A Sustainable Complex Fenestration System using Recycled Plastics

Islam A. Mashaly

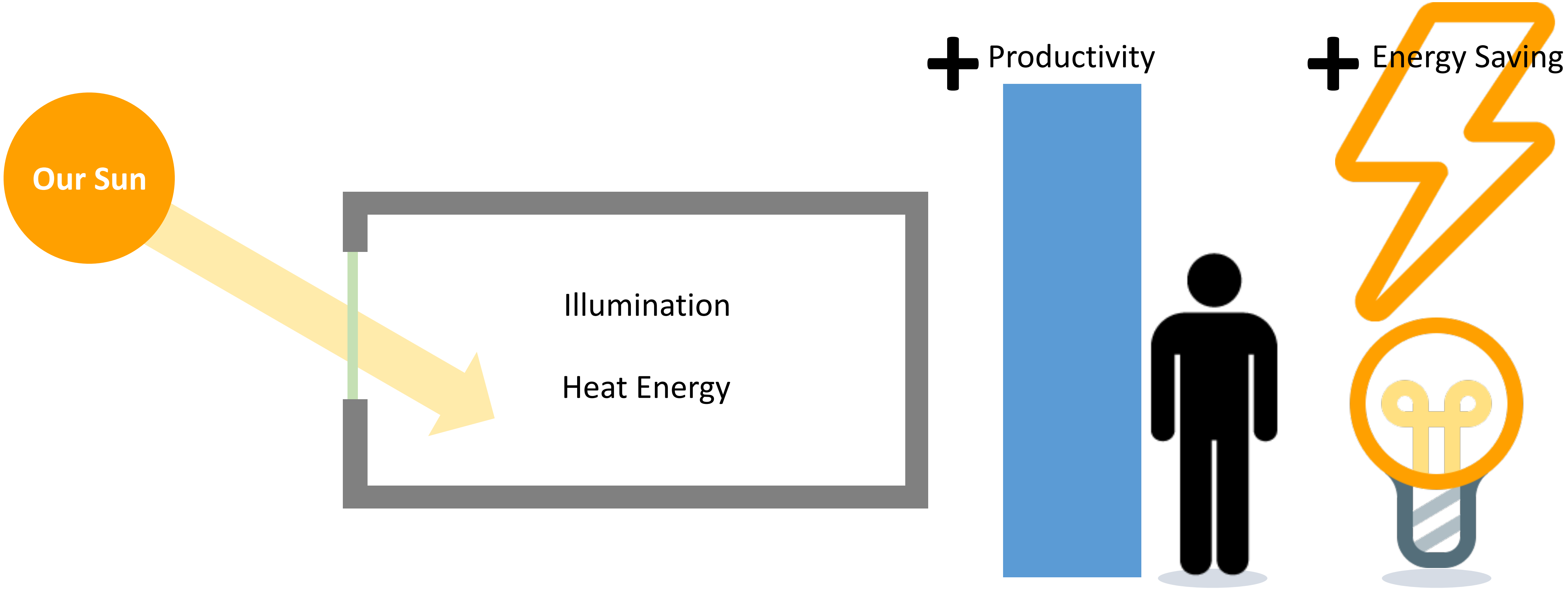
Dr. Khaled Nassar

Outline

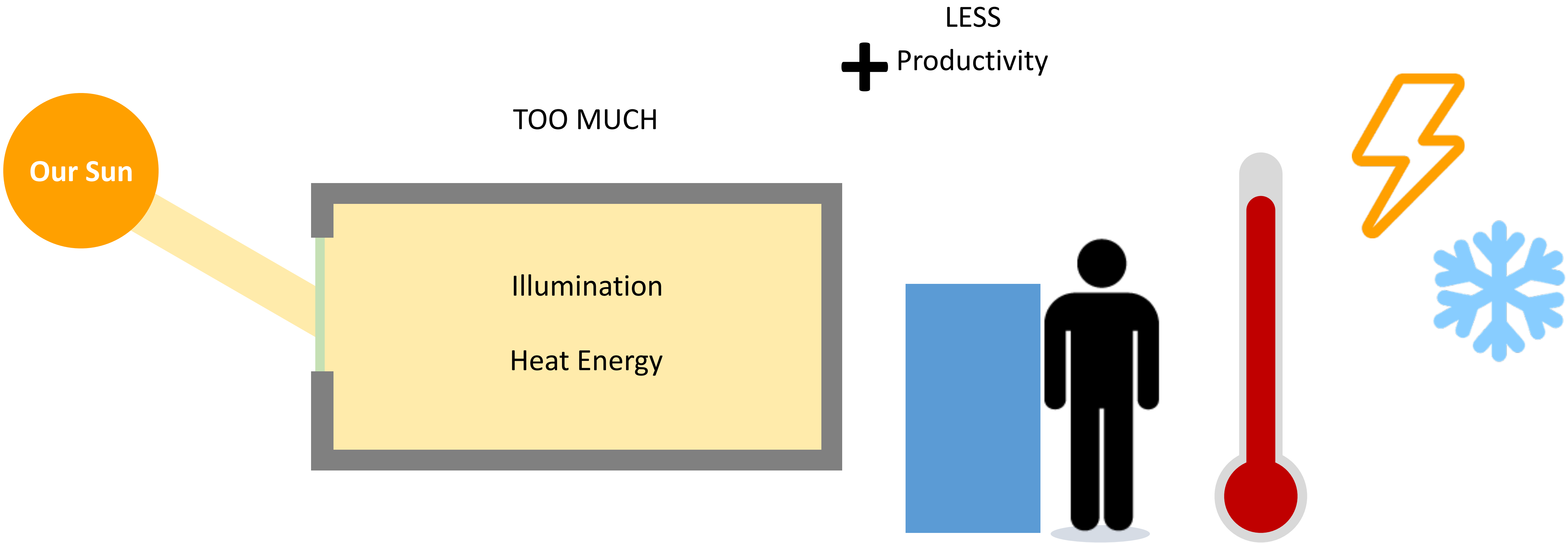
- Introduction
- Literature Review
- Prism Design
- Daylight Simulation
- Physical Model Setup and Measurements
- Conclusions

Introduction

What is Daylighting? Why is it important?

