
Reliability of PV-modules

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

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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

Duration: 1/2005 – 12/2008

Folie 2

Encapsulating components





PERFORMANCE SP 5: Service life assessment of PV-modules

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



PERFORMANCE SP 5: Service life assessment of PV-modules

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

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

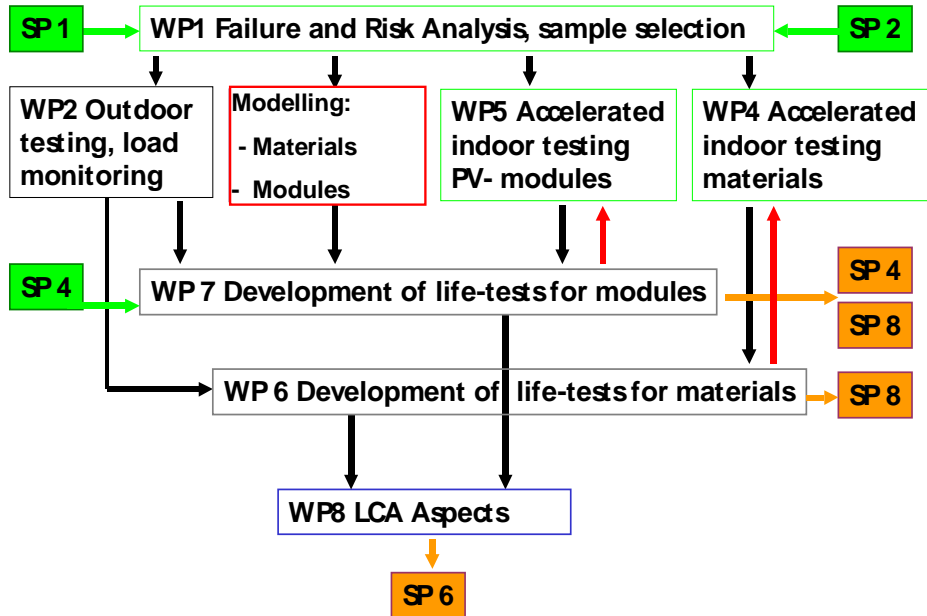


Schott Solar, Alzenau, DE





PERFORMANCE SP 5: Service life assessment of PV-modules



PERFORMANCE SP 5: Service life assessment of PV-modules

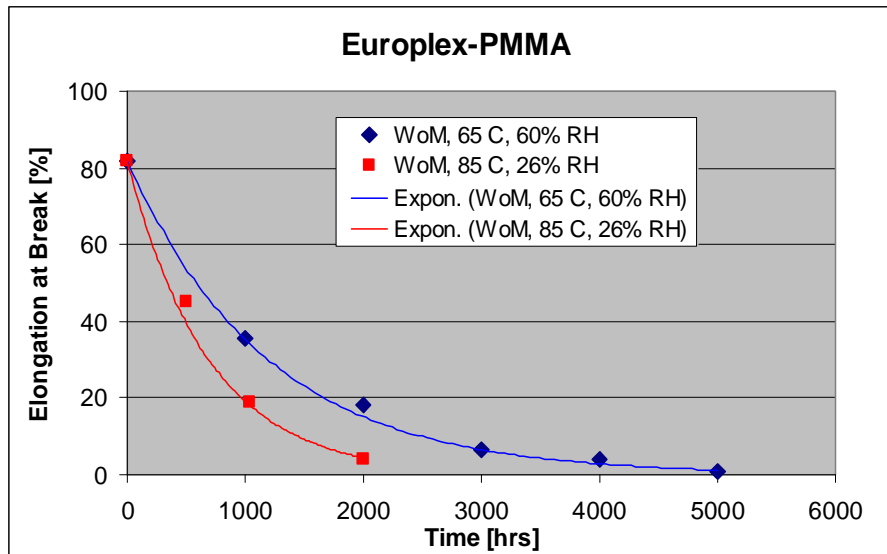
Candidate materials identified in WP 5:1

Name	Composition	Trade name	Manufacturer
encapsulant			
EVA	ultra fast cure ethylene vinyl acetate	Vistasolar	Etimex (D)
ionomer			
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)





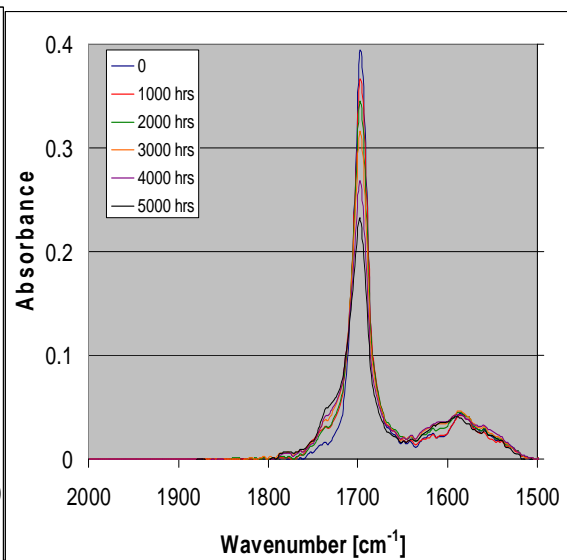
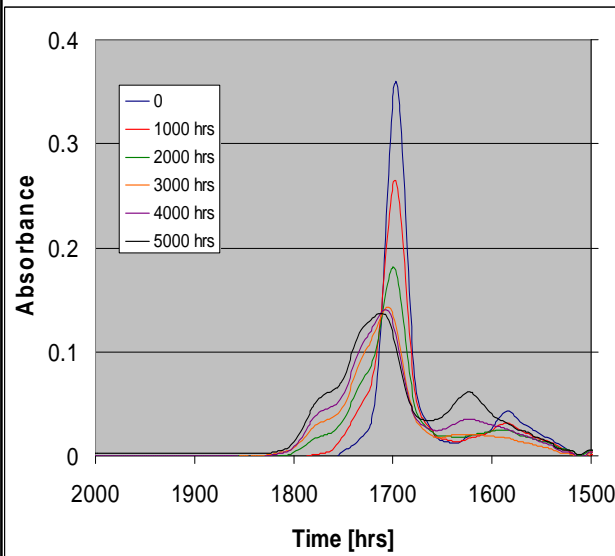
PERFORMANCE SP 5: Service life assessment of PV-modules



