DERIVATION OF ADJUSTED TESTS FOR SOLAR MODULES IN EXTREME CLIMATES

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Fraunhofer CSP

QUESTIONS

- Extreme climates?
- Evaluation of reliability and fatigue of PV modules – how?
- Digitalization – why?
- Standard test or derivation?
- Benefits and further ideas?

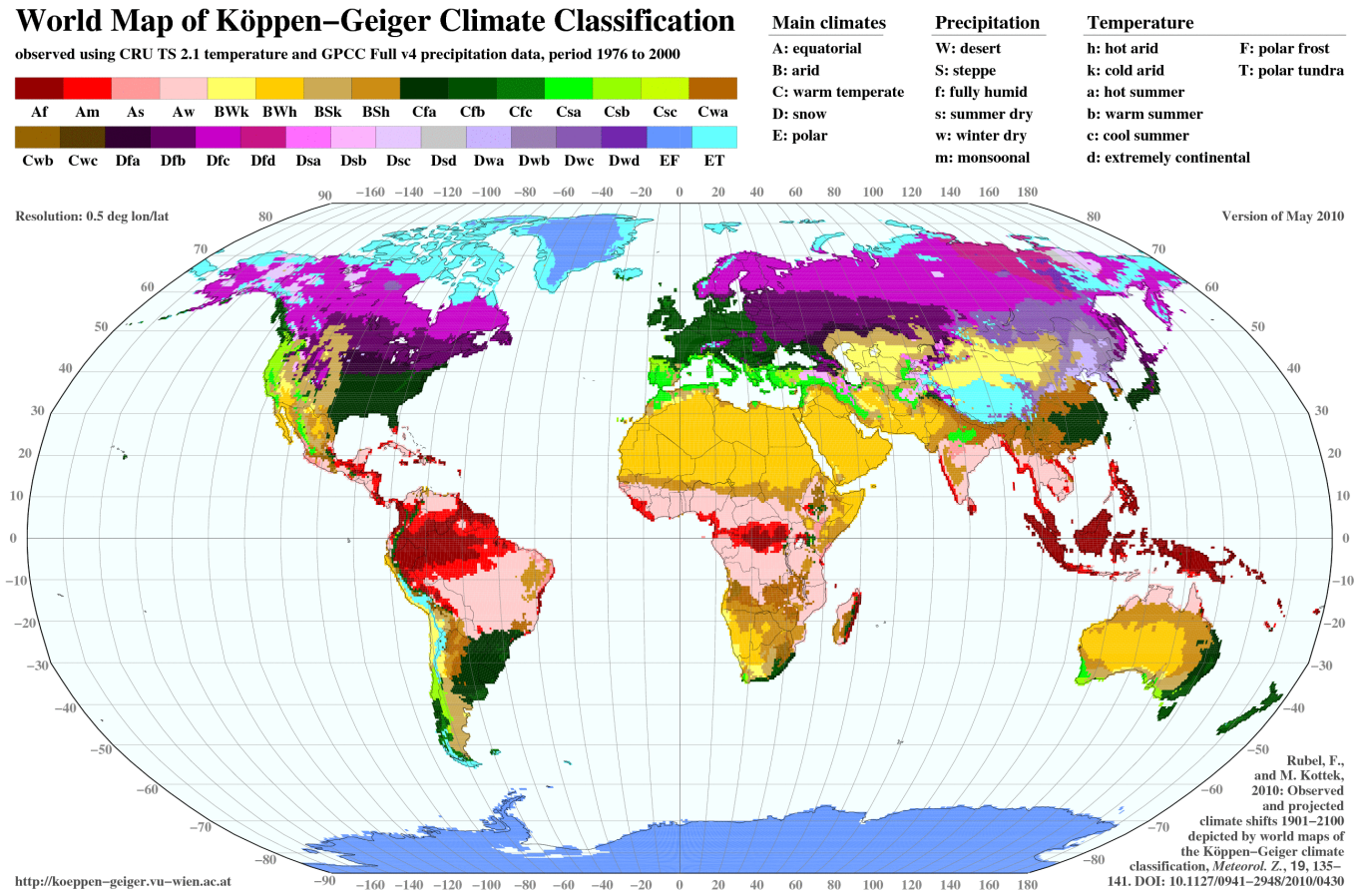
Extreme climates
Categorization

- Systemizing by general climate definition

➔ Relevant extreme climates?

Desert / Dry Climates

Tropical Climate



Source: Kottek et al, Meteorol. Z., pp. 259-263, 2006, DOI: 10.1127/0941-2948/2006/0130

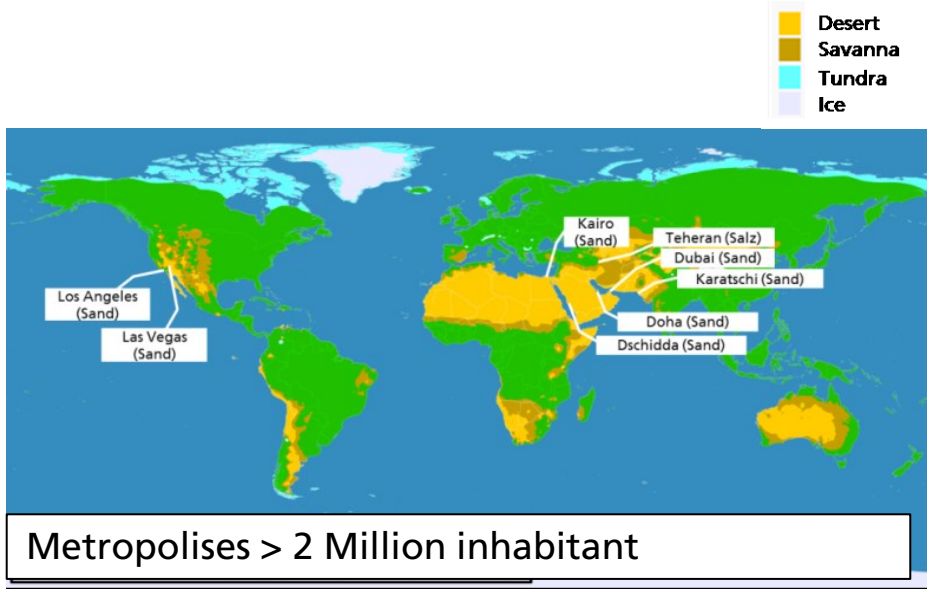
Extreme climates
Categorization

- Systemizing by general climate definition
- Selection of metropolitan areas
  - Relevance as commercial markets

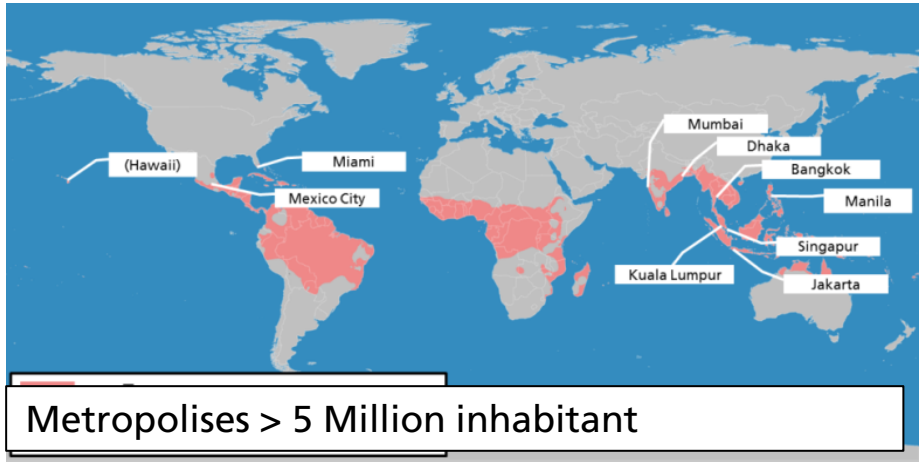
Desert / Dry Climates

- Acquisition of climate data
  - Software INSEL
  - Deutscher Wetter Dienst

Tropical Climate



Metropolises > 2 Million inhabitant



Metropolises > 5 Million inhabitant

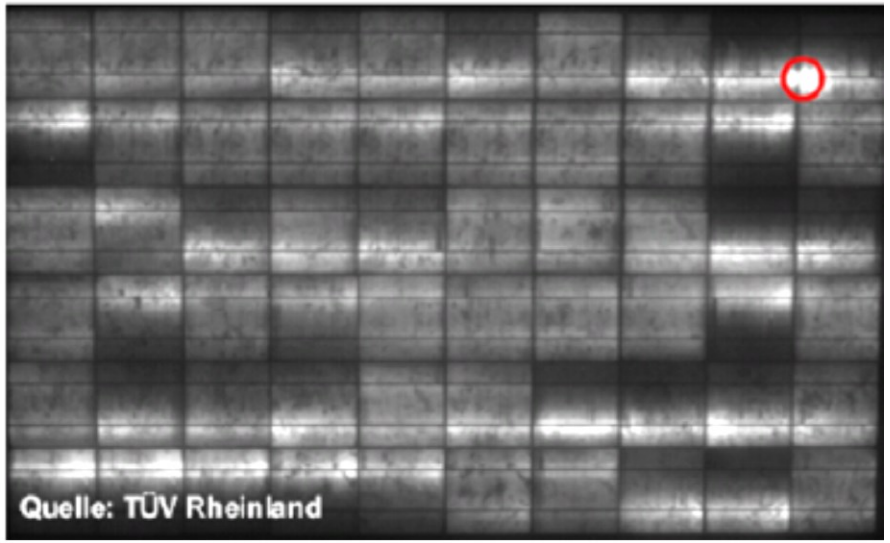
Reliability and fatigue of PV modules
Local durability

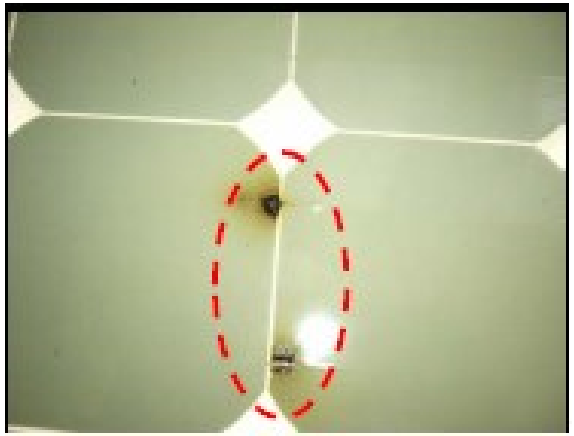
- Durability depends on local conditions:
  - Temperature (mean, change) → main objective of this work
  - Relative humidity
  - Irradiance [W/m²] (amount of UV)
  - Wind
  - ...

