Reliability of PV-modules

Natural, accelerated and simulated degradation
Projects PV-Zuverlässigkeit and Performance SP5

Michael Köhl
Fraunhofer ISE, Freiburg, Germany

Fraunhofer Institut Solare Energiesysteme

TÜVRheinland®
Genau. Richtig.

PV-Zuverlässigkeit **funded by BMU/PTJ and industry**

Project partners:

Fraunhofer ISE, Freiburg, DE

TÜV Rheinland, Cologne, DE

Industry involvement:

Schott Solar, DE
Scheuten Solar, DE
Solon, DE
Solarwatt, DE
Solarworld, DE

Focus:

Crystalline Silicon based modules

Encapsulating components

Duration: 1/2005 – 12/2008

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Develop ageing models based on `real life´ stress factors

Develop new accelerated ageing procedures

Facilitate innovation in module technology

Provide manufacturers with service life data for setting their guarantee specifications

Increase planning reliability for investors

Focus:

Duration: 1/2006 – 12/2009

Thin Film based modules

Encapsulating components

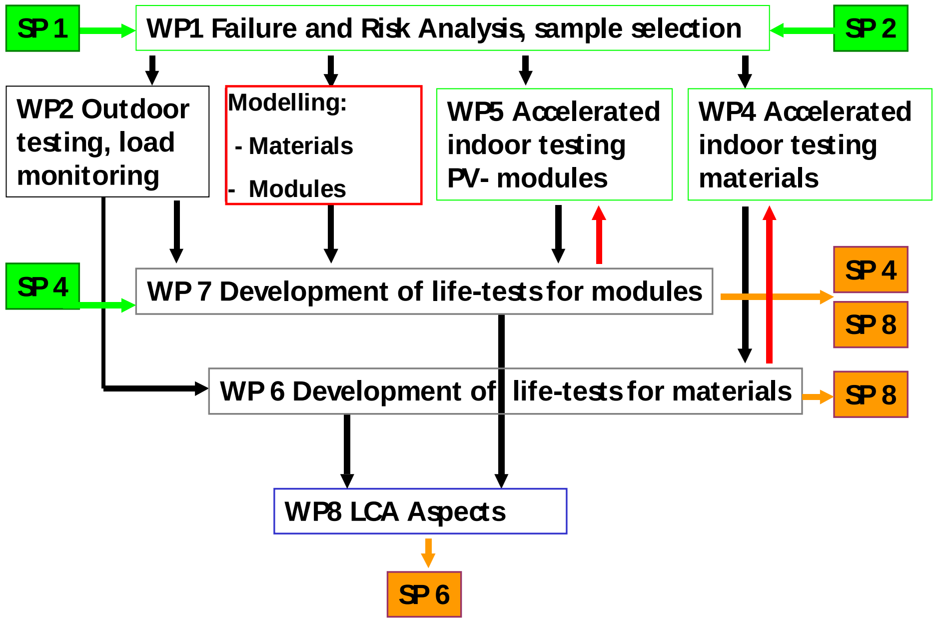
Project partners:

Fraunhofer ISE, Freiburg, DE
Joint Research Centre, Ispra, IT
TÜV, Cologne, DE
ECN, Petten, NL
ZSW, Stuttgart, DE
CREST, Loughborough University, UK
EPIA, Brussels, BE
GENEC, Cadarache, FR
SP, Boras, S
PCCL, Leoben, AT
Meteoconsult, München, DE
Schott-Solar, Alzenau, DE

Industry involvement:

Schott Solar, DE
Evonik, DE
Juraplast, DE
Flexcell, CH
Würth, DE
Sharp, J/DE
Avancis, DE
Unisolar, USA/DE
First Solar, USA/DE

