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Anidolic Daylight Concentrator of Structural Translucent Concrete Envelope

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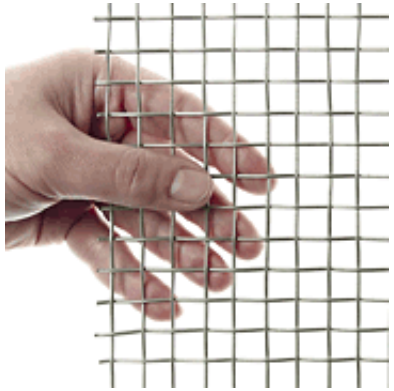
Outline

1. Translucent Concrete (**TC**) Panel Prototype Production
2. Light Transmission Tests of the TC Panel
3. Light Transmission Simulation of the Optical Fiber (**OF**)
4. Light Concentration Analysis
5. Light Transmission Modeling of TC Panel
6. Conclusions and Future Goals

Translucent Concrete Panel Prototype Construction

Specimen Details

- Volume ratio of the optical fibers = 5%
- Diameter of the optical fibers = 0.079 in. (2 mm)
- Clear distance of the optical fiber = 0.229 in.
- Number of pre-drilled holes = 1600
- Distance between neighboring holes = 0.308 in.
- Wire mesh 1 in.×1 in.
- Normal Mortar

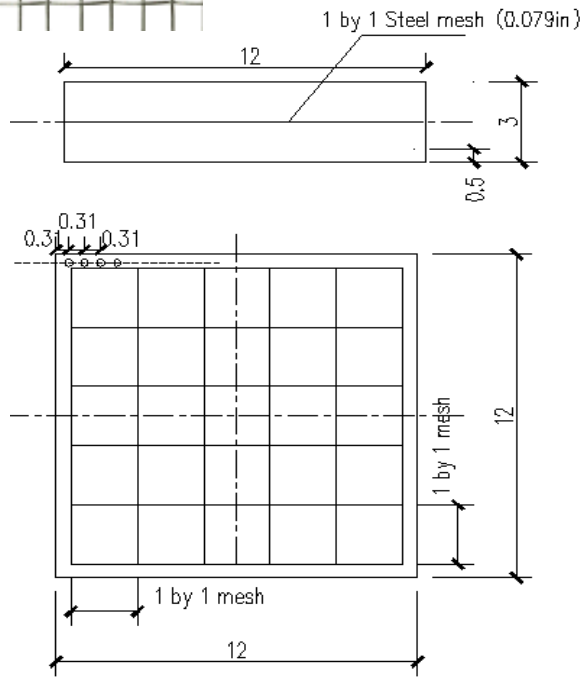


Wire Mesh

Details of Optical Fiber

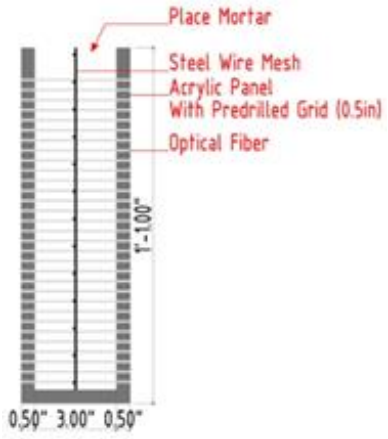
Property	Value
Core Material	Polymethyl-Methacrylate Resin
Cladding Material	Fluorinated Polymer
Core Refractive Index	1.49
Refractive Index Profile	Step-index
Numerical Aperture	0.50
Number of Fibers	1
Core Diameter	1840 – 2080 µm
Cladding Diameter	1880 – 2120 µm
Approximate Weight	2.8 g/m

http://i-fiberoptics.com/fiber-detail.php?id=110&sum=90

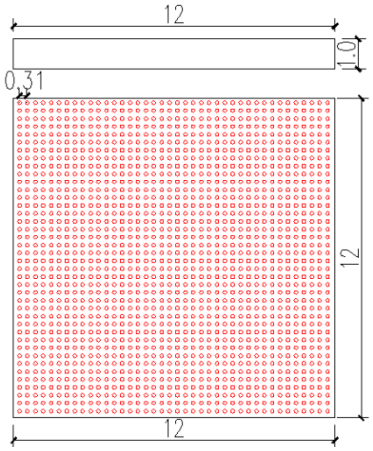


Wire Mesh Arrangement
(Not to scale)

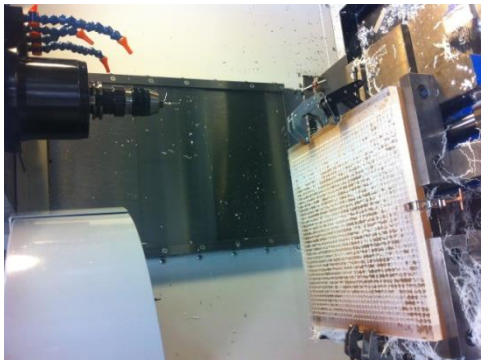
Translucent Concrete Panel Prototype Construction



