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Instituto de Energía Solar

Thermal Effects and Other Interesting Issues with CPV Lenses

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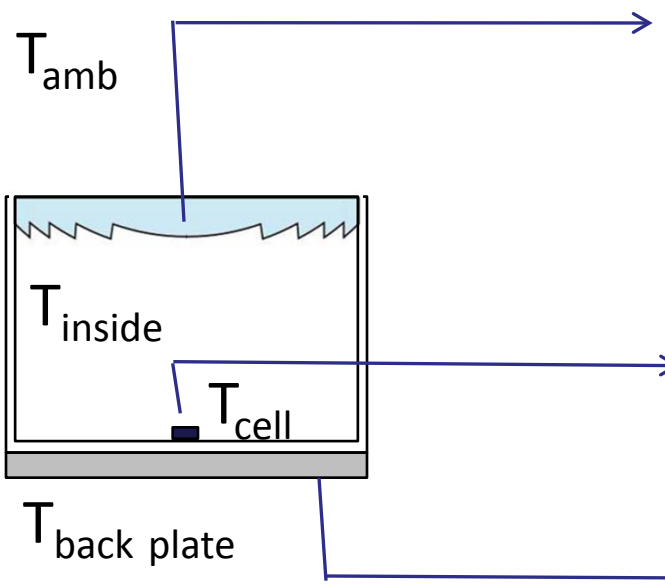
Outline

- Temperature dependence of lenses
  - PMMA Vs. SoG
- Lens characterization with temperature
  - Method
  - Measurements
- Recommendations for designing optical systems for SoG concentrators
- Conclusions

Temperature dependence of CPV modules ([1])



Lens Thermal Dependence

$\approx T_{amb} + 20K$

Cell Temperature Coefficients

- β and α temperature coefficients

$\approx T_{back\ plate} + 20K$

Module Thermal Expansion

-Solar cell shifts from original position

$\approx T_{amb} + 20K$

Which are the effects of temperature on lens performance?

How do we measure these effects?

How can we avoid these effects while designing a CPV module?

(1) G. Peharz, J.P. Ferrer, G. Siefer and A. W. Bett , Prog. Photovolt: Res Appl. 2011; 19:54-60

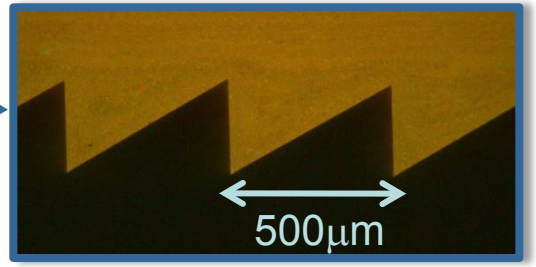
Silicone On Glass (SOG [2]) Vs PMMA Fresnel lenses

Glass

- Flat
- Rigid
- Tough (doesn´t scratch)
- Long-term reliability

Silicone

- Precise (draft angle)
- Refractive indexes match



* Image courtesy of Reflexite

PMMA

- Cost ?
- Lower weight

How do the lenses perform with temperature?

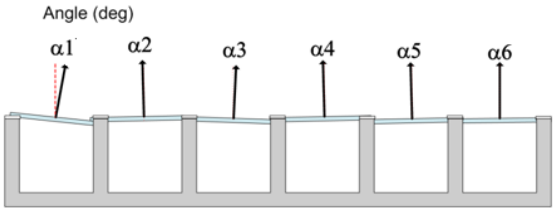
Which are the effects of temperature on lens performance?

Temperature dependence of lenses

Geometry

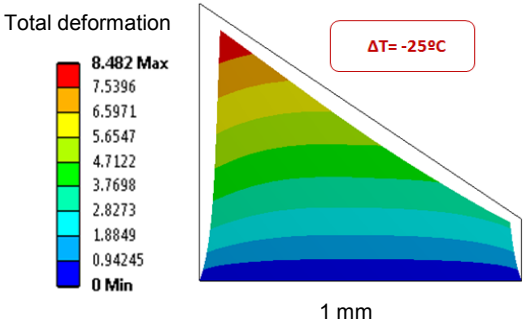
PMMA: Isotropic thermal expansion??