PERFORMANCE SP 5: Service life assessment of PV-modules

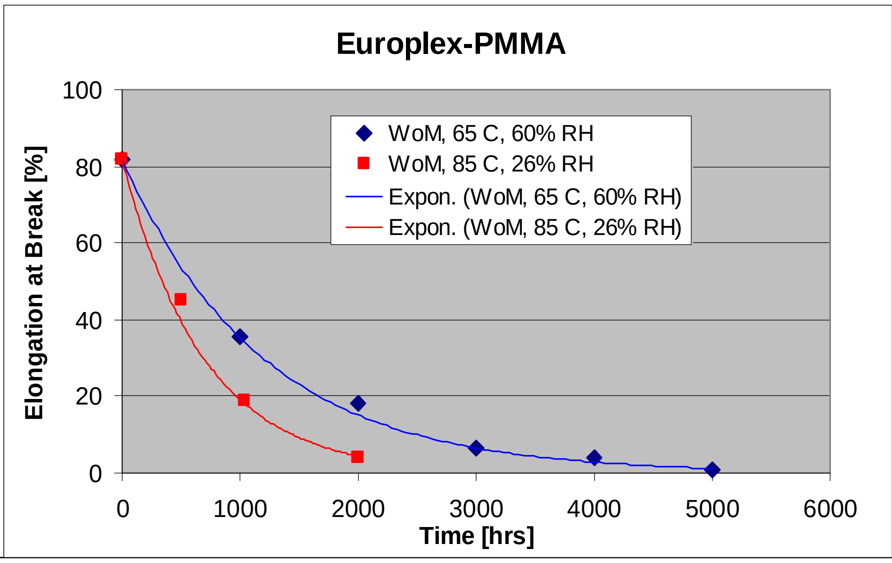


PERFORMANCE SP 5: Service life assessment of PV-modules

Candidate materials identified in WP 5:1

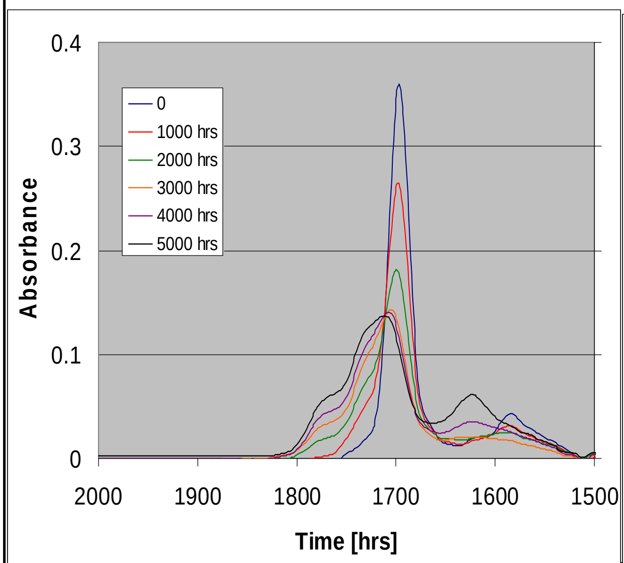
Name	Composition	Trade name	Manufacturer
	encapsulant		
EVA	ultra fast cure ethylene vinyl acetate	Vistasolar	Etimex (D)
Ionomer 1	ionised ethylene acrylic acid copolymer	Jurasol	Juraplast (D)
Ionomer 2	ionised ethylene acrylic acid copolymer	Jurasol	Juraplast (D)
	glazing/backsheet		
Europlex	coextruded PMMA-PVDF film polymethylmethacrylate (PMMA) polyvinylidenfluoride (PVDF)	Clear HC 99710	Degussa (D)
	backsheet		
TPT	PVF-PET-PVF multilayer film polyethylene terephthalate (PET) polyvinylfluoride (PVF)	Icosolar	Isovolta AG (AUT)
Polyester	PET-PE multilayer film polyethylene terephthalate (PET) polyethylene (PE)	Toyalsolar	Toyo Aluminium KK (J)

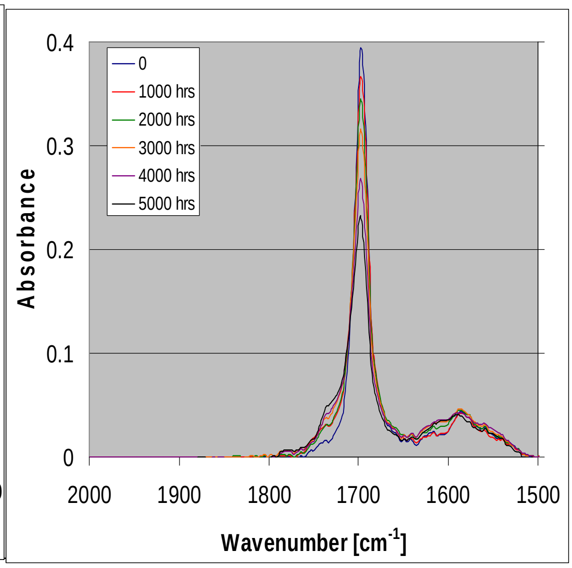
PERFORMANCE SP 5: Service life assessment of PV-modules



PERFORMANCE SP 5: Service life assessment of PV-modules

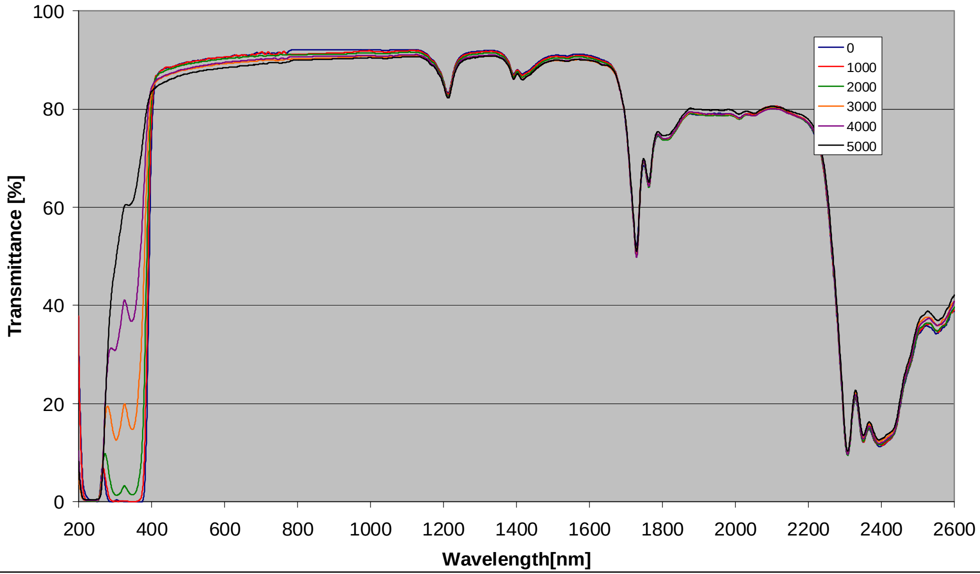
Ionomer 1 – WoM: 65 C, 60% RH, Front **Back**





PERFORMANCE SP 5: Service life assessment of PV-modules

UV-VIS-NIR: Ionomer 1 – WoM: 65 C, 60% RH



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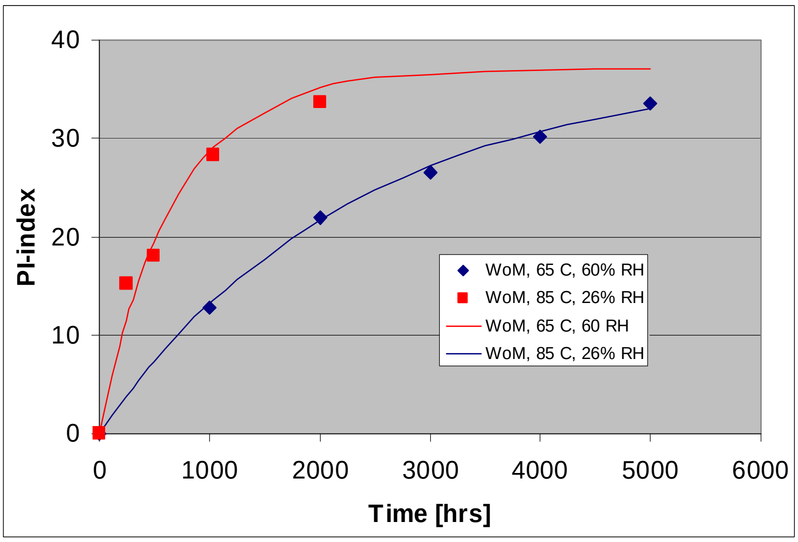
PERFORMANCE SP 5: Service life assessment of PV-modules