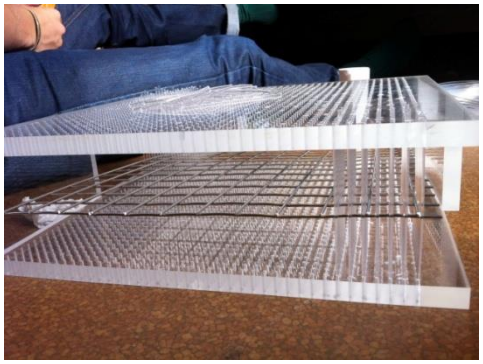
Form Setup



Pre-drilled Holes



Drilling Holes in Acrylic Panel



Installing the Optical Fibers

Finished Form

Before Mortar Placement

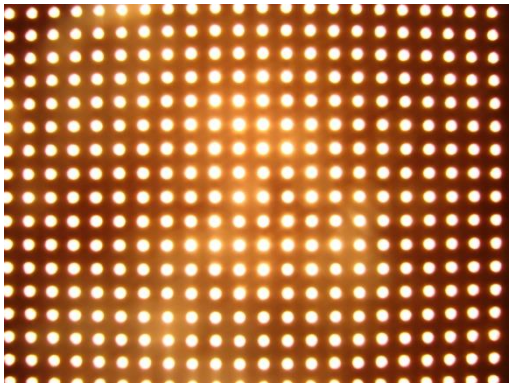
Placing Mortar

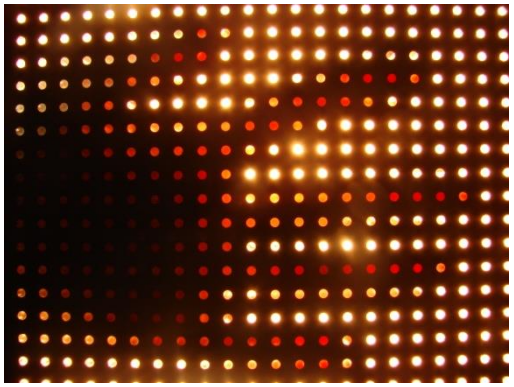
Finished Specimen

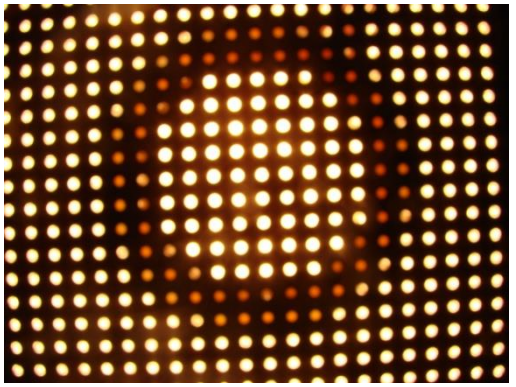
Translucent Concrete Panel Prototype Construction

Form Removal

TC Panel

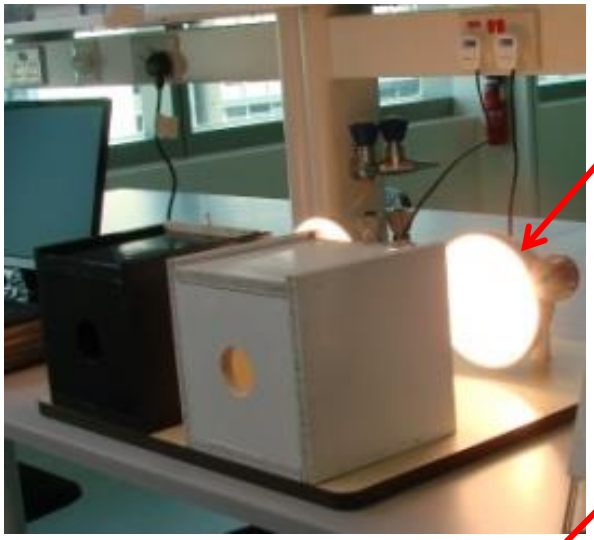






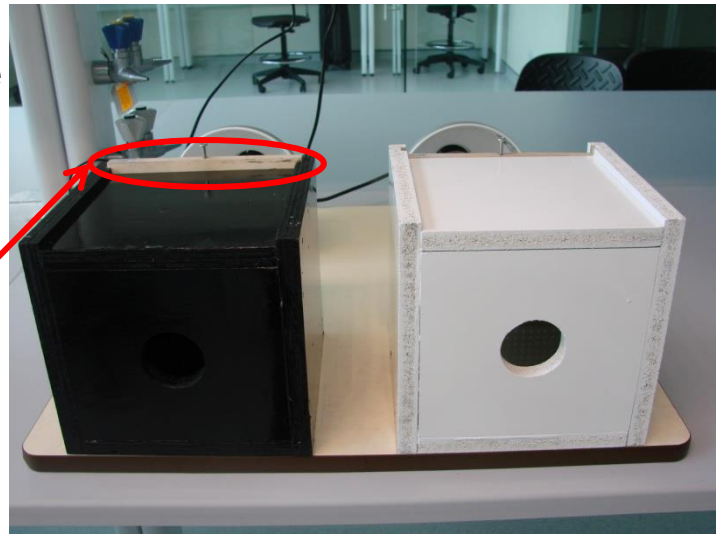
Light Transmission

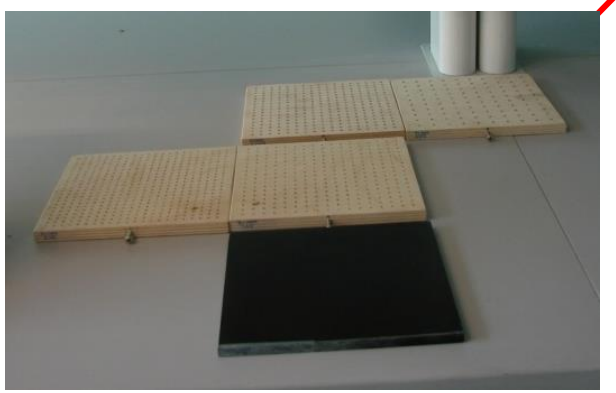
Light Transmission Tests of TC Panels



Light Source

Test Setup





Preliminary TC Panels (made of wood)

Experimental Setup

- 7 in.×7 in.×0.5 in. hard wood panel
- 7 in.×7 in.×7 in. white & black hard wood boxes
- Incandescent lamp (80 W)
- 2 mm & 3 mm Optical Fibers