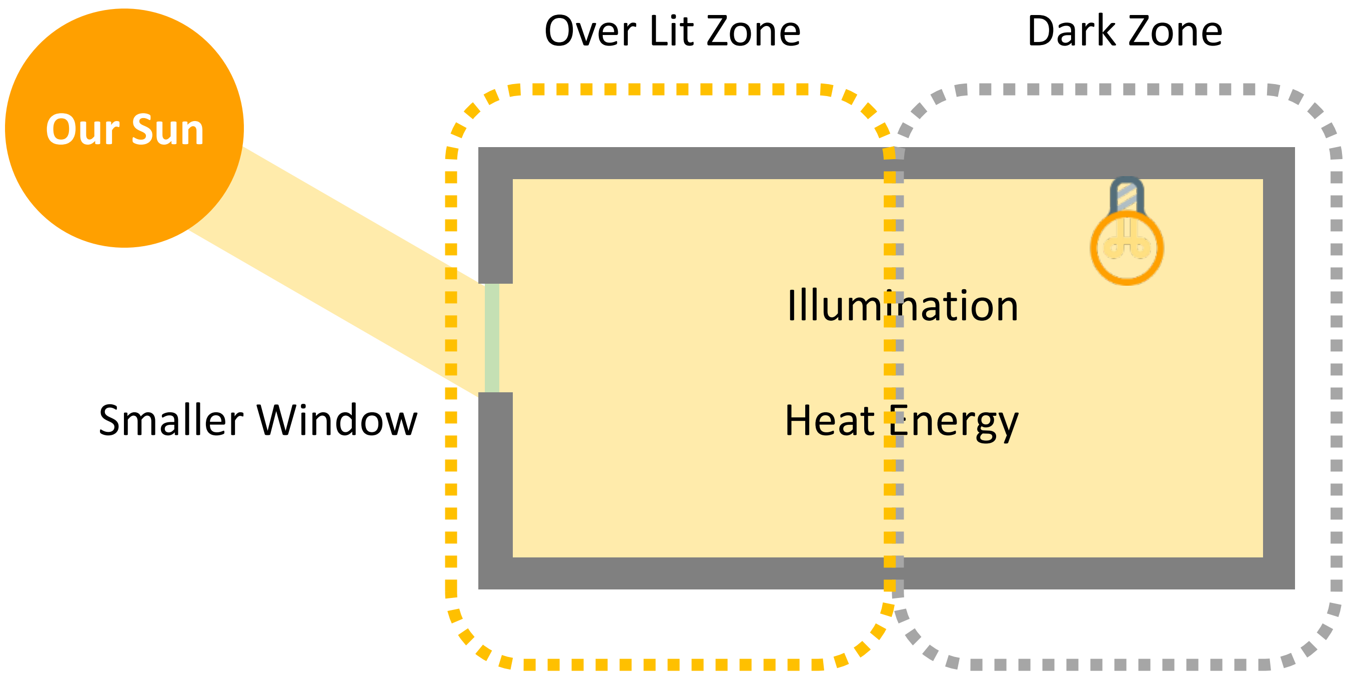


Daylighting Problem



Daylighting Problem

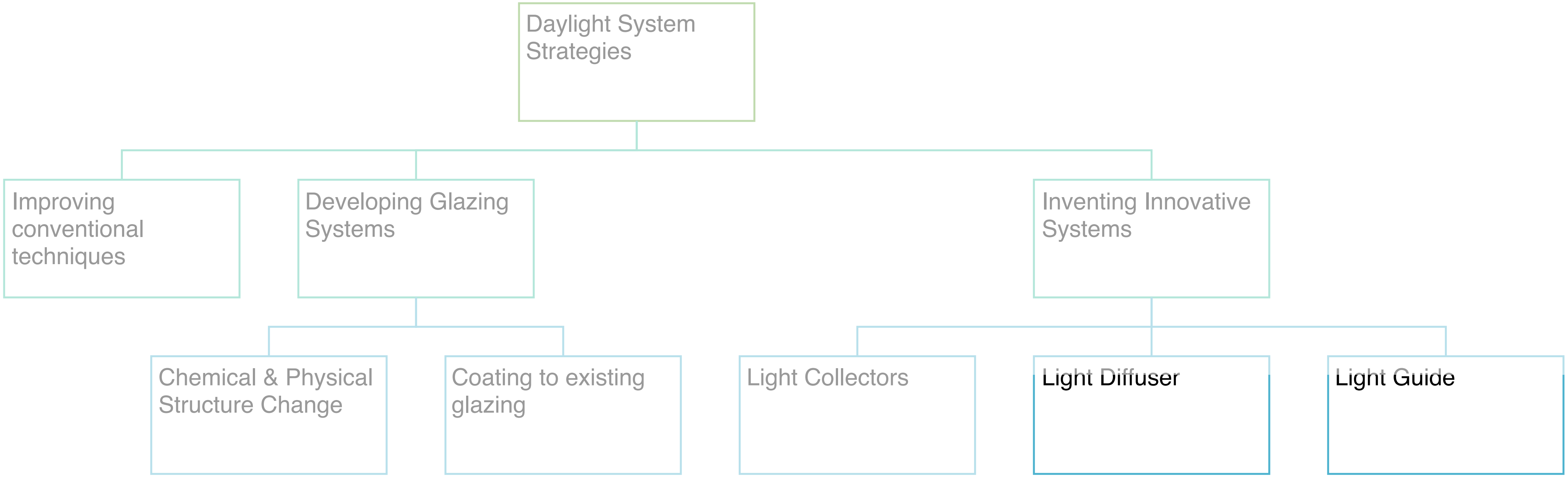
“The Cave Effect”



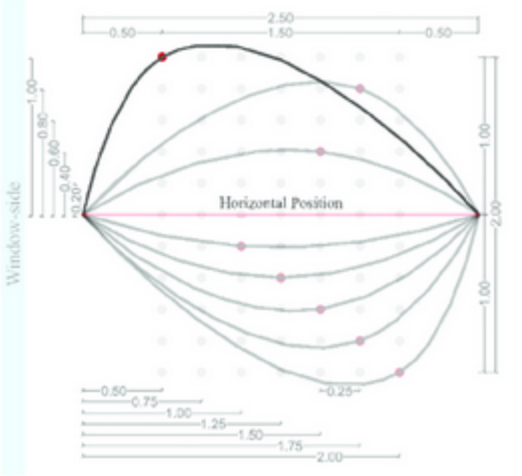
Discomfort in Vision
Glare

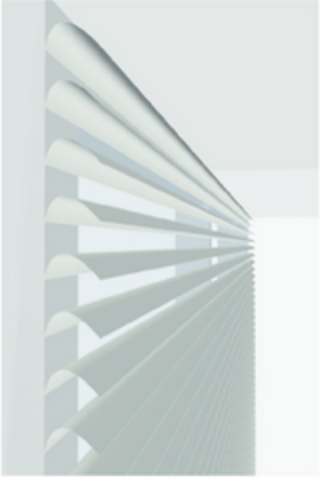
Artificial Lighting

Available Solutions



Available Solutions





◀ Electro Chromatic

Internal Blinds ▲

(Sherif et. al., 2016)

(Granqvist, 1995)

Light Shelves ▲

(Nassar et.al., 2014)

Solar Tubes ▶

(Solatube, 2015)

Plastics Waste

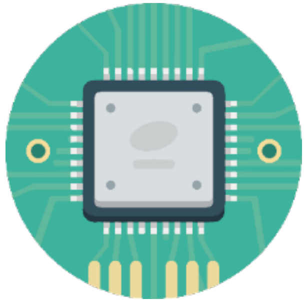
5% Reused

30% Recycled

980,000 tons

(Plastic Recycling Development Strategy, 2008, Plastic Technology Center)