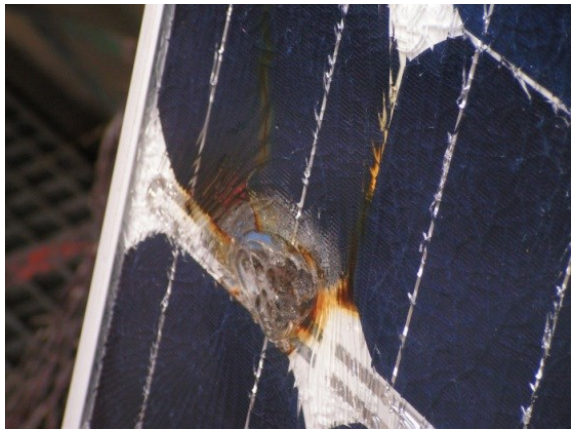
} in progress

Reliability and fatigue of PV modules
Weakest link in chain – interconnector

- Power loss
- violation of integrity of the complete module (e.g. Arcing, Hot Spots)
- Possible root causes
  - Manufacturing process of ribbon and module
  - Bending of laminate (wind, snow)
  - Temperature changes (day/night, sessions)





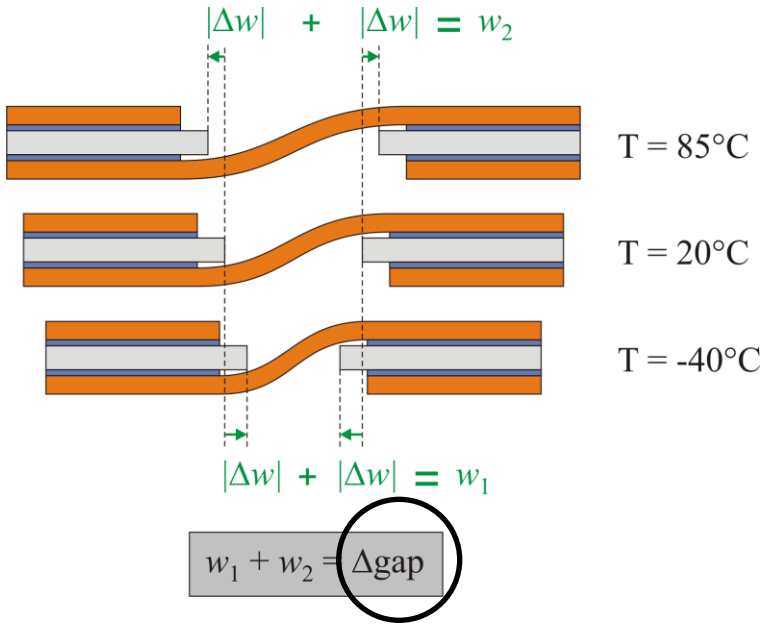


Sources: Hermann, W., SPIE 7773, 2010, Kato et al., PVMRW 2012, NREL, Fraunhofer ISE

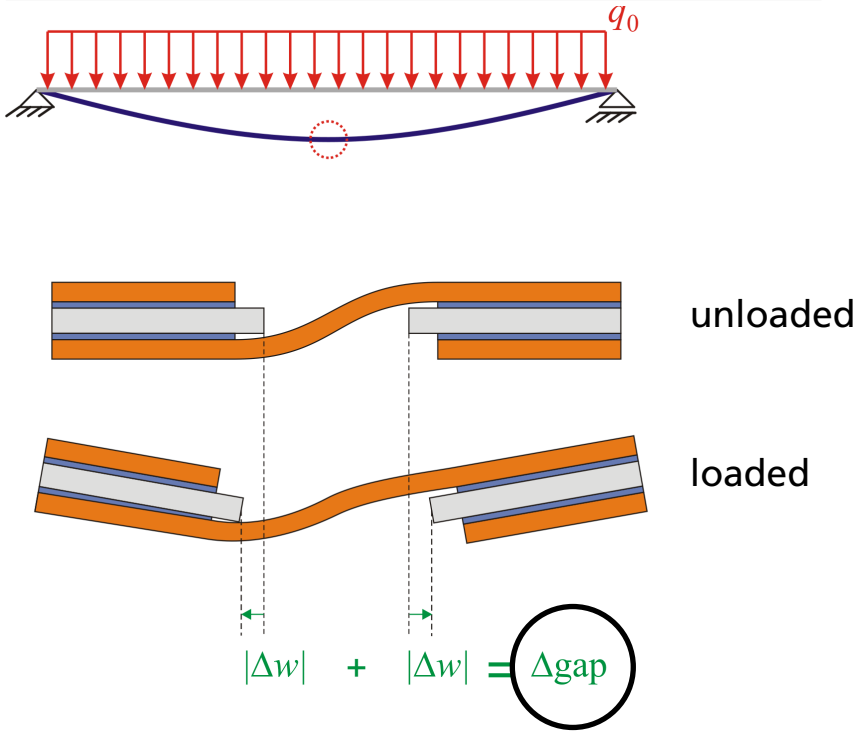
Reliability and fatigue of PV modules

Mechanics of interconnector fatigue

Temperature Cycling (TC)



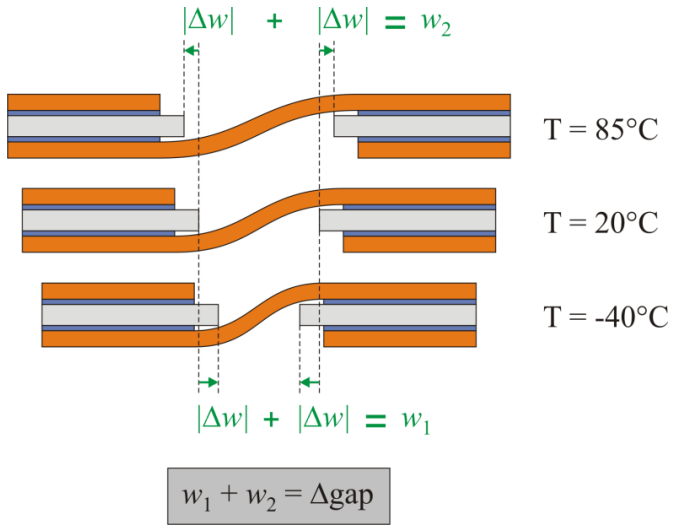
Cyclic Mechanical Loading (CML)



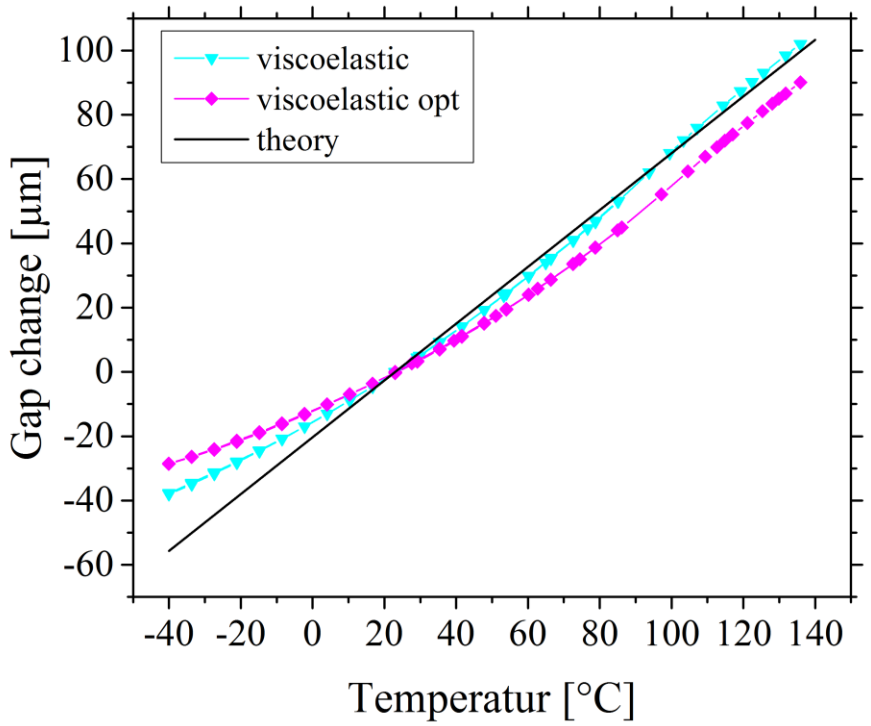
➔ Ribbon fatigue caused by change of cell gap due to relative cell shifting

Reliability and fatigue of PV modules
Influence of Encapsulant Stiffness

- Viscoelastic material captures stiffness changes within temperature range
  - ➔ increased gap change at elevated temperature
  - ➔ lower gap change below glass transition