PERFORMANCE SP 5: Service life assessment of PV-modules

Ionomer 1 – W_oM: 65 C, 60% RH, Front

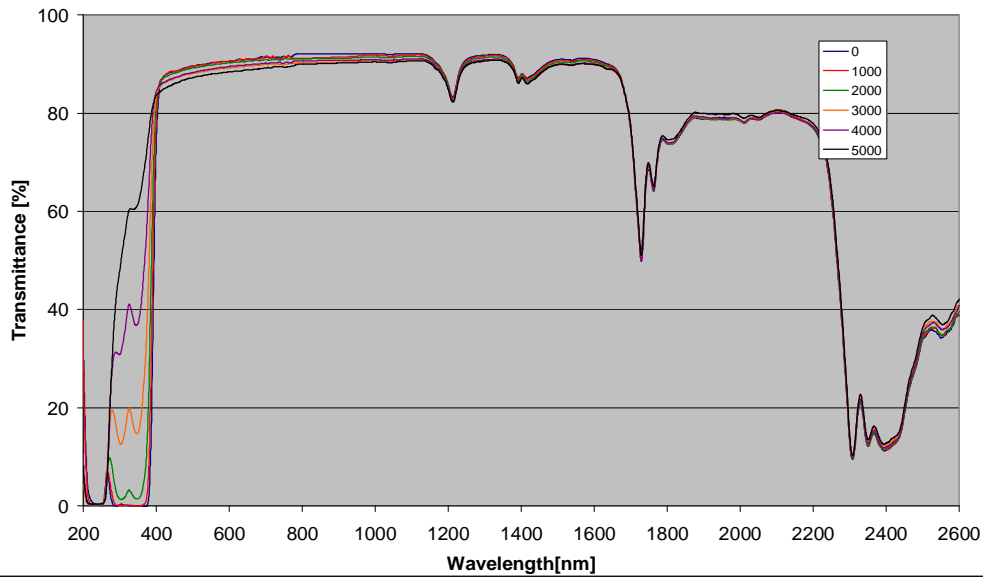
Back





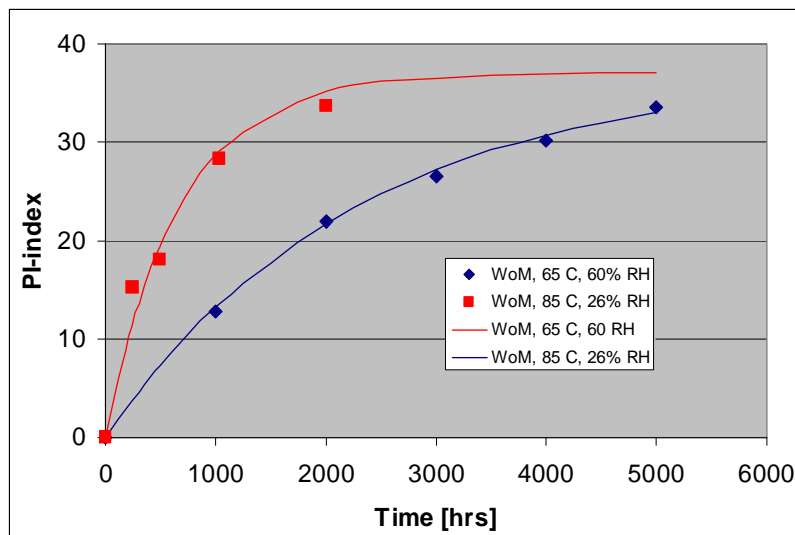
PERFORMANCE SP 5: Service life assessment of PV-modules

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

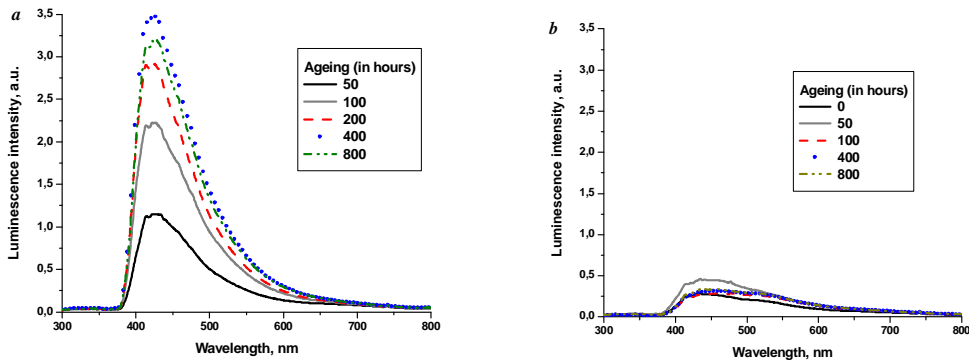


PERFORMANCE SP 5: Service life assessment of PV-modules

PET, Photo-oxidation Indexes



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.