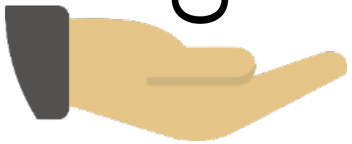
The Problem



Technology
+Material availability
+Cost efficiency
+Maintenance

Sustainability issues

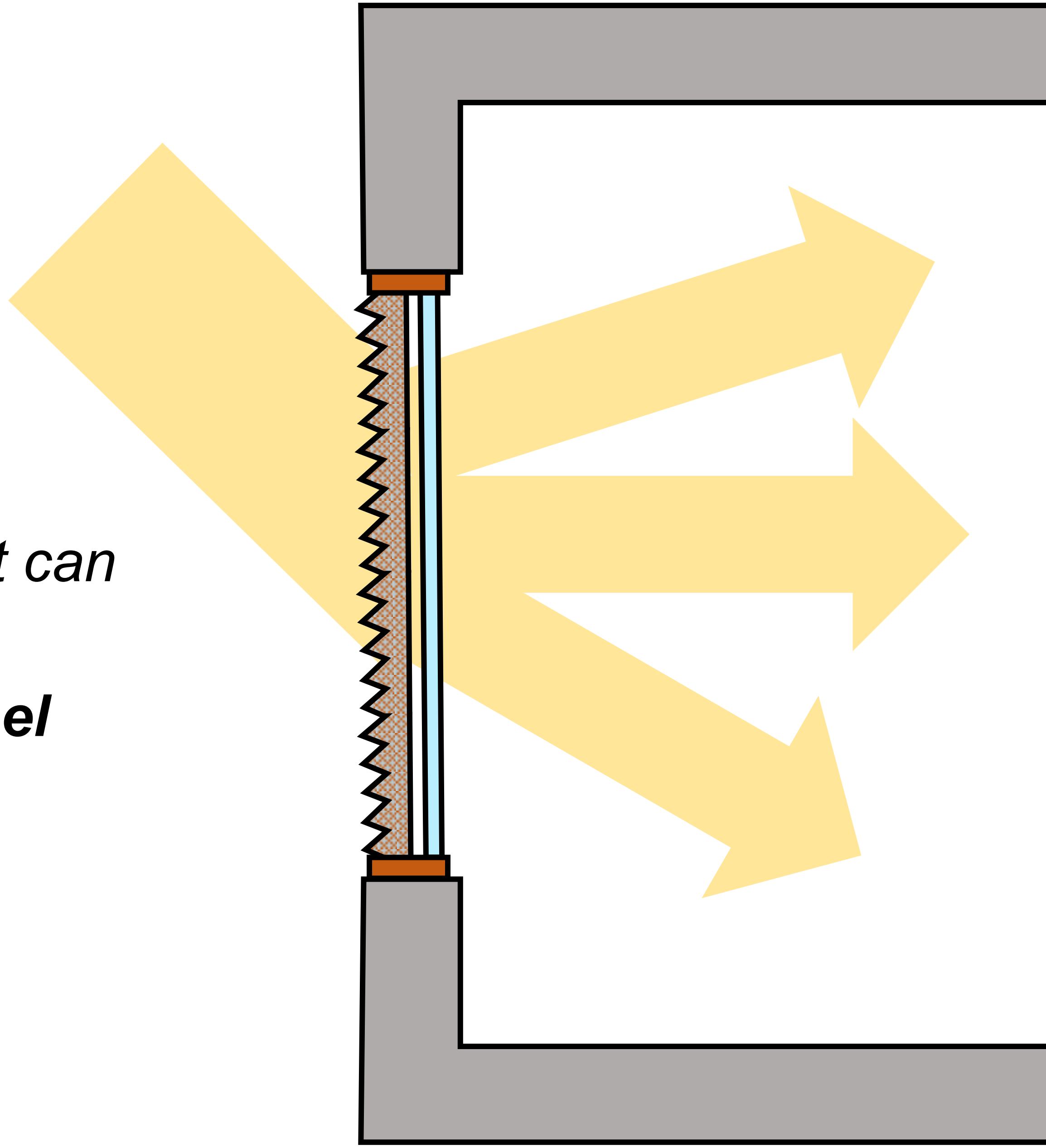
On the other hand



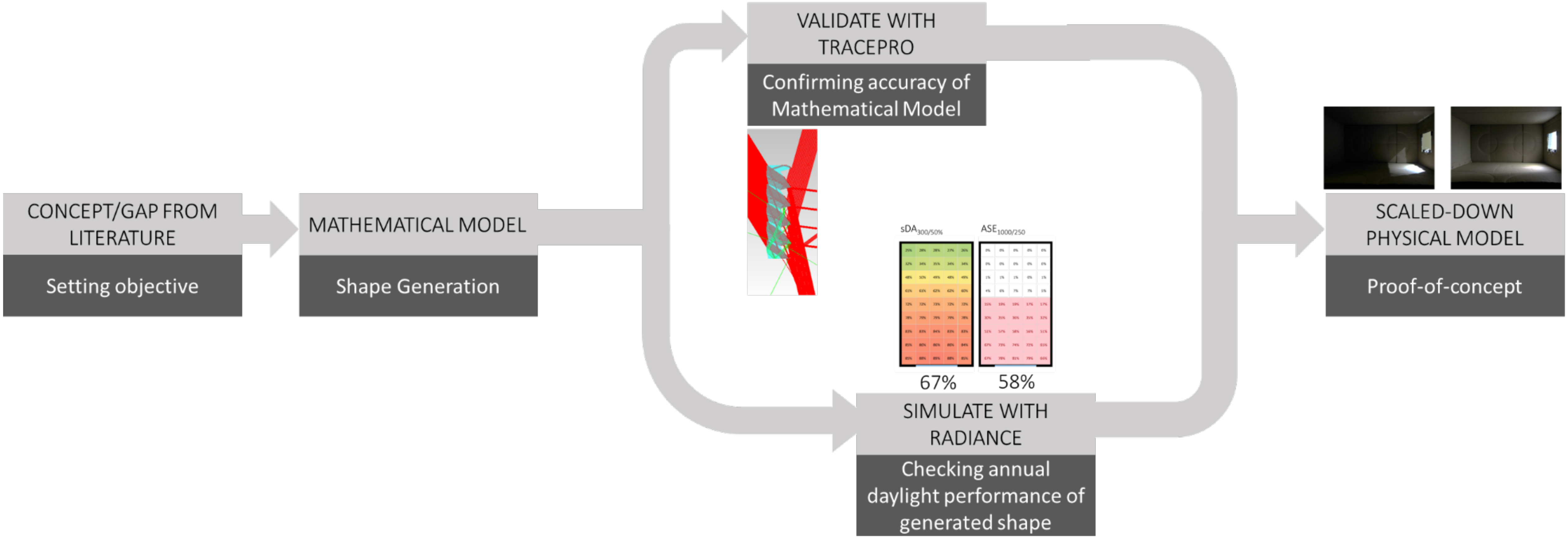
- Unutilized plastic waste
- Limited Application of recycled plastic in the glazing industry

Aim

The aim is to achieve a ***sustainable*** *complex fenestration system (CFS) design that can* ***diffuse*** *and* ***redirect*** *sunlight deep inside rooms through an* ***optimized prismatic panel*** *on its* ***translucent layer****.*



Outline


CONCEPT/GAP FROM LITERATURE
Setting objective
MATHEMATICAL MODEL
Shape Generation
VALIDATE WITH TRACEPRO
Confirming accuracy of Mathematical Model
sDA300/50%
ASE1000/250
67%
58%
SIMULATE WITH RADIANCE
Checking annual daylight performance of generated shape
SCALED-DOWN PHYSICAL MODEL
Proof-of-concept

VIEW ON THE STRUCTURE IN A RAY TRACING SIMULATION REDIRECTING LIGHT UPWARDS IN
TH ANGLES 30° (LEFT) AND 60° (RIGHT) (KISCHKOWEIT-LOPIN, 1997)

99) used a macro prismatic structure in crop illumination by placing the panels
ng the tilt angle. Other researches focused on different regions that are in the higher
structured panels that use hybrid polymers developed by the institute of Solar

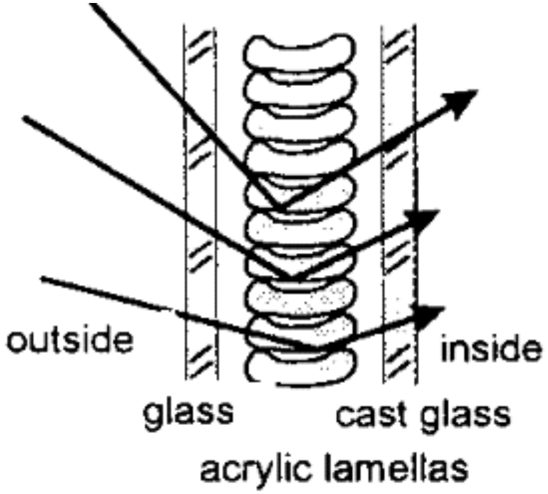
Literature Review

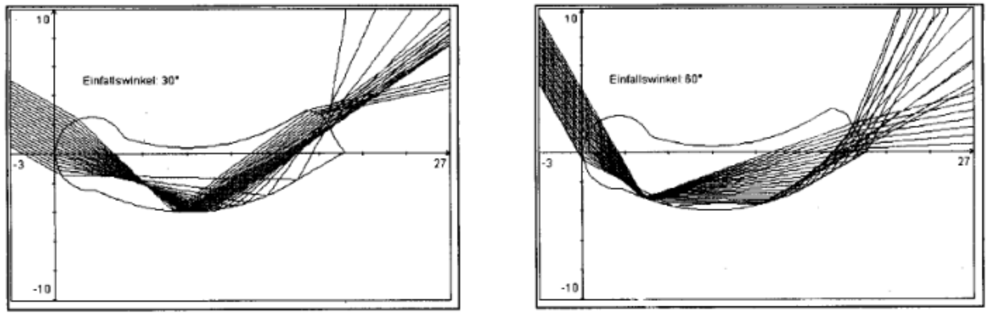
urg (Walze G. , et al., 2005). (Klammt, Neyer, & Muller, 2012) combined a micro-
geometry in order to increase the efficiency of redirection of light. The micro-prism
vas made of acrylic and the upward and downward transmission were measured
solar altitudes.

Complex Fenestration Systems

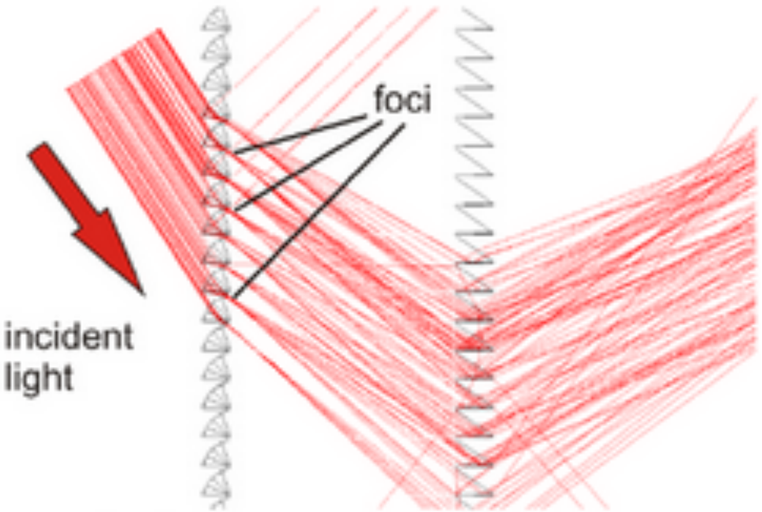
Any light transmitting window technology that features at least one non-transparent layer or one layer with switchable properties

(Bueno, Wienold, Katsifaraki, & Kuhna, 2015)