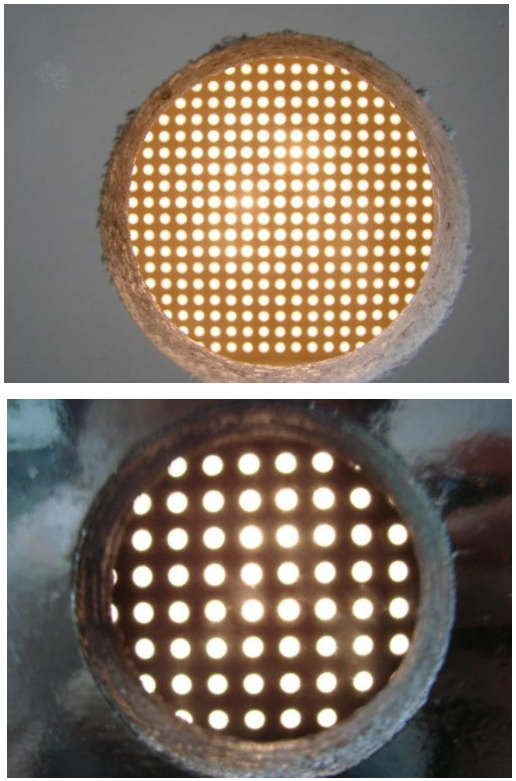
Instrumentation

- LUX meter
- Camera: Sony H5

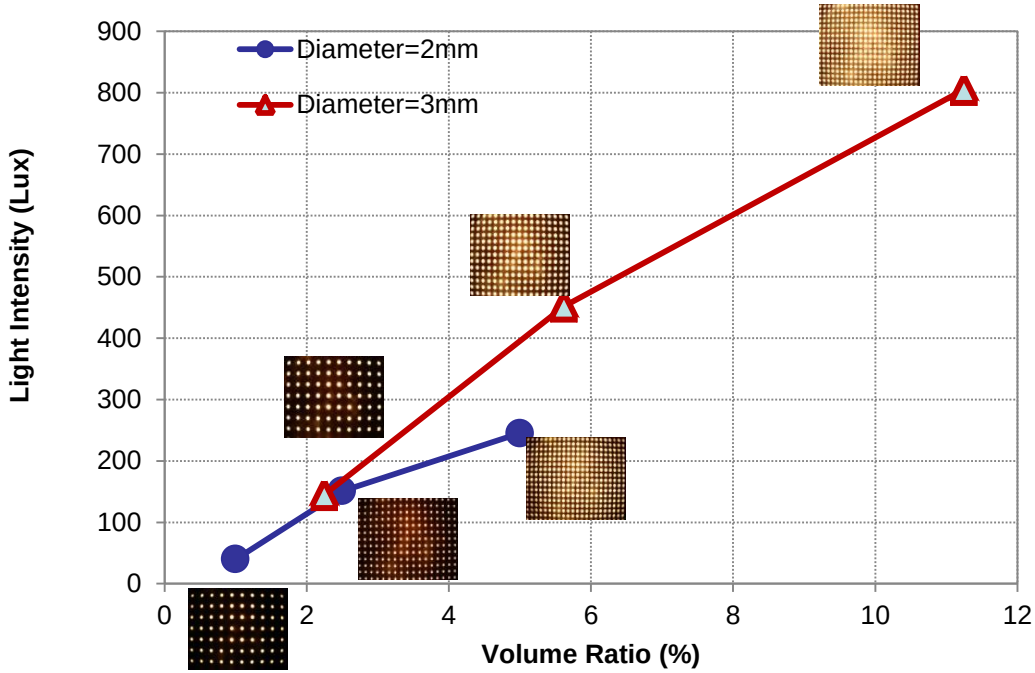
Light Transmission Tests of TC Panels

Details of the TC Panels

Optical Fiber		Volume Ratio (%)		
Diameter	2mm	1	2.5	5
	3mm	2.25	5.625	11.25



Visual Effects



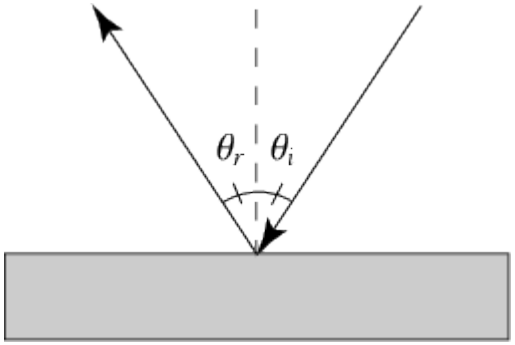
Transmitted Luminous Flux with Different Volume Ratios

Light Transmission Simulation of the OF

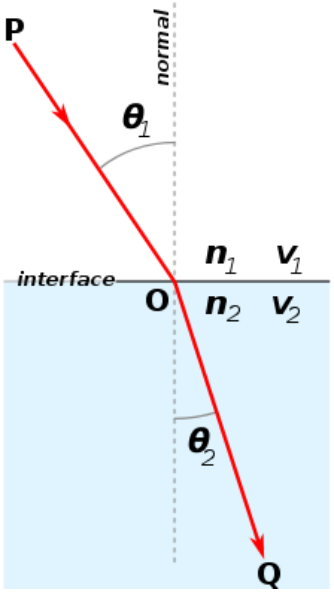
- Light Transmission Mechanism
- Daylight Properties
- Light Transmission Simulation of Straight OF
- Bending Effect Simulation of the OF

Light Transmission Mechanism

Law of Reflection: $\theta_r = \theta_i$



Snell's Law:



$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

v = Velocity of light

n = Refractive index

Ray and Flux Transfer Efficiencies

Number of rays that reside on a target after ray tracing in comparison to the number traced from the source:

$$\eta_{\text{ray}} = \frac{N_{\text{target}}}{N_{\text{source}}}$$

Flux transfer efficiency:

$$\eta_{\text{trans}} = \frac{\sum_{j=1}^{n_{\text{target}}} P_{\text{target},j}}{\sum_{i=1}^{n_{\text{source}}} P_{\text{source},i}}$$

P_{target} = Power of rays that strike a target
P_{source} = Power of rays from a source

Optical Concentration

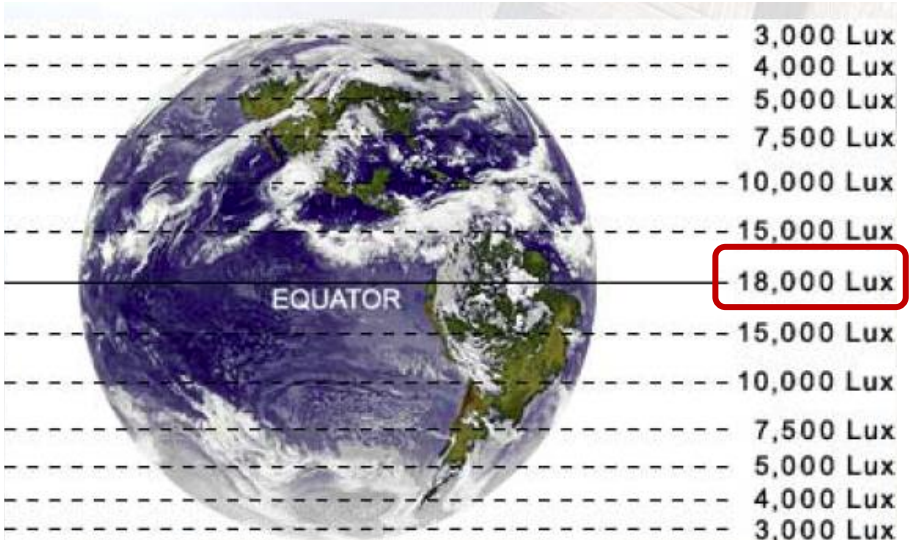
$C = A_{\text{input}} / A_{\text{output}}$