Folie 11

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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 :

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

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

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

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Folie 13



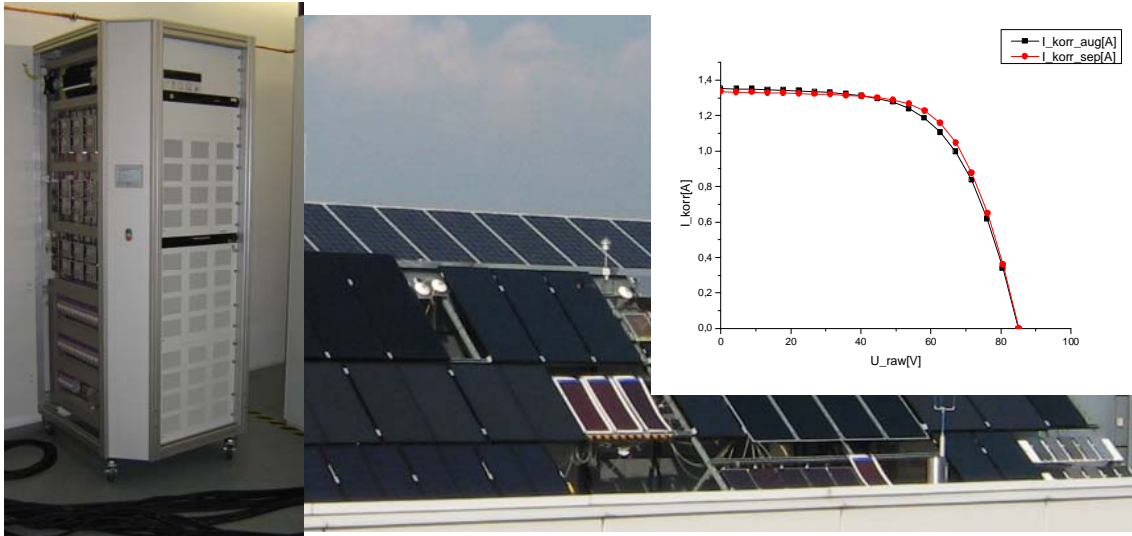
PERFORMANCE SP 5: Service life assessment of PV-modules

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
μ c-Si /a-Si	Sharp Solar NA-901WQ	106
a-Si	Flexcell Sunslick 7 Watts	6,75



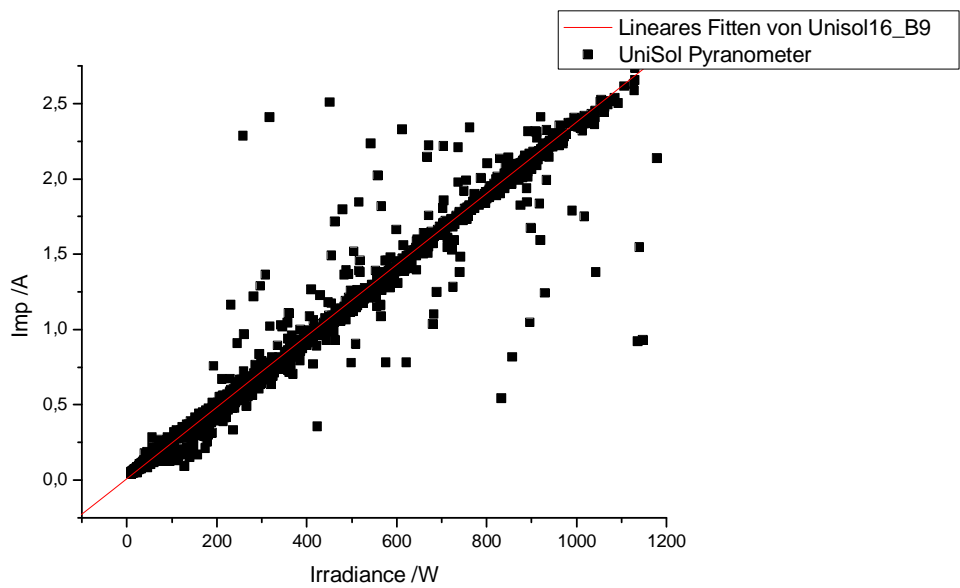
PERFORMANCE SP 5: Service life assessment of PV-modules



