Sequential or simultaneous combination of stress factors

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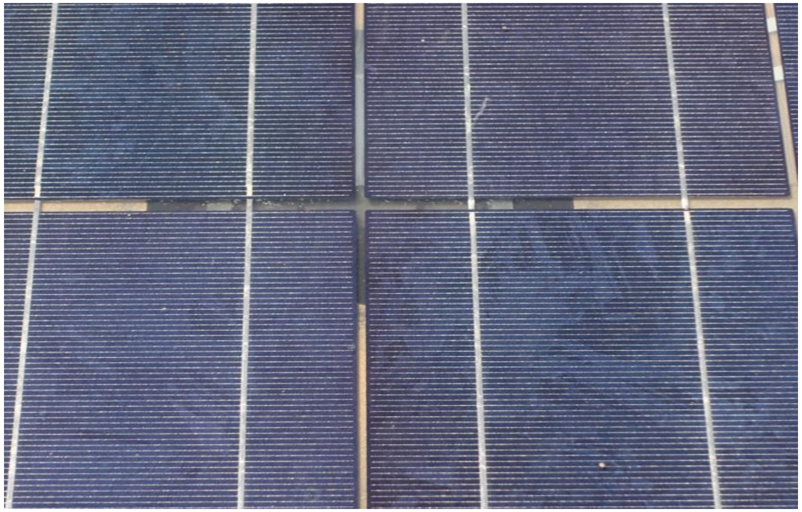
Evaluation of the service life time and energy yield in different climates:

weathering

The stressors are acting simultaneously:

- Sun-light
- Temperature
- Temperatur cycles (thermomechanical stresses)
- Mechanical stresses (wind, snow)
- Moisture
- Electrical current and voltage
- Soiling or bio-contamination
- Pollutants (salt, SO2….)



The stressors are to be tested simultaneously, but

The stressors cannot be applied together !

Acceleration by enhanced stress levels

- Correlated (G, T, thermomech. pressure)
- Non-correlated (Mech, T)
- Anti-correlated (T ⇔ rh)

No suitable test cabinets !?

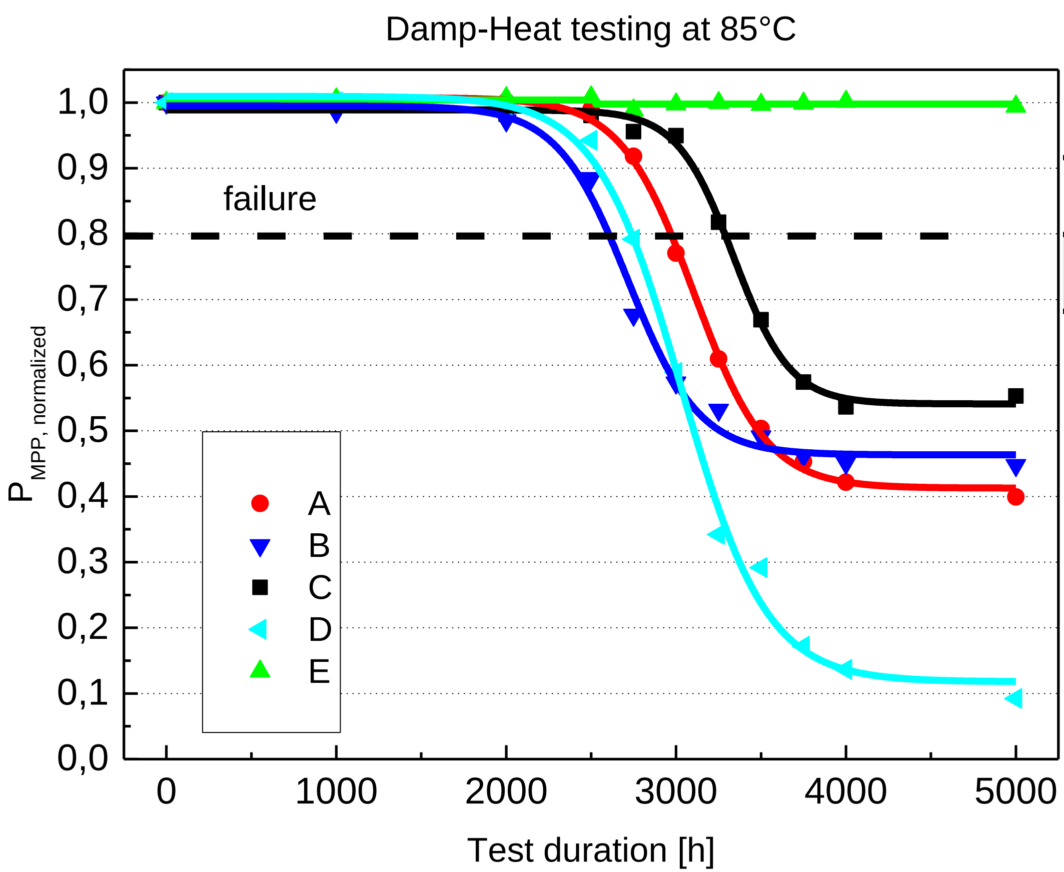
The stressors cannot be applied together !

Time constants:

irradiation < voltage < wind < temperature < humidity < soiling

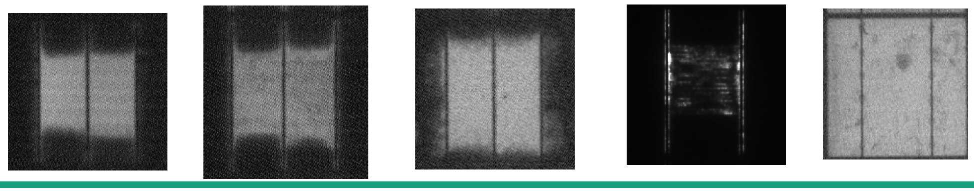
=> sequential testing   => cyclic testing

Extended damp-heat testing (85% rh)



Five commercial c-Si modules

	C	A	D	B
ttf[h]	3270	2950	2730	2600



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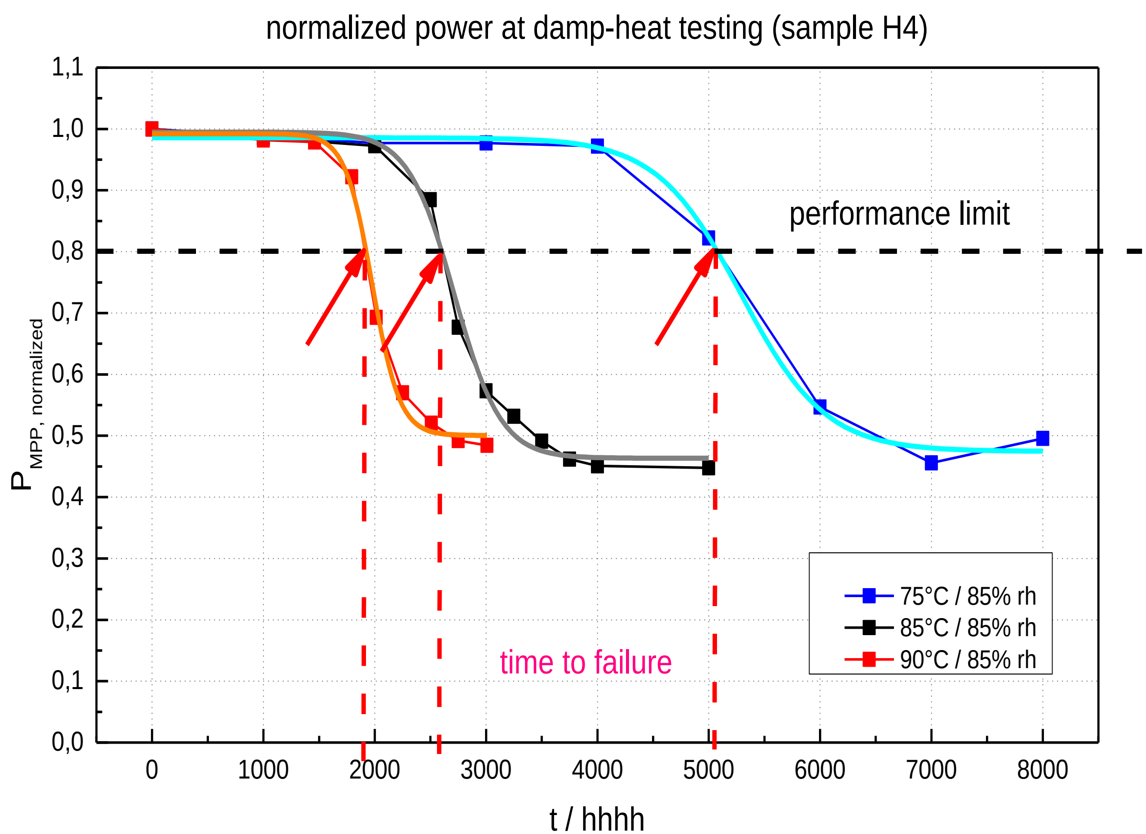
Accelerated damp-heat testing (85% rh) at different temperature levels



Acceleration factor 75°C vs. 85°C

	H1	H2	H4	H5
a	1,85	1,7	1,95	1,85
ttf@ 85°C	3270	2950	2600	2730

Activation energy

	H1	H2	H4	H5
E_A*	63,7	55	69,2	63,7

*E_A in kJ/mol

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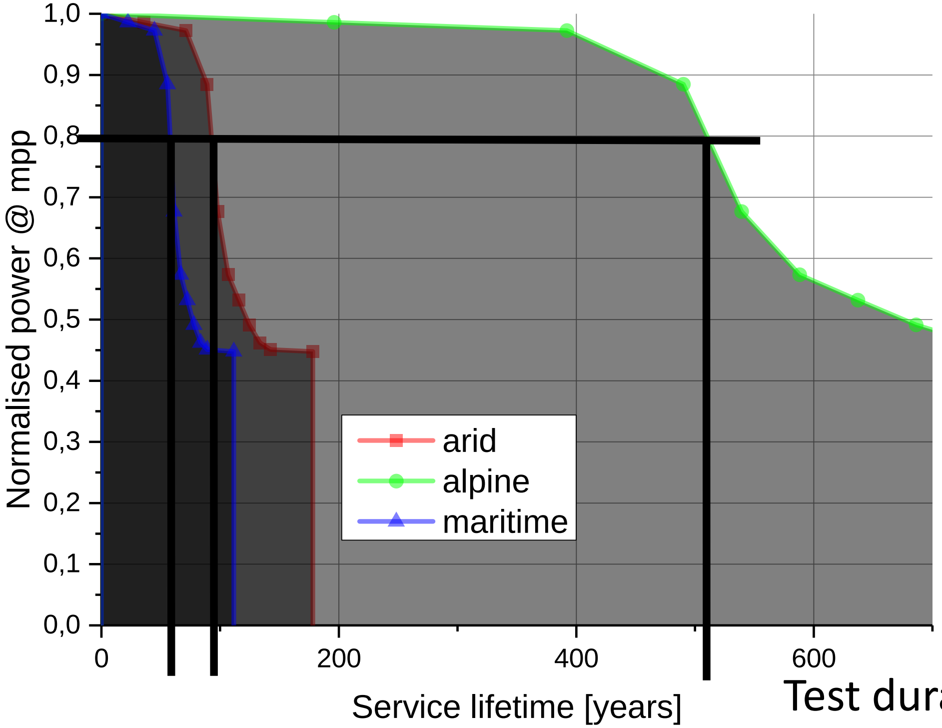
Evaluation of the service life time and energy yield in different climates