PET, Photo-oxidation Indexes



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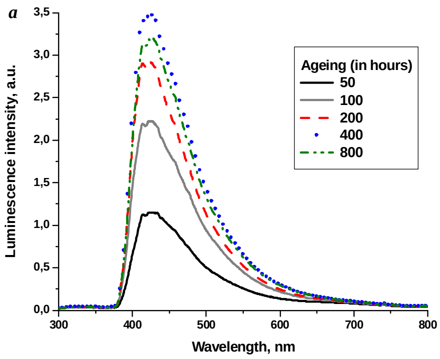
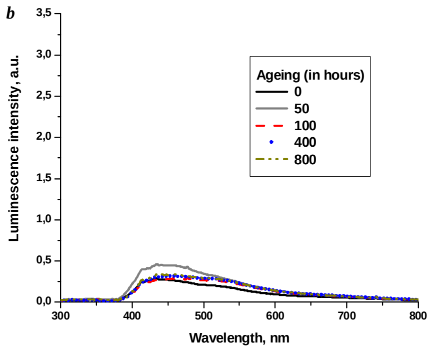
Development of degradation indicators at Humboldt Universität zu Berlin





Fluorescence of samples containing EVA-UFC as polymer with TPT back foil at different ageing times.

(**a**) Aging with DH 85/85 (**b**) Aging with UV /85°C.

PERFORMANCE SP 5: Service life assessment of PV-modules

Modelling:

1. Modules: IV-curves, efficiency (irradiation, temperature)

2. **Materials degradation, energy and mass transport in modules, worst case climates**

3. Module degradation, worst case climates, extreme climates

4. Energy yield (life-time), for any climate of operation

The change ΔP in a property P :

UV-dose

$$\Delta P(t=t_i)=r_P\Delta t(t=t_i)=A_{ph}I_{UV}(t=t_i)\cdot$$
$$\exp(-E_{ph}/RT(t=t_i))\Delta t(t=t_i)+$$
$$A_{aq}c_{aq}\exp(-E_{aq}/RT(t=t_i))\Delta t(t=t_i)$$

and the total change from t_i=0 to t_i=t_n:

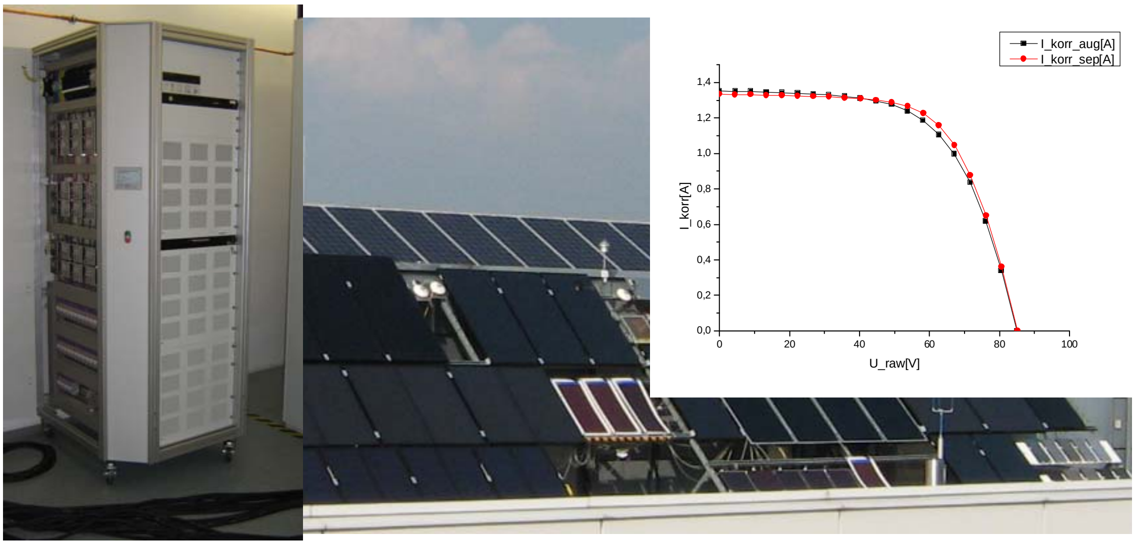
$$P_n(t=t_{i=n})=\sum_{i=0}^{i=n}\Delta P(t=t_i)$$

PERFORMANCE SP 5: Service life assessment of PV-modules

Module characterisation **measured by JRC** and labeled

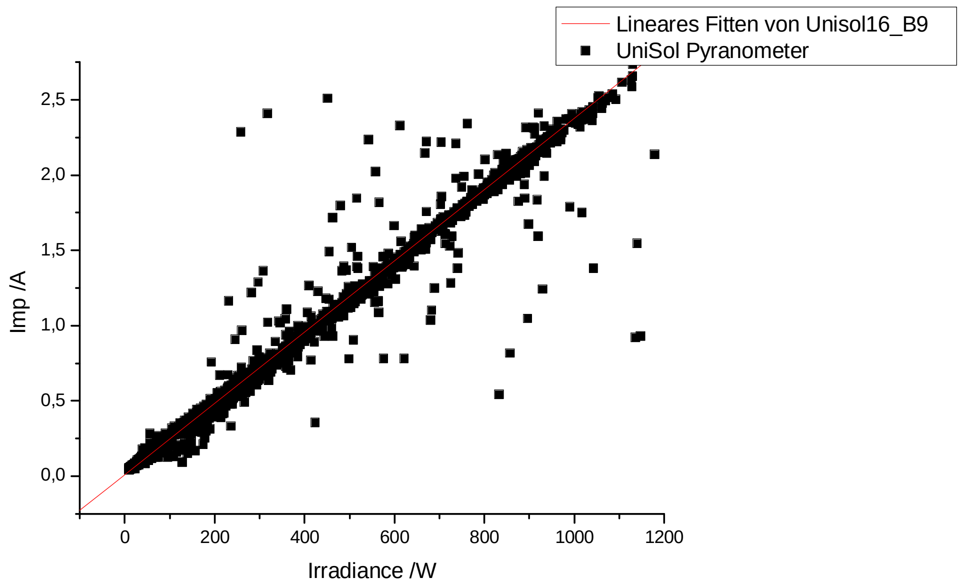
Cell	Product	Pmpp /W
a-Si	Schott ASI F10 Exp.	12,5
CdTe	First Solar FS-270	70
CIS	AVANCIS Shell	85
a-Si	Unisolar ES-62T	62
CIS	Würth WSG0036E080	80
c-Si	Schott Reference ASE-165	168
µc-Si /a-Si	Sharp Solar NA-901WQ	106
a-Si	Flexcell Sunslick 7 Watts	6,75

