BEARS | SinBerBEST

# Translucent Concrete Panels: Construction, Light Transmission and Thermal Analysis

Khalid M. Mosalam I Baofeng Huang I Núria Casquero-Modrego I
Jaume Armengou I Sing-Ping Chiew

Supported by:

Funded by:
NATIONAL RESEARCH FOUNDATION

## Motivation and Overview

- **Optimal utilization of daylight for the façade system can reduce the carbon footprint and enhance the working efficiency of the indoor environment.**
- **Develop a daylight transmitting translucent concrete structural panels for building façades.**

**Compared to traditional electric lighting system, daylight is more energy efficient and healthy for human beings as it contains full spectrum of the sunlight. The IR spectral band could be filtered or used to generate heat or electricity, while the other bands could be filtered selectively and then guided into buildings.**

**Due to existence of the optical fibers, the novel translucent concrete panel permits some light to be transmitted through to the indoor environment.**

## Main Objectives

1. **Translucent concrete panel prototype construction**
2. **Light transmission tests of the translucent concrete panel**
3. **Light transmission simulation of the optical fibers**
4. **Light concentration analysis:**
   - **Convex lens for light collection simulation**
   - **Compound parabolic concentrator for light collection simulation**
5. **Thermal insulation analysis of the translucent concrete panel**

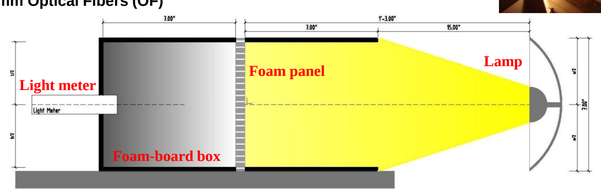
## Tasks Research Addressed

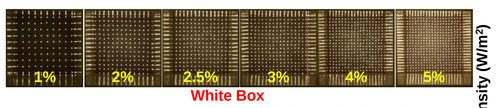
1. **Concrete cement selection**
2. **Optical fiber selection and spatial arrangement**
3. **Formwork development and construction procedure**
4. **Light transmission test setup and light transmission property description**
5. **Numerical modeling for light transmission simulation**
6. **Light collection section**
7. **Thermal insulation property description**

## Light Transmission Tests

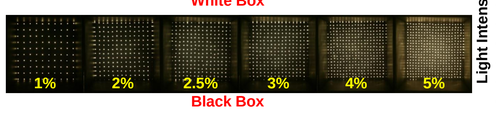
**Experimental Setup:**
- 7 in.×7 in.×0.5 in. foam panel
- 7 in.×7 in.×7 in. white & black foam-board boxes
- Incandescent lamp (250 W)
- 2 mm Optical Fibers (OF)

**Instrumentation:**
- Light meter
- Camera: Canon EOS 5D Mark IIL

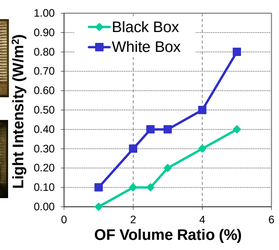



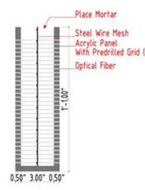

White Box



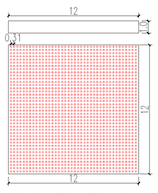

Black Box



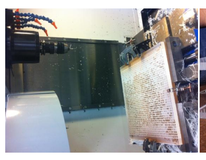

## Translucent Concrete (TC) Panel Construction Process



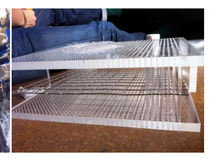

Form Setup



Holes Distribution



Drilling Holes in Acrylic Panel

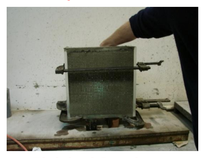


Installing the Optical Fibers

Finished Form

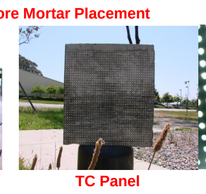
Before Mortar Placement

Placing Mortar

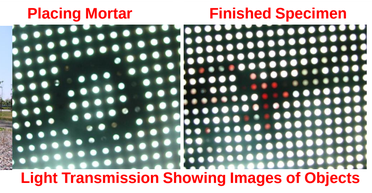


Finished Specimen

Form Removal



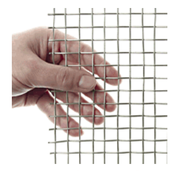
TC Panel



Light Transmission Showing Images of Objects

## Translucent Concrete Panel Details

**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.



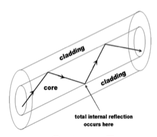
Wire Mesh

**Mortar mix:**
- Vulcan sand passed through #8 sieve
- Type I/II cement
- Type F fly ash
- ADVA 190 super plastisizer
- VMA 362 viscosity modifier