Outdoor exposure in Freiburg, Germany and Cadarache, France

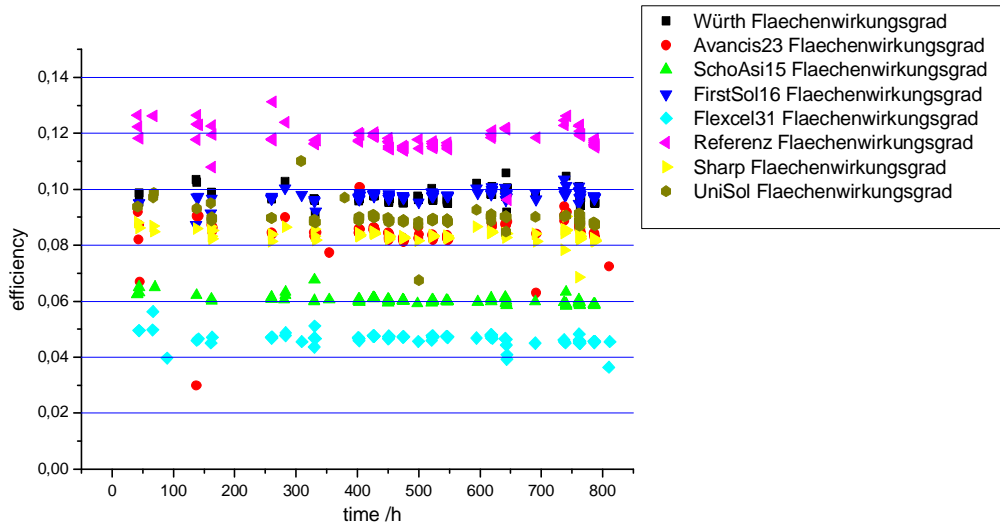


PERFORMANCE SP 5: Service life assessment of PV-modules

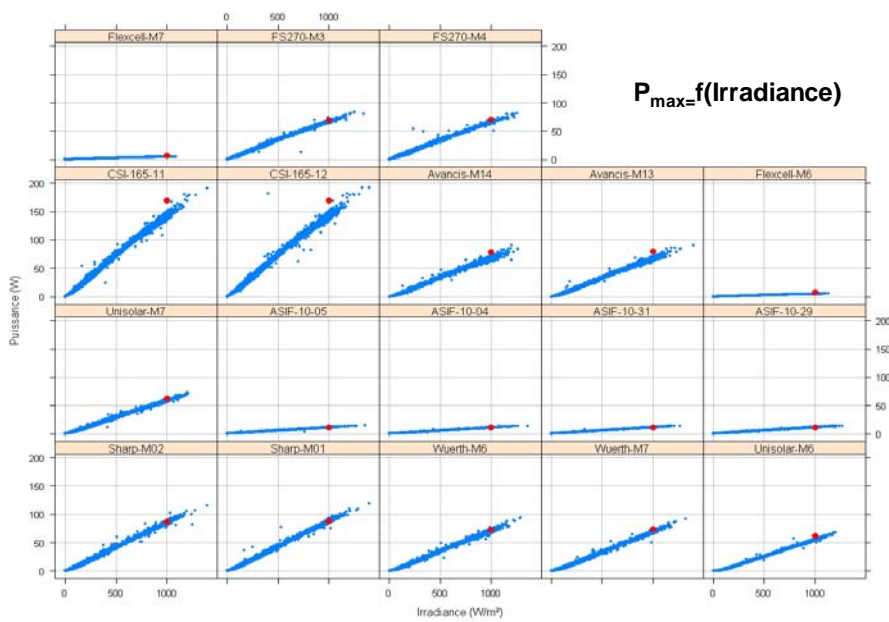




PERFORMANCE SP 5: Service life assessment of PV-modules



PERFORMANCE SP 5: Service life assessment of PV-modules



Modelling:

1. **Modules: IV-curves, efficiency (irradiation, temperature)**
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4. Energy yield (life-time), for any climate of operation

Folie 19

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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 weak points

Validation of accelerated indoor tests

Folie 20

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Outdoor testing

City
Cologne
Germany

Alpes
Zugspitze
Germany



Desert
Sede Boqer
Israel

Tropics
Serpang
Indonesia

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Folie 21


Fraunhofer
Institut
Solare Energiesysteme

Outdoor testing

Alpine mounting



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Fraunhofer
Institut
Solare Energiesysteme

Outdoor testing

Module degradation



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 brought 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

Folie 23

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Outdoor testing

Module degradation



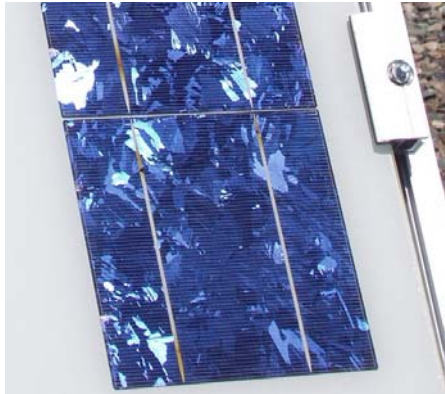
Deterioration of test modules after
12 months at the alpine test site

Folie 24

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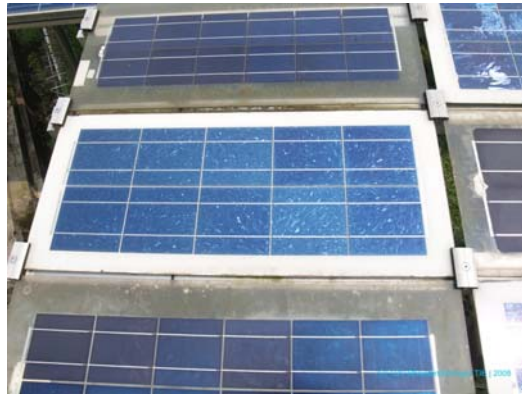


Outdoor testing



Corrosion of cell connectors
after 24 months in Arizona

Module degradation



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

Folie 25

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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

Folie 26

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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:

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

For dynamic load:

$$\Delta P_j = \sum_{i=1}^j \{ \sum_p (A_p I_i^n \Delta t_i \exp[-E_p / RT_i] \exp [C_p * rF_i]) \}$$