- Lower effect than lens parquet deformation

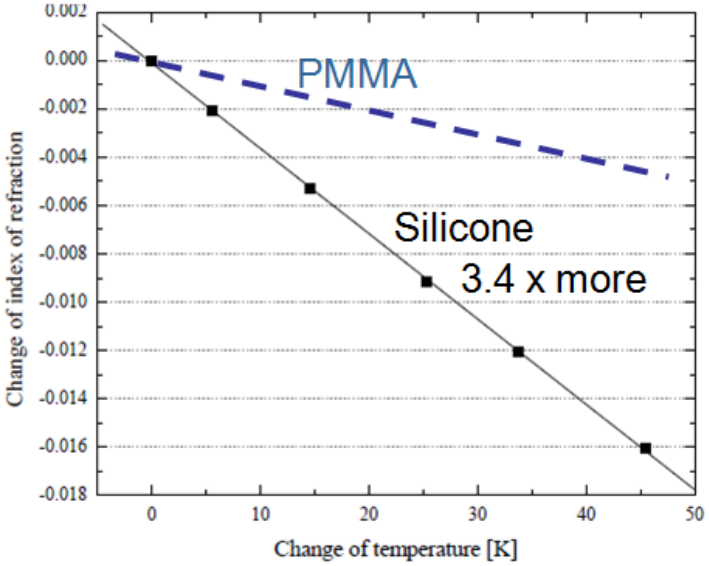


SoG: CTE Mismatch

- Change in facet slope



Refractive Index changes

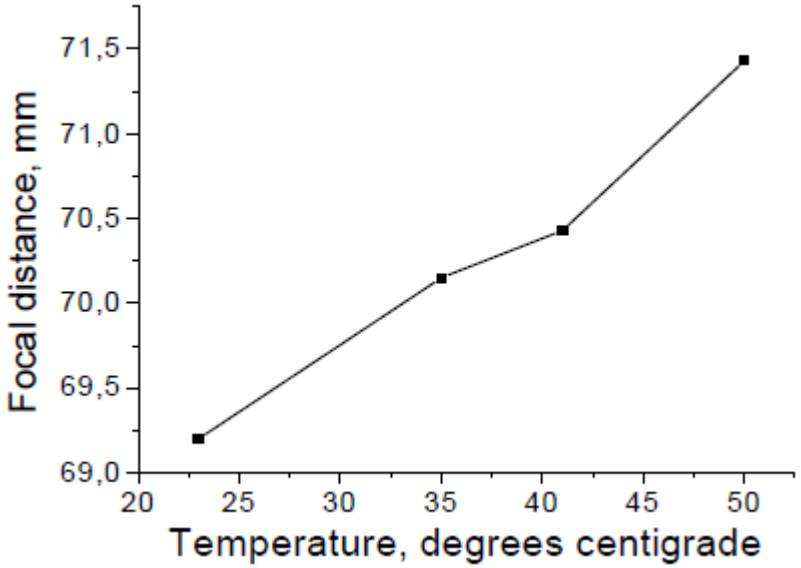


(3) T. Schult, M. Neubauer, Y.Bessler, P. Nitz, A. Gombert, Proc. of *2nd International Workshop on Concentrating Photovoltaic Optics and Power*, Darmstadt, 2009

Higher change of geometry and refractive index for SoG

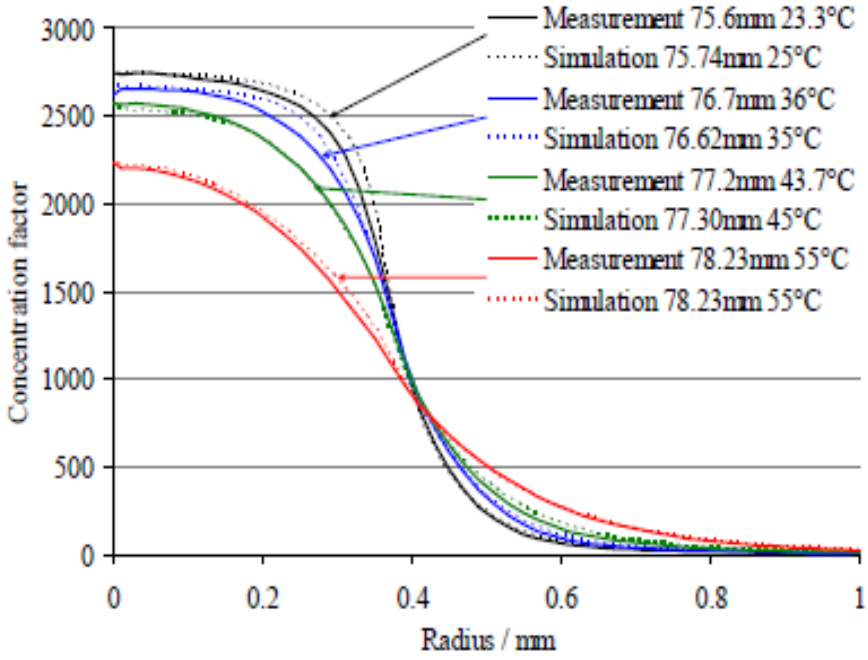
Previous Work I

- Measurements of optimum focus vs. T (SoG)
  - Electrical measurements



(4) Rumyantsev et al., Thermal Regimes of Fresnel Lenses and Cells in "All-Glass" HCPV Modules, CPV-6, Freiburg 2010

- Measurements and simulations of light profile (SoG)
  - Monochromatic light
  - Single focal distance

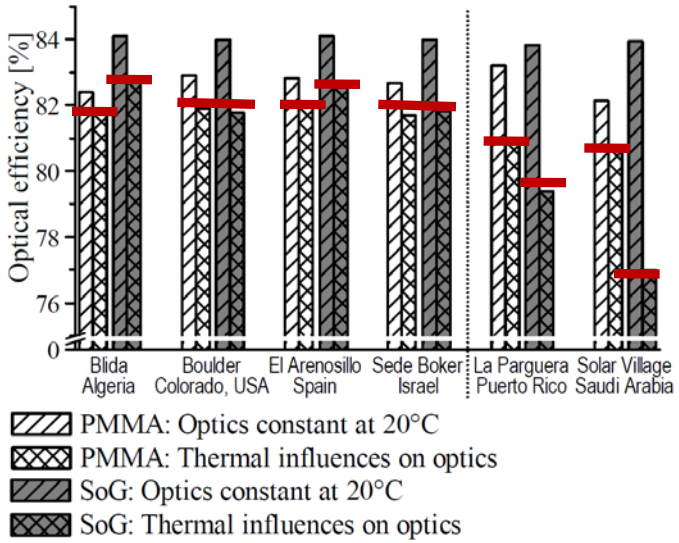


(5) Hornung et al., Temperature Dependent Measurement And Simulation of Fresnel lenses for concentrating Photovoltaics, CPV-6, Freiburg 2010

Focal length increases with temperature causing defocus for fixed lens-to-cell distance

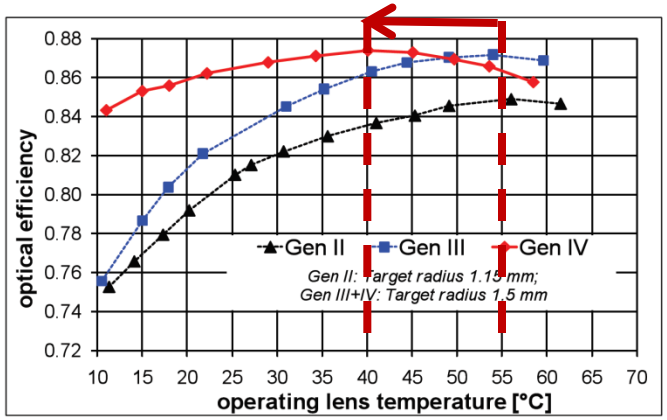
Previous Work II

- Estimation of energy generation:
  - Computer simulations
  - Six different locations
  - PMMA Vs. SoG



(6) Hornung et al.,Estimation of the influence of Lens Temperature on Energy Generation of a Concentrator Photovoltaic System, CPV-7, Las Vegas 2011

- New Fresnel lens design for reducing temperature depence of the optical efficiency