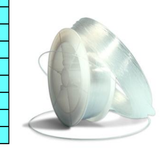
**Details of Optical Fiber**

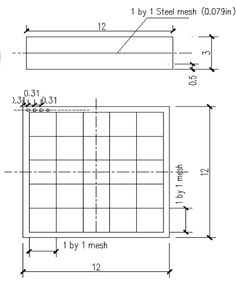
| Property | Value |
|---|---|
| Core Material | Polymethyl-Methacrylate Resin |
| Cladding Material | Fluorinated Polymer |
| Core Refractive Index | 1.49 |
| Refractive Index Profile | Step-index |
| Numerical Aperture | 0.50 |
| Number of Fibers | 1 |
| Core Diameter | 1840 – 2080 μm |
| Cladding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

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




Optical Fiber






Wire Mesh Arrangement
(not to scale)

## Optical Fiber Simulation TracePro

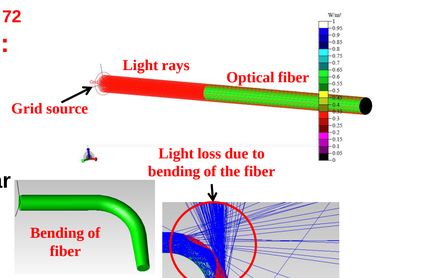
Software package: **TracePro 72**

**Optical Fiber Details:**
- Diameter: 2 mm
- Cladding: 0.2 mm
- Core: 1.8 mm

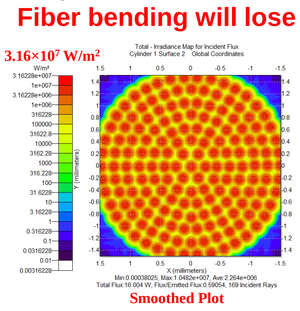
**Grid Light Source:**
- Grid boundary: Annular
- Grid pattern: Circular
- Flux per ray: 0.1 Watts

**No polarization**

**Fiber bending will lose light**

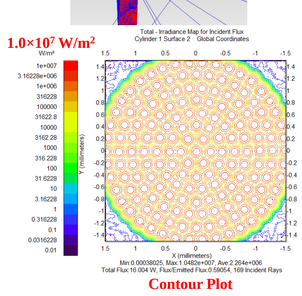



$3.16\times10^{7}$ W/m²



Smoothed Plot

$1.0\times10^{7}$ W/m²

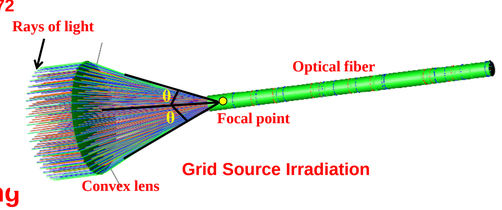


Contour Plot

## Light Concentration of Convex Lens TracePro

Software package: **TracePro 72**

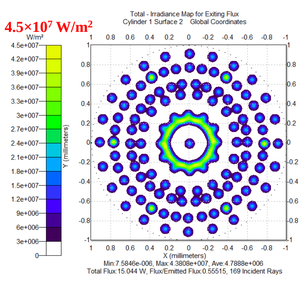
**Convex Lens:**
- Focal length: 50 mm
- Diameter: 38 mm
- Lens thickness: 3 mm
- Material: Glass



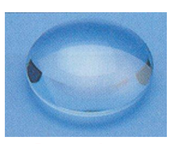

Grid Source Irradiation

**Grid Source Modeling**

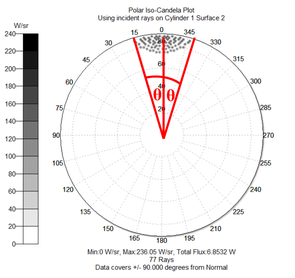
$4.5\times10^{7}$ W/m²



Irradiation Map for Exit Flux
(Concentration efficiency higher than fibers only)