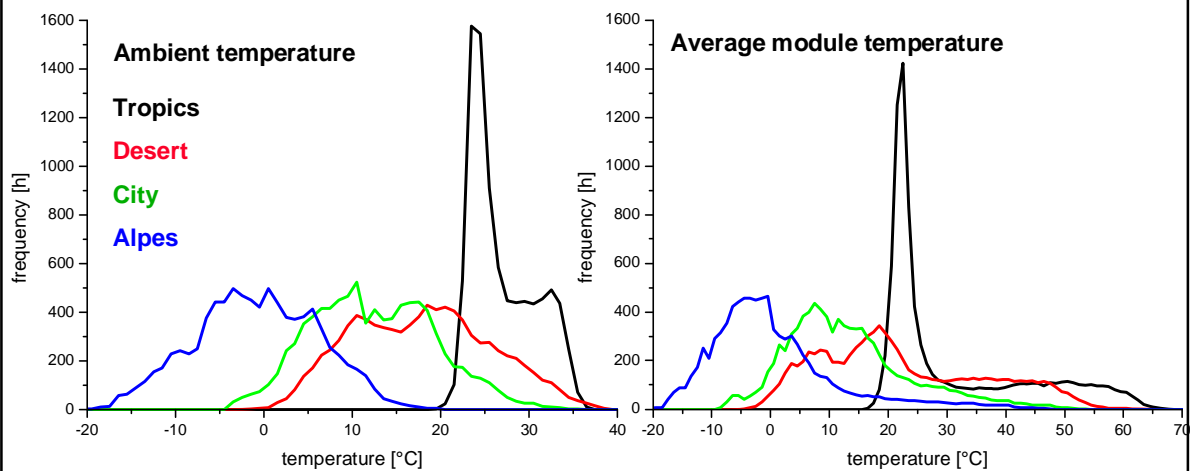
Degradation process parameters

Folie 27

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Outdoor testing

Temperature



Folie 28

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Outdoor testing

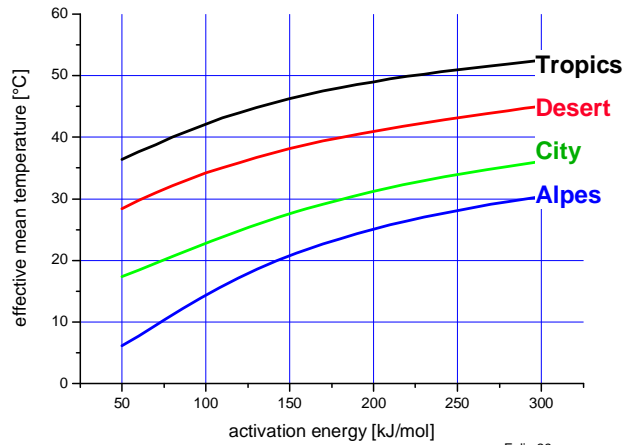
Temperature

$$\exp[-E_p/RT_{\text{eff}}] = 1/(t_{\text{max}}-t_{\text{min}}) \int_{t_{\text{min}}}^{t_{\text{max}}} \exp[-E_p/RT(t)] \Delta t$$

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



Folie 29

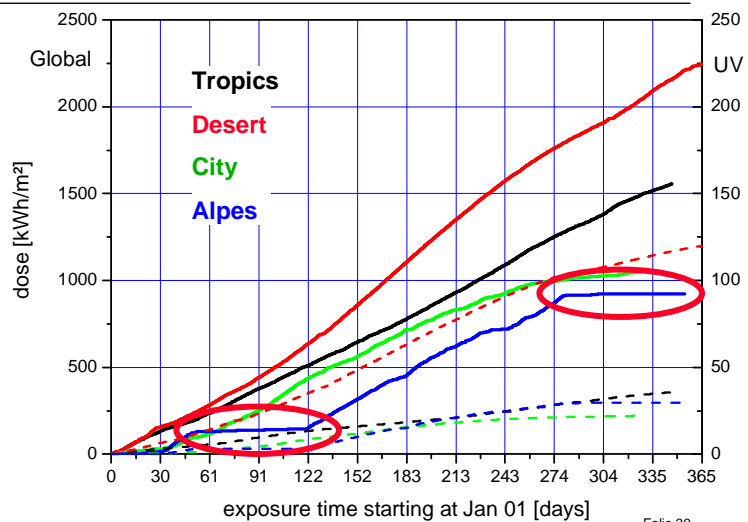
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Outdoor testing

Radiation

Accumulated dose of UV-
and solar radiation
for one year

Snow on the sensors



Folie 30

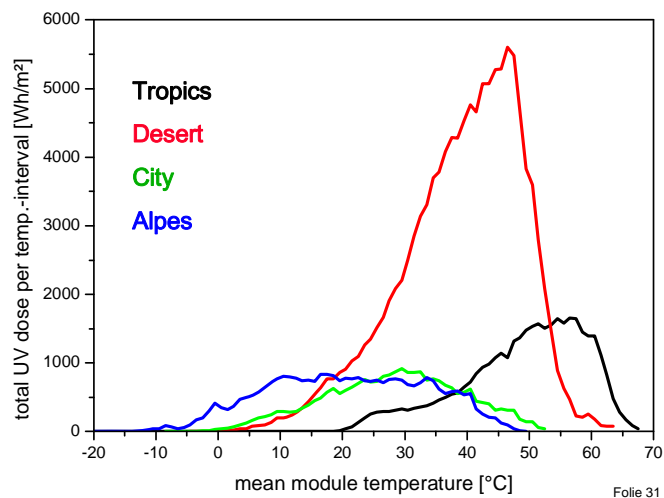
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Outdoor testing