A_{input} = The light entrance area
A_{output} = The light exit area

Daylight Properties

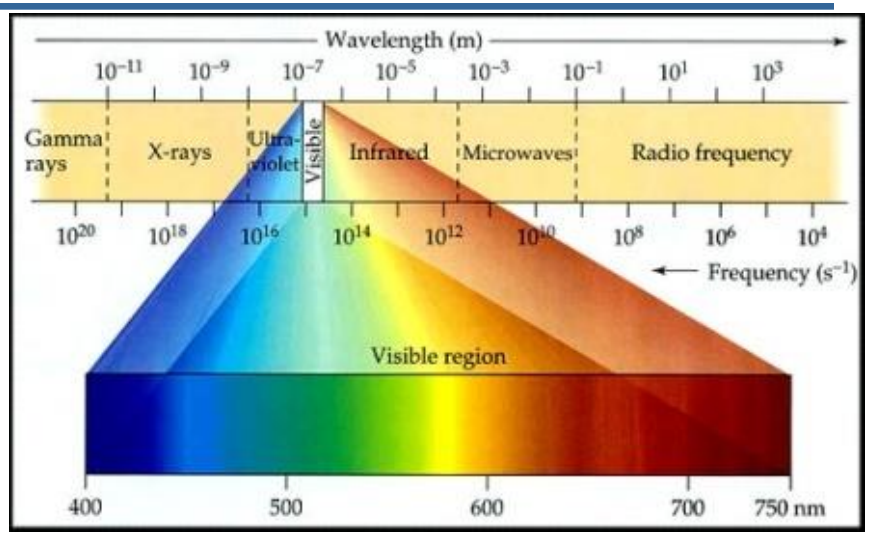
Sunlight

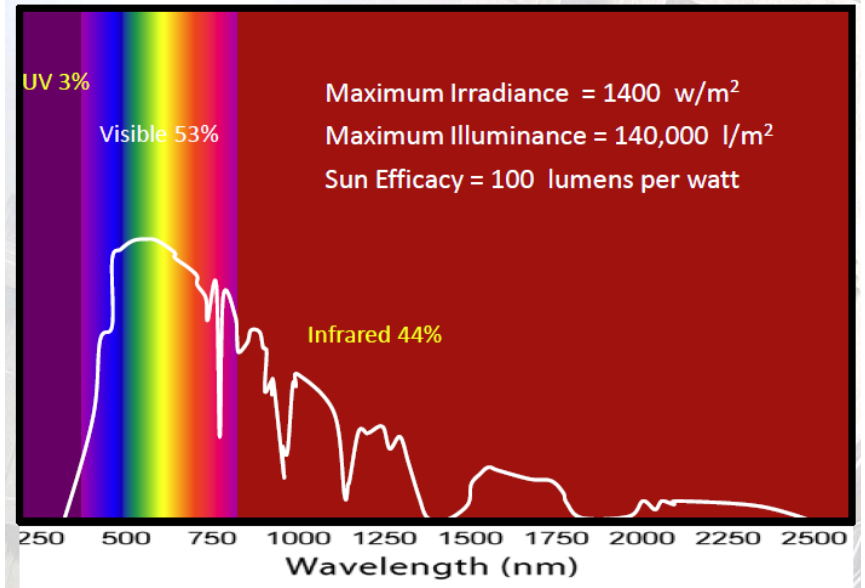
1) Visible light wavelength is from **400 nm~750 nm**
2) Infrared lights have high energy content (**44%**)



Solar Radiation Distribution on Earth

Courtesy of BENYALIGHTING DESIGN
http://www.benyalighting.com/Daylighting%20Basics%20July%2015.pdf