PERFORMANCE SP 5: Service life assessment of PV-modules

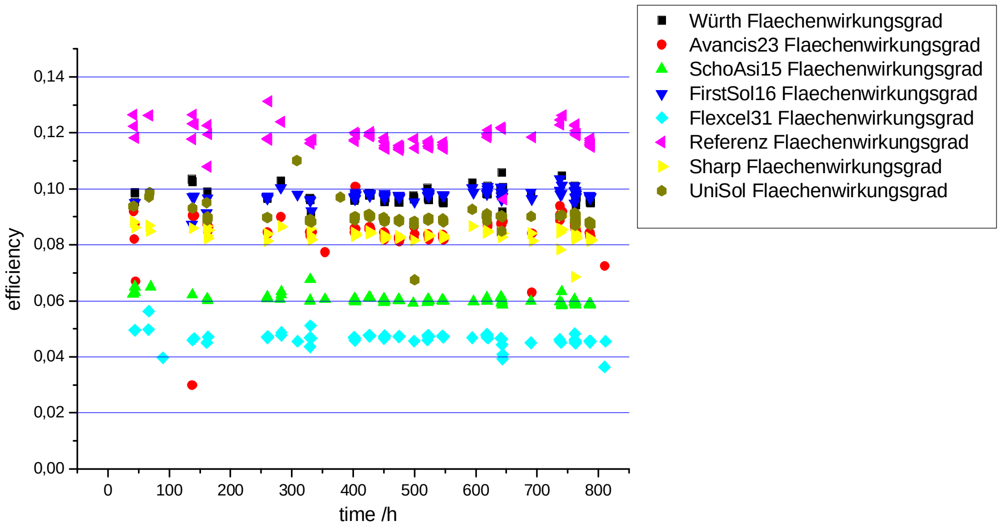


Outdoor exposure in Freiburg, Germany and Cadarache, France

PERFORMANCE SP 5: Service life assessment of PV-modules



PERFORMANCE SP 5: Service life assessment of PV-modules



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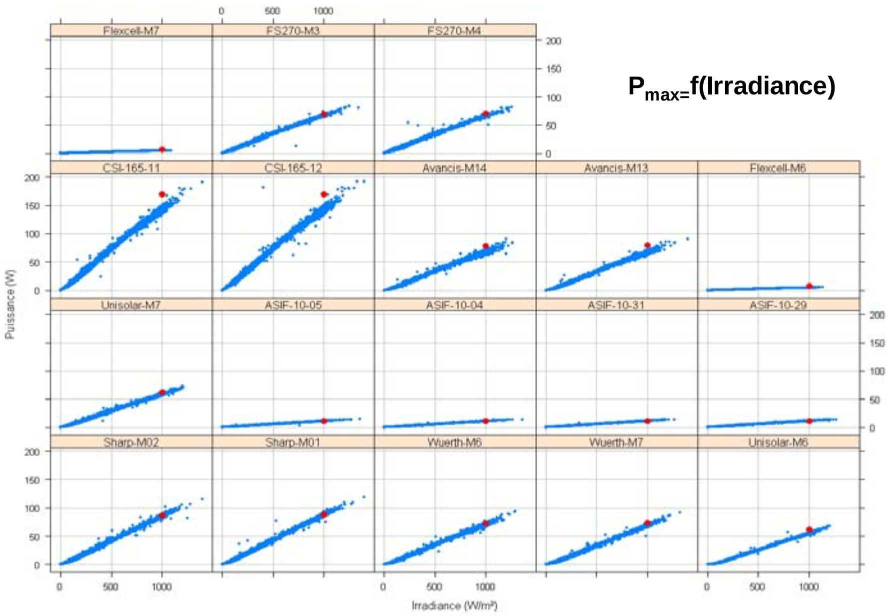
PERFORMANCE SP 5: Service life assessment of PV-modules



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Modelling:

1. **Modules: IV-curves, efficiency (irradiation, temperature)**
2. Materials degradation, energy and mass transport in modules, worst case climates
3. Module degradation, worst case climates, extreme climates
4. Energy yield (life-time), for any climate of operation

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Outdoor testing

Outdoor monitoring of climatic loads:

Radiation (UV, solar)

Humidity

Temperature (ambient and sample)

Wind and mechanical loads

Outdoor testing of innovative PV-modules and new materials:

Impact of extreme, but natural loads

Identification of week points

Validation of accelerated indoor tests

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Outdoor testing

City
Cologne
Germany

Alpes
Zugspitze
Germany

Dessert
Sede Boqer
Israel

Tropics
Serpang
Indonesia

Folie 21

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Outdoor testing

Alpine mounting

Michael Köhl, Fraunhofer ISE, SPIE 7048-4, 8/2008

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Outdoor testing — Module degradation

solar glass · Scheuten · SCHOTT solar · solar fabrik · SOLARWATT · SOLARWORLD · SOLON AG für Solartechnik

Crystalline Silicon based modules from each industrial partner

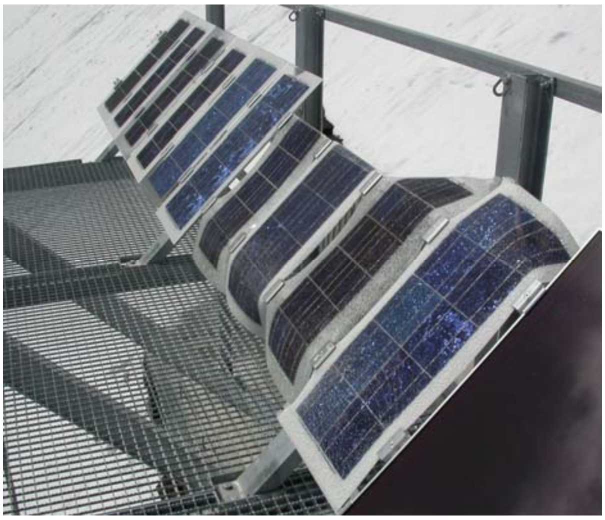
3 exposed at the 4 test sites after initial characterisation according to IEC 61215