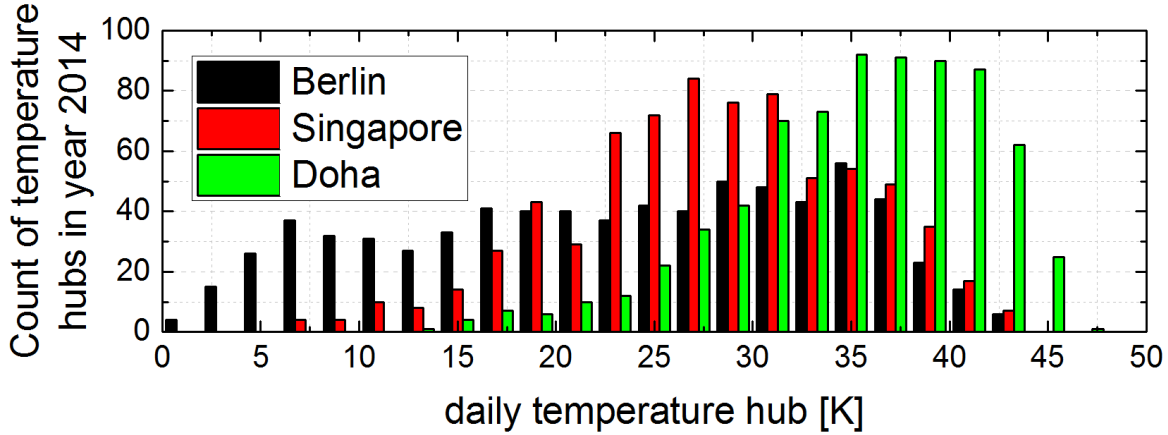
$w_1 + w_2 = \Delta gap$

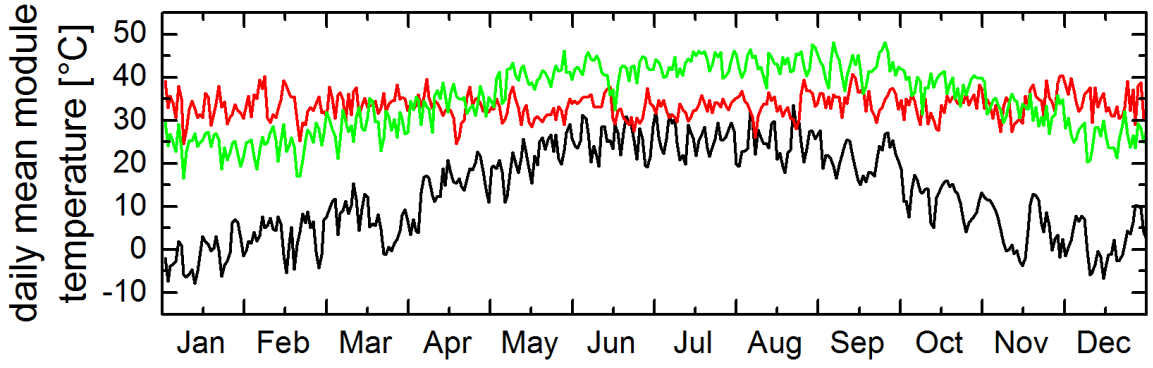


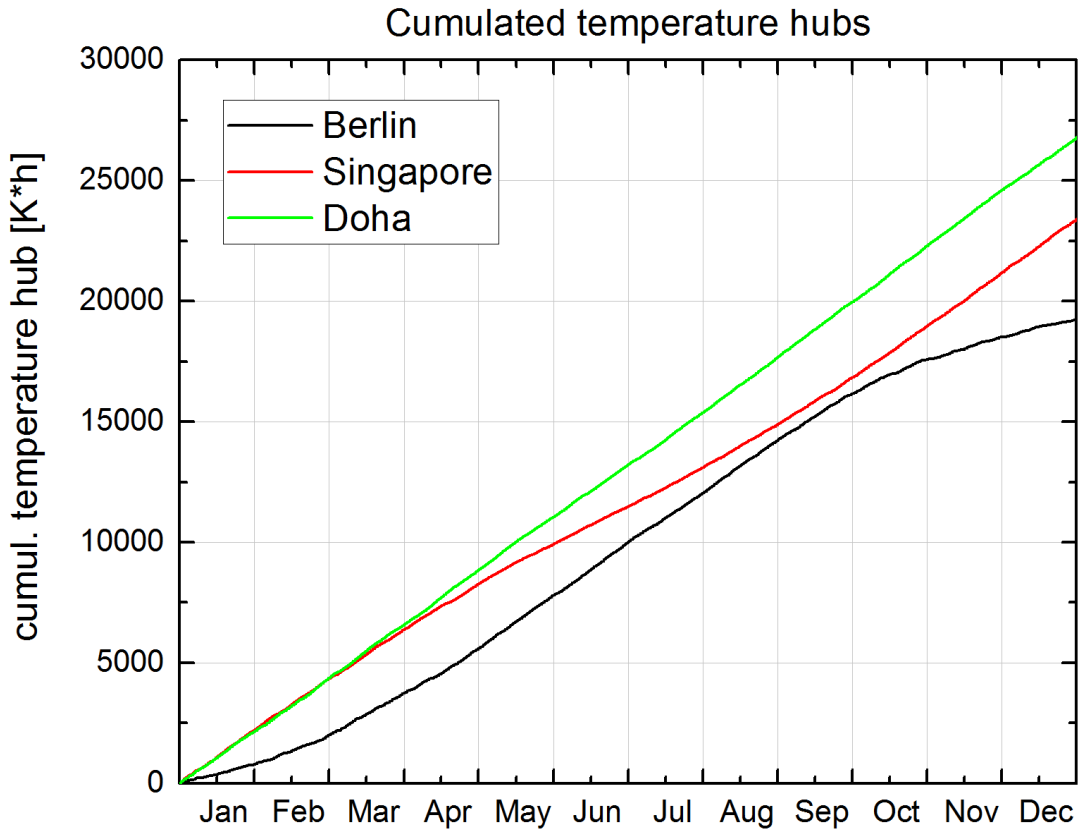
gap change between -40 and 140°C in a solar module with 3 mm initial gap, **comparison of different encapsulant stiffness and viscoelastic model**