Spectral Power Distribution

Light Transmission Simulation of Straight OF

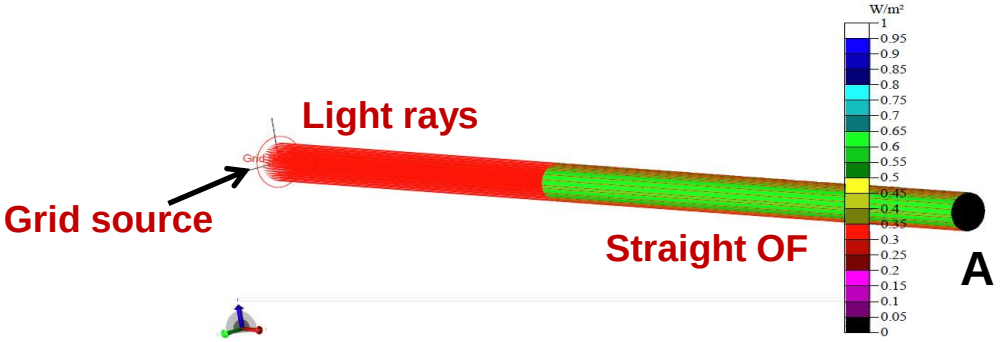
Optical Fiber Details

- Diameter: 2 mm
- Cladding: 0.2 mm
- Core: 1.8 mm

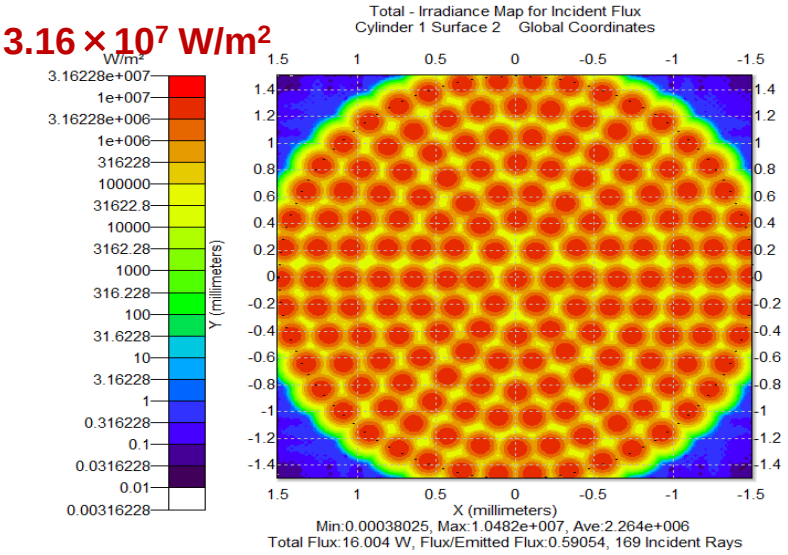
Grid Light Source

- Grid boundary: Annular
- Grid pattern: Circular
- Flux per ray: 0.1 Watts
- No polarization

Software: TracePro



3.16×10^7 W/m²

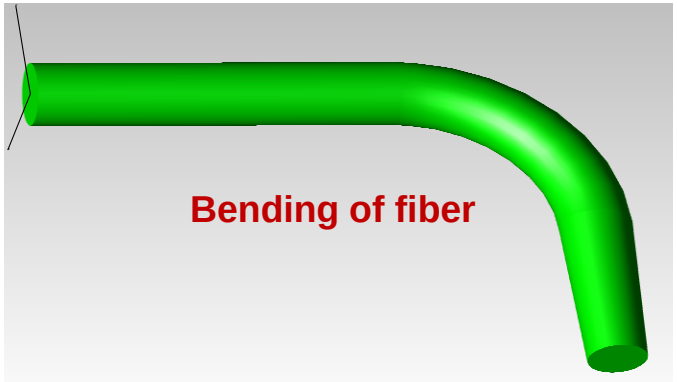


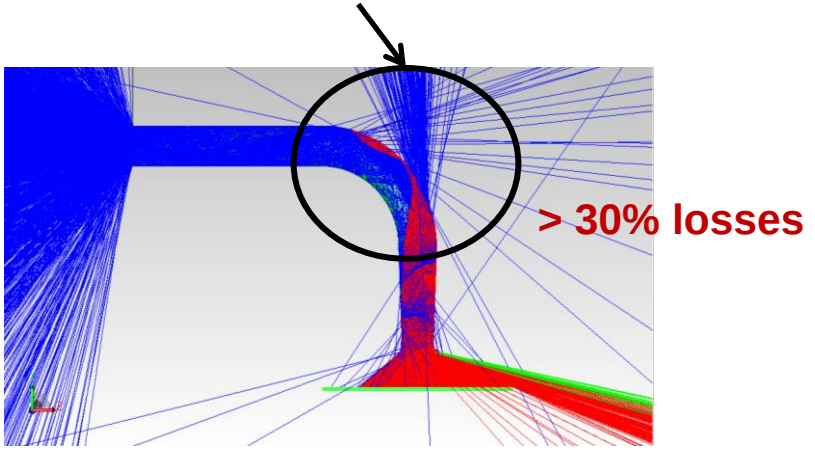
Irradiation Map for Incident Flux: on cross-section A: Almost 100% of Rays is Transmitted [No Attenuation]

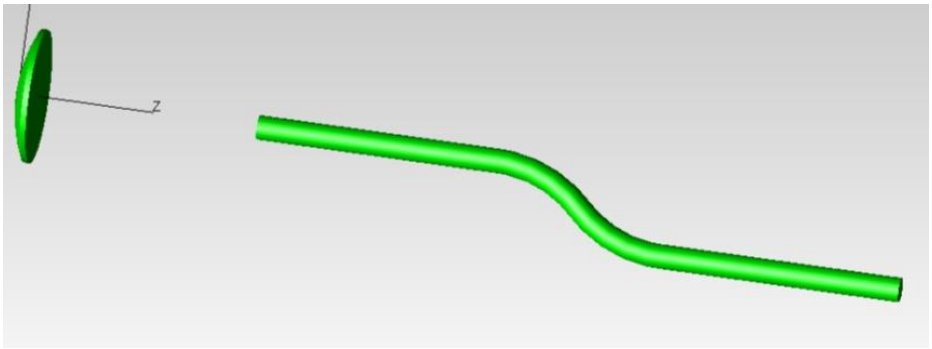
Bending Effect Analysis of the OF

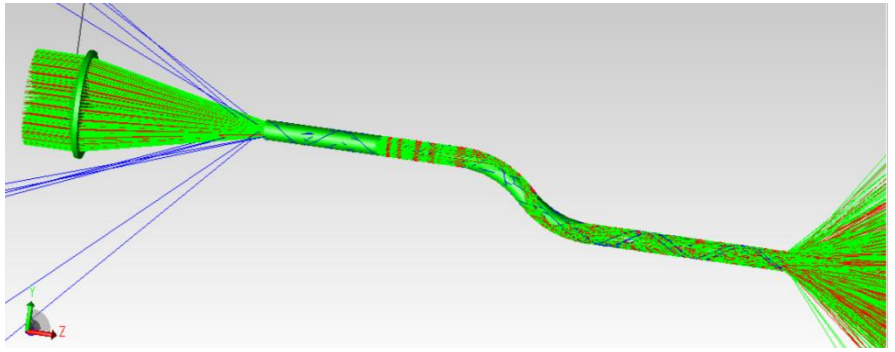
During the Actual Process of Construction,
Bending of the OF is unavailable