H4



$$\frac{\int_0^{t_{lt}} P(t)dt}{\int_0^{t_{lt}} P(0)\,dt}$$

Test duration for 25years ALT: 130h – 3000h

	Gran Canaria	**maritime**		**Negev**	**arid**		**Zugspitze**	**alpine**	
Sample	lifetime [a]	normalised yield	relative yield	lifetime [a]	normalised yield	relative yield	lifetime [a]	normalised yield	relative yield
H2	24	23,6	**98,3**	38	37,5	**98,7**	168	165	**98,2**
H5	41	40,3	**98,3**	66	65	**98,5**	333	327	**98,2**
H1	53	51,7	**97,5**	84	82	**97,6**	430	420	**97,7**
H4	58	56	**96,6**	93	90	**96,8**	511	495	**96,9**

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Modelling of the mechanical stress levels

- **Static mechanical loads by wind**
- **Daily temperature - changes**
- **Vibrations**

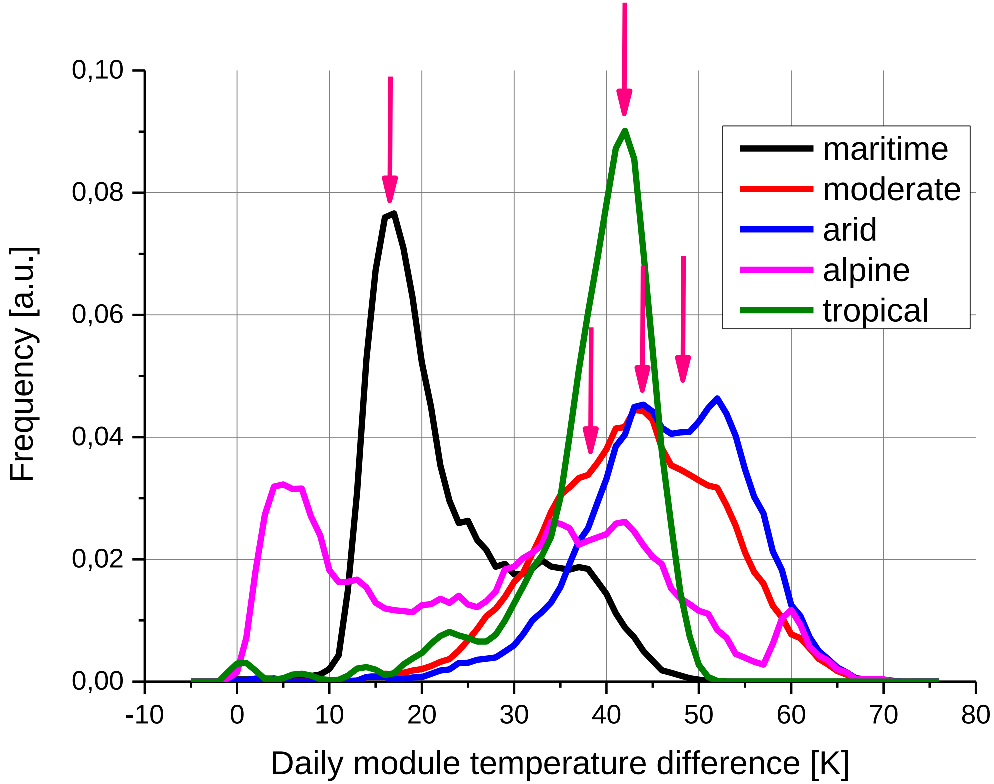
	Wind @ 130km/h	Thermo-mech	Vibrations	IEC 61215	
Maximum Δ T		**48**		125	K
Maximum Δ d	12,00	**1,60**	0,25	4,17	mm
Maximum Δ p	1200	**160**	25	417	Pa
Maximum Δ l	4,00	**0,58**	**0,08**	1,50	%
# of cycles	**x/a**	**9125**	10-20 Hz	200	

Elongation to break or fatigue ?

Temperature induced mechanical stress

Day/night temperature differences

	maritime	moderate	arid	alpine	tropical		IEC 61215
Maximum Δ T	17	44	48	40	42	K	125
Maximum Δ d	0,57	1,47	1,60	1,33	1,40	mm	4,17
Maximum Δ p	56,67	146,67	160,00	133,33	140,00	Pa	416,67
Maximum Δ l	0,20	0,53	0,58	0,48	0,50	%	1,50



Factor 3 in climate impact between maritime and arid

Factor 3 in acceleration between arid and Tc test

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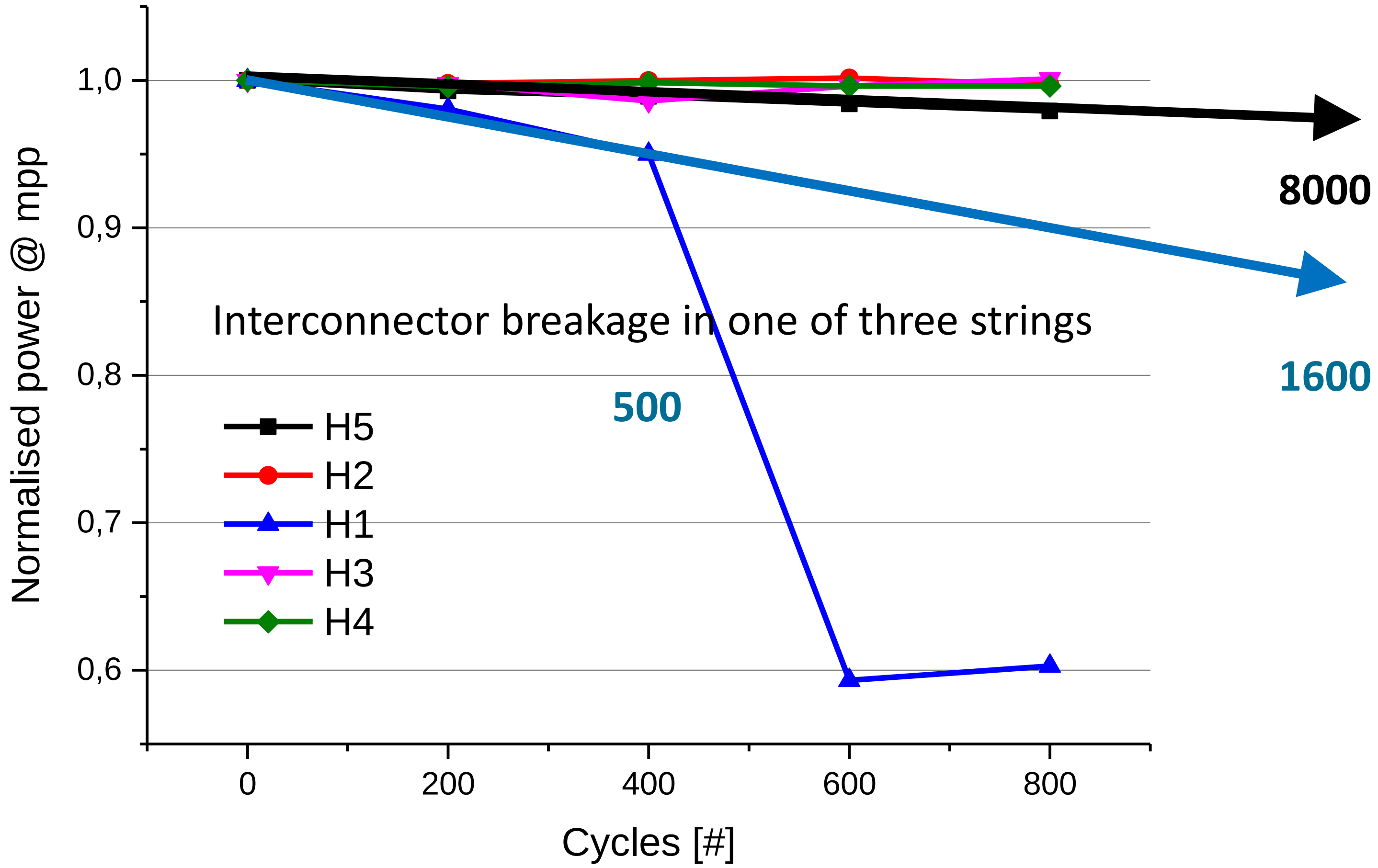
Thermo-mechanical stress by temperature cycling

Tc – testing according to IEC 61215 from -40°C to 85°C



Coffin-Manson Modell for temperature cycling (-40°C / 85°C)

	maritime	moderate	Arid	alpine	tropical	
Maximum Δ T	**17**	**44**	**48**	**40**	**42**	**K**
acceleration	**7,4**	**2,8**	**2,6**	**3,1**	**3,0**	**K**
lifetime 1600 cycles	**32,2**	**12,5**	**11,4**	**13,7**	**13,0**	**a**
lifetime 8000 cycles	**161,2**	**62,3**	**57,1**	**68,5**	**65,2**	**a**