The first was brougt to the lab for re-measurement after 1 year

Identical modules are in accelerated testing now

Experimental samples were made with new encapsulation/back-sheet combinations

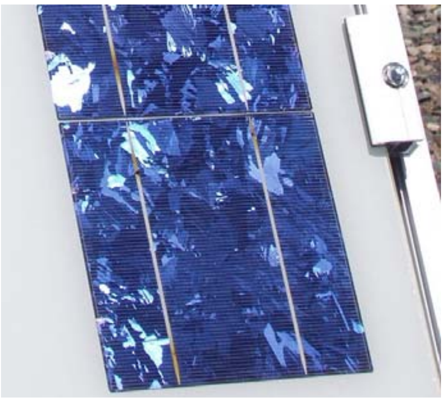
Outdoor testing — Module degradation



Detoriation of test modules after 12 months at the alpine test site

Outdoor testing

Module degradation



Corrosion of cell connectors after 24 months in Arizona

Degradation of the encapsulant after 12 months at the tropical test site

Modelling:

1. Modules: IV-curves, efficiency (irradiation, temperature)

2. Materials degradation, energy and mass transport in modules, worst case climates

3. **Module degradation, worst case climates, extreme climates**

4. Energy yield (life-time), for any climate of operation

Modeling

Deterministic model for aging processes

Changes of the degradation indicator P_i after the testing time Δt_i is for p degradation processes:

For constant load:

$$\Delta P_i = \Sigma_p \left(A_p\, I^n\, \Delta t_i \exp[-E_p / RT] \exp[C_p * rF]\right)$$

For dynamic load:

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

Degradation process parameters

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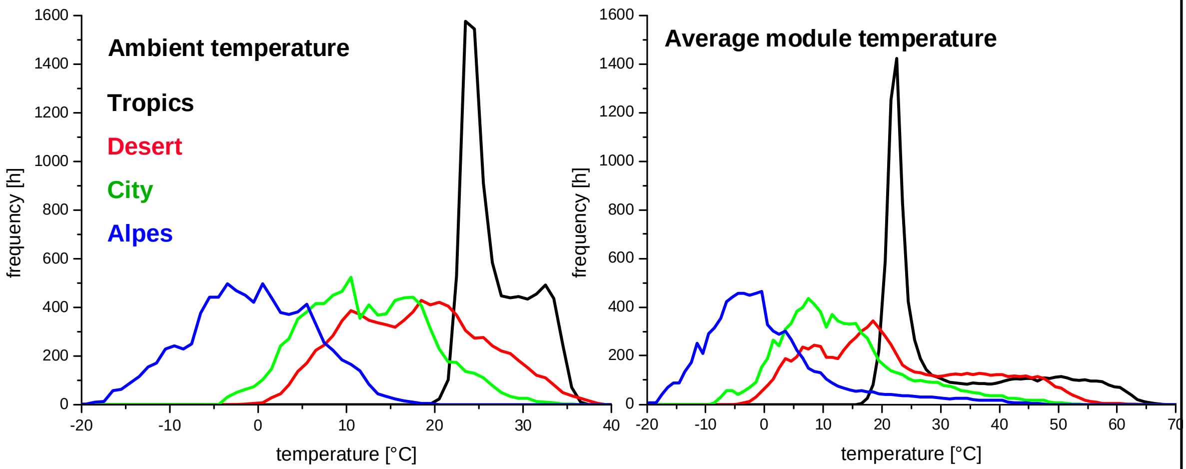
Outdoor testing

Temperature



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Outdoor testing

Temperature

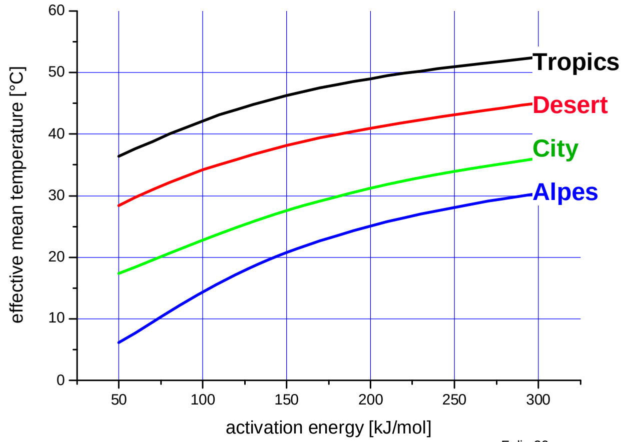
$$\exp[-E_p/RT_{eff}] = 1/(t_{max}-t_{min})\ \Sigma^{tmax}_{tmin} \exp[-E_p/RT(t)]\Delta t$$