Software: TracePro







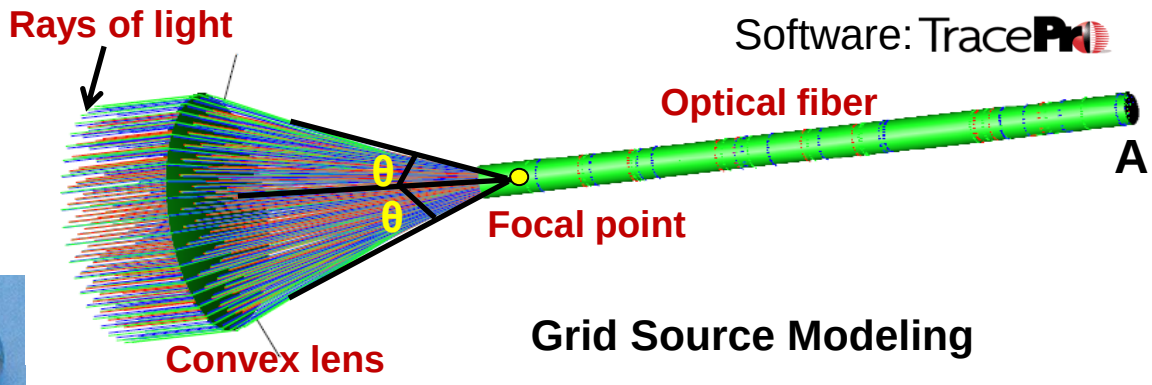


Bending radius should be <15 times fiber diameter
(Harry Dutton,1998)

Light Concentration Analysis

- Convex Lens
- Compound Parabolic Concentrator (CPC)

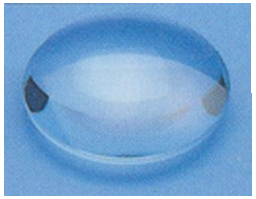
Convex Lens for Light Concentration



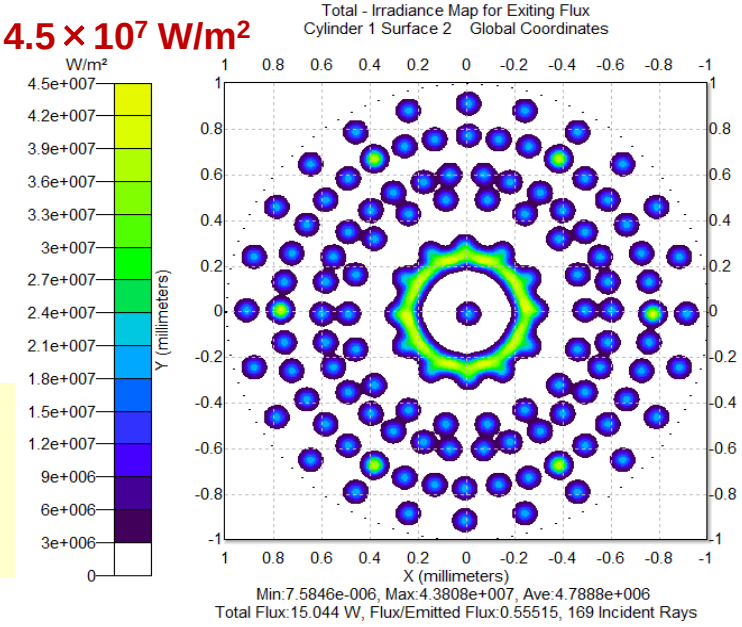
Grid Source Modeling

Convex Lens

- Focal length: 50 mm
- Diameter: 38 mm
- Lens thickness: 3 mm
- Material: Glass



4.5×10^7 W/m²



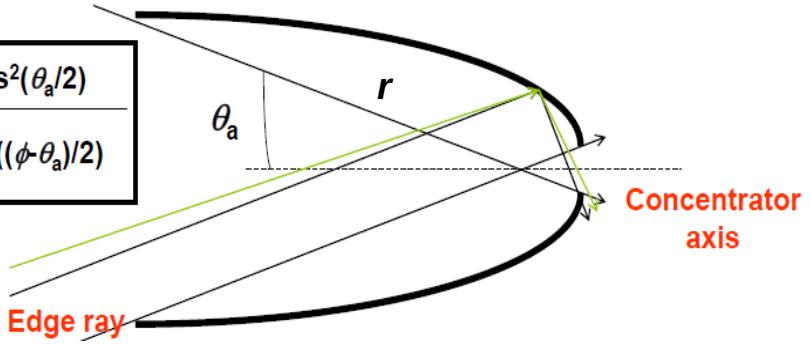
Irradiation Map for Exiting Flux from cross-section A: Concentration efficiency higher than OF only

CPC for Light Concentration

CPC

- A 2D concentrator of light onto edge of a receiver
- Used to design non-imaging devices
- Its generalization is “edge-ray principle” and is the basis of non-imaging optics.

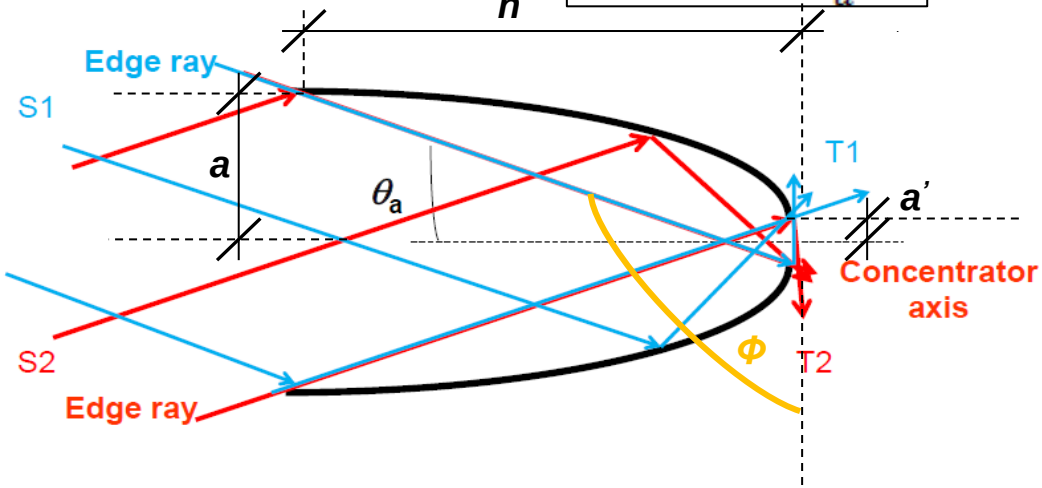
$$r = a' \frac{\cos^2(\theta_a/2)}{\cos^2((\phi-\theta_a)/2)}$$