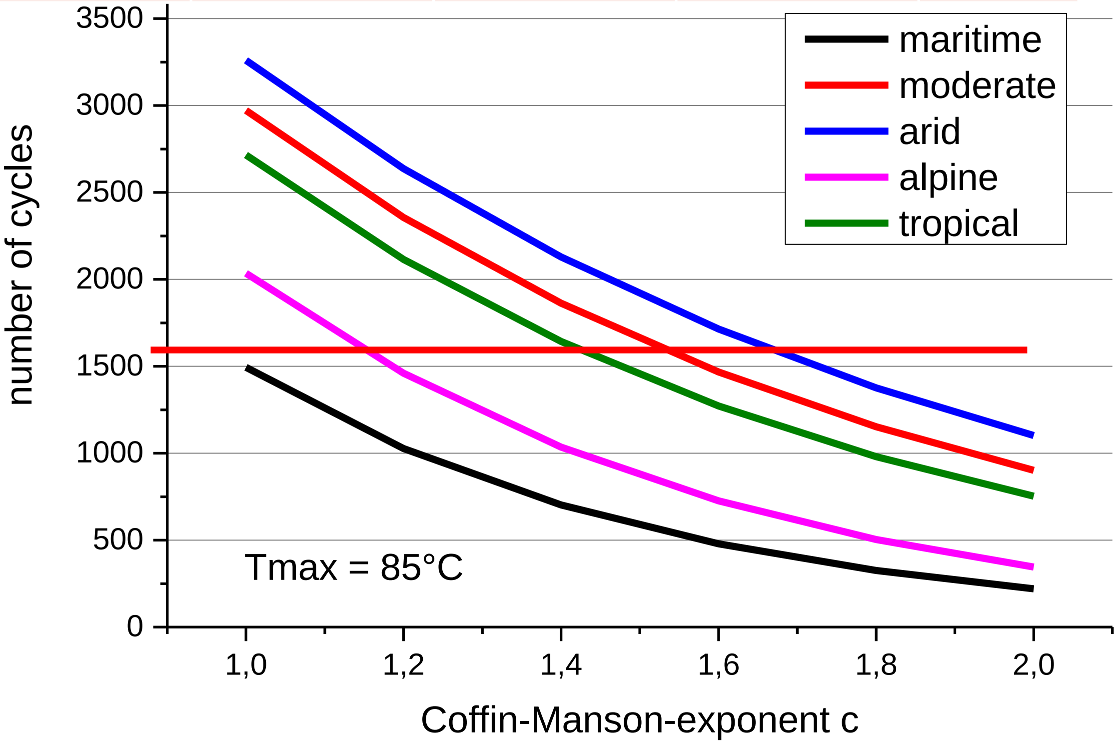
$\Delta\ T_{test} = 125K$

Acceleration factor:
$a = (\Delta T_{test} / \Delta T_{meas})^{C}$

25 years := 9125 cycles

C ist material-dependend parameter, to be determined (literature: 1 – 3)

Climate-Impact: Factor 2 - 4



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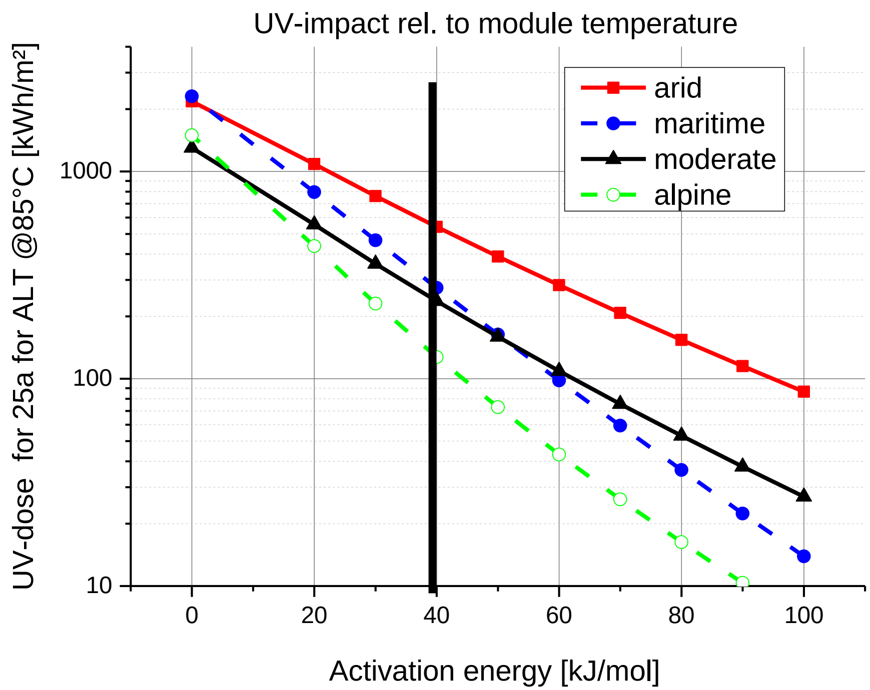
UV testing for different climates

Factor 2 – 4 for different climates is possible

But about a factor of 10 for testing times compared to IEC 61215 (15kWh/m² @ 60°C)

ALT at **85°C** sample temperature



	Ea (kJ/mol)	arid	maritime	moderate	alpine	for 25a
	0	**2261**	**2368**	**1388**	**1294**	**kWh/m²**
Tamb	**40**	**154**	**135**	**77**	**34**	**kWh/m²**
Tmod	**40**	**541**	**275**	**237**	**127**	**kWh/m²**

Cooling

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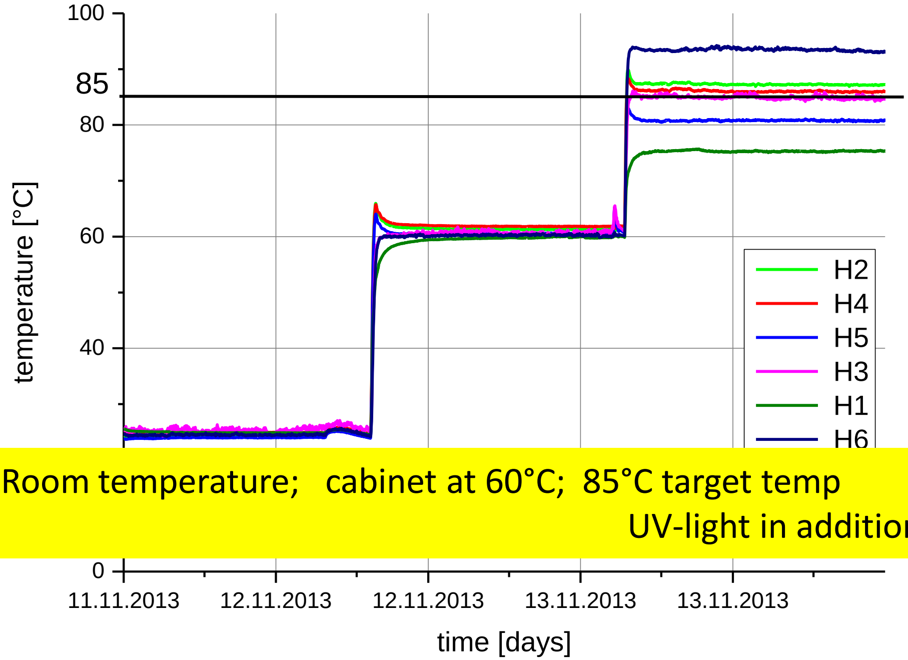
Temperature of different modules in UV-testing cabinet

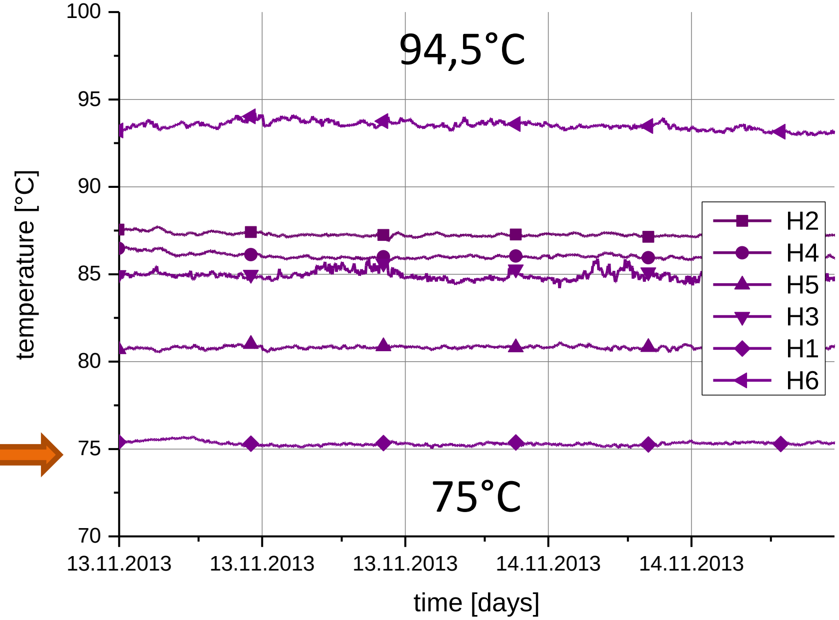
Position dependence because of circulating air-cooling (worst example)