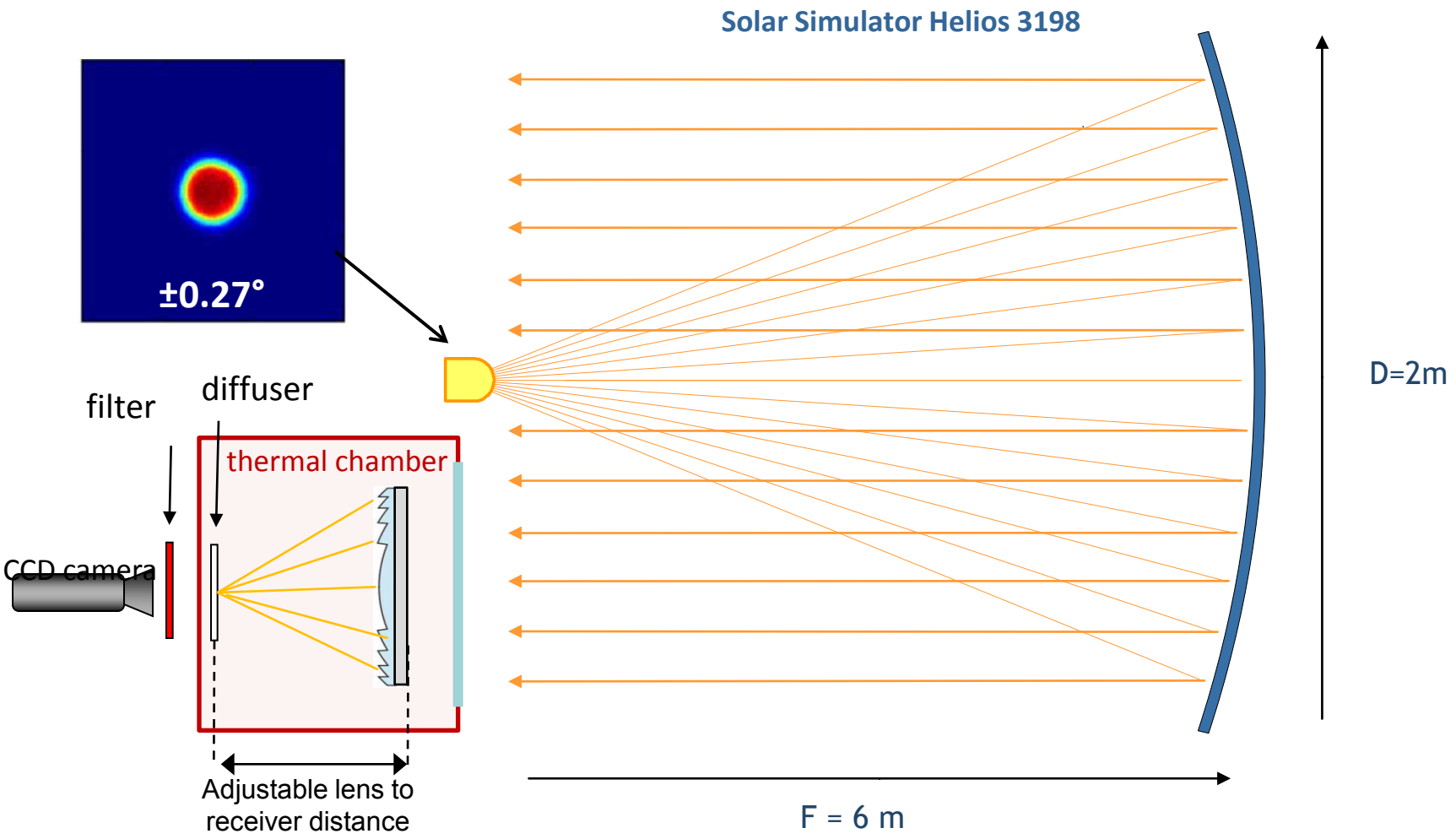


(7) Van Riesen et al.,Concentrix Solar's progress in developing highly efficient modules, CPV-7, Las Vegas 2011

Optimizing lens performance for a lower temperature improves average performance

How do we measure these effects?

How do we measure these effects?