UV-radiation

UV-dose during one year

Has to be corrected for calibration errors



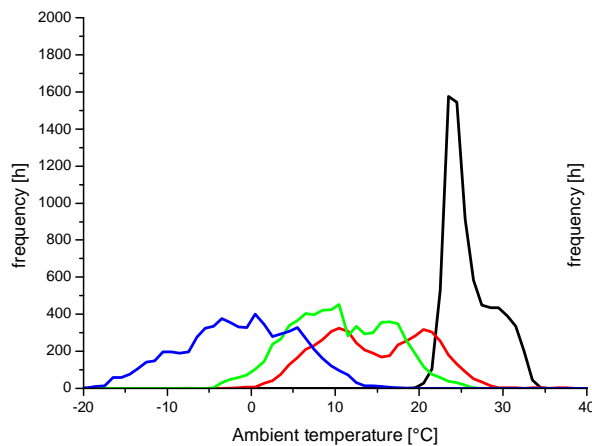
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Folie 31

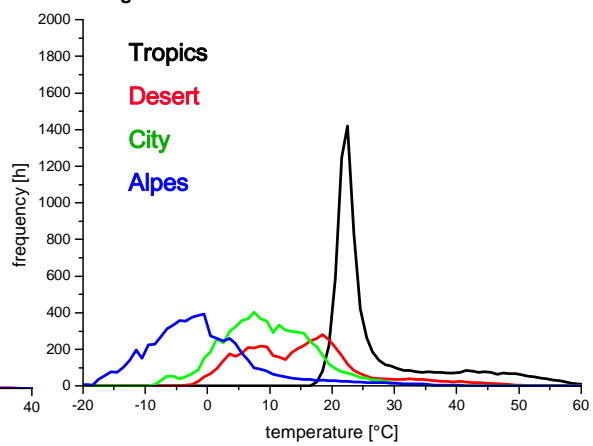
Outdoor testing

Humidity

Tamb if RH>=60%



Tavg if RH>=60%



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Folie 32

Outdoor testing

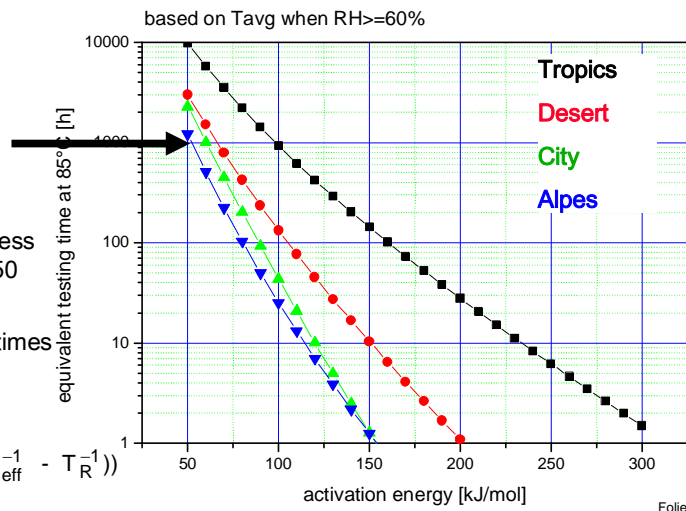
Humidity

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

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



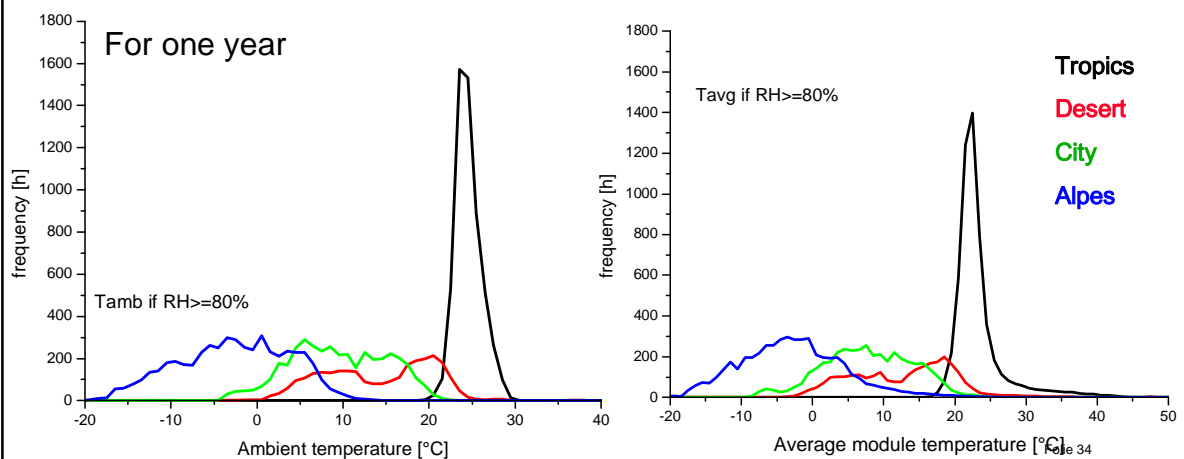
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Folie 33

Outdoor testing

Humidity

Humidity above 80% (TOW = time of wetness)