Room temperature; cabinet at 60°C; 85°C target temp

UV-light in addition

20kW load



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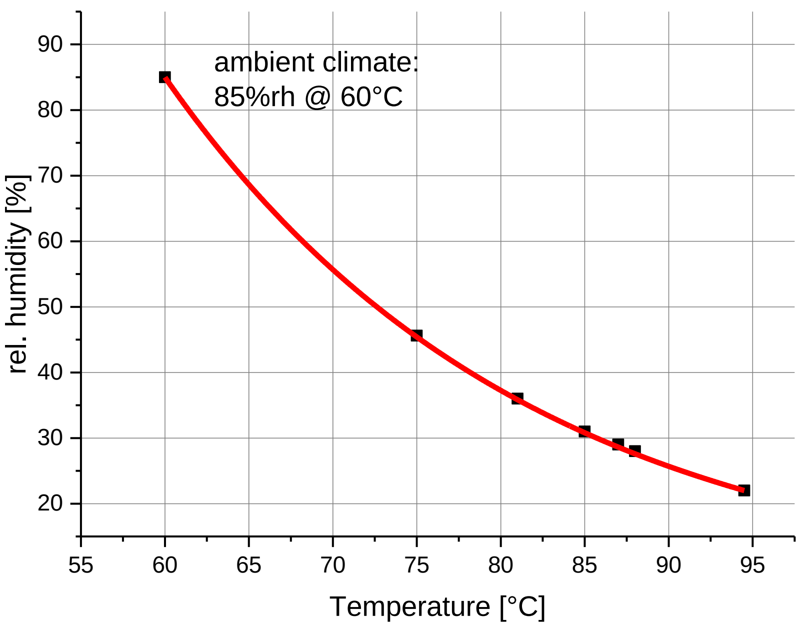
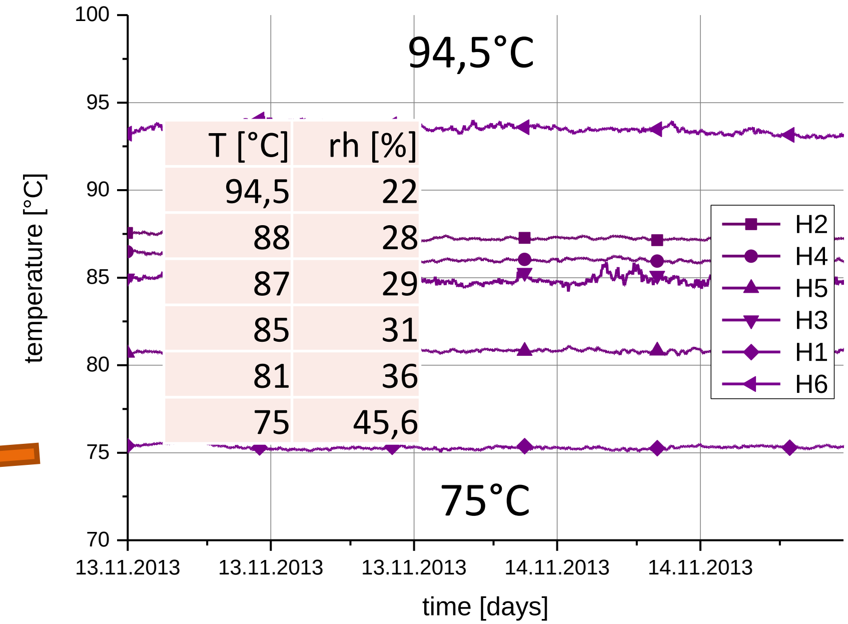
Temperature of different modules in UV-testing cabinet

Position dependence because of circulating air-cooling (worst example)





T [°C]	rh [%]
94,5	22
88	28
87	29
85	31
81	36
75	45,6

Climatic cabinet at 60°C; 85%rh

Surface temperature with UV-light in addition

Different acceleration:

- Factor 2 in humidity gradient
- Factor 3 in acceleration by temperature (@60kJ/mol)

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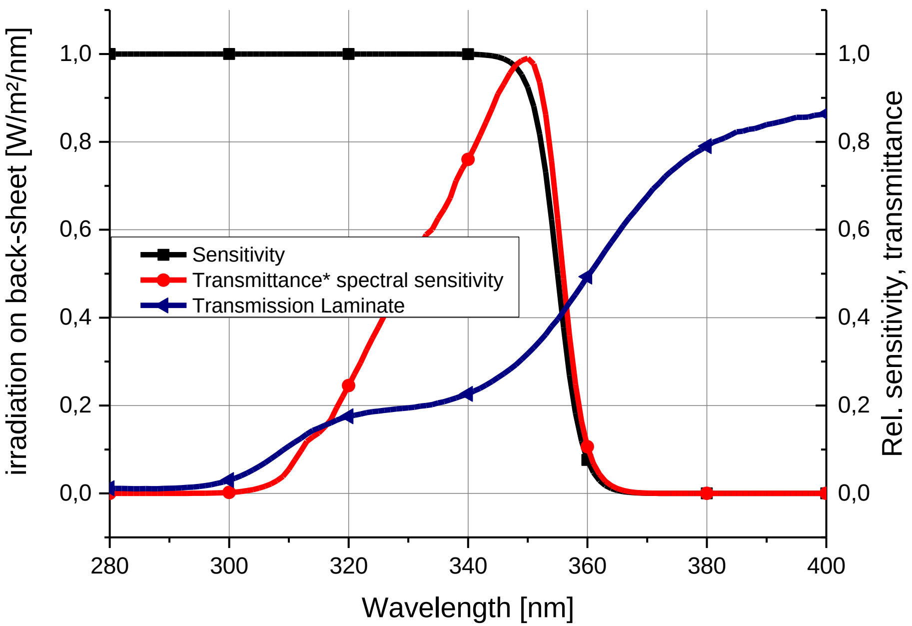
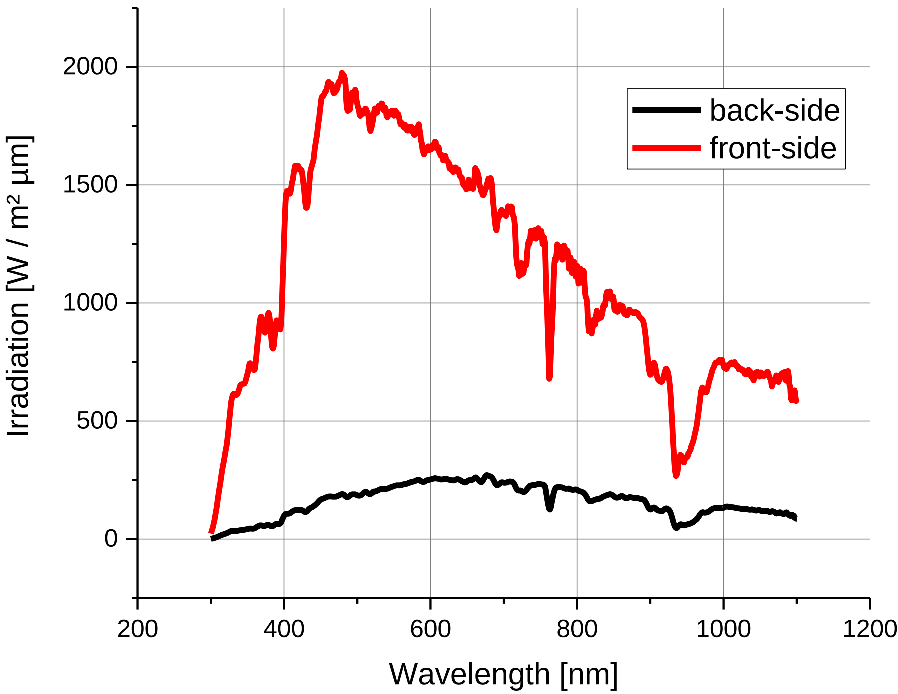
Relevant spectral irradiation from solar side onto back-sheet

Photodegradation Heating



SOPHIA backsheet round robin

Front-side or back-side impact



Measurements from Canary island

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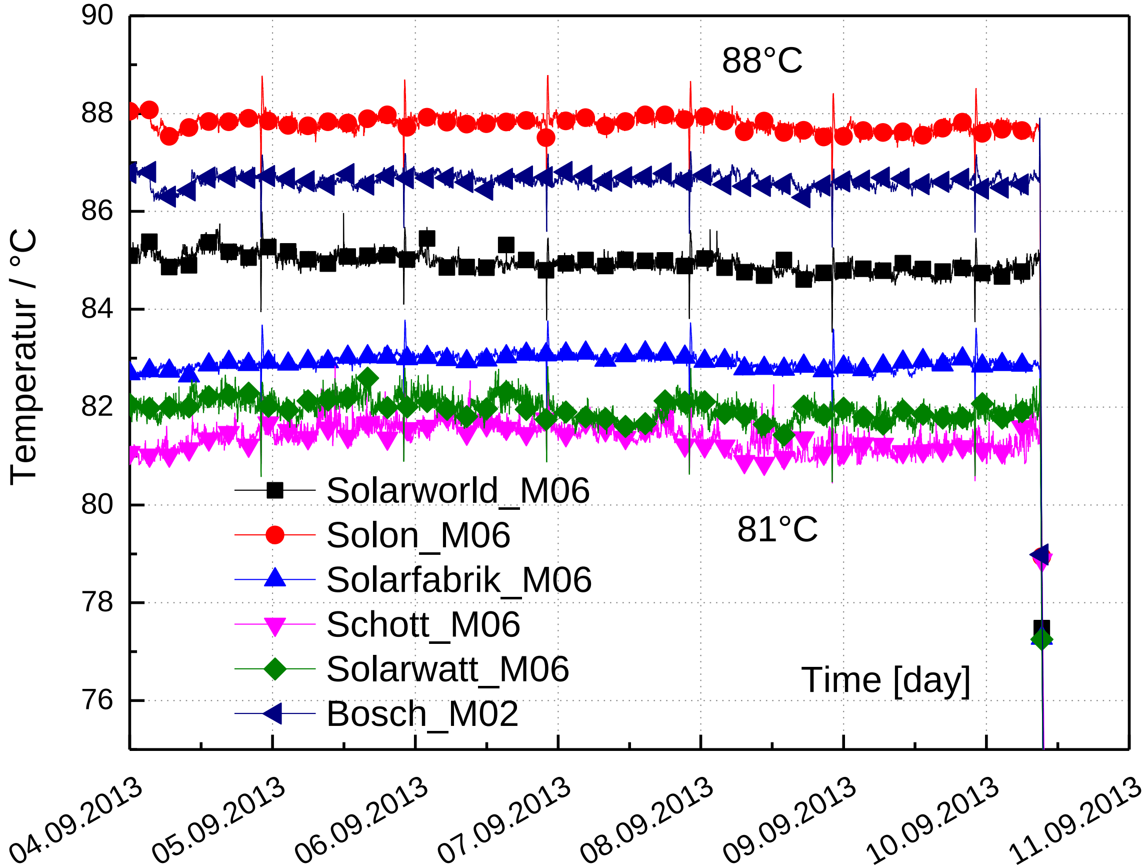
Module temperature during UV-D/H testing after ventilation improvement



Different acceleration:

- Factor 1.3 in humidity gradient
- Factor 1.5 in acceleration by temperature (@60kJ/mol)