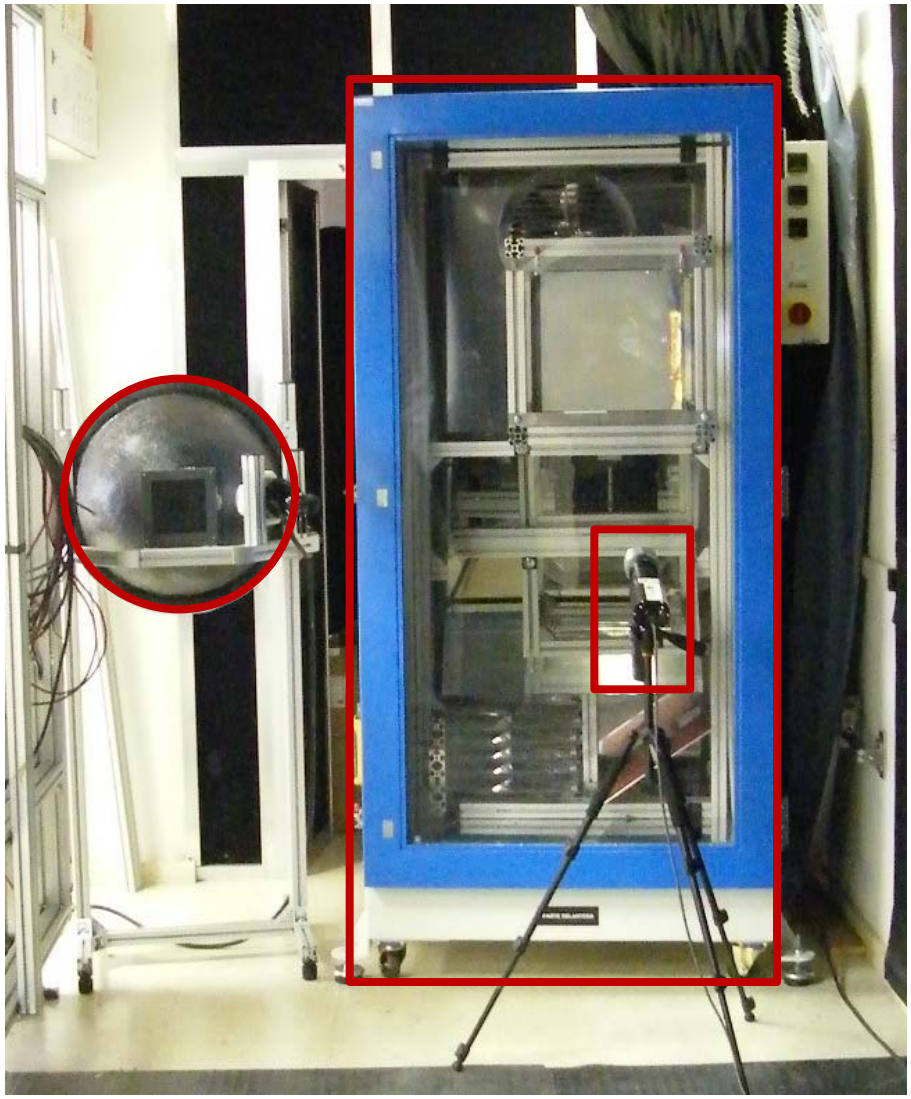


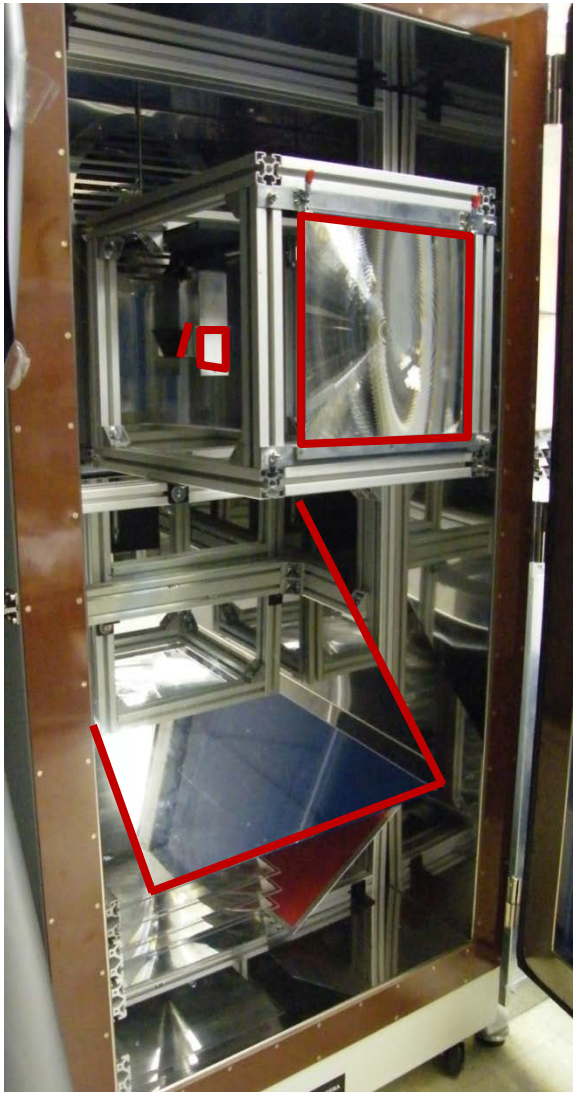
CPV solar simulator at IES provides “real” illumination:

White (AM1.5D) light and 0.27°

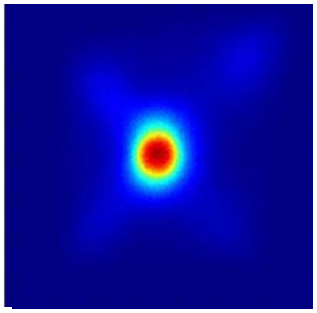
(8) Askins et al.,Effects of Temperature on Hybrid Lens Performance, CPV-7, Las Vegas 2011

Experimental set up





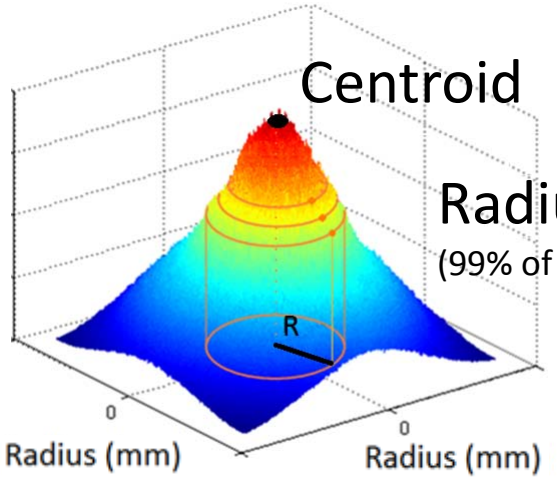
Imaging the Focal Plane



Light spot CCD image

- Lens
- Temperature (25 C - 65 C)
- Focal distance → F number

$$\text{F-number} = \frac{\text{focal distance}}{\text{Lateral lens size}}$$



$$C_{Geom} = \frac{A_{lens}}{\pi \cdot Radius(99\%)^2}$$

Imaging is evaluated using the geometric concentration, varying focal length and temperature

Lens characterization

Empirical study SOG lenses performances at different temperatures and lens-to-receiver distances

"Real" illumination: White (AM1.5D) light and 0.27

What is the effect of silicone cure temperature ?

- Can we confirm that lenses behave best at $T_{operation} = T_{cure}$?

Can facets deformation be decreased by increasing the silicone layer?