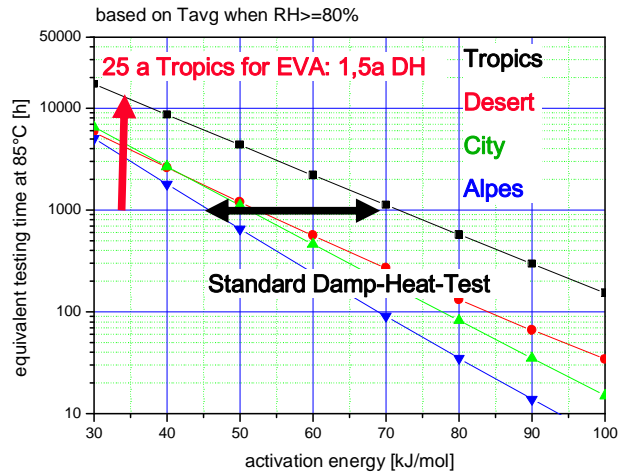
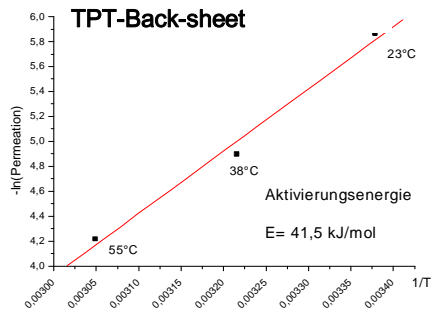


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Folie 34

Outdoor testing

Humidity



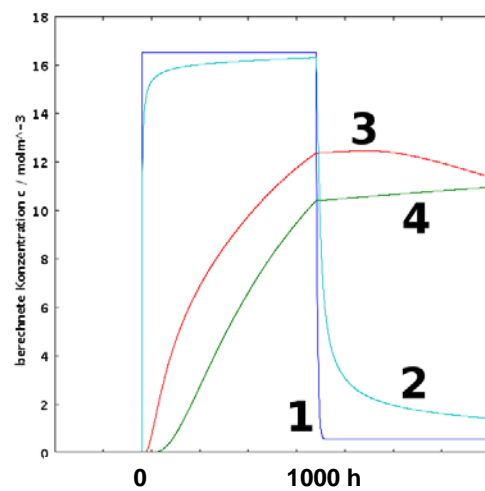
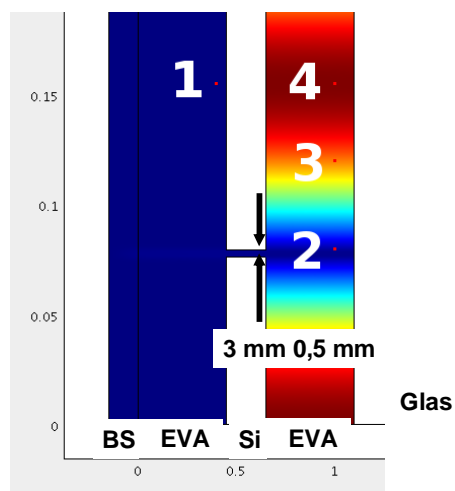
Water vapour diffusion in encapsulant

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

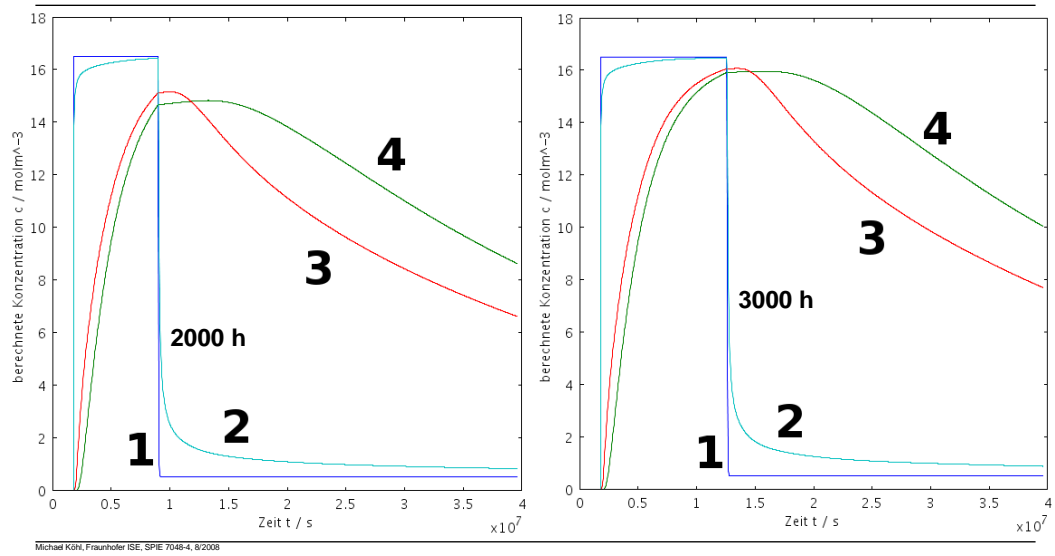
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Simulation

Damp-Heat



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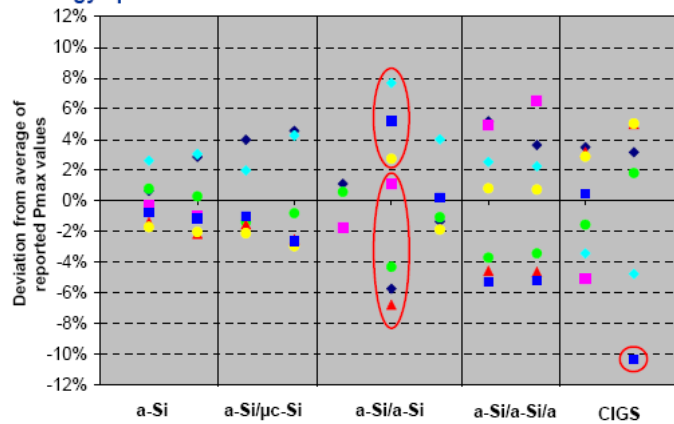