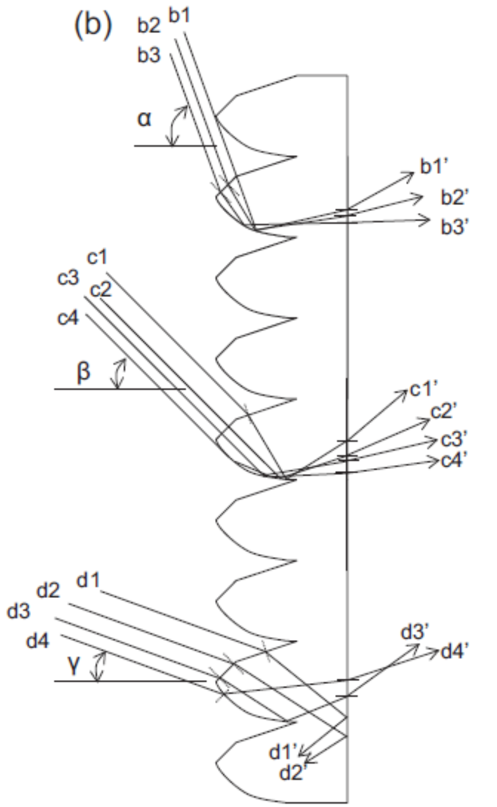




(Kischkoweit-Lopin, 1997)



(Klammt et. al., 2012)



(Huang et. al., 2015)

CFS Literature

Publications / Features	**Rubbert, 1999 LUMITOP®**	(Edmonds & Pearce, 1999) **LCP**	**Walze et. al., 2005**	**Vlachokostas et. al., 2012**	(Padiyath, 2013) **3M™ Film**	**Buß et. al., 2013**	**Klamm et et. al., 2013**	(Thanachareonkit, Lee, & McNeil, 2013)	**ElHenawy et. al., 2014**	**Nassar et. al., 2014**	(Huang, et al., 2015)
Targeted Solar Altitude	Low	Low	Low	Low	N/A	N/A	Low	Low	High	High	Medium
Prism Structure Scale	Macro	Macro	Micro	Macro	Micro	Nano	Micro	Micro	Macro	Macro	Micro
Manufacturing Sophistication	High	High	High	High	High	High	High	High	Low	Low	High
Controlled Angular Redirection		●		●					●		
Commercial	●	●			●			●			
Use of Additive/ coating			●	●		●					●

Physical Model

Suggested recycled material used for prism design

- **Polypropylene**
  - Refractive Index: 1.49
  - Transparent plastic cups, transparent plastic containers
  - Fairly economic, found in vast quantities

- **Polystyrene**
  - Refractive index: 1.60
  - Light weight Foam dishes, expanded polystyrene
  - Very Cheap, found in vast quantities

- **Polycarbonate**
  - Refractive index: 1.58
  - Roof tops
  - One of the most expensive plastics, found only as construction waste

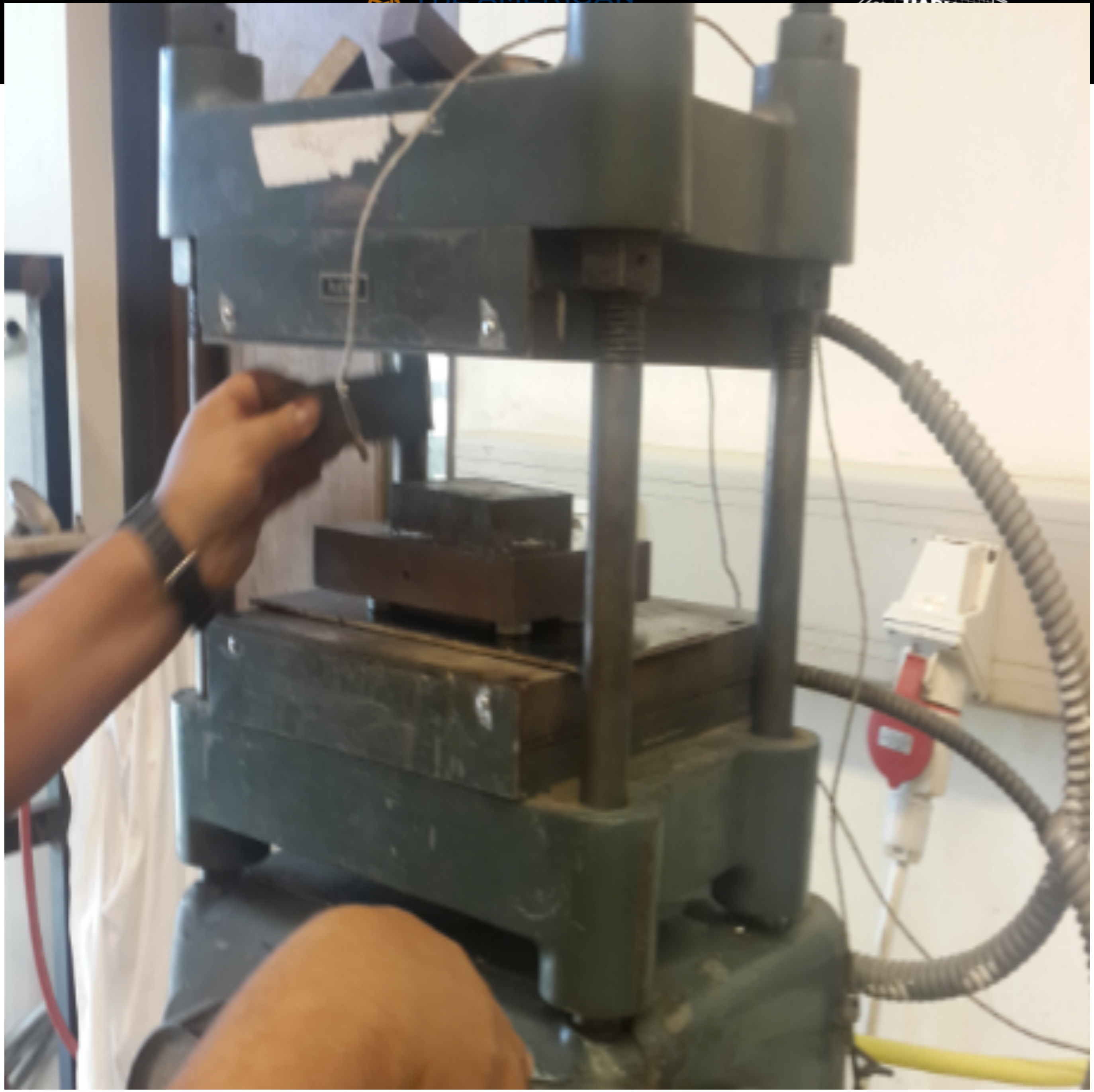
Setting up the material for recycling

- Collecting different plastic waste
- Cleaning and washing
- Shredding of different types of plastics

Adding the pellets to the mold

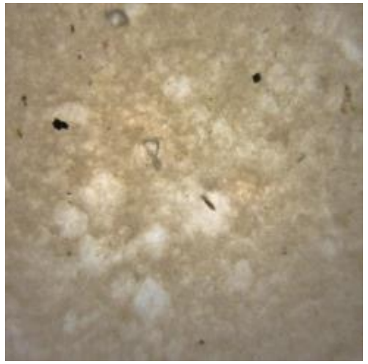
Pressing Machine

Material	Temperature (°C)	Pressure (psi)
PC	150-170	2000
PS	105-110	1500
PP	120-140	2000
Acrylic	110-120	1000



Properties of the recycled plastics

PC



PS

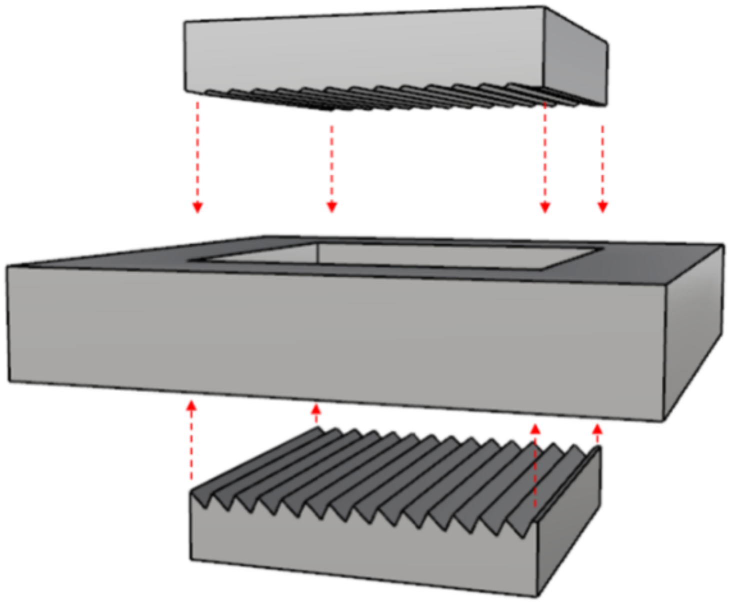
PP

Material	Transmittance		Reflectance	
	Diffused	Specular	Diffused	Specular
RPC	8.6%	20.0%	34.0%	37.4%
RPS	2.5%	2.8%	45.1%	49.6%
RPP	2.2%	2.4%	45.5%	50.0%