- Easiest geometrical parameter to change

6 different SOG samples all with the same profile provided by Reflexite® ENERGY SOLUTIONS

Reference sample (x2) → Tcure , base thickness (0.9mm)

+ 2 different cure temperatures→ 25º , 35º

+ 2 different silicone base thicknesses→ 1.8mm , 1.1mm

Same Mold

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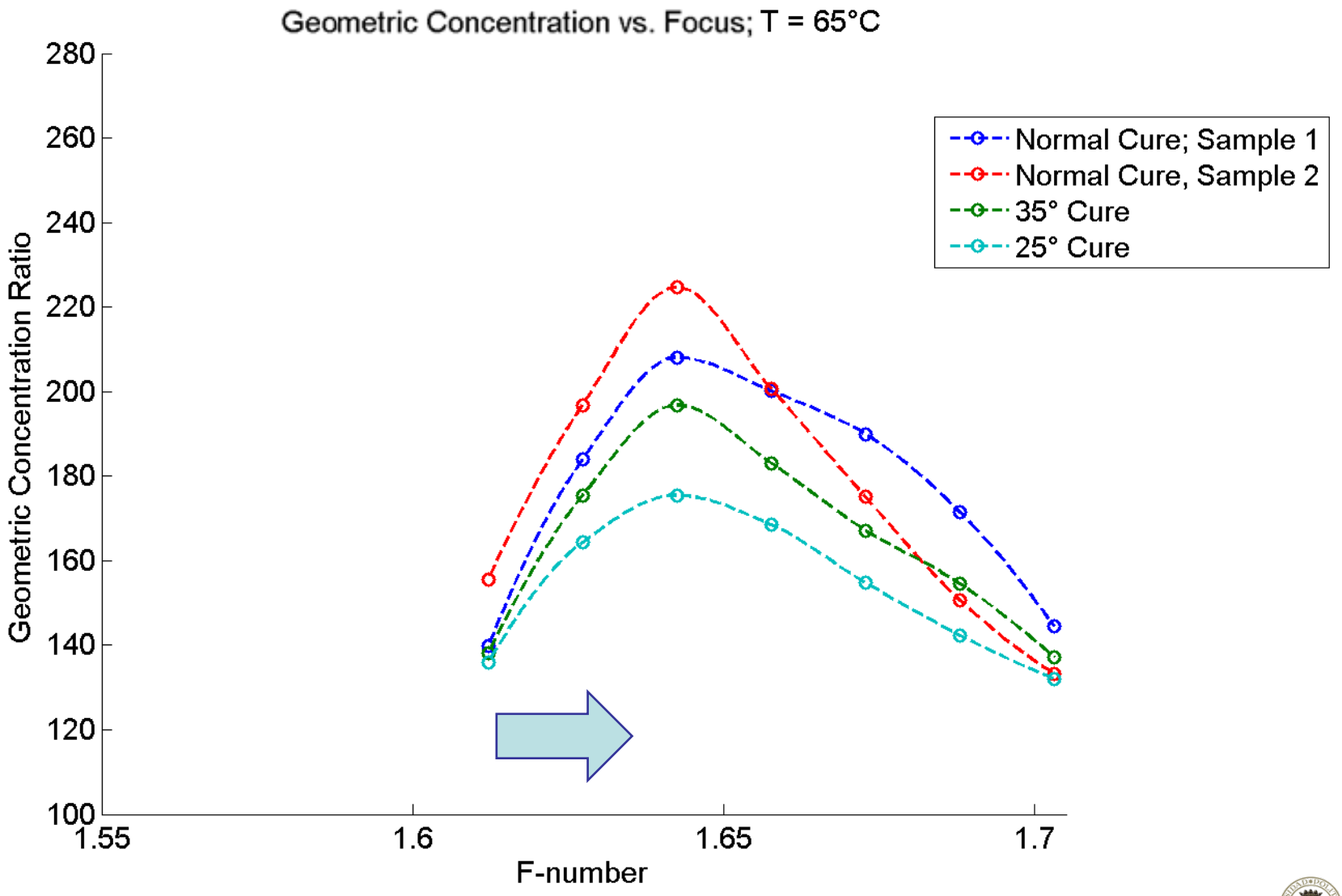
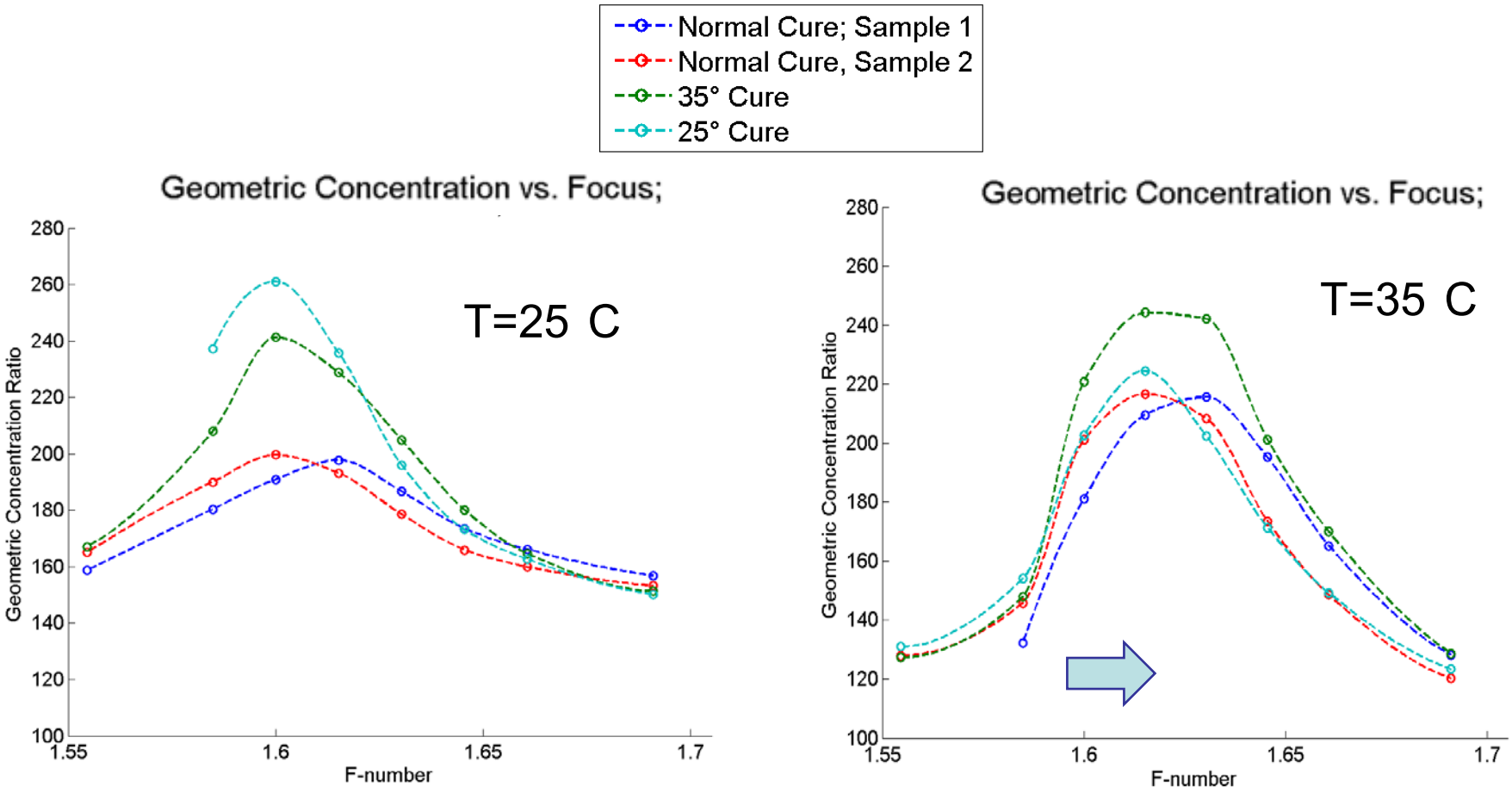
Measurements