Effective Mean Temperature,

Constant test temperature that

Corresponds to the natural load in the same period

Depends on the activation energy of the degradation process



Outdoor testing

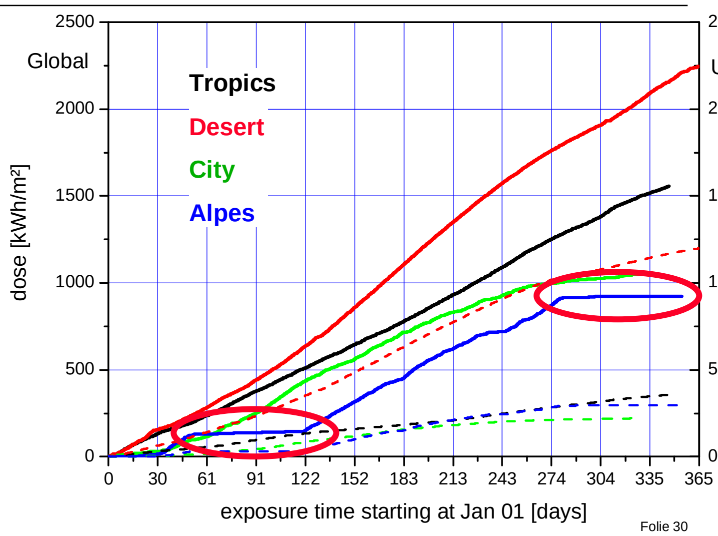
Radiation

Accumulated dose of UV-

and solar radiation

for one year

Snow on the sensors

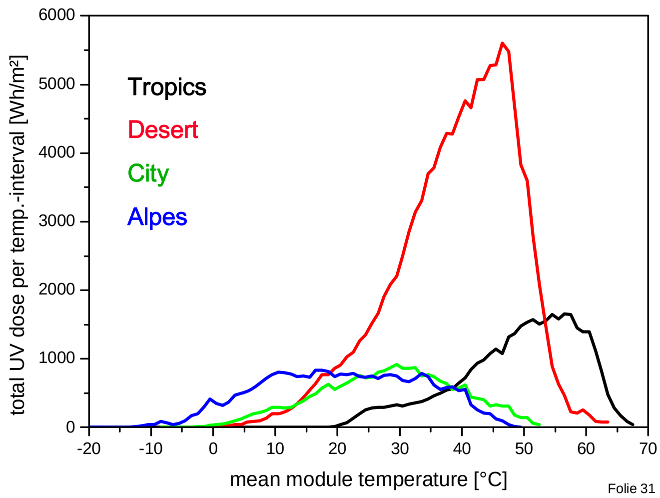


Outdoor testing

UV-radiation

UV-dose during one year

Has to be corrected for calibration errors



Folie 31

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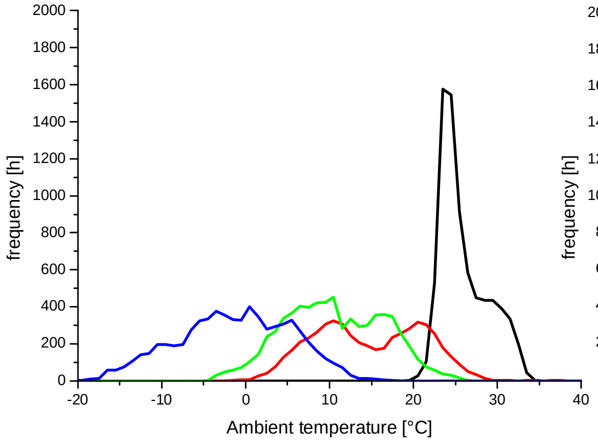
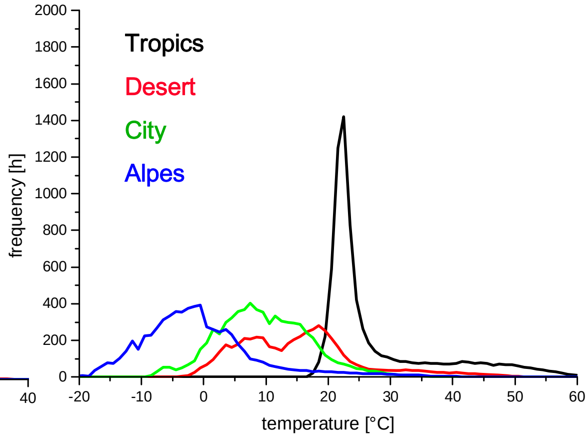
Outdoor testing

Humidity

Tamb if RH>=60%



Tavg if RH>=60%



Folie 32

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Outdoor testing

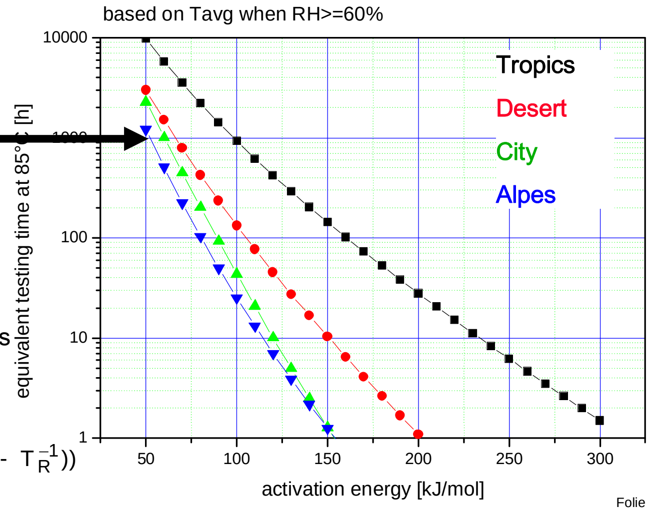
Humidity

Actual Damp-Heat-Test

Would be appropriate for the alpine location and a rate dominating degradation process with an activation energy of 50 kJ/mol

Tropical climate requires 10 times more

$$t_R = 25*8760 \exp\left(-\frac{E_T}{R}\left(T_{eff}^{-1} - T_R^{-1}\right)\right)$$



Folie 33

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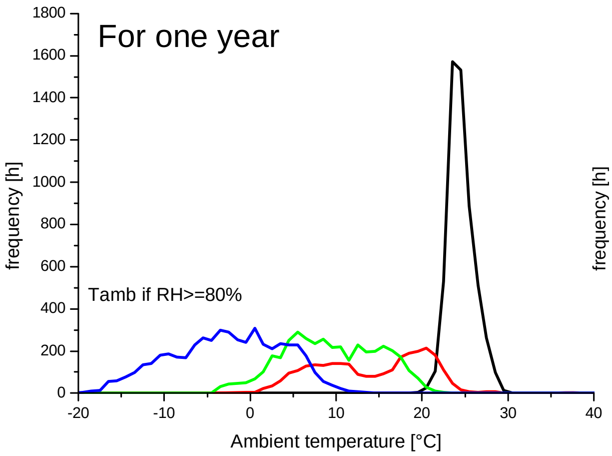
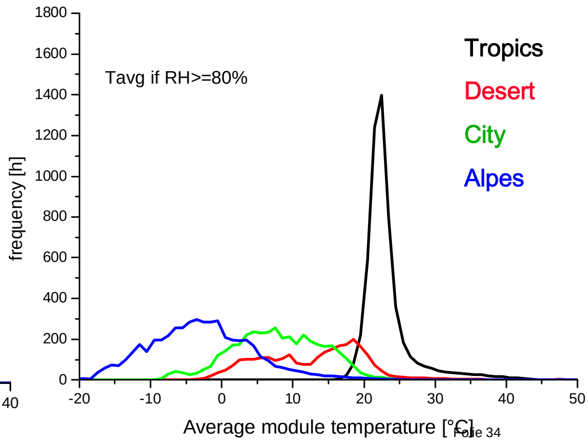
Outdoor testing