Convex Lens



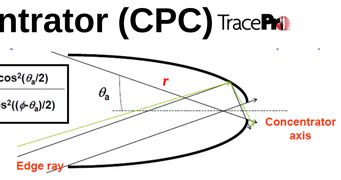
Polar ISO Candela Distribution

## Compound Parabolic Concentrator (CPC) TracePro

Software package: **TracePro 72**

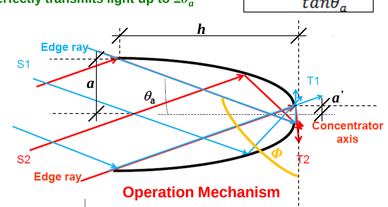
**CPC: A 2D concentrator designed to concentrate light onto the edge of a receiver. This basic principle can be used to design non-imaging devices. Its generalization is the " edge-ray principle" and is the basis of non-imaging optics.**

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

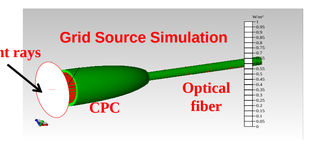


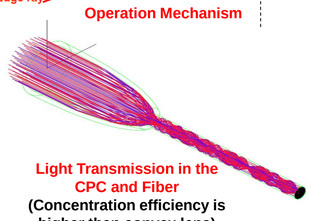

**Properties:**
- –Source at "infinity"
- –Planar input and output apertures
- –Perfectly transmits light up to $\pm\theta_a$

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

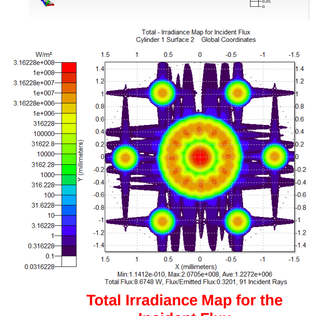



Operation Mechanism



Light Transmission in the CPC and Fiber
(Concentration efficiency is higher than convex lens)



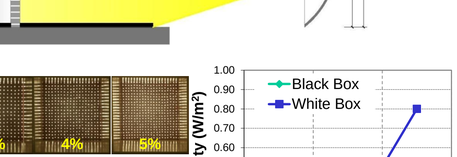
Total Irradiance Map for the Incident Flux

## Thermal Flux Analysis

Software package: **COMSOL Multi Physics 4.2**

**Technical details:**
- Heat transfer time: 4 hours
- Temperature difference: 100°
- Environmental Temperature: 20°

| Concrete properties | |
|---|---|
| Properties | Values |
| Density | 2300[kg/m3] |
| Thermal conductivity | 1.8 [W/(m*K] |
| Heat capacity at constant pressure | 3800 |
| Young's modulus | 25e9 [Pa] |
| Coefficient of thermal expansion | 10e-6 [1/K] |
| Possion's ratio | 0.33 |
| **Fiber properties** | |
| Properties | Values |
| Density | 891.7[kg/m3] |
| Thermal conductivity | 0.15 [W/(m*K] |
| Heat capacity at constant pressure | 5000 |
| Young's modulus | 7e10 [Pa] |
| Possion's ratio | 0.16 |




5% volume ratio Note: 273K=0°




Temperature variations: Midpoint of Thickness

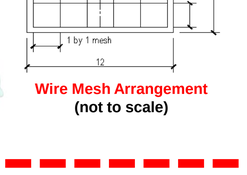



## Conclusions

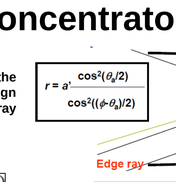
1. **Translucent concrete (TC) can represent an energy efficient solution as a material for building envelop**
2. **Construction of TC panel is feasible**
3. **Daylight transmission properties of the TC is controlled by the volume ratio of the fibers**
4. **Light collection property of the TC can be improved by utilization of convex lens and CPCs.**
5. **Light concentration efficiency of CPC can be optimized by changing its 3D shape.**
6. **The bending of the fiber should be minimized as it affects the light transmission performance**
7. **Thermal insulation performance of the TC panel is affected by the concrete material, thickness of the panel, and volume ratio of the optical fibers.**

## Future Goals

1. **Active sun tracking system implementation**
2. **Optimal design of CPC**
3. **CPC spatial arrangement in the TC panel**
4. **Daylight collection of CPC and fibers**
5. **Thermal insulation performance optimization of TC panel**




Daylight simulation






Sunlight irradiance at 1 pm