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Small changes of the electrical properties to be detected

Technology specific results

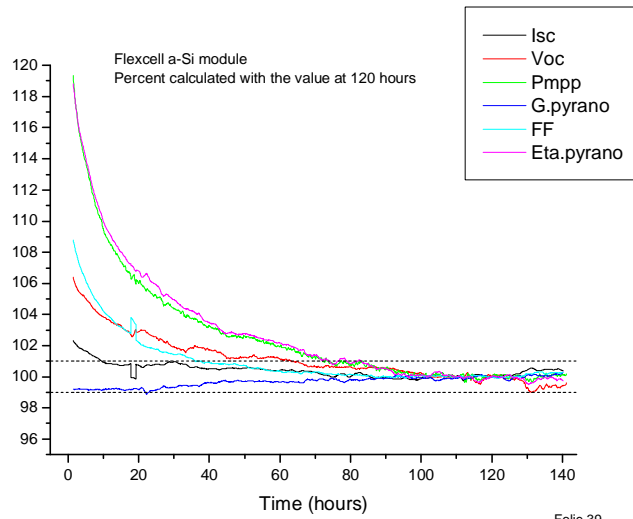


Folie 38

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Power measurements and lightsoaking of Thin Film Modules



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Task 5.5.2: Screening testing – Test conditions / test programme

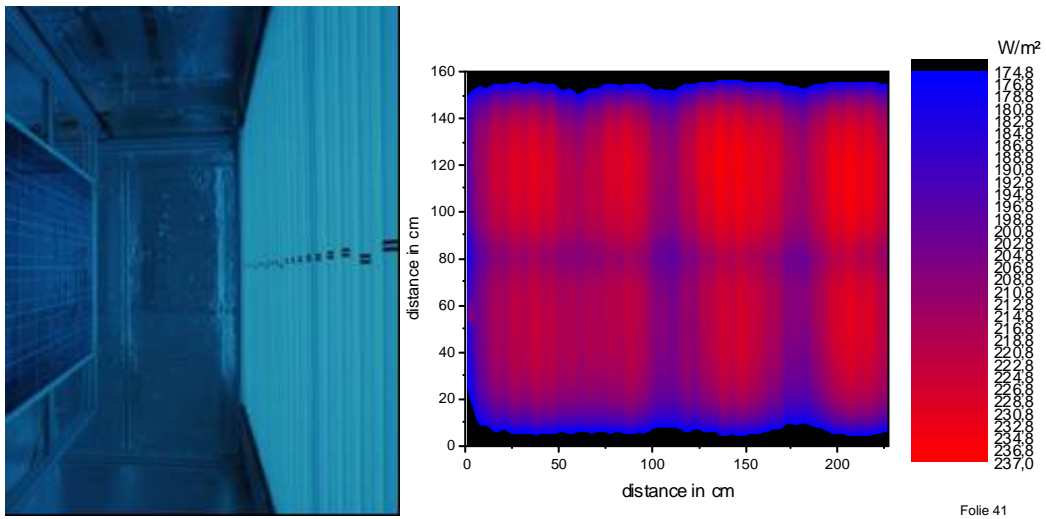
Institute	T (°C)	Rh (%)	UV* (-)	modules	Start measuring	Exposure time (h)
JRC	85	85	0	2 x 8	May	250, 1000, 2000, 4000
SP	65	85	0	2 x 8	October	1000, 2000, 4000
SP	85	50	0	2 x 8	October	1000, 2000, 4000
ISE	65	85	?	2 x 8	April 09	250, 1000, 2000, 4000
ISE	85	50	?	2 x 8	Februar 09	250, 500, 1000, 2000, 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

Folie 40

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Indoor testing

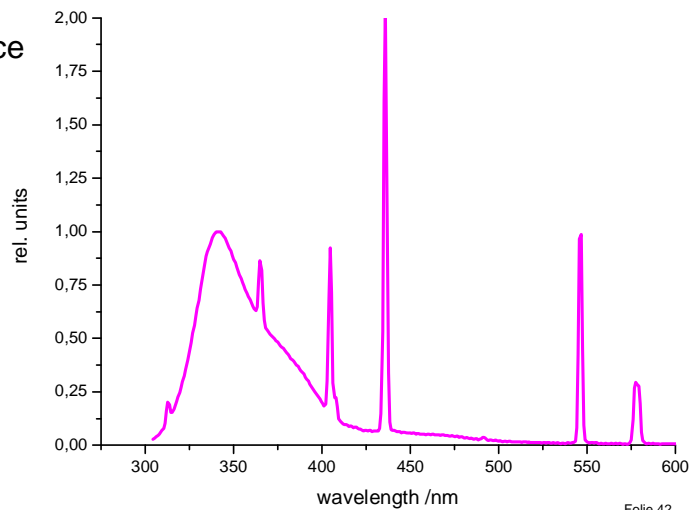
UV-radiation



Outlook indoor testing

Powerful UV-light source to be developed

Combination UV – damp-heat for entire modules



Outlook

Evaluation of outdoor exposure

Indoor testing

Comparison accelerated indoor testing – outdoor testing

Modelling service life

Service life test procedure

Folie 43

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