Humidity

Humidity above 80% (TOW = time of wetness)

For one year





Folie 34

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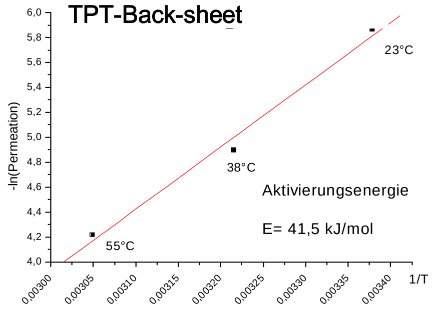
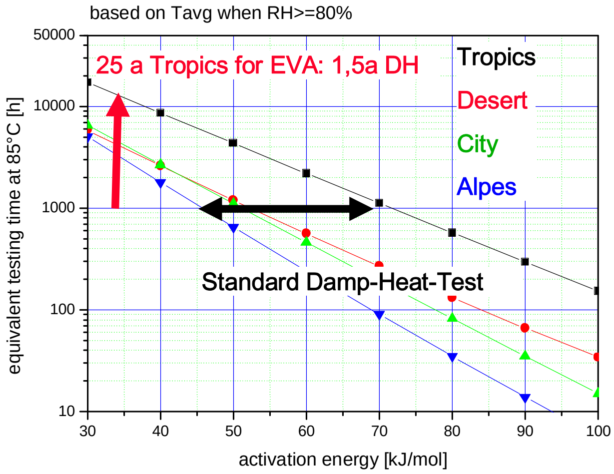
Outdoor testing

Humidity





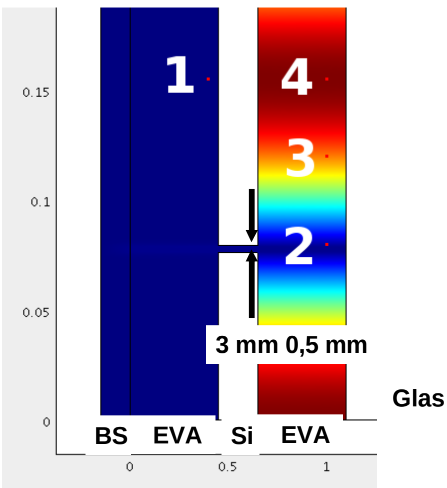
Testing times for 25 years service life for the different locations

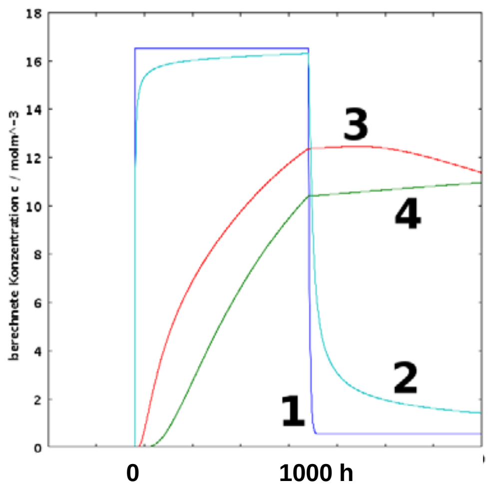
Water vapour diffusion in encapsulant

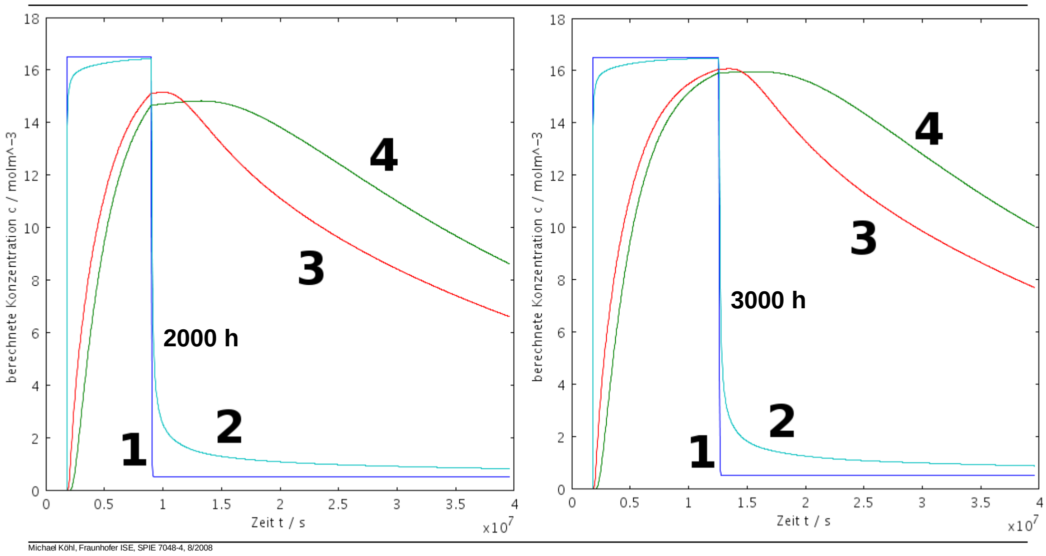
	Diffusionswerte in cm^2/s		
Temperatur	EVA	TPU	PVB
26°C	$8{,}7\ 10^{-7}$	$6{,}6\ 10^{-7}$	$2{,}0\ 10^{-7}$
36°C	$12{,}9\ 10^{-7}$	$9{,}8\ 10^{-7}$	$4{,}0\ 10^{-7}$
70°C (berechnet)	$50{,}0\ 10^{-7}$	$32{,}7\ 10^{-7}$	$36{,}0\ 10^{-7}$
E_A in k J/(molK)	34	31	56