Digitalization
Data implementation

- Transfer of climate data (complete year 2014) into simulation model

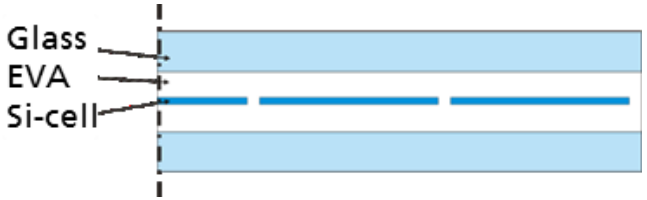


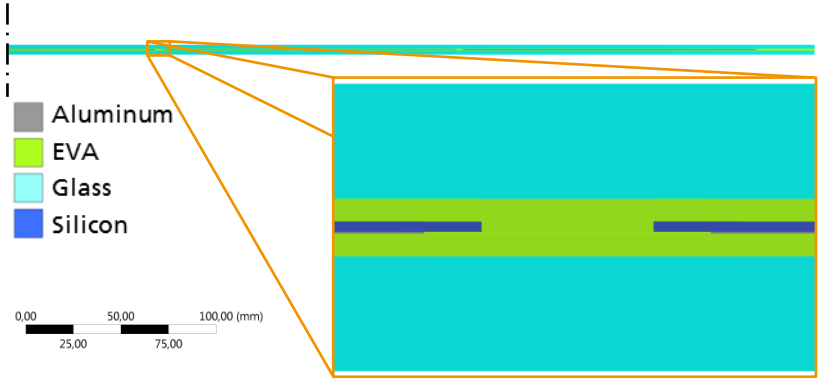




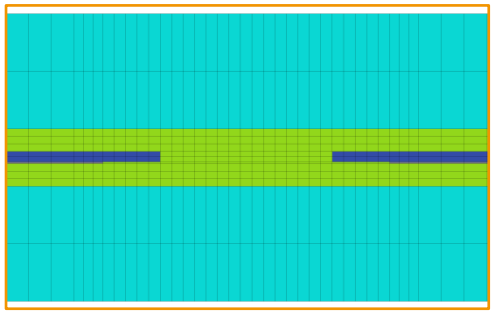
Digitalization
Finite element analysis

- Global model

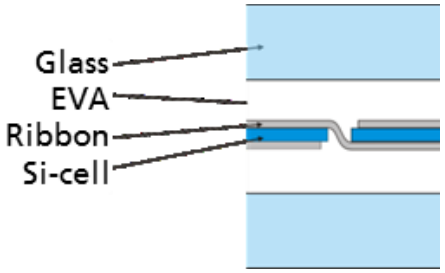


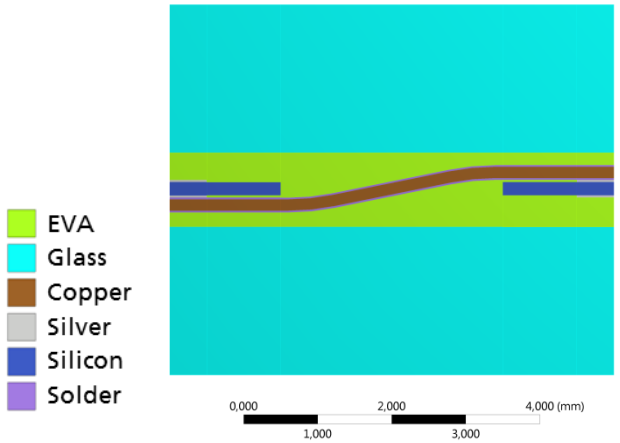


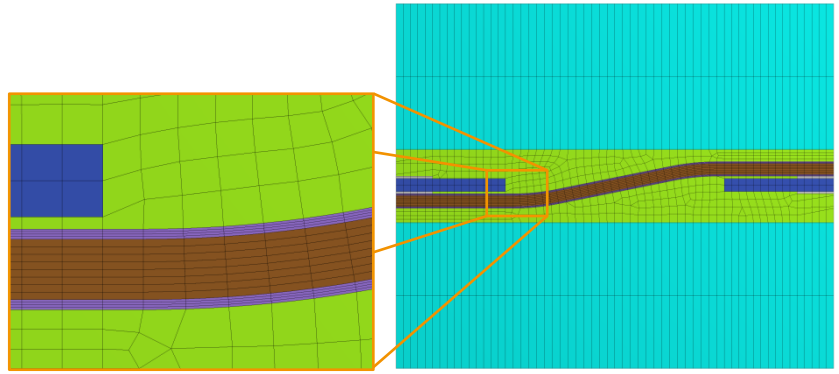
- FE mesh



- Sub model

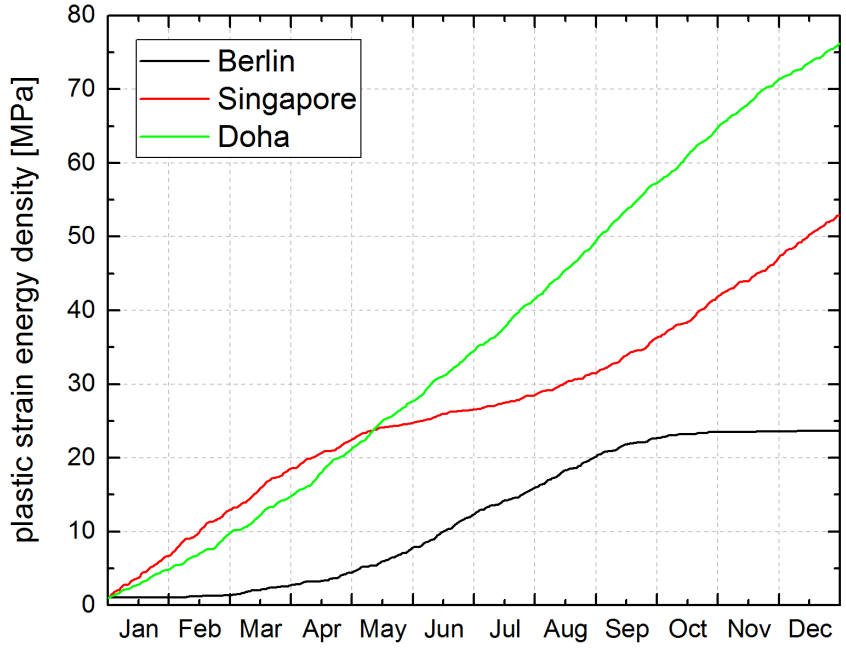


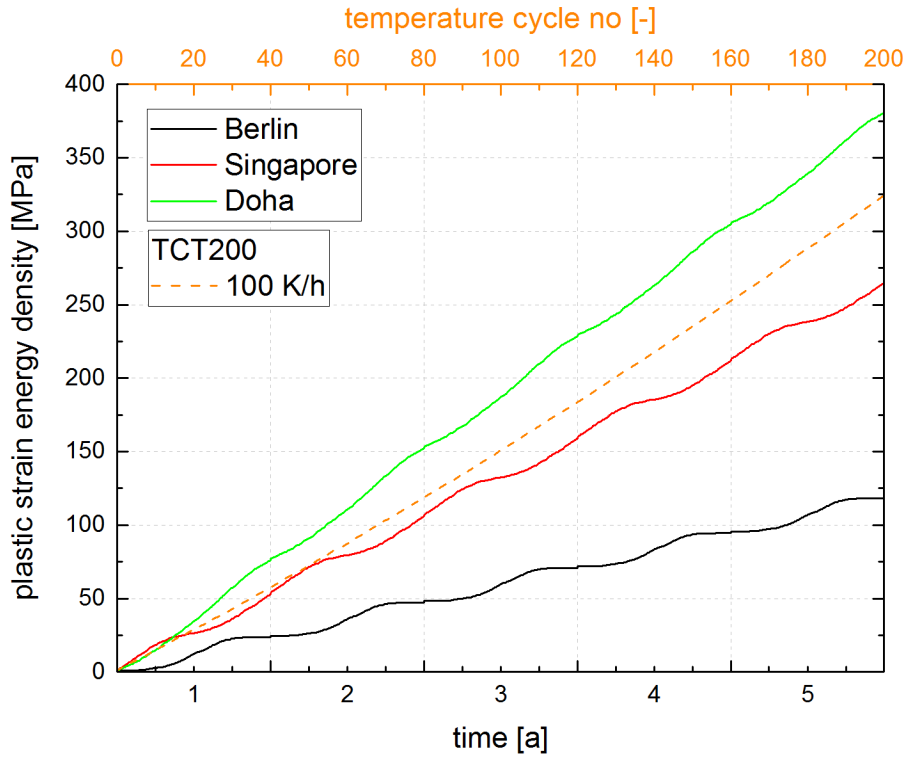




Digitalization
Finite element analysis

- Failure fatigue criterion: plastic strain energy density[1]
- Extreme climates 2 – 3x more severe than moderate climate





[1]Kujawski, D. „Fatigue failure criterion based on strain energy density“, JTAM Vol.27 (No 1) 1989, pp. 15-22

Standard test or derivation
Adjustment of testing scenarios

- Standard temperature cycle test (IEC 61215)