Properties

- Source at “infinity”
- Planar input and output apertures
- Perfectly transmits light within $\pm\theta_a$

$$h = \frac{a(1+sin\theta_a)}{tan\theta_a}$$



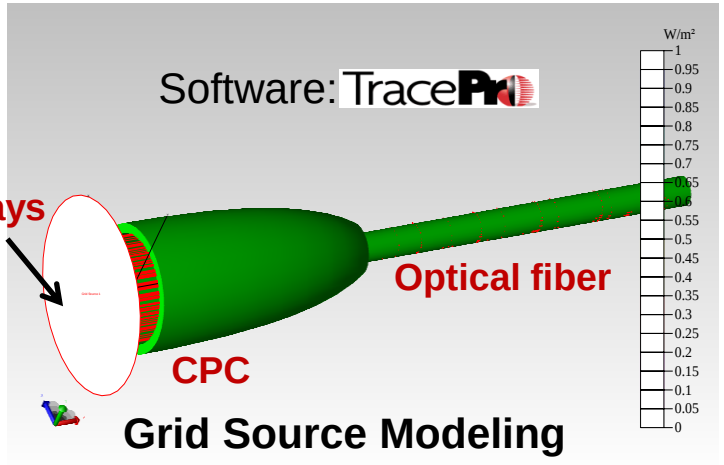
CPC for Light Concentration

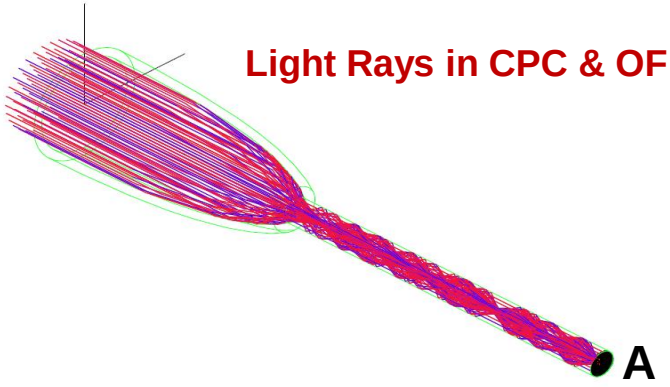
Light transmission modeling of CPC & OF

- The cross-section of light beam was concentric with the cross-section of the fiber
- The light concentration efficiency depends on the acceptance angle of the CPC:

$$\theta_{\max} = \arcsin\left(\frac{1}{C}\right)$$

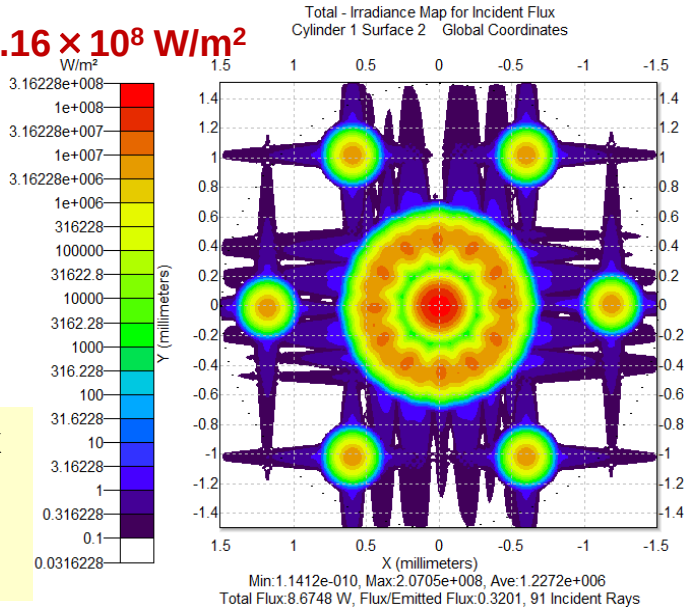
C = Maximum possible concentration





Light Rays in CPC & OF

3.16×10^8 W/m²



Irradiation Map for Incident Flux on cross-section A: Concentration efficiency higher than convex lens

Light Transmission Modeling of TC Panels

Light Source

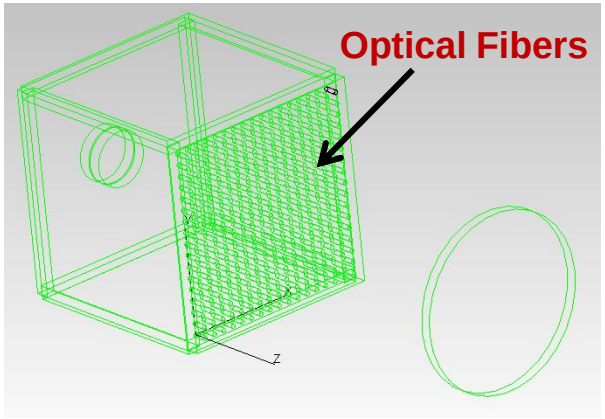
- Surface Source: **LED** Cree C450TR3041
- Total Rays: **4 Million**
- Calculated wavelength: **380 – 530 nm**

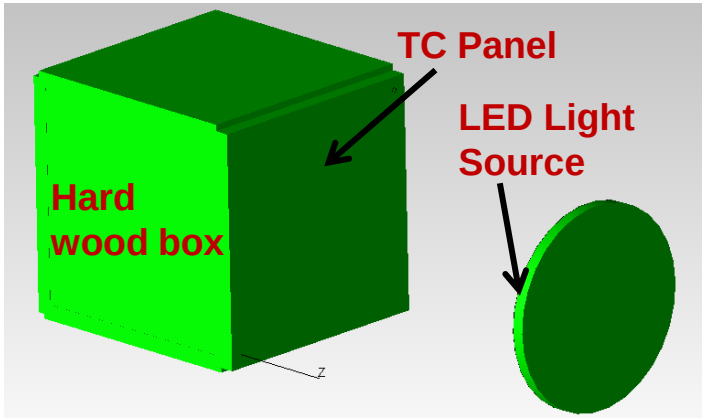
Properties of Boxes

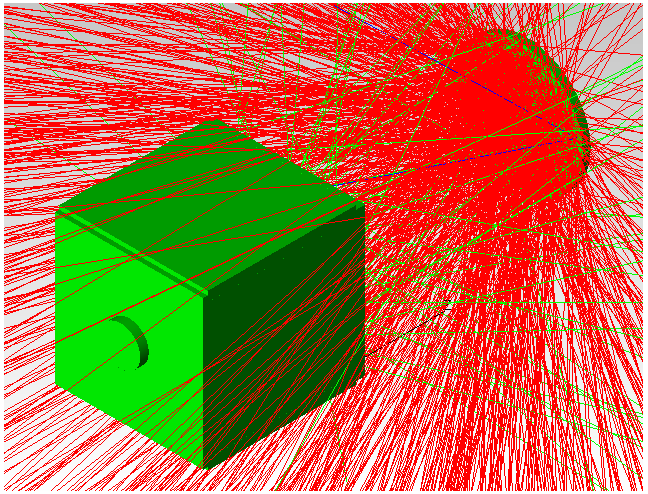
- Black paint, Refl. Coef.=**0.2**
- No paint, Refl. Coef.=**0.6**
- White paint, Refl. Coef.=**0.9**