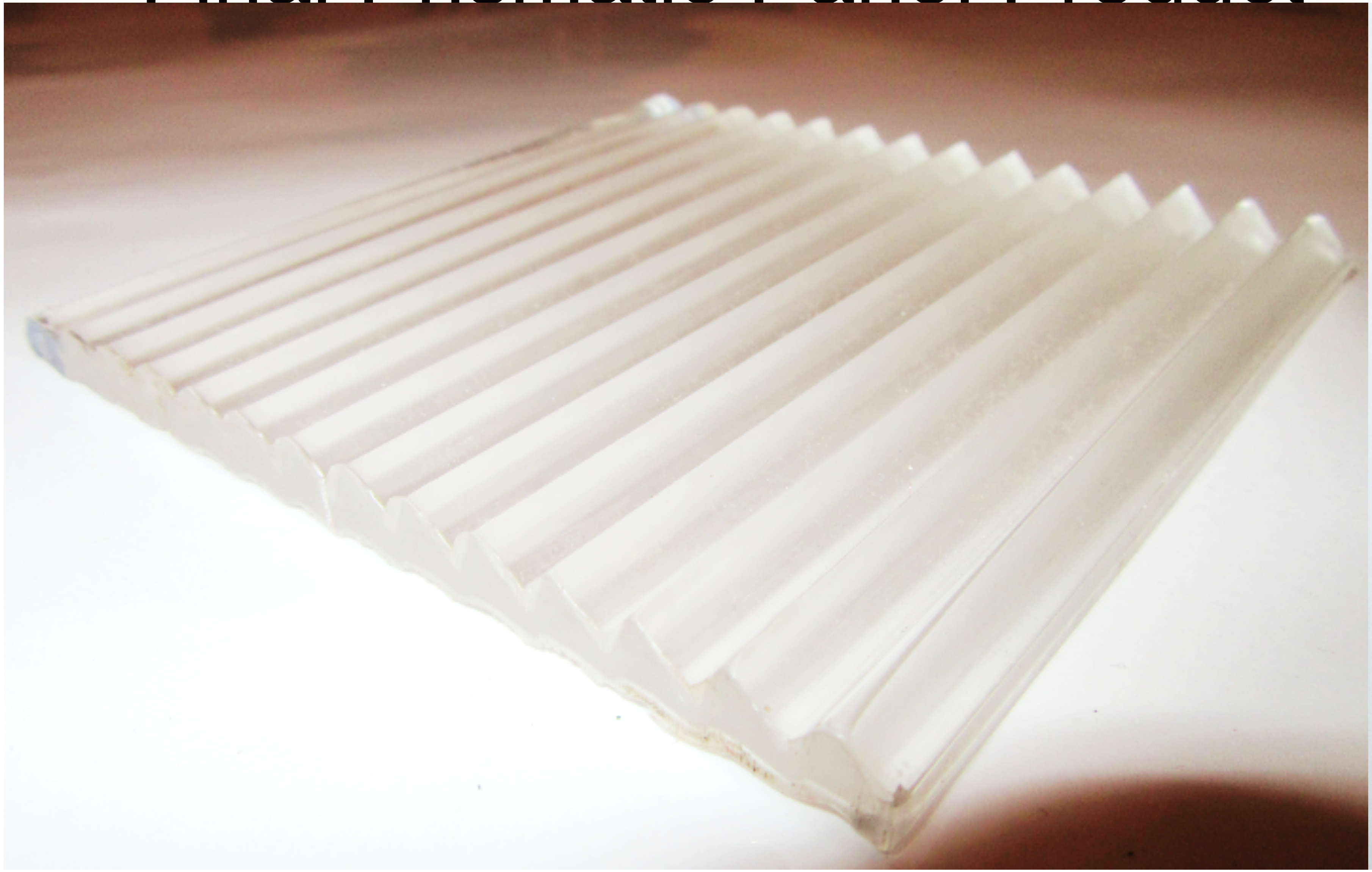
UV/VIS Spectrophotometer

Creating the mold

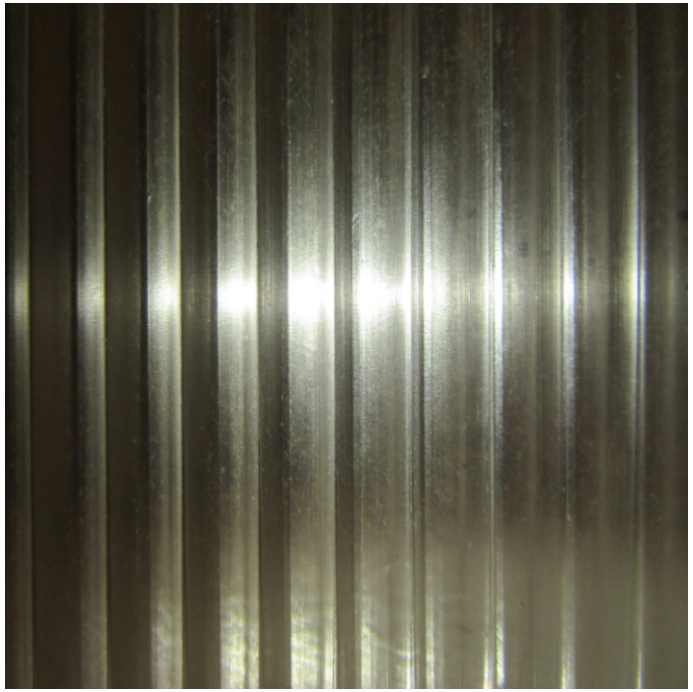
- Inverse of the shape is created on a 10 x 10 cm mold
- Prismatic array count is 15 with 0.7 cm per period