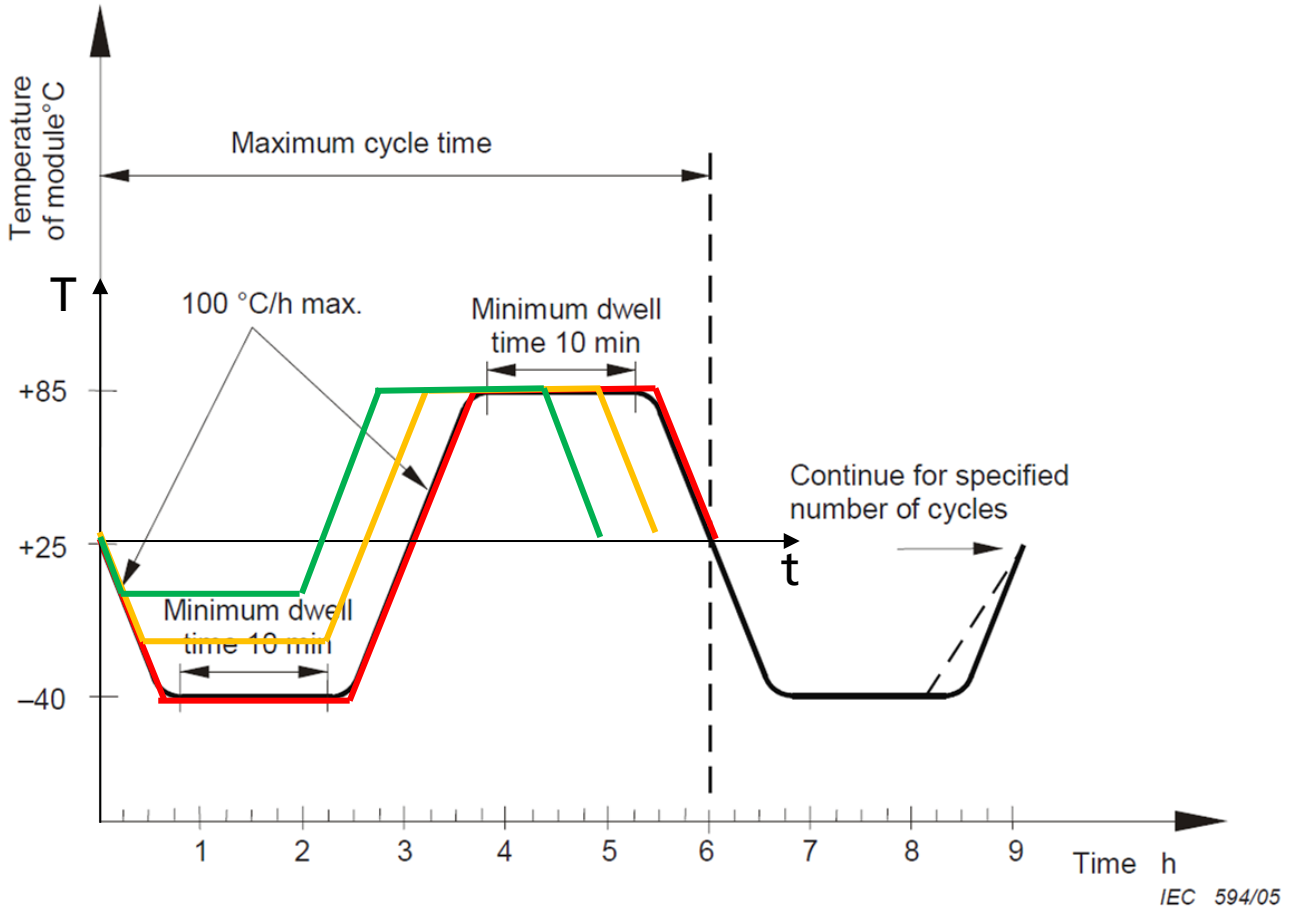
  Standard temperature profile

  Adjusted temperature profile

  Adjusted temperature profile

➔ Elevation of minimum temperature

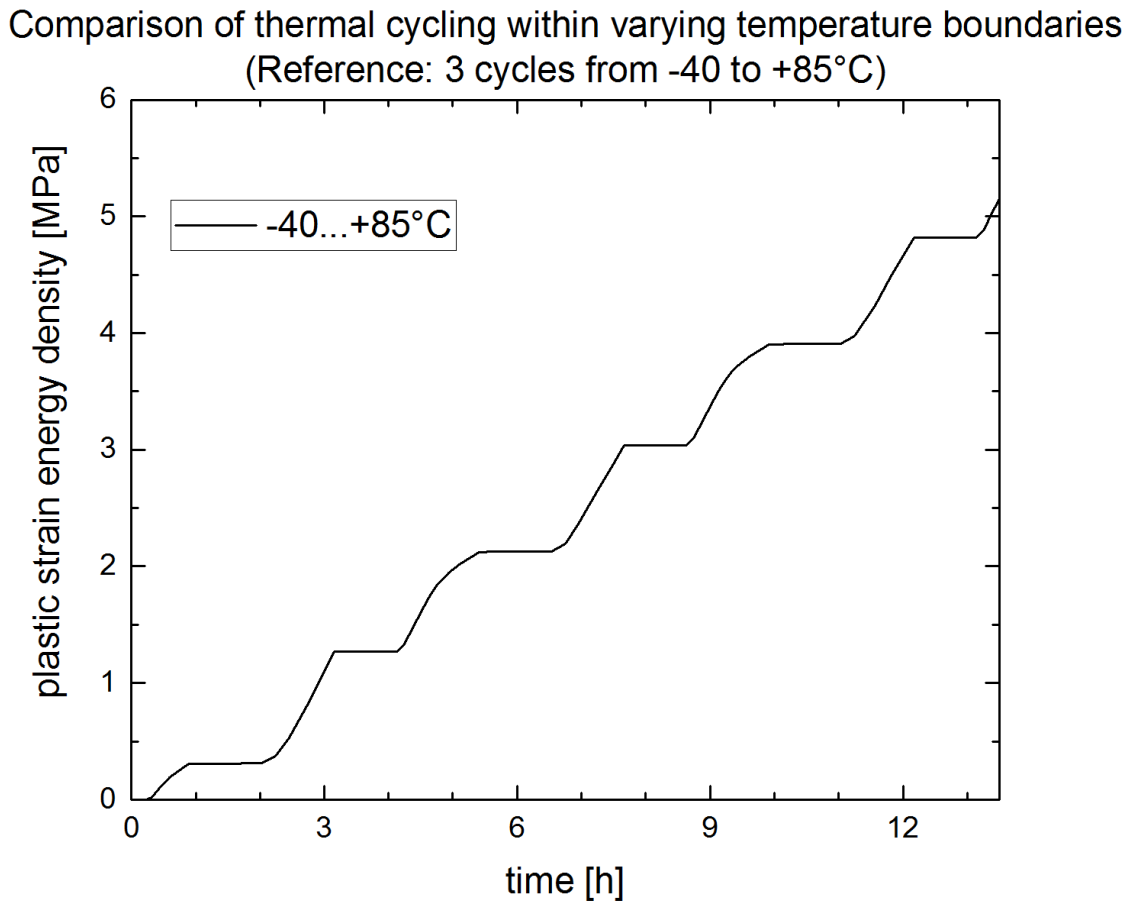
➔ Reduction of cycle time



Standard test or derivation
Adjustment of testing scenarios

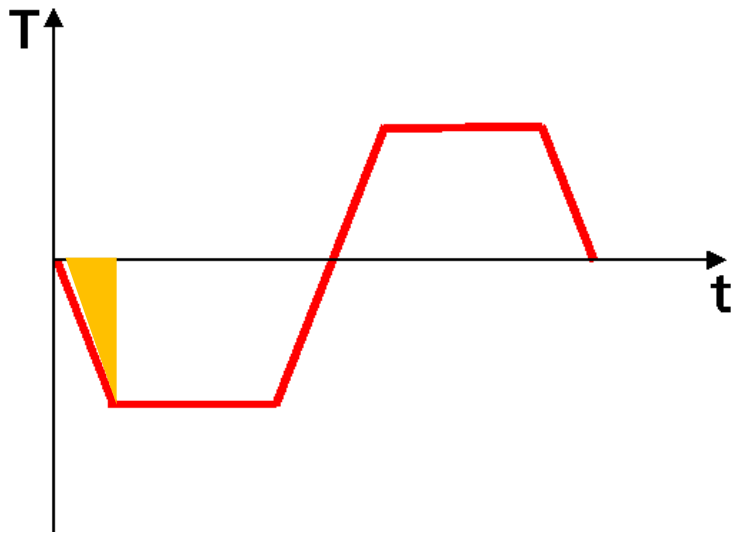
- Simulation of adjusted TCT200
- Condition:
  - Equal fatigue of interconnector
- Aim:
  - Reduced test time
  - Reduced test costs

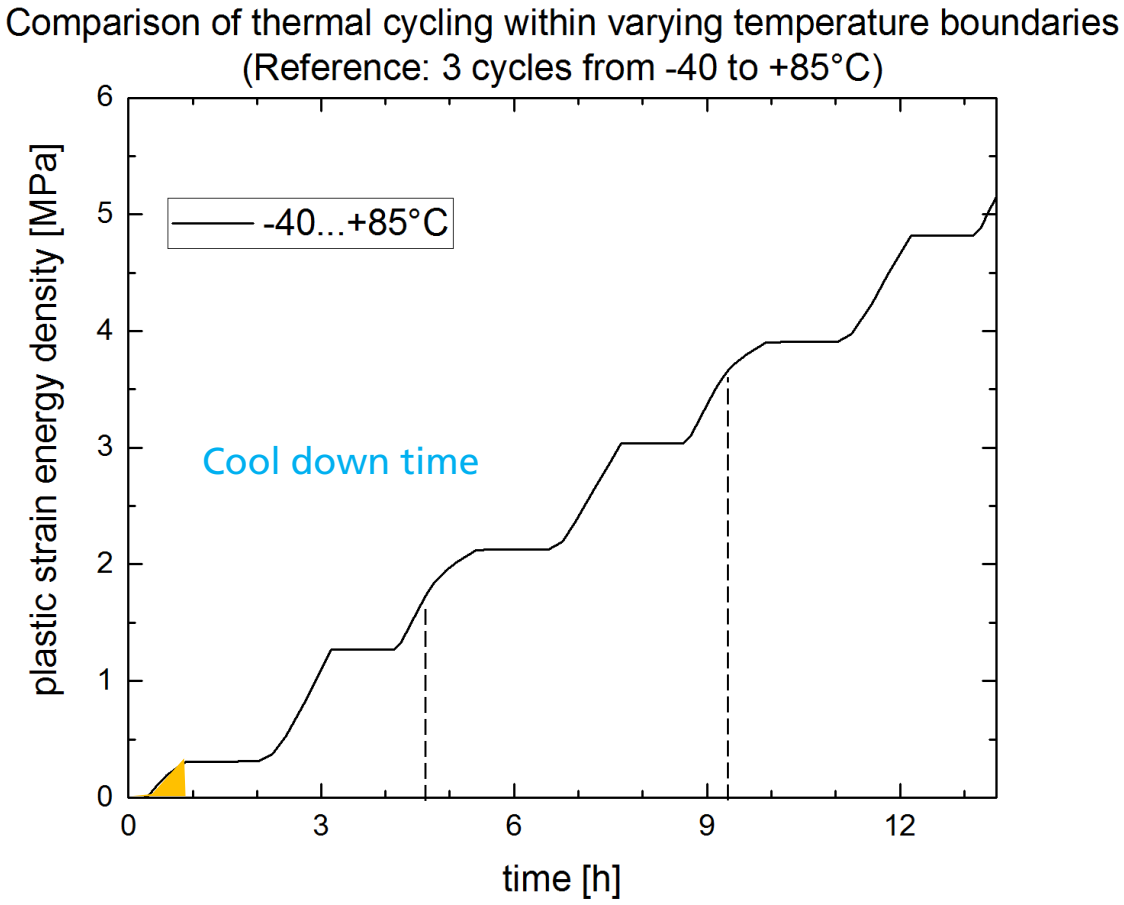
- Real parameters:
  - Temperature ramp of 88 K/h
  - Dwell time of 50 min



Standard test or derivation
Adjustment of testing scenarios

- Single steps of temperature cycle
  - ➔ Influence on failure fatigue criterion





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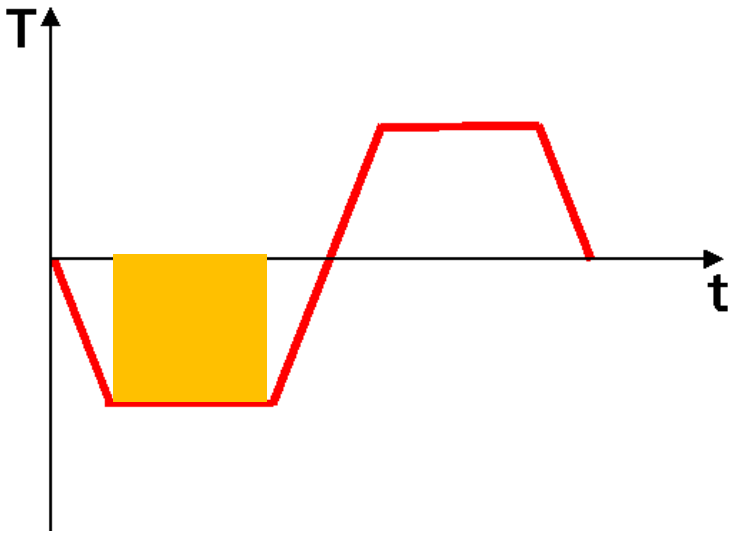