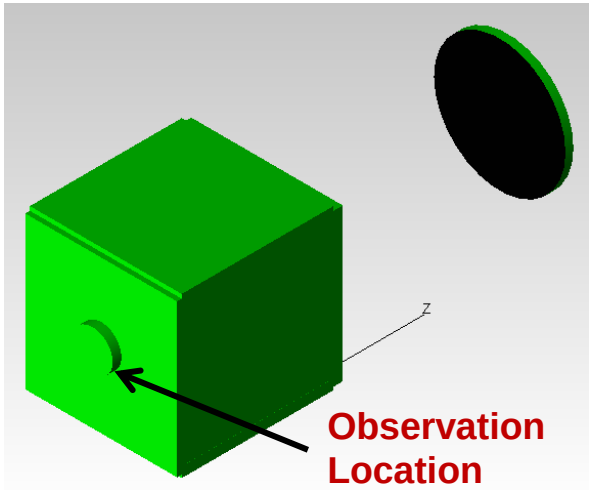
TC Panel

- **2 mm** optical fibers
- Volume ratio = **2.5%**









Ray Tracing

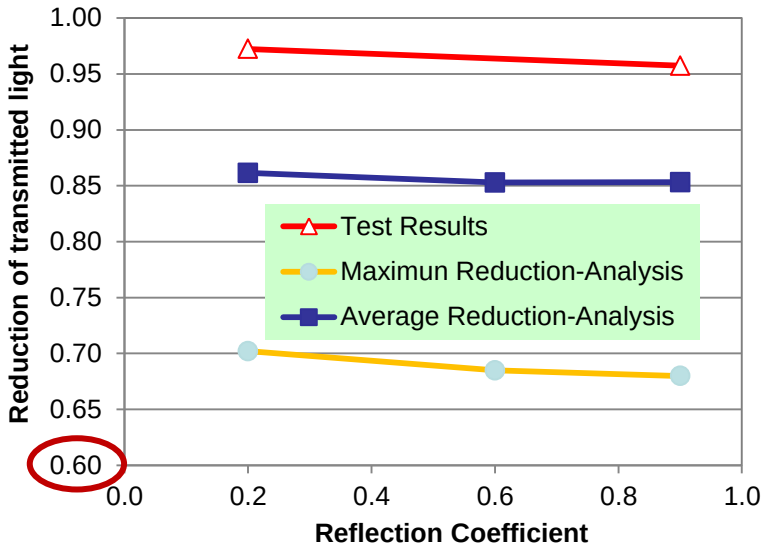
Light Transmission Modeling of TC Panels

Light Transmission Efficiency

The light transmission property of the boxes is described by the surface flux of the TC panel and the flux of the observation window:

$$R = (F_s - F_w)/F_s$$

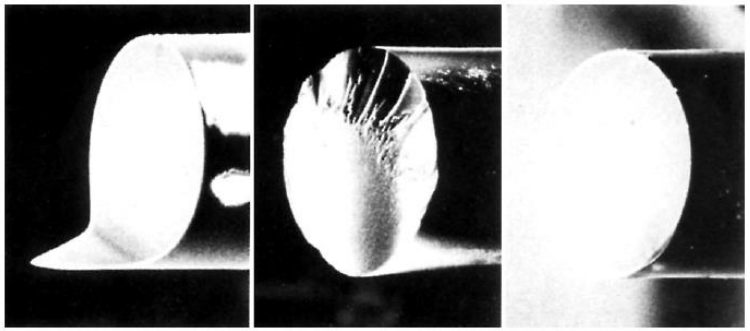
R = Flux reduction ratio
$\mathbf{F_s}$ = Surface flux of the TC panel
$\mathbf{F_w}$ = Flux at the location of the observation window



Light Transmission Efficiency Comparison

Differences between the model and the test are due to:

1) Actual surface properties;
2) The sources of light;
3) **Damages of the end face of the optical fiber**



End face of optical fibers
(Fedor Mitschke, 2009)

Conclusions

1. Translucent concrete (TC) can represent an energy efficient solution for the building envelope.

2. Construction of the TC panel is feasible.

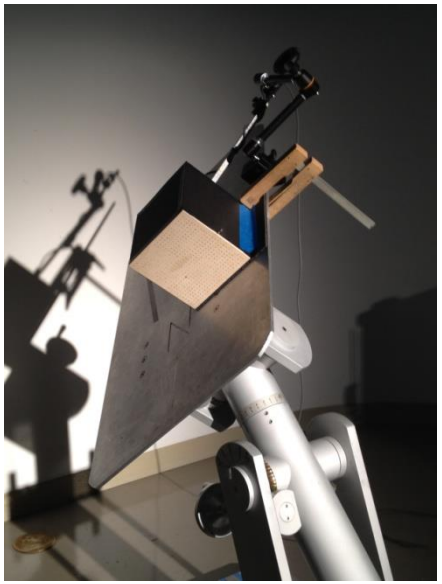
3. Daylight transmission properties of the TC panel is controlled by the volume ratio of the fibers.

4. Light collection property of the TC panel can be improved by utilization of convex lens and CPCs.

5. The bending of the fiber should be minimized as it affects the light transmission performance.

Future Goals

1. Dynamic modeling of the sun inclination
2. Optimal design of the CPC
3. CPC spatial arrangement in the TC panel
4. Daylight collection of the CPC and optical fibers
5. Thermal insulation performance optimization of the TC panel



Heliodon Test

Thanks for your attention!

Questions / Comments?