Final Prismatic Panel Product - Acrylic



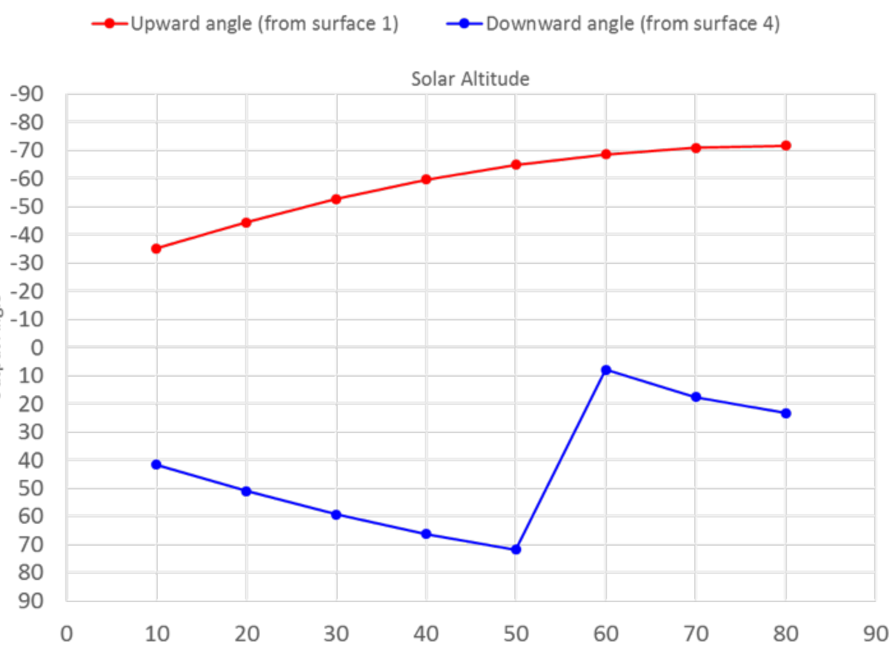
Final Prismatic Panel Product



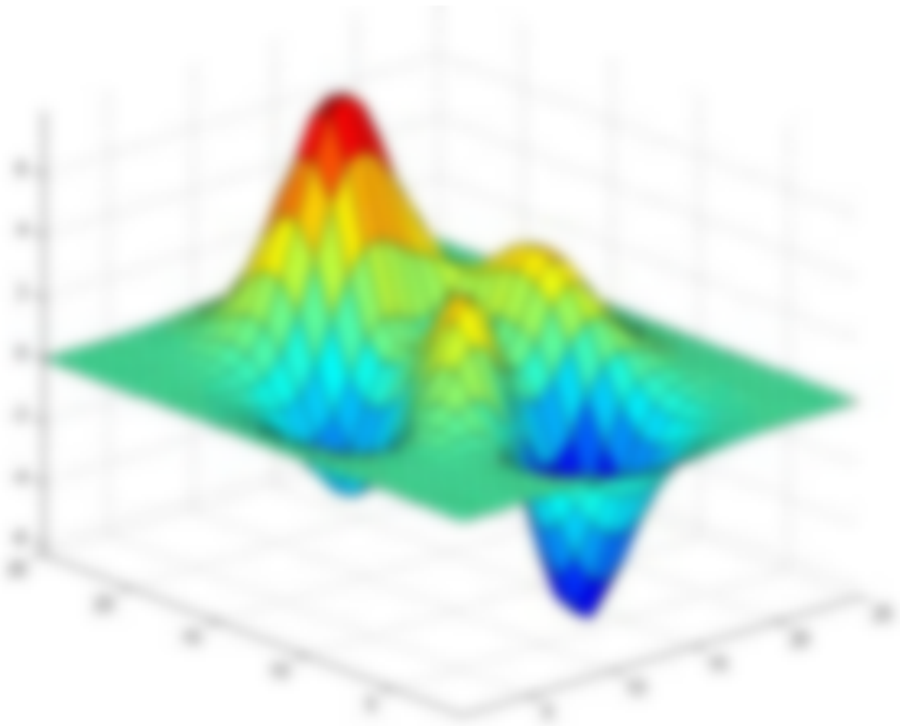
Acrylic

Polycarbonate

Polystyrene

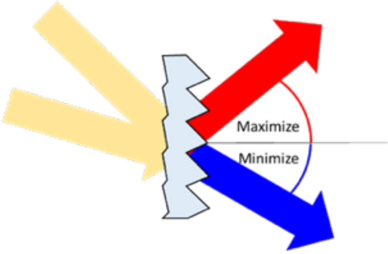


Prism Design



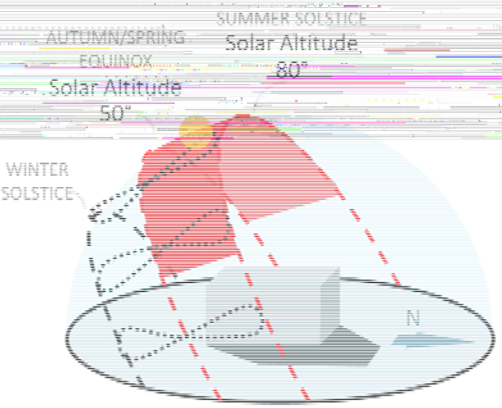
$$\mathcal{R} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ k_x[\rho' - (n/n')\rho] & n/n' & 0 & 0 \\ k_y[\rho' - (n/n')\rho] & 0 & n/n' & 0 \\ k_z[\rho' - (n/n')\rho] & 0 & 0 & n/n' \end{pmatrix}.$$

Mathematical Model



OBJECTIVE

- Minimizing downwards output angle
- Maximizing upwards output angle



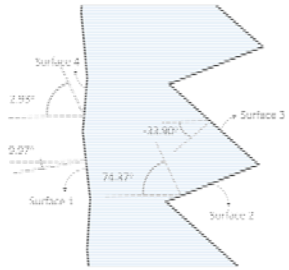
INPUT

- Refractive Index
- Target solar Altitude

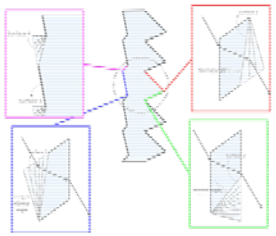
ALGORITHM

OUTPUT

- Normal angles of the 4 surfaces



CONSTRAINTS



- Normal angles of the 4 surfaces
- Incident ray angles on the 4 surfaces

Introduction to ray tracing

- **Snell's Law**

$$n \sin I = n' \sin I'$$

  - Refraction Index (n)

$$n_{air} = 1.0003$$

$$n'_{acrylic} = 1.4983$$

  - Angle of Incidence input (I)
  - Angle of incidence output (I')