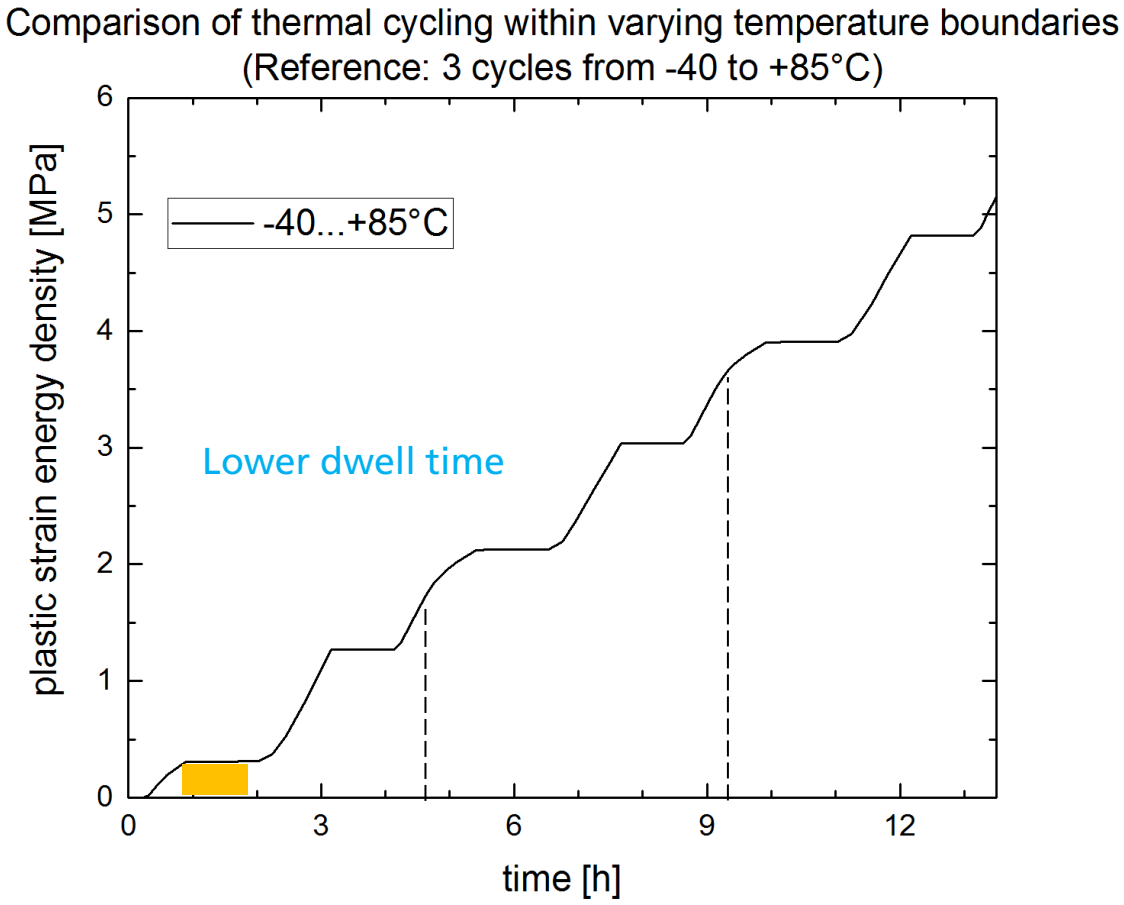

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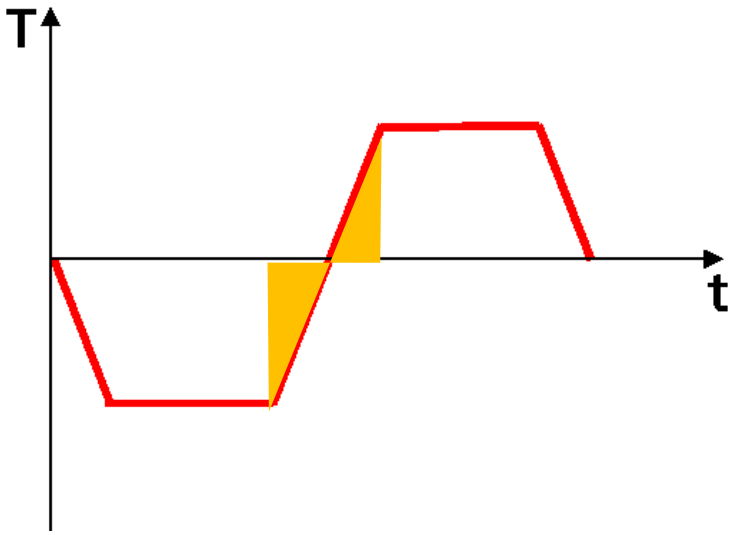

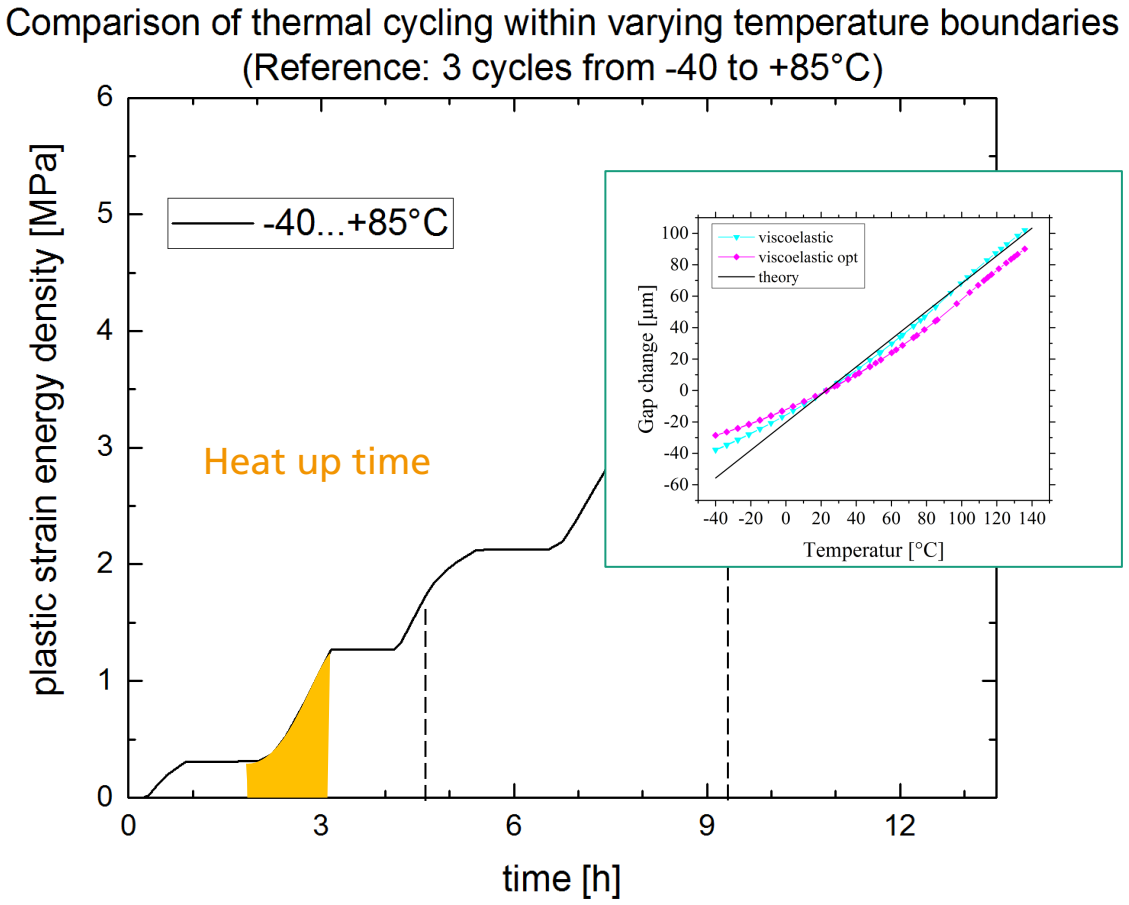

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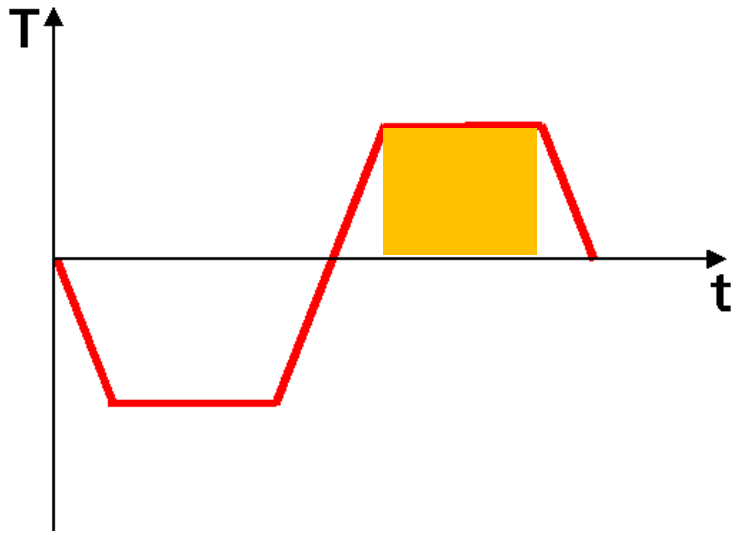