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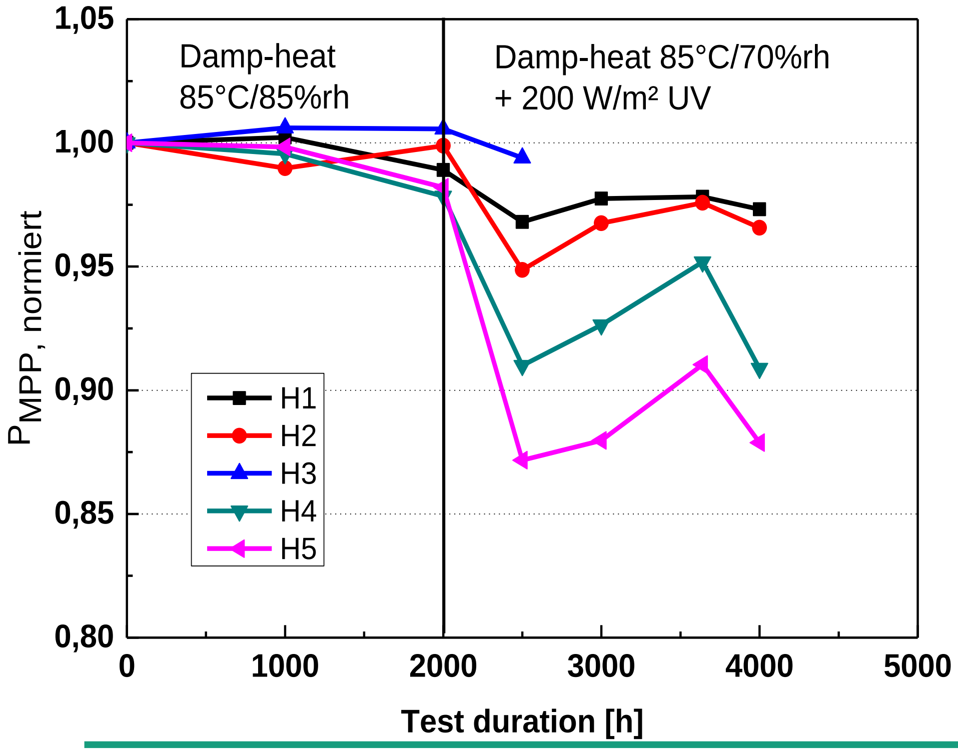
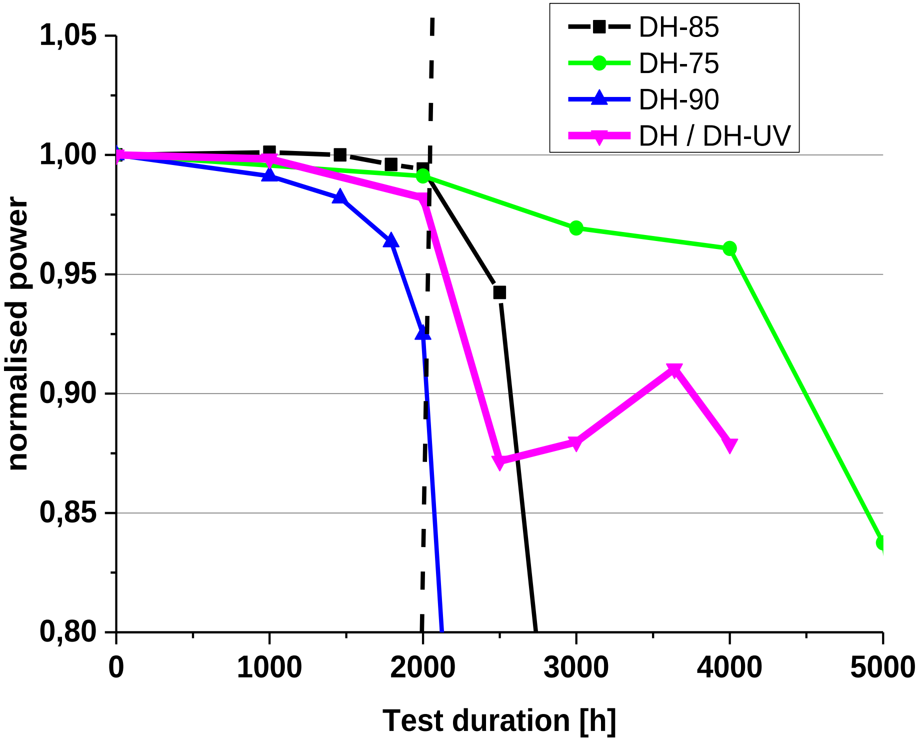
Combi tests: first humidity permeation, than UV with humidity

Is high humidity relevant?

Is irradiation healing?

Is constant load testing relevant?





Sequential combi-test procedure

based on the IEC standard tests because of convenience

Initial cycle for setting humidity level:

1000 h 85°C / 85% rh > 30%

100 Tc -40°C / +85°C **=> humidity freeze testing** **< 20%**

500 h combined DH/UV at ~85°C module temperature (100kWh/m²) > 20%

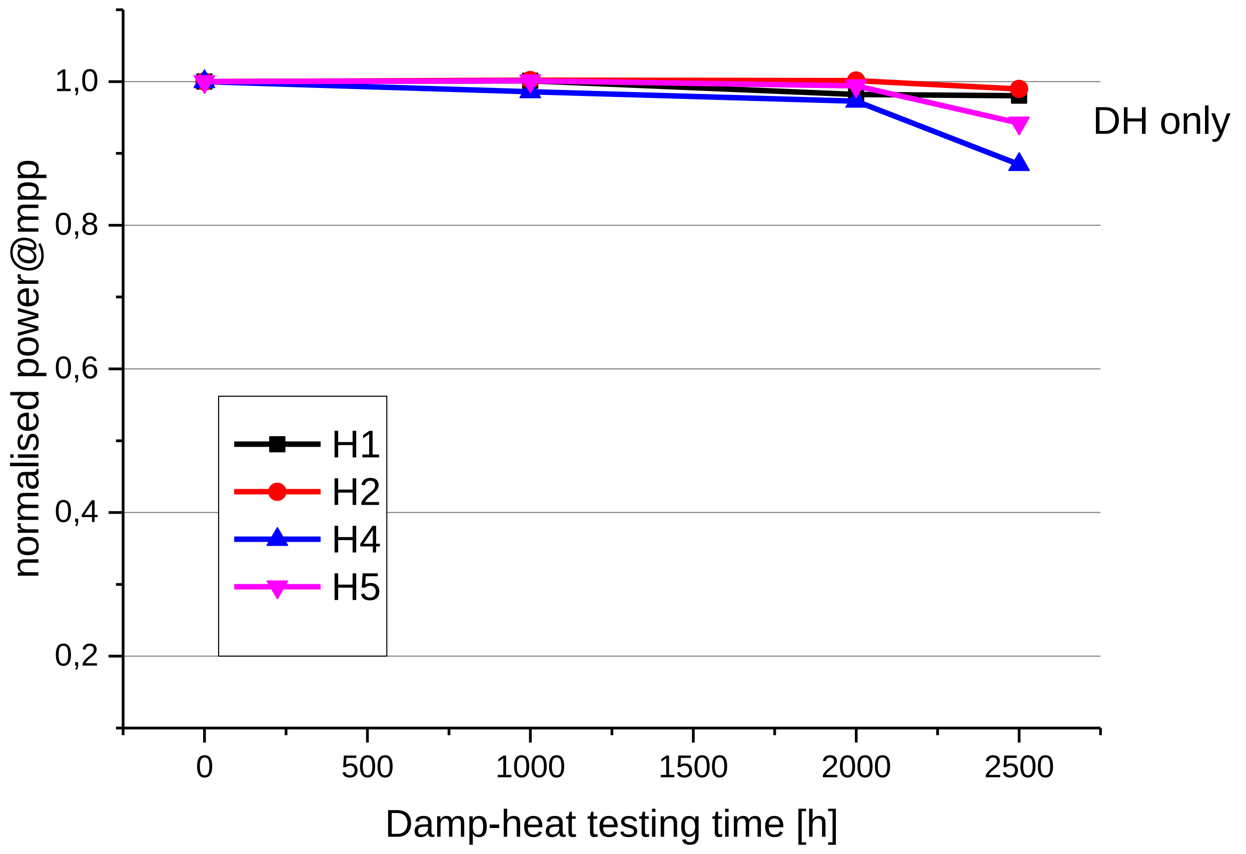
Repeated cycles:

500 h 85°C / 85% rh for refreshment of humidity in the encapsulant < 15%

100 Tc -40°C / +85°C **=> humidity freeze testing** **> 20%**

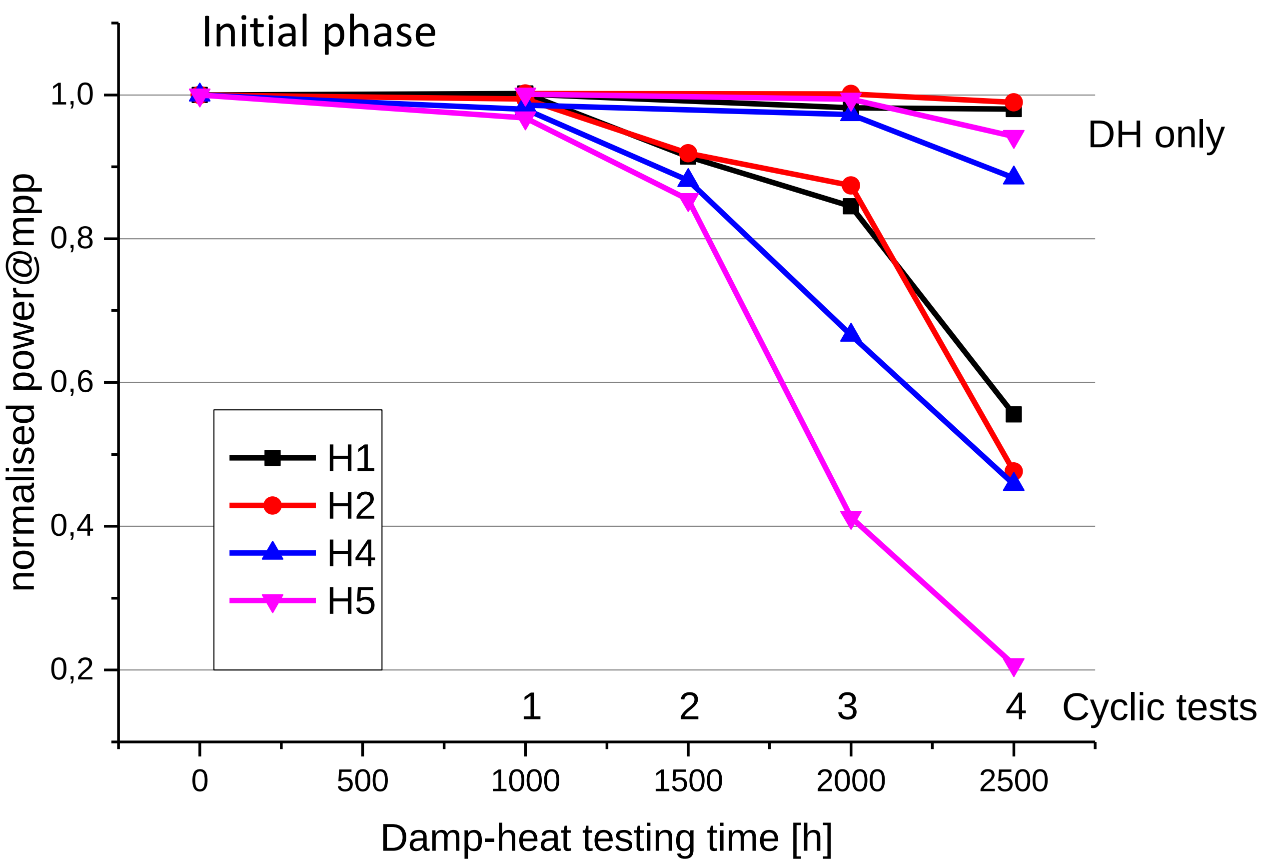
500 h combined DH/UV at ~85°C module temperature > 20%