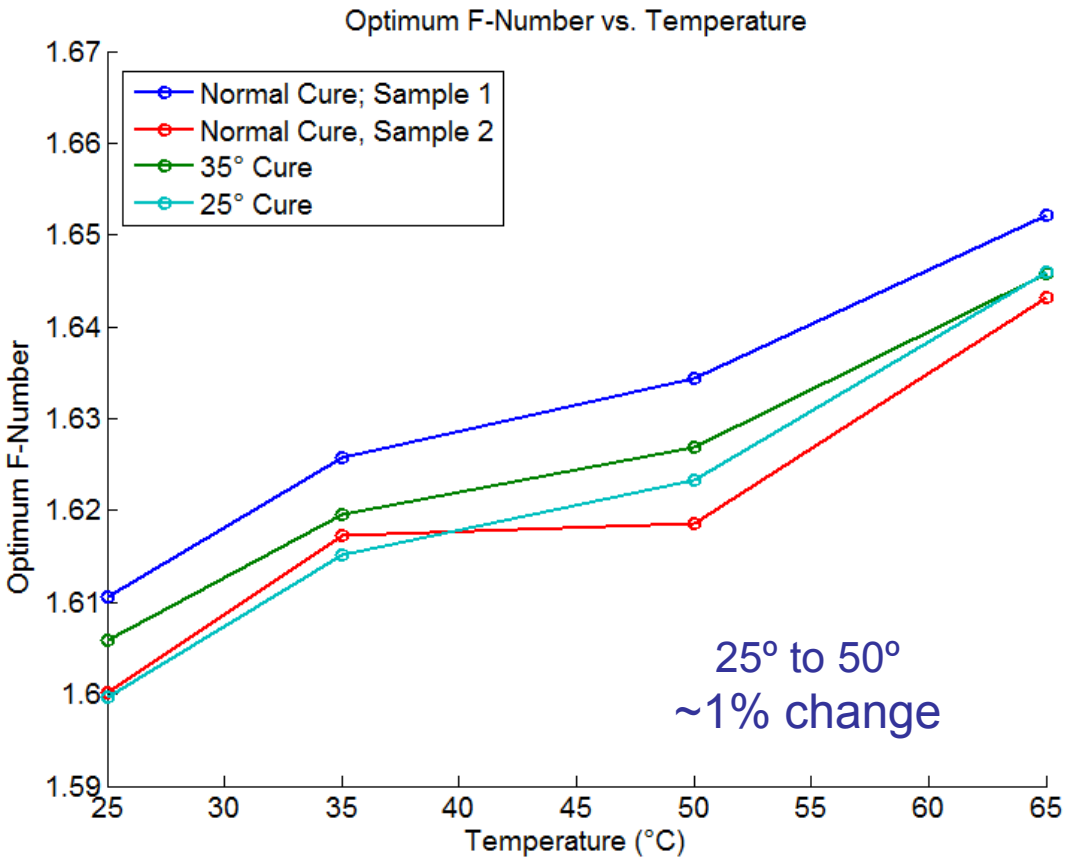
Measurements

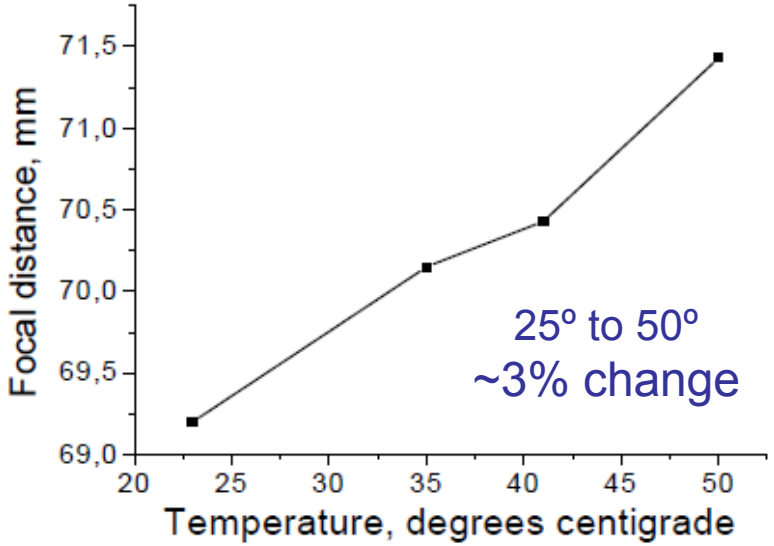


Focal length increases with temperature causing defocus for fixed alignment

Highest concentration at cure temperature

Focal Distance Change



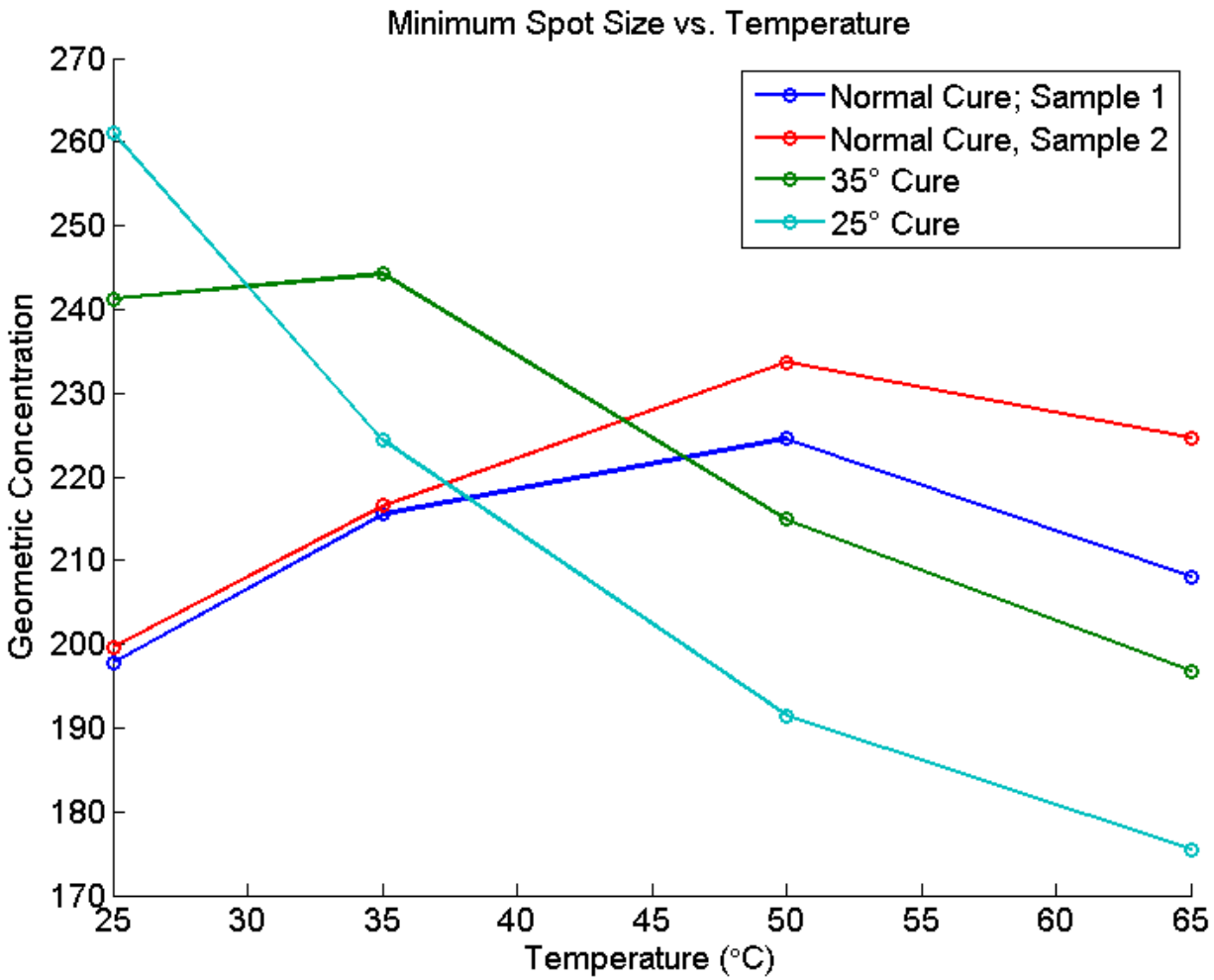


*Rumyantsev et al., Thermal Regimes of Fresnel Lenses and Cells in "All-Glass" HCPV Modules, CPV-6, Freiburg 2010