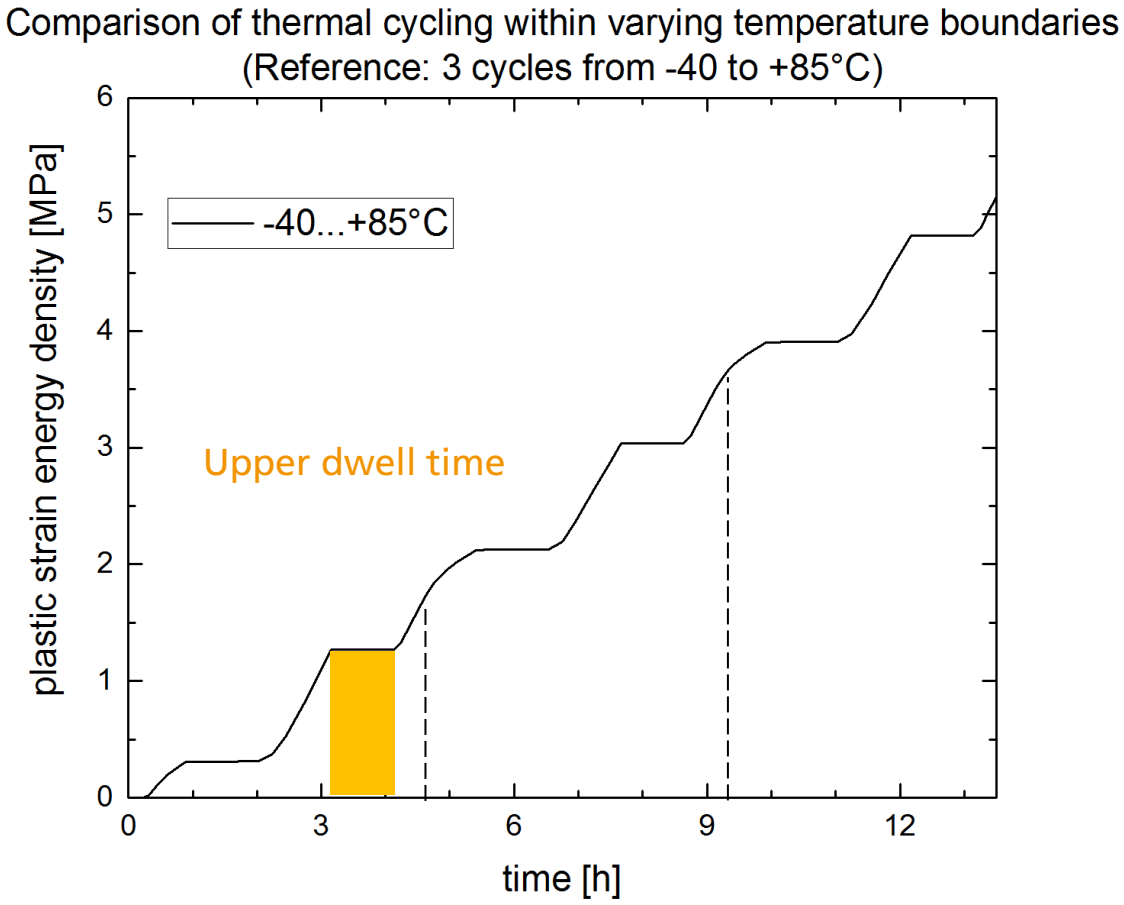

Standard test or derivation
Adjustment of testing scenarios

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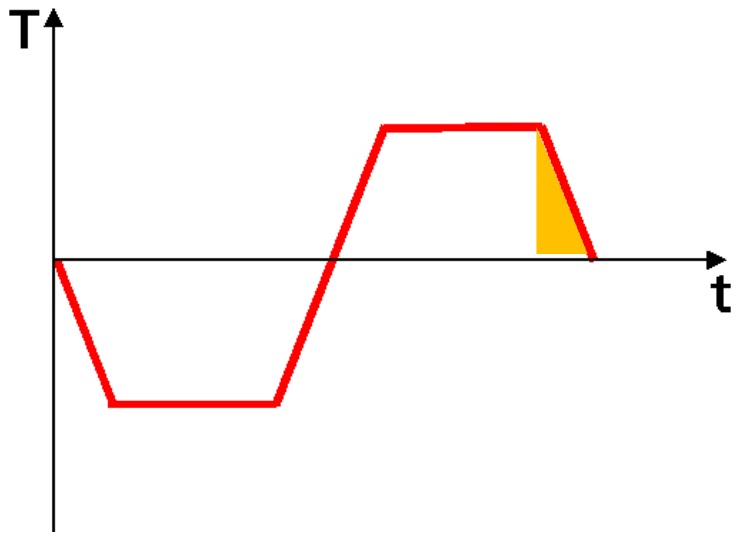
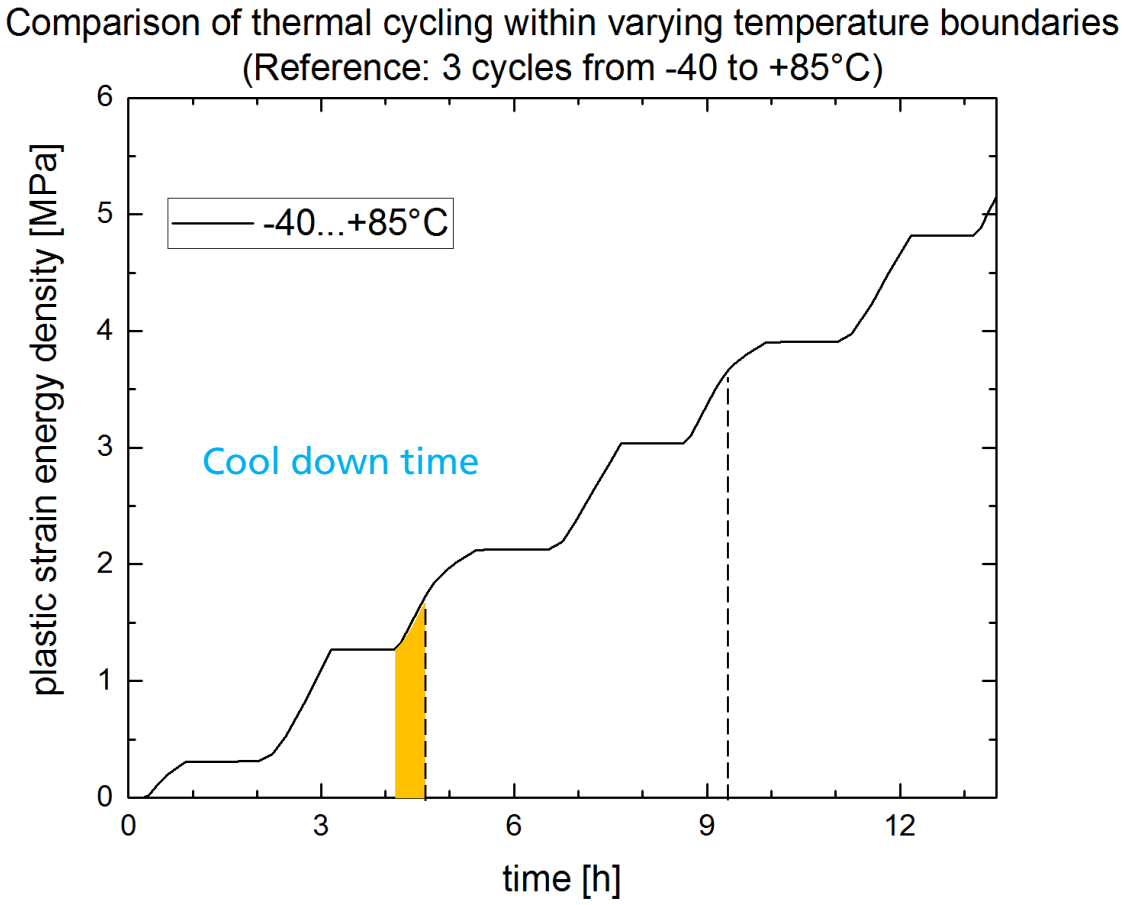
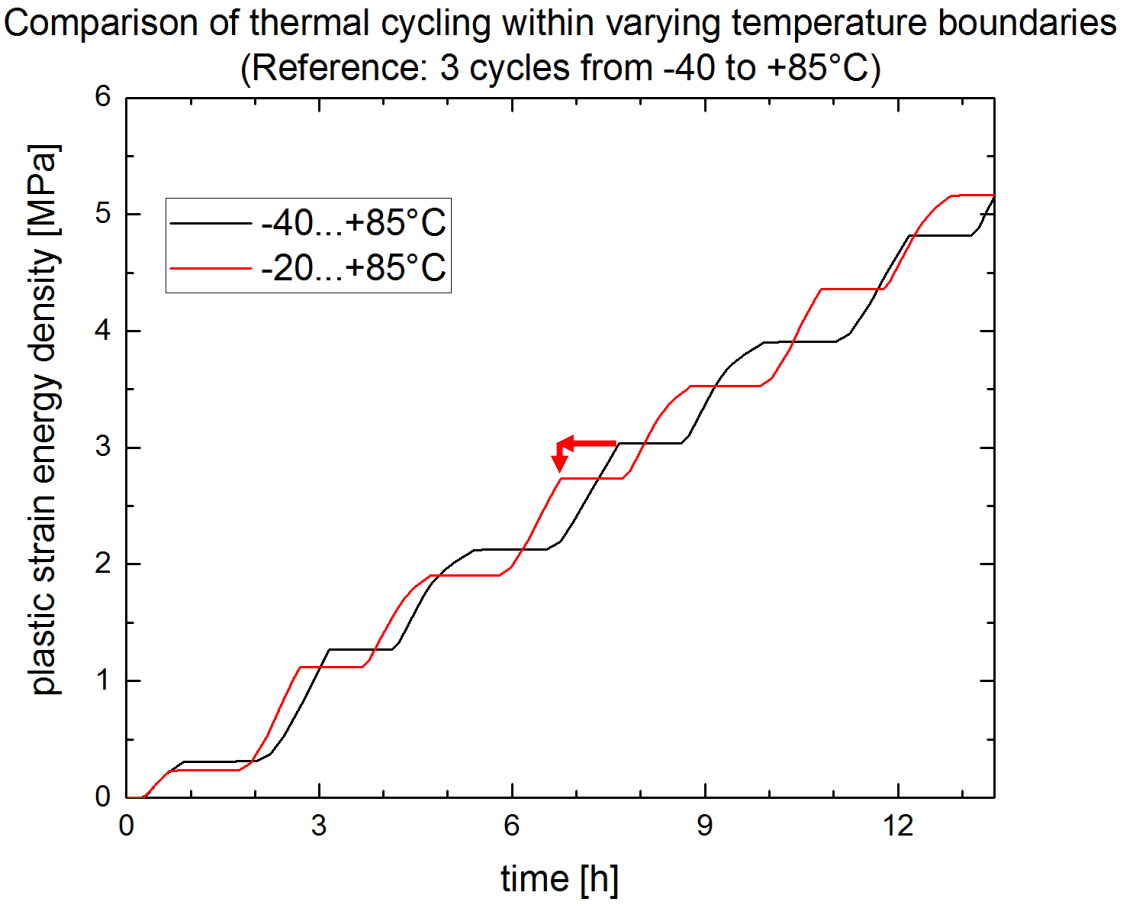