Combi-testing compared to extended damp-heat-testing



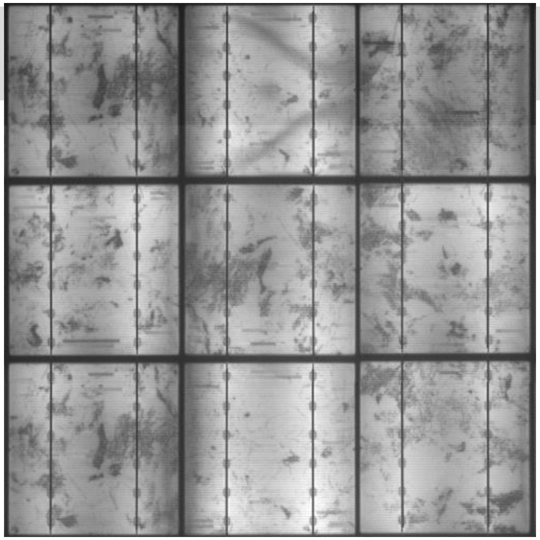
Combi-testing compared to damp-heat-testing

Faster degradation with cyclic testing



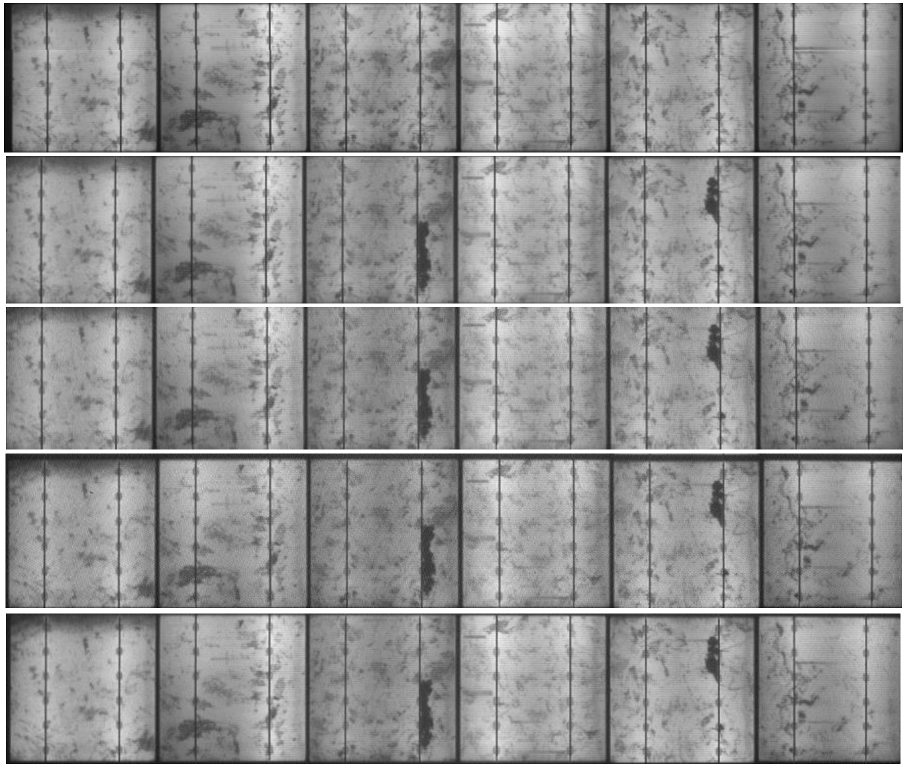
Four cycles combi tests

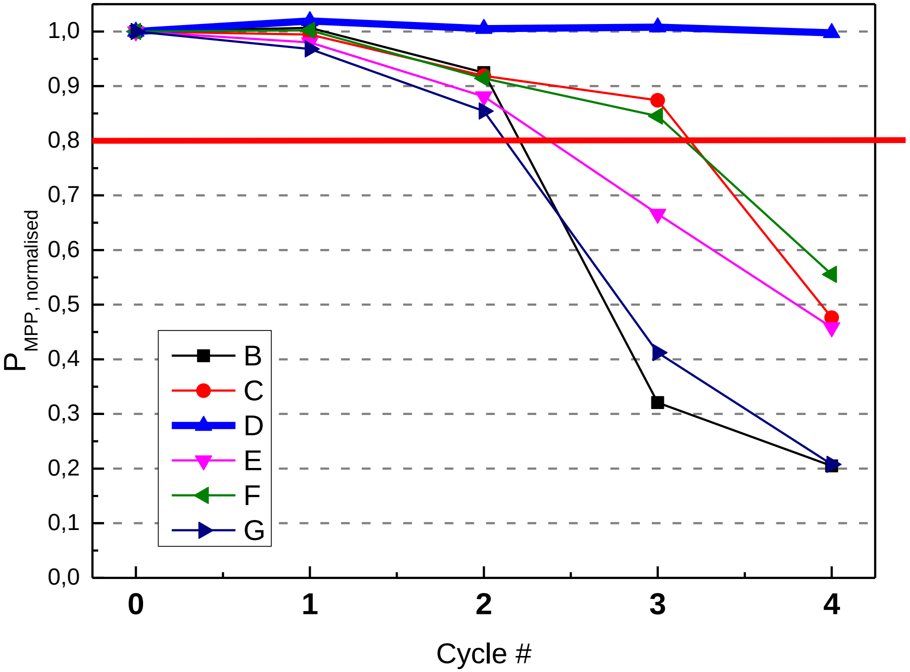
Damp-Heat



Sample H3

0
1
2
3
4





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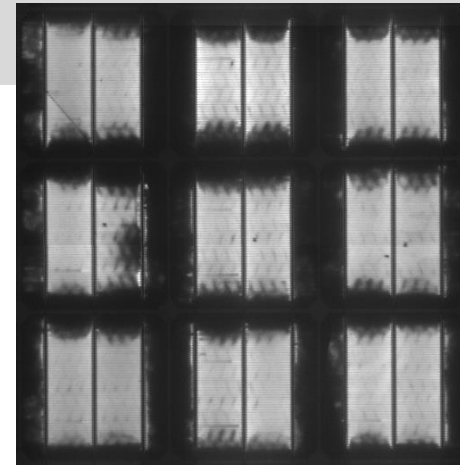
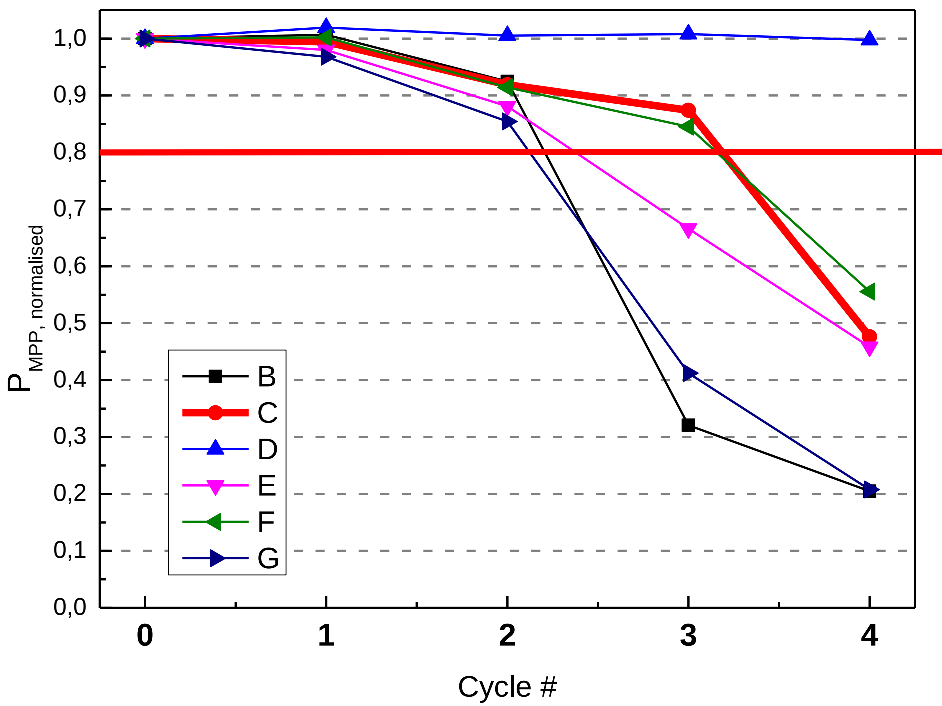
Four cycles combi tests