- **Total internal reflection**

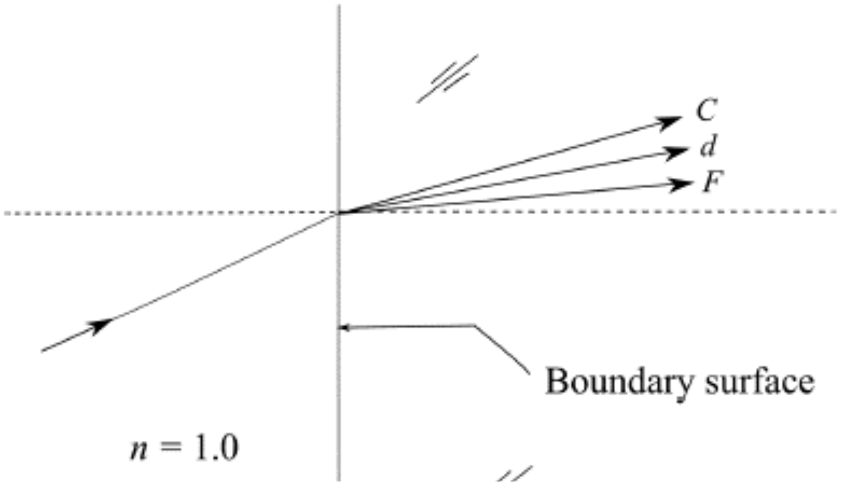
$$I_{crit} = \arcsin(n'/n)$$

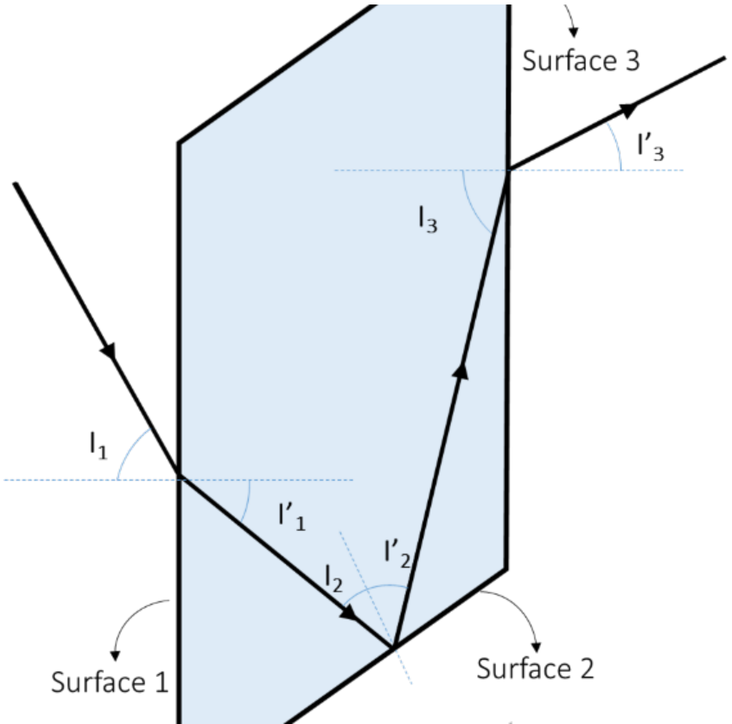
- **Law of Reflection**

$$K' = K - 2k \cos I$$

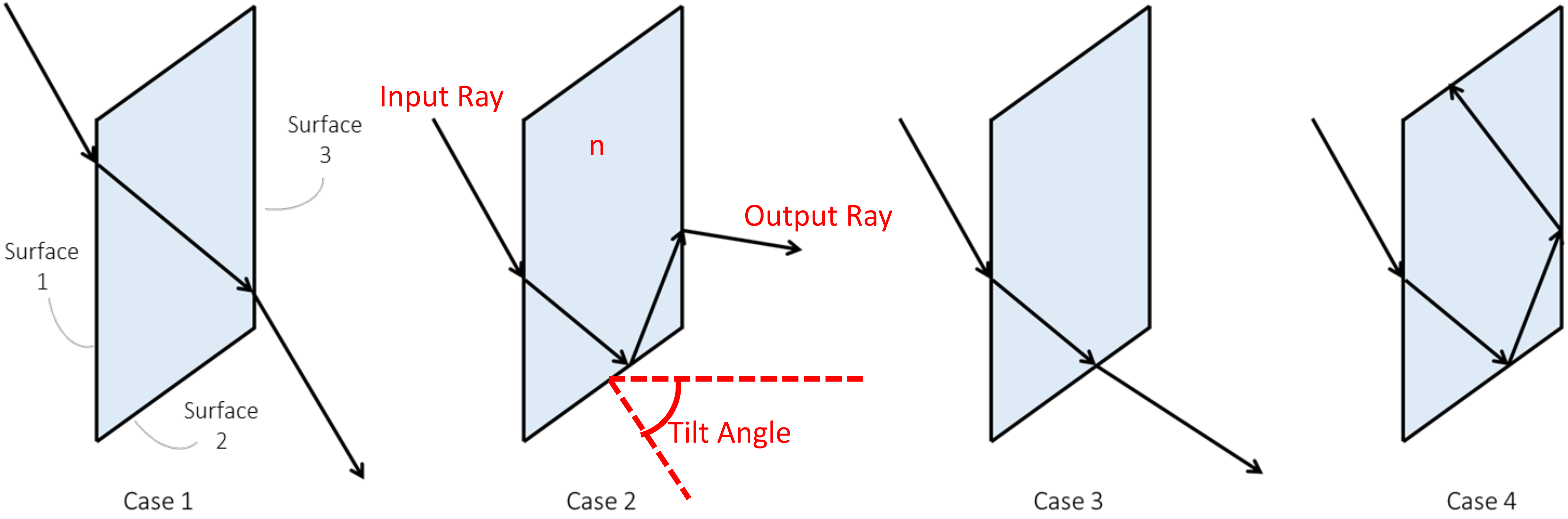
- **Law of Refraction**

$$K' = (n/n')K + k(\cos I' - (n/n')\cos I)$$

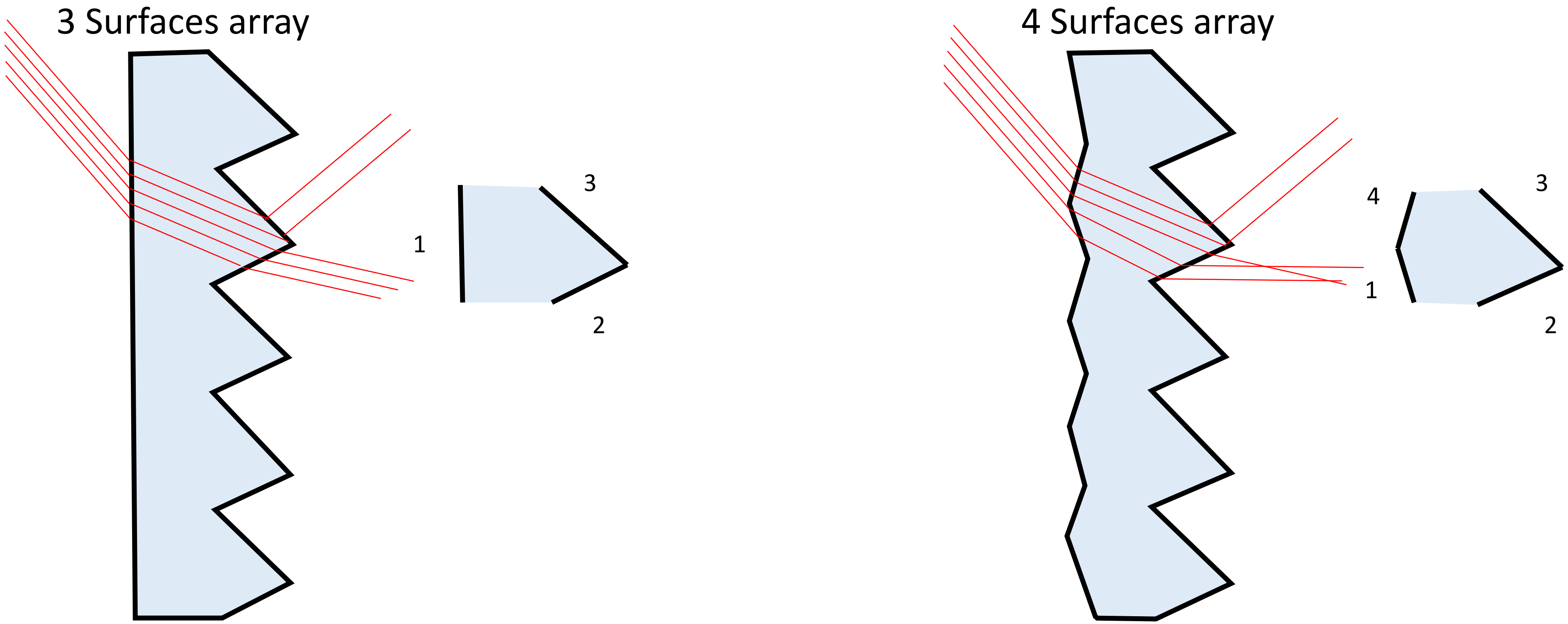




Basic Raytracing Cases

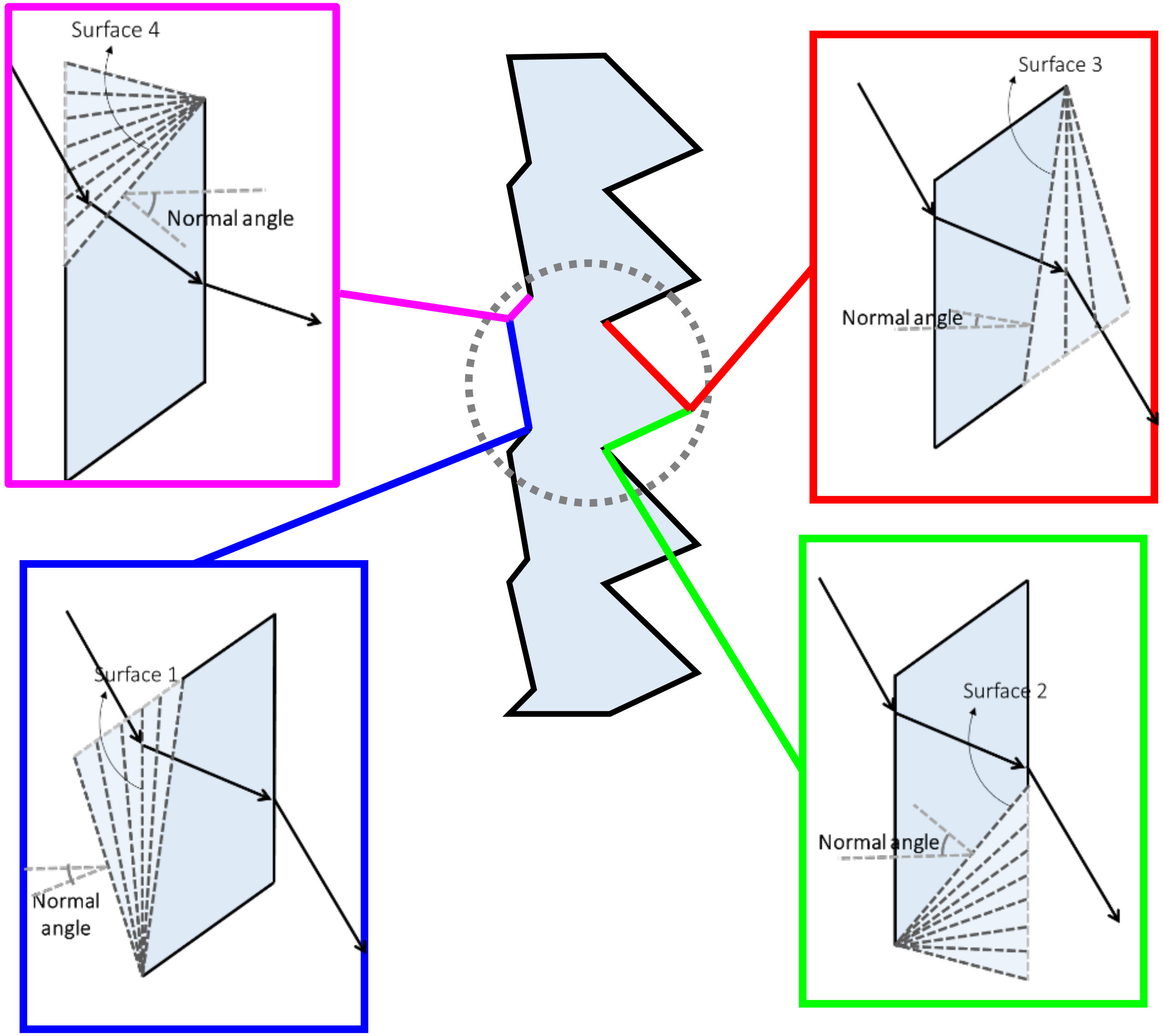


Choosing the Prism Structure

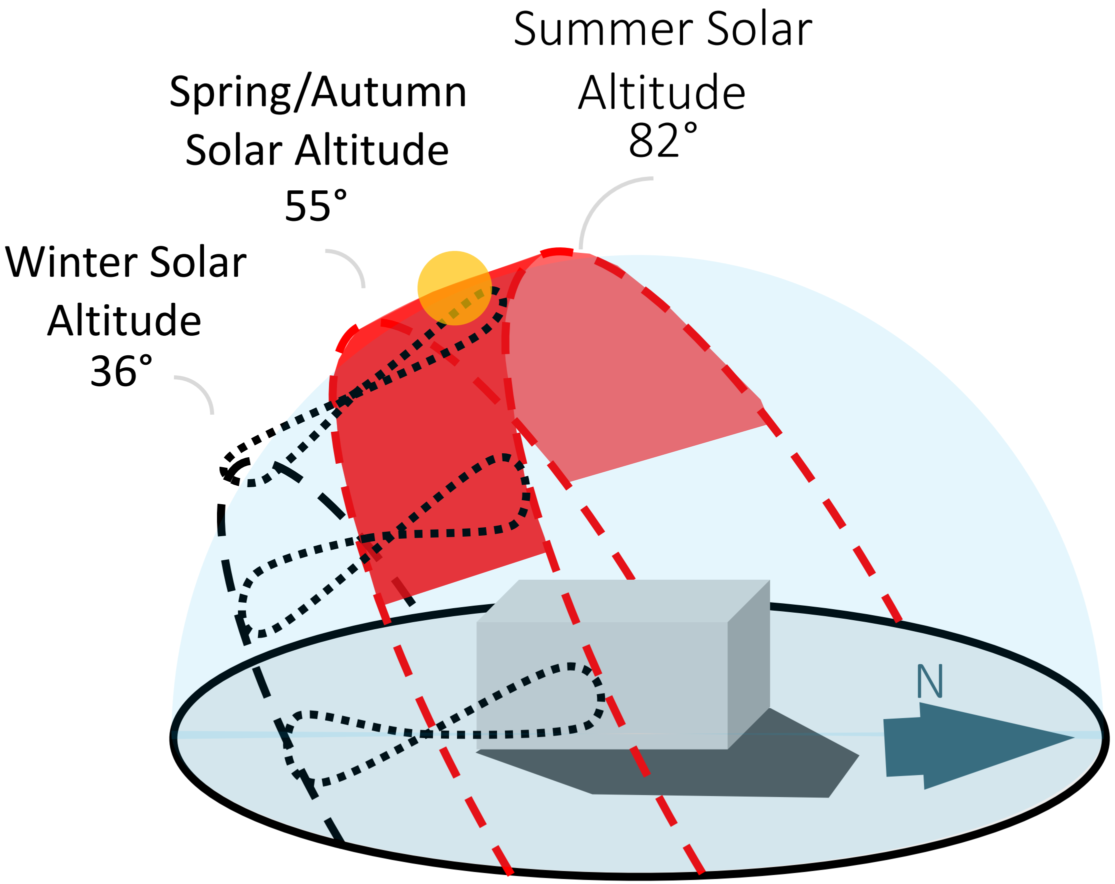


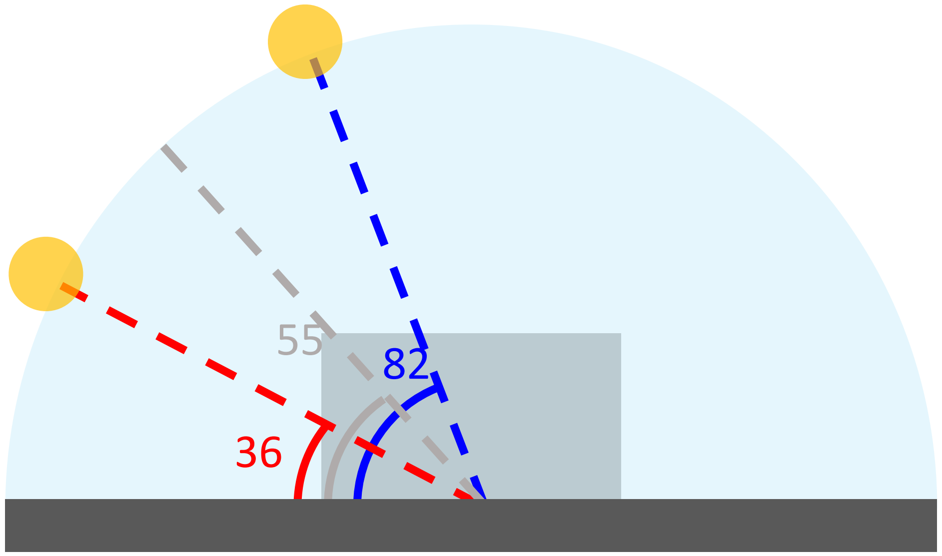
Variables and Constrains

Parameter	Constraint
Refractive index (n)	1.55