Standard test or derivation
Adjustment of testing scenarios

- Elevation of lower temperature
  - ➔ Reduction in time and fatigue



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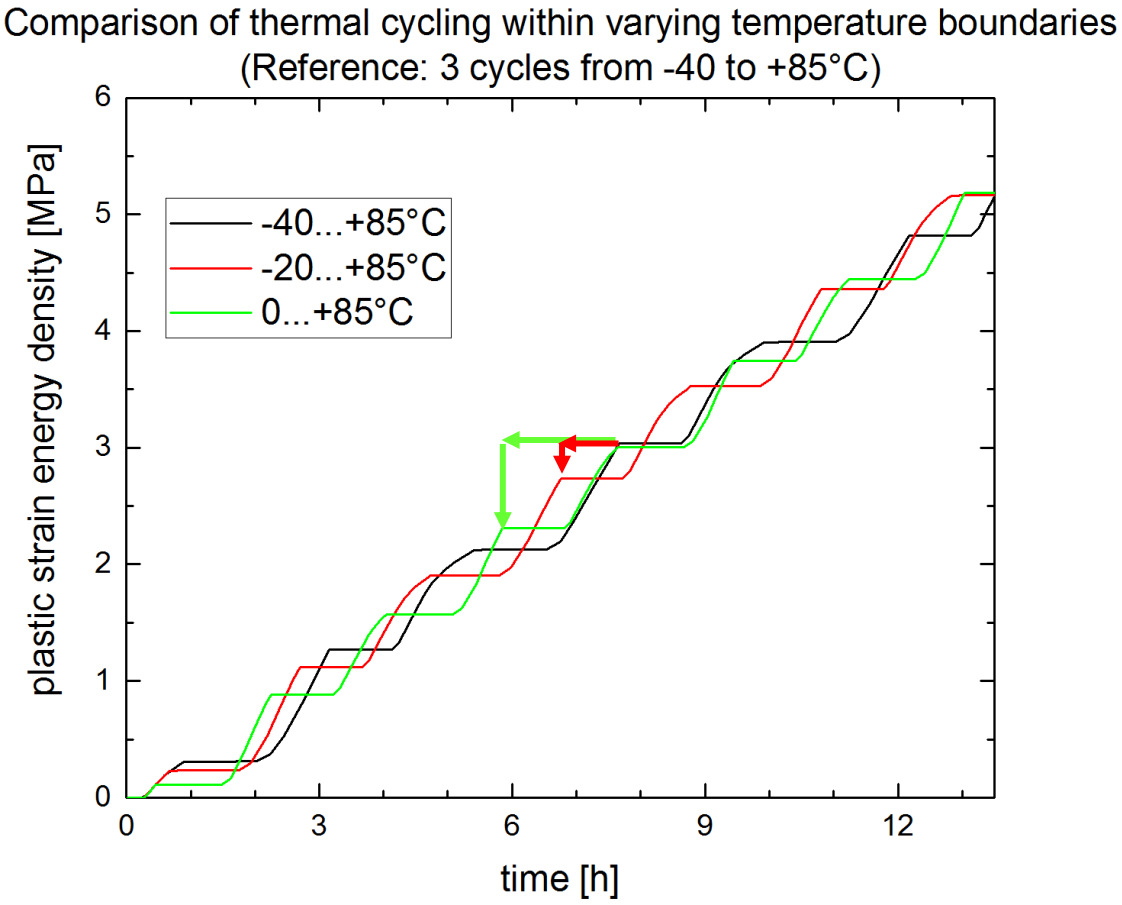
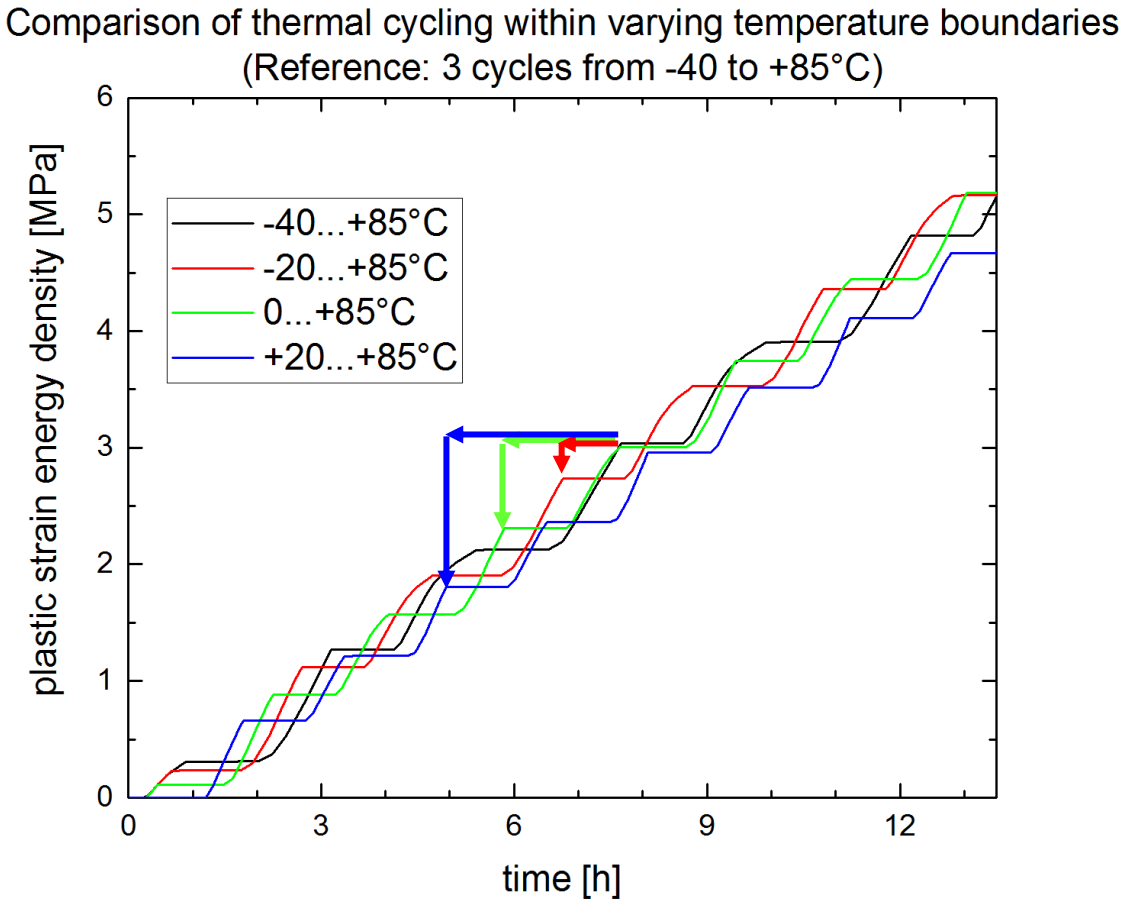


Standard test or derivation
Adjustment of testing scenarios

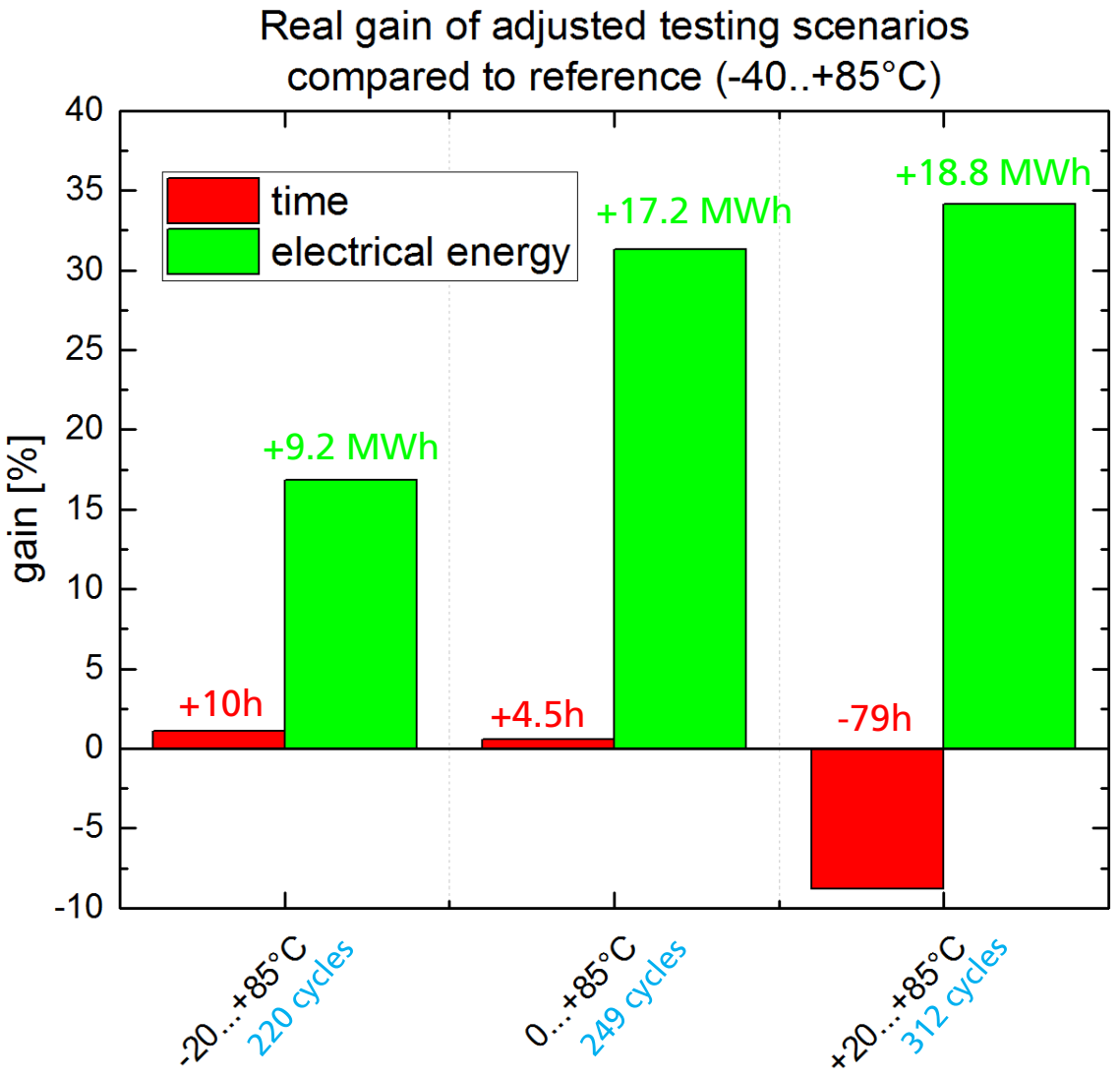
- Elevation of lower temperature
  - ➔ Reduction in time and fatigue
- Condition of equal fatigue:
  - ➔ Increase of cycle number
    - ➔ Optimization



Standard test or derivation
Adjustment of testing scenarios

- Simulation of adjusted TCT200
- Condition:
  - Equal fatigue of interconnector
- Result:
  - Slight reduction of total time up ~1%
  - Reduction of electrical energy up to 34%

➔ Results from 1,500 l climate chamber with given parameters of 88 K/h temperature ramp and 50 min dwell time (-40…+85°C: 900h, 55MWh)



Benefits and further ideas?

- Local (extreme) conditions may influence interconnector fatigue & failure by factor 3 (compared to moderate climate)
- Location based reliability analysis and PV-module design important in terms of ribbon fatigue
- Derived testing scenarios especially for interconnector fatigue ➔ standard test **AND** derivation
  - ➔ Reduction of testing time
  - ➔ Reduction of costs (energy consumption)

? Increase of temperature ramp up to 100 K/h (and more) ?

? Reduction of dwell time ?

? ... ?

Acknowledgments

- This work in the project: PV-Extrem was financed by the Federal Government of Saxony-Anhalt Contract Number 1604/00009.