After 5000h
Damp-Heat



Sample C



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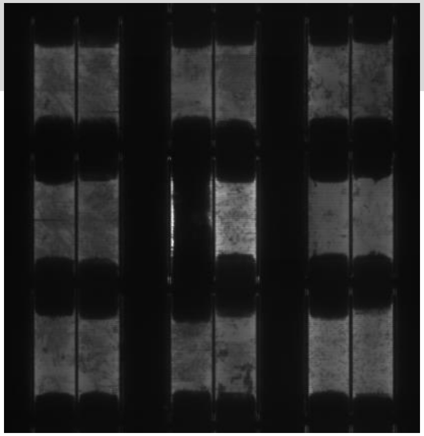
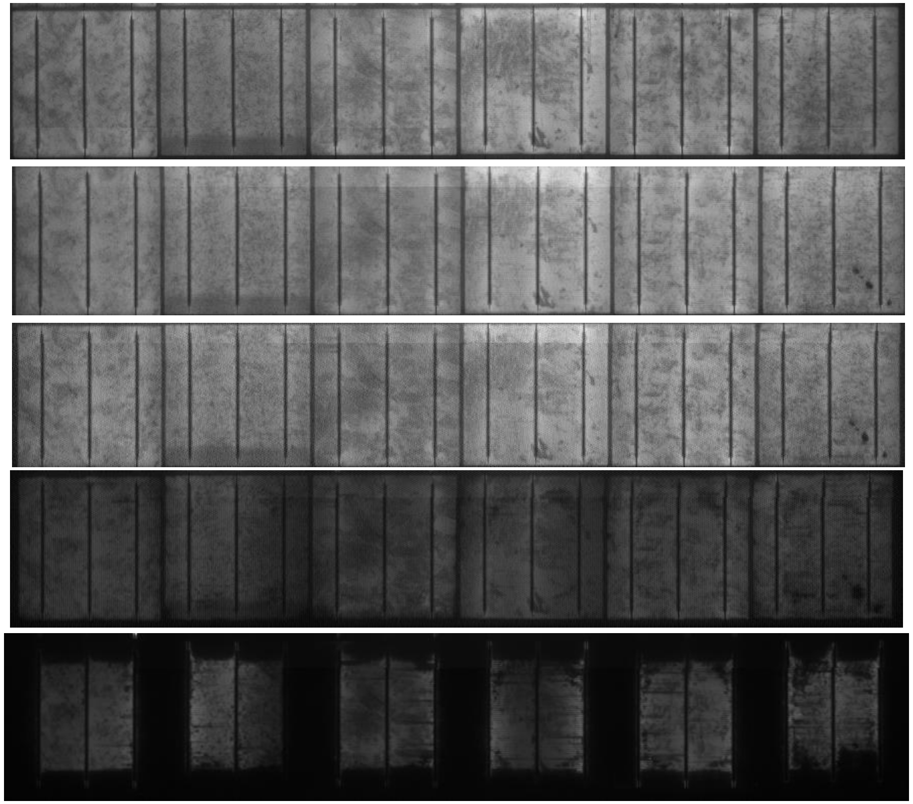
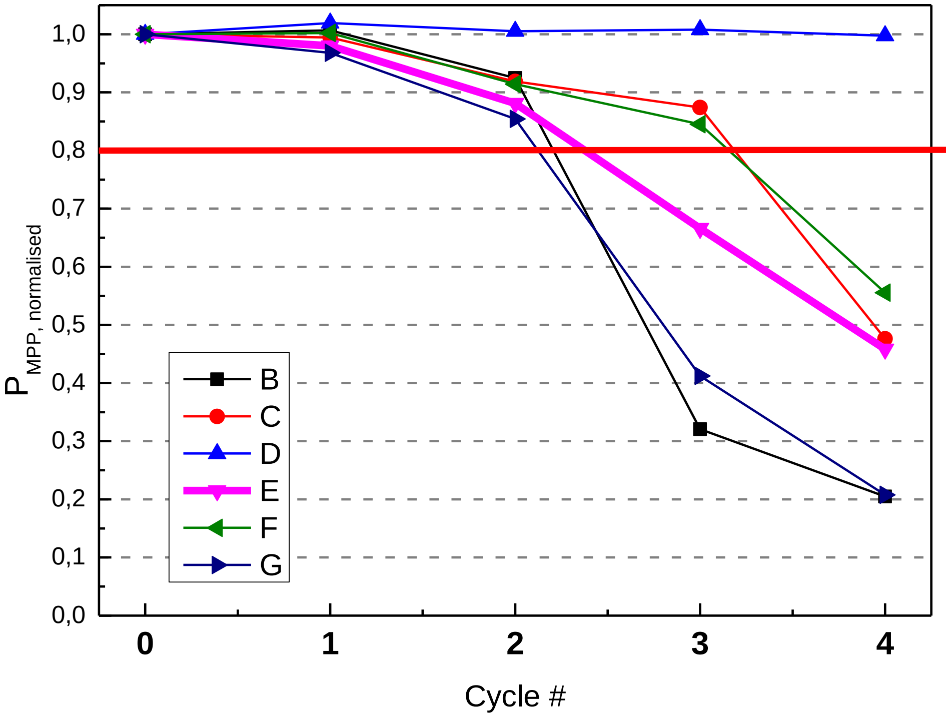
Four cycles combi tests



From damp-heat

Sample E





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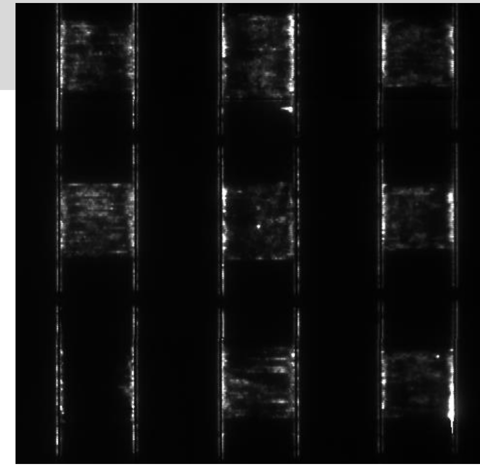
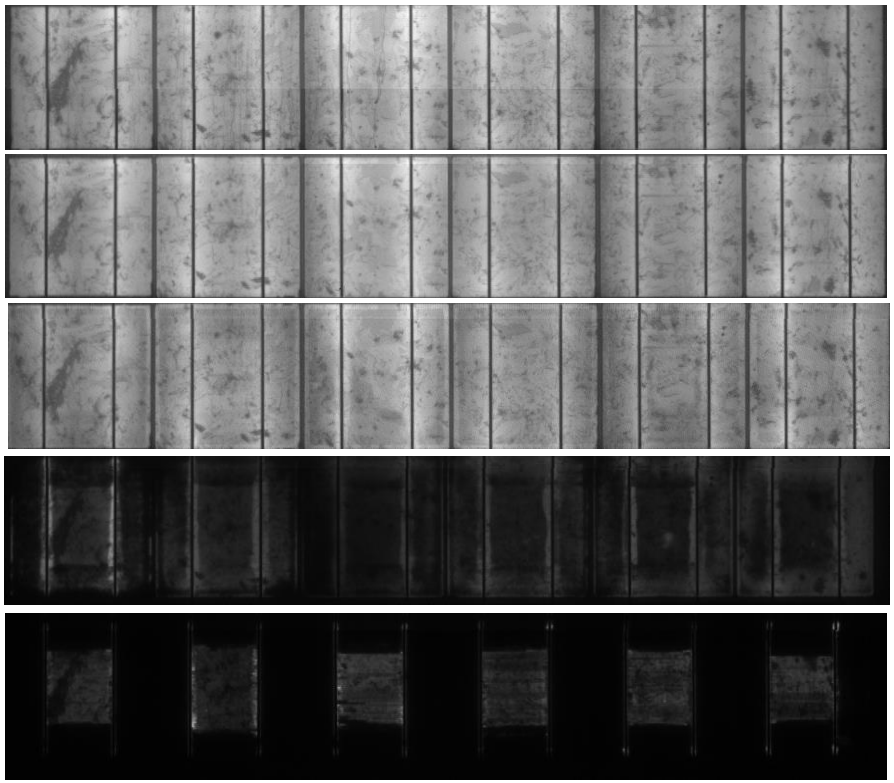
Four cycles combi tests