Simulation

Damp-Heat







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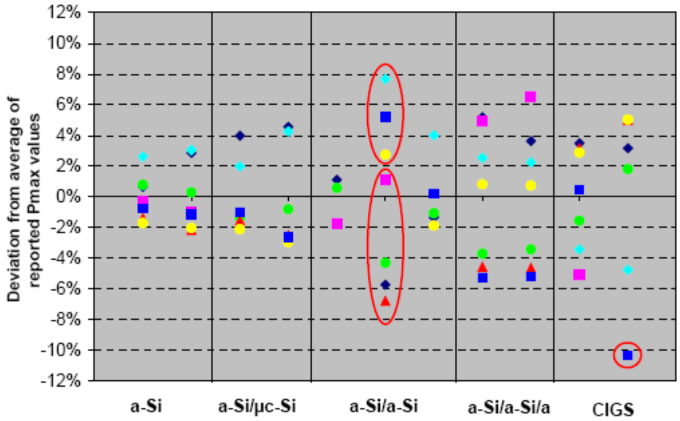
Small changes of the electrical properties to be detected

Technology specific results



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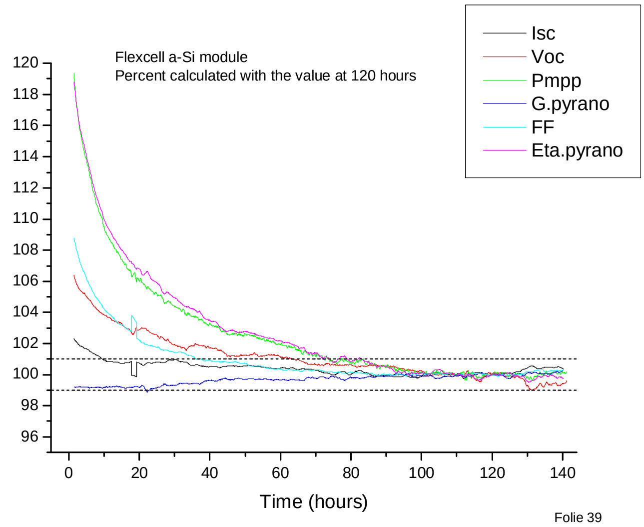
Power measurements and lightsoaking of Thin Film Modules



Folie 39

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Task 5.5.2: Screening testing – Test conditions / test programme

Institute	T (°C)	Rh (%)	UV*(-)	modules	Start measuring	Exposure time (h)
JRC	85	85	0	2 x 8	May	250, 1000, 2000, 4000
SP	65	85	0	2 x 8	October	1000, 2000, 4000
SP	85	50	0	2 x 8	October	1000, 2000, 4000
ISE	65	85	?	2 x 8	April 09	250, 1000, 2000, 4000
ISE	85	50	?	2 x 8	Februar 09	250, 500, 1000, 2000, 4000
ZSW	85	85	600V	1 x 8	November	250, 500, 1000, 2000, 4000
TÜV	85	high	5	2 x 8	January 09	100, 250, 500, 1000, 2000
TÜV	85	low	5	2 x 8	January 09	100, 250, 500, 1000, 2000

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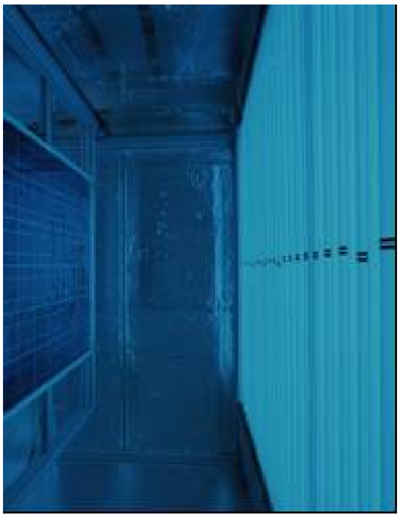
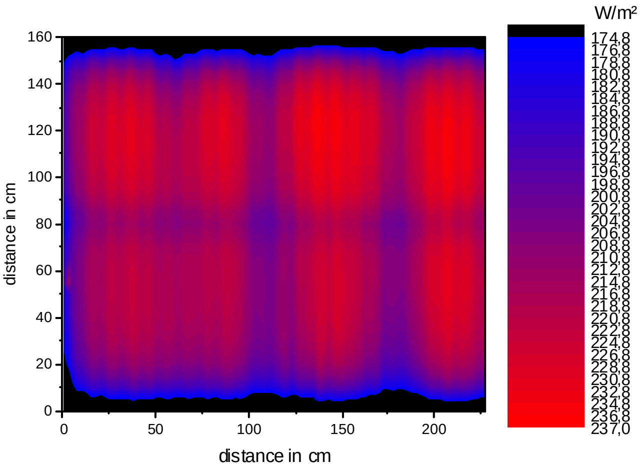
Indoor testing

UV-radiation





Folie 41

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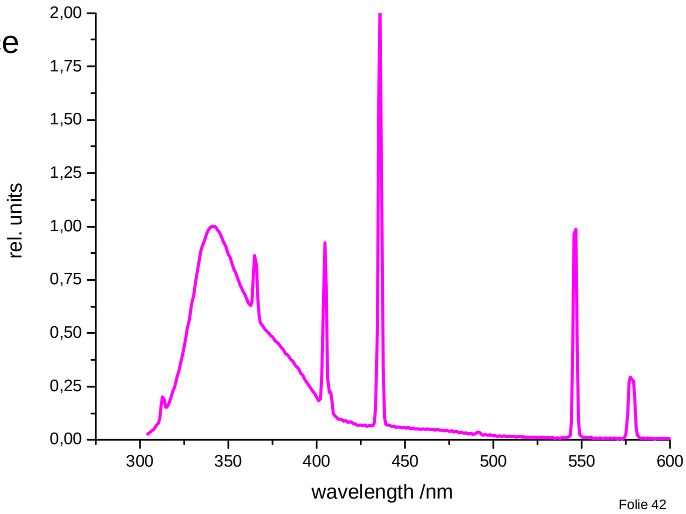
Outlook indoor testing

Powerful UV-light source to be developed

Combination UV – damp-heat for entire modules



Folie 42

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Outlook

Evaluation of outdoor exposure

Indoor testing

Comparison accelerated indoor testing – outdoor testing

Modelling service life

Service life test procedure

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