Focal distance changes depend only on silicone index change

Un-avoidable for this material

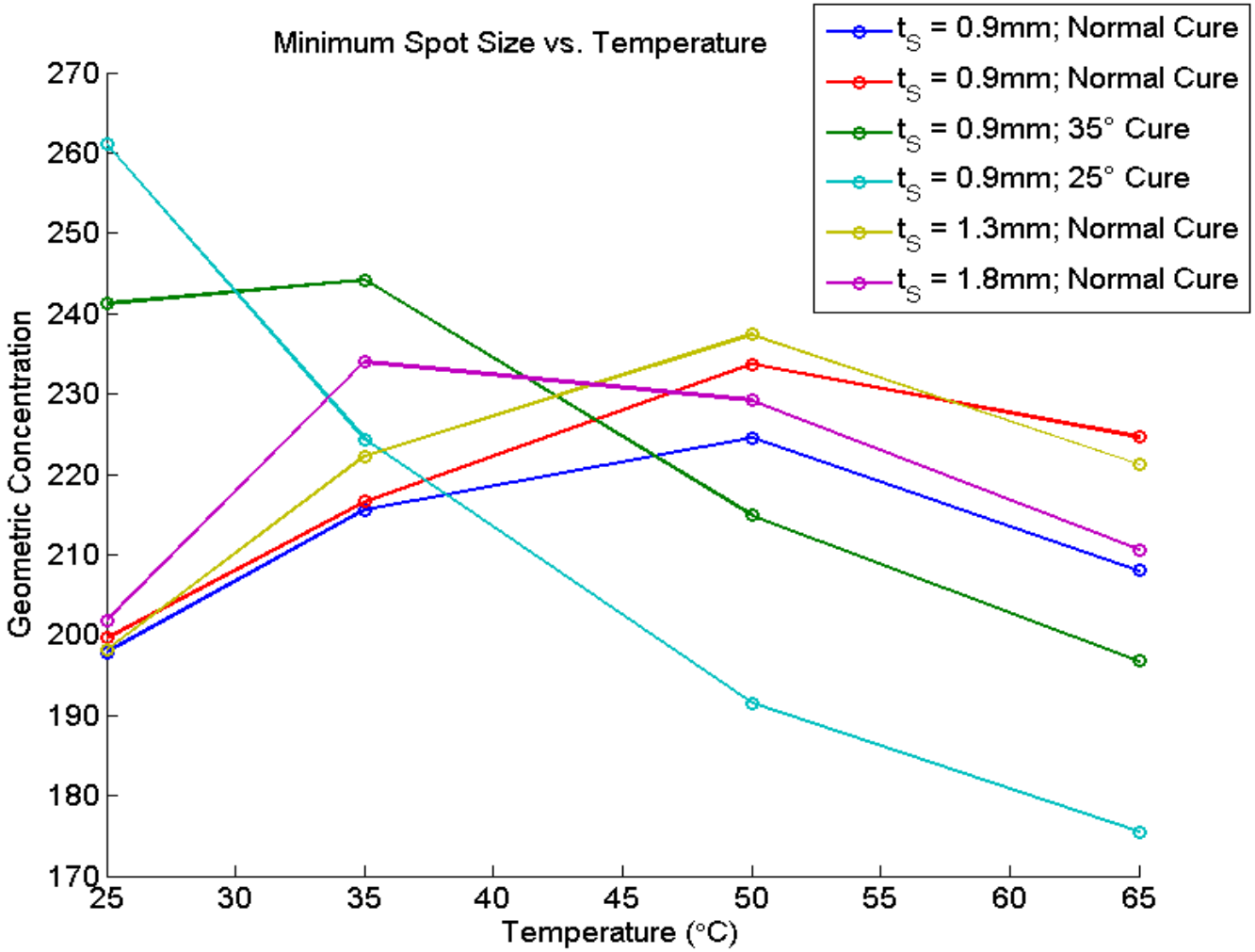
Maximum Concentration vs. Temp



(Optimum focal distance at each temperature)

Lens best performance at cure temperature

Effect of Additional silicone



No measureable effect seen with additional silicone

No stress relief on facets

How can we avoid temperature effects while designing a CPV module?

Optimization of tolerant optical systems for SoG concentrators ([9]) I

- Optimum lens focal distance depends on temperature

  (index of refraction change)

  – n(Tdesign)

  -Cure temperature

  – Focal distance optimization at several temperatures

  - Operation temperature

- Lens best performance at cure temperature

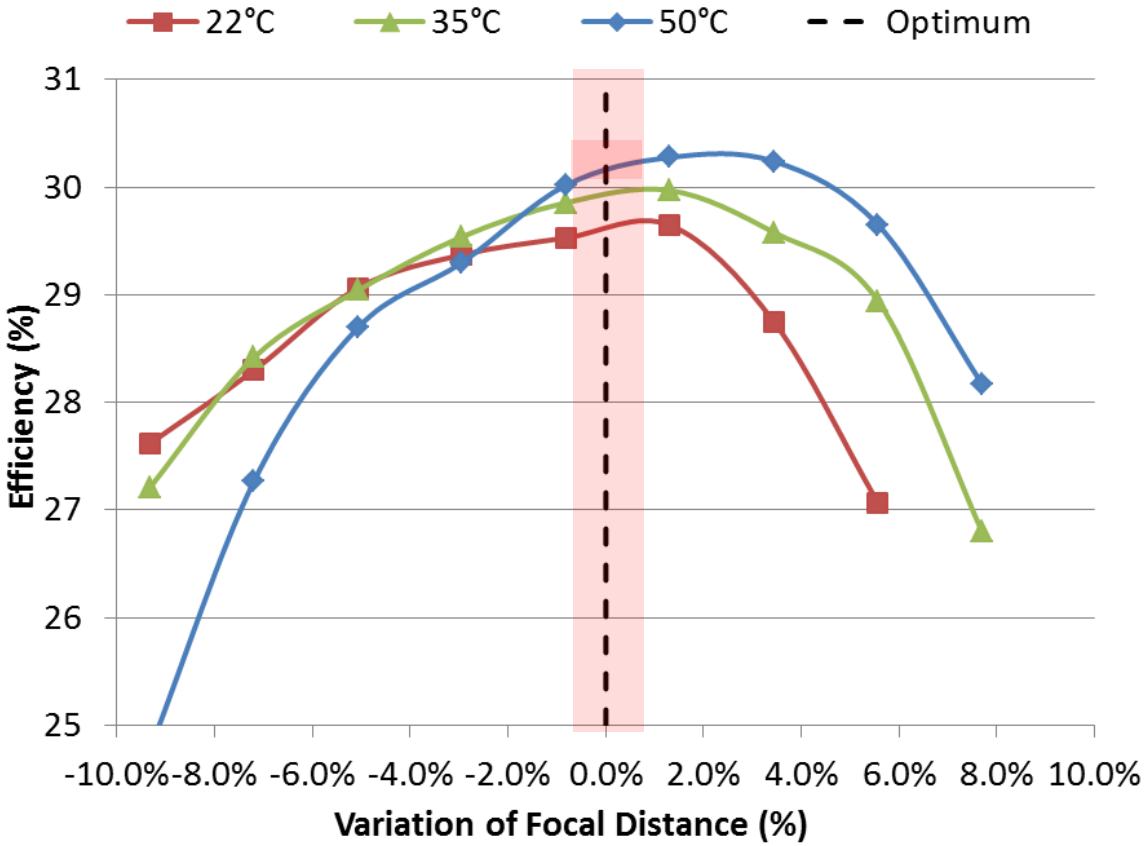
  (geometrical deformation)

  - Operation temperature

(9) Askins et al., Optimization of tolerant optical systems for silicone on glass concentrators , CPV-8, Toledo,2011

Optimization of tolerant optical systems for SoG concentrators ([9]) II

- Good optical system performance at different temperatures



Optimum focal distance at several temperatures

Best performance at operation temperature

Electrical measurements for primary Fresnel lens and refractive secondary optical system

Secondary Optical Element (SOE) must be tolerant to changes in spot size

Conclusions

- Focal length increases with temperature causing defocus for fixed lens-to-receiver distance
- Lens geometry changes with temperature when silicon is not in a stress-free state
- Understanding temperature behavior of SOG lenses will allow a good optical system performance at different temperatures
  - SOE tolerant to changes in light spot size

Open questions …

- Is it worth it to design lens facets taking into account the deformation produced by working at different temperature from cure temperature?
  - Several working temperatures
- Is the CPV module performance dependence with temperature well reproduced by this method?
  - Module thermal expansion
  - Multi-Junction solar cell performance

Thank you for your attention…