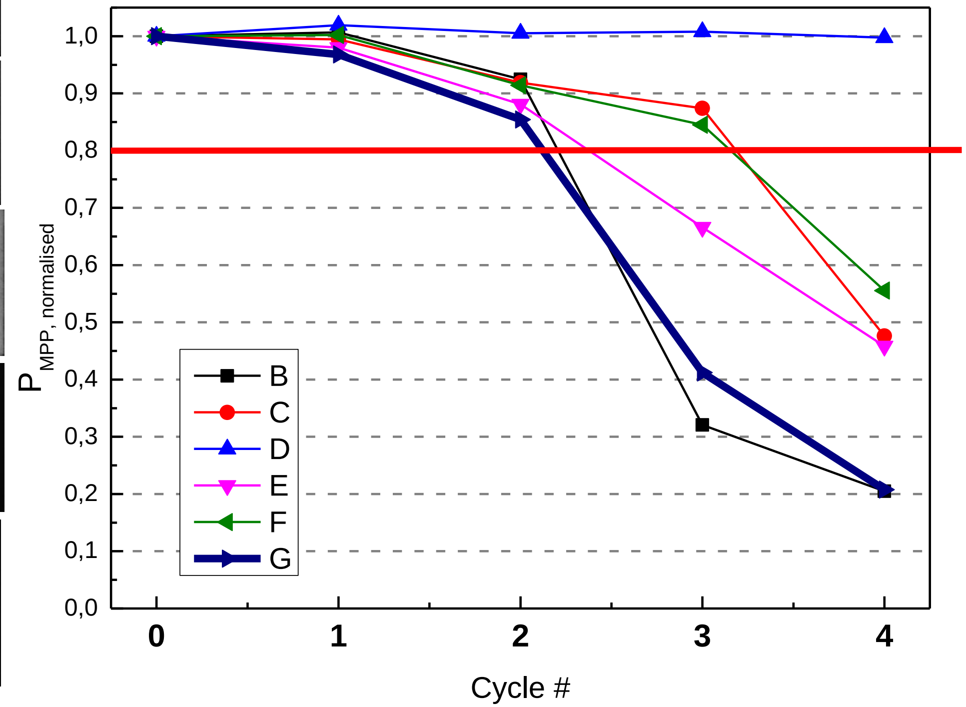


Damp-Heat

Sample G

0
1
2
3
4





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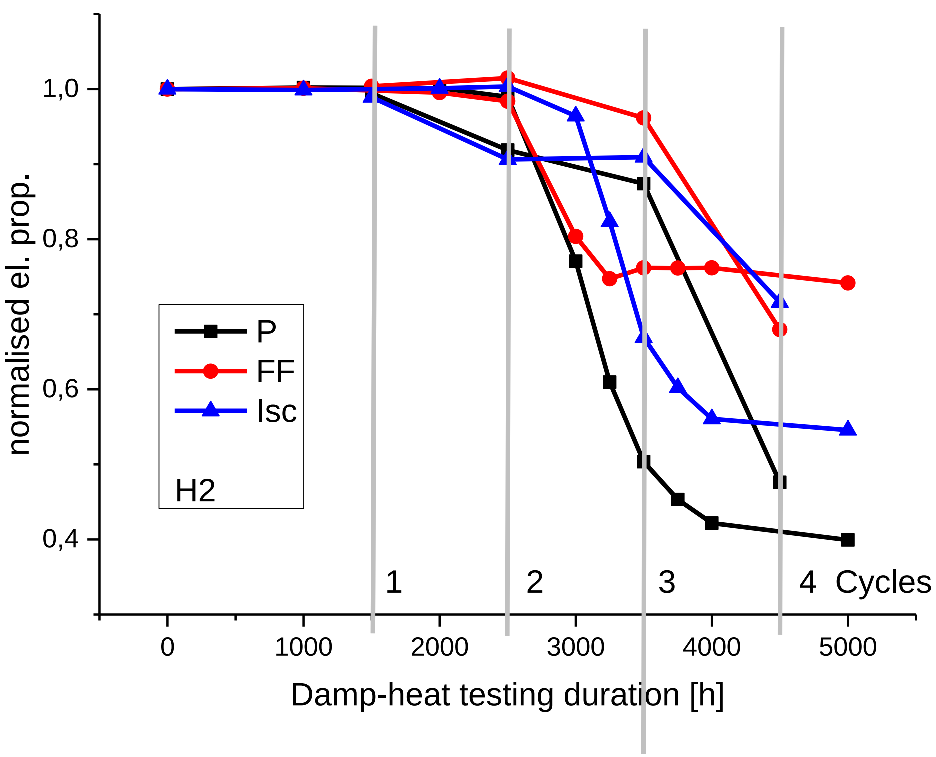
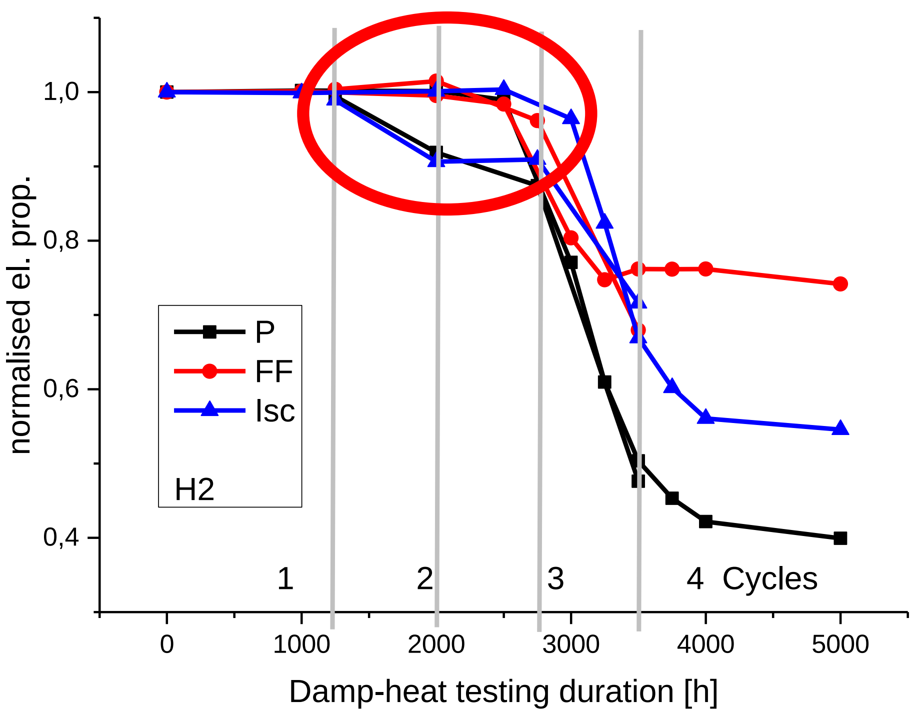
Results from combi-test-cycles compared with damp-heat

Isc drop because of UV

Factor 1.0 for UV



Factor 0.5 for UV



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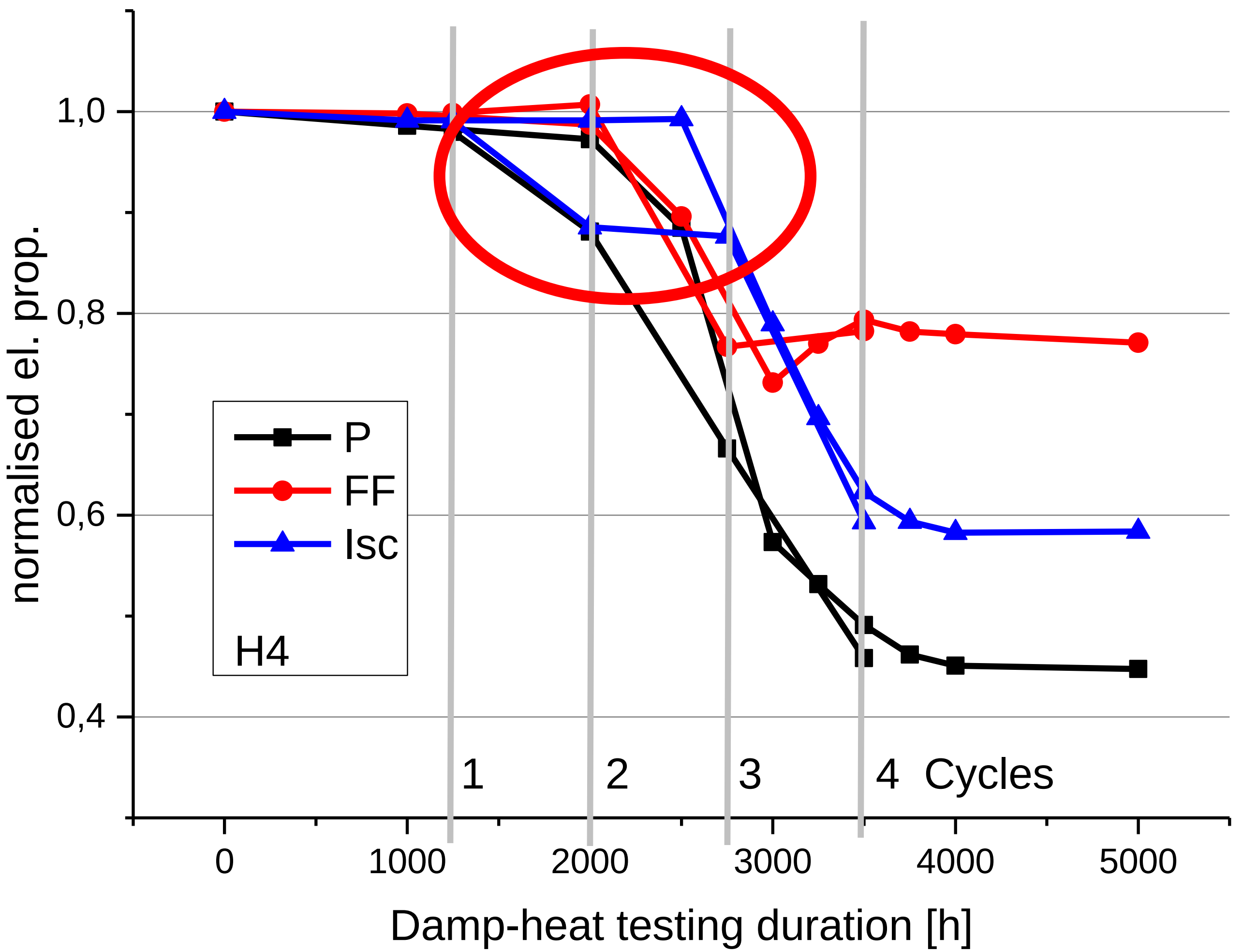
Results from combi-test-cycles compared with damp-heat

Time-transformation 0.5 for UV-testing (sample temperature)



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Challenges:

Development of models for accelerated aging

Impact of voltage/current

Evaluation of a test-sequence representing real life for a certain time-period

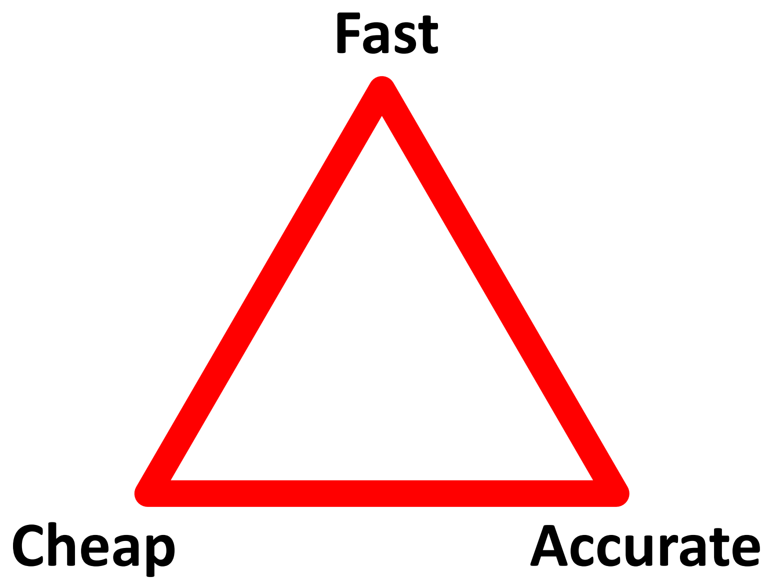
Development of test-sequences for different climatic locations

Evaluation of test-sequences representing different stress levels for service life-time assessment

Development of suitable test equipment

Comparison with field failures (modules proven to be stable must be old)

Accelerated life testing



Select two of them !!!