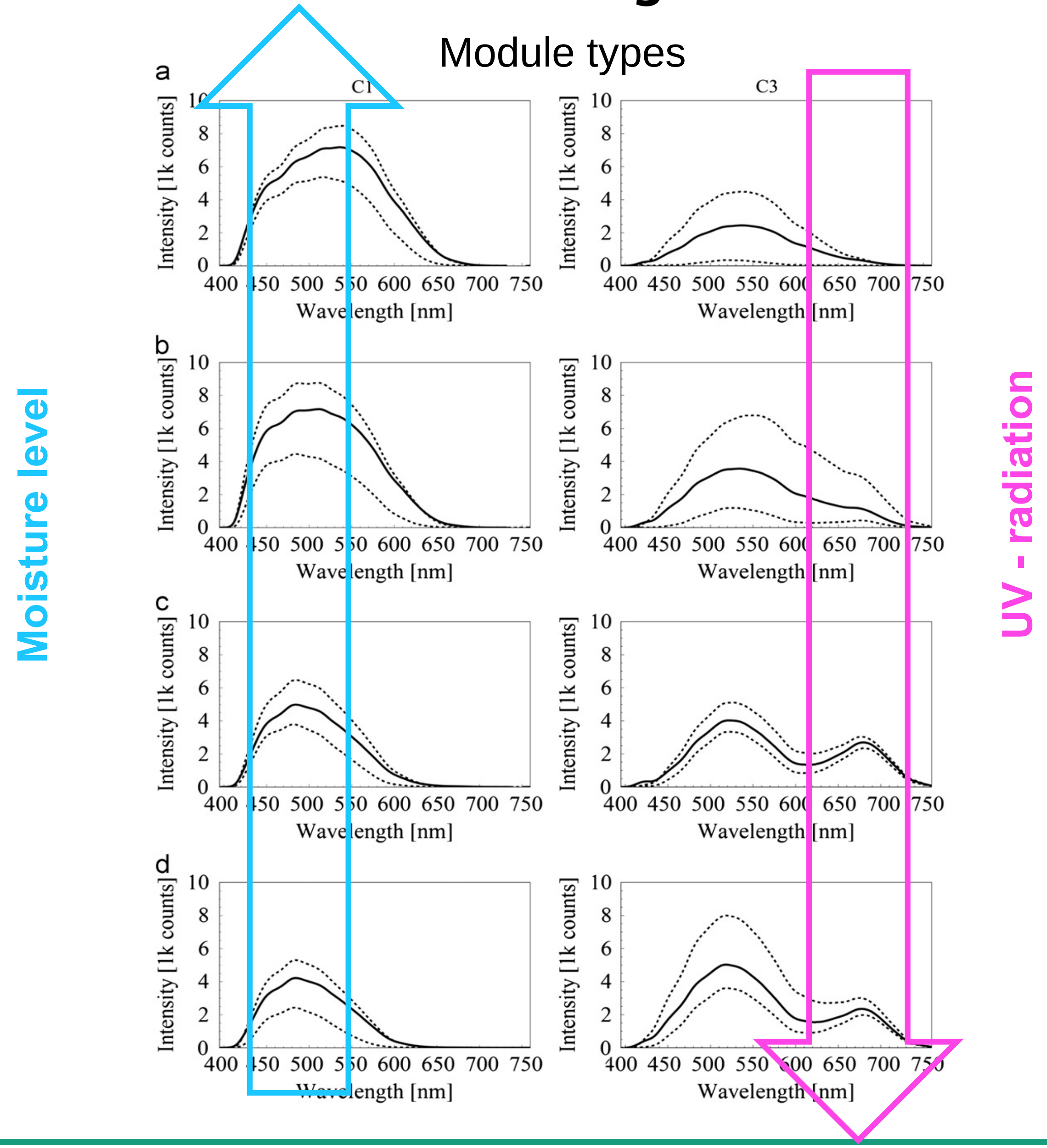
Browning and photo-bleaching - UV-induced fluorescence



2 a desert outdoor exposure

Combination of electroluminescence and fluorescence

Effect of outdoor weathering on fluorescence spectra



a) Tropical

b) Arid

c) Moderate

d) Alpine

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

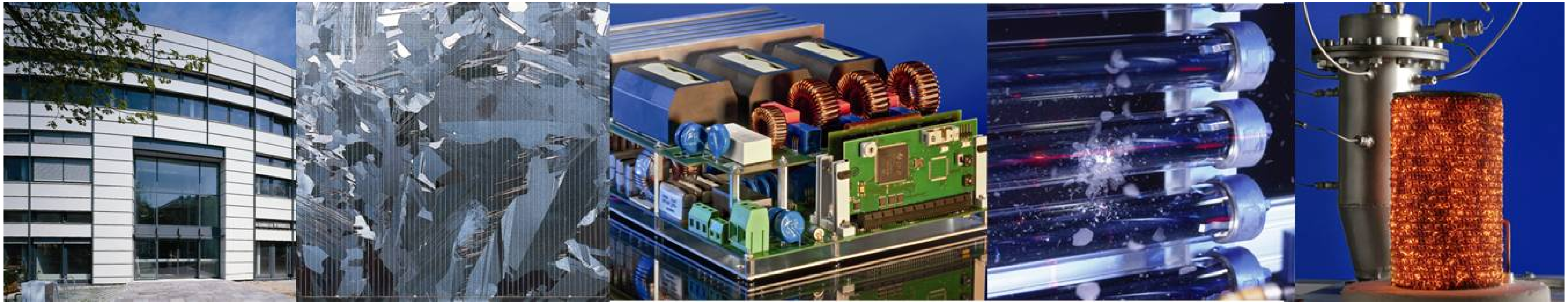
- Based on monitored climatic data
- Modelled micro-climatic stress conditions
- Modelled kinetic of the degradation processes

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

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