Incident angle on surface 1	0° - 80°
Variables	
Normal of surface 1 range	-60° → 0°
Normal of surface 2 range	0° → 90°
Normal of surface 3 range	0° → -60°
Normal of surface 4 range	0°→ 60°

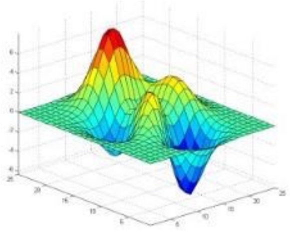


Targeted Solar Altitude



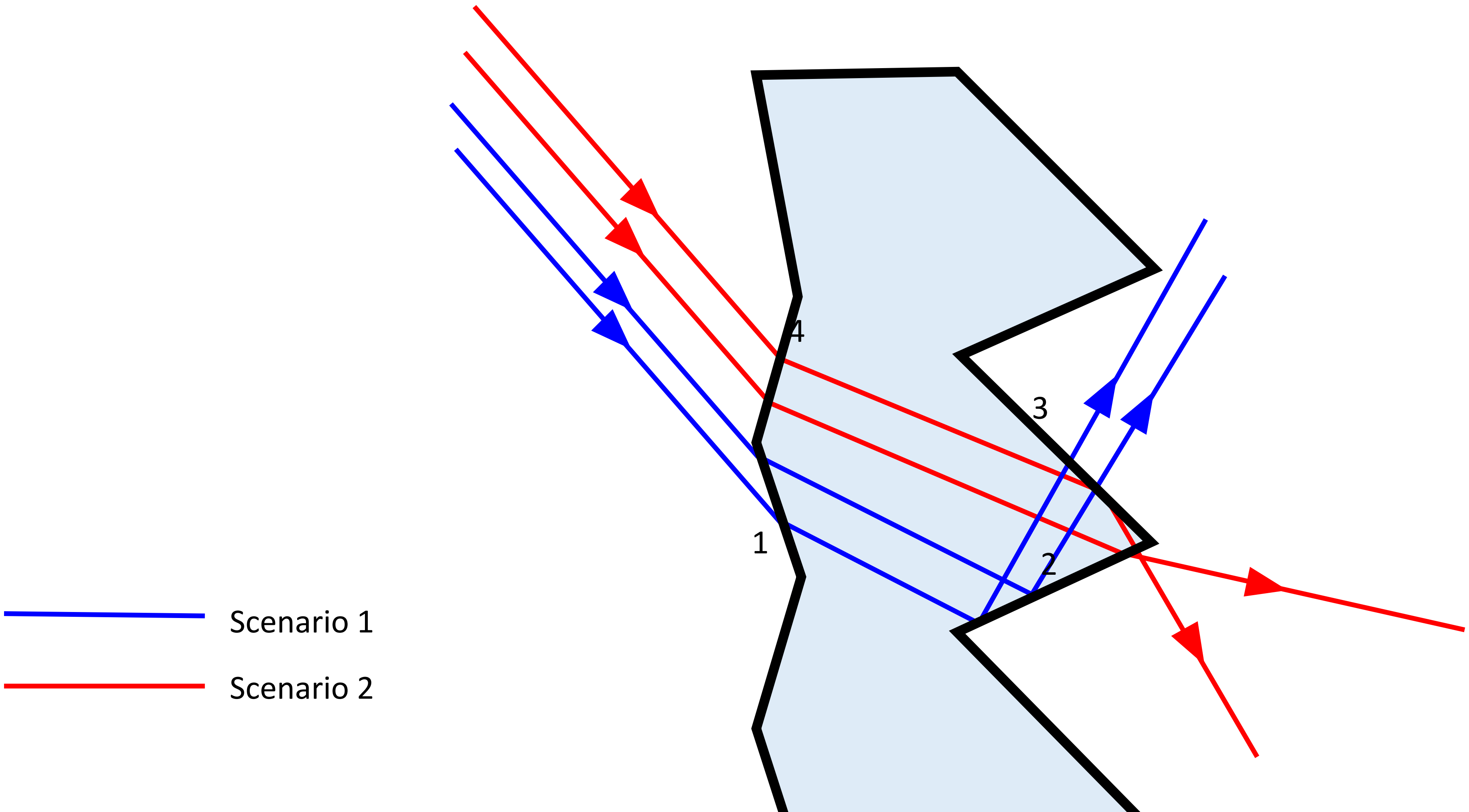


Judging Criteria	
Targeted solar altitude	50°- 80°



Genetic Algorithm Optimization

Scenarios



Scenario 1 – Surface 1

Solar Altitude ray vector (Absolute angle)

Angle = 10º ▶ $Cartesian\ Coord. = K = \begin{bmatrix} 1 \\ 0.17 \\ 0 \\ 0.98 \end{bmatrix}$

Normal Surface Angle

Angle = -9.9º ▶ $k = \begin{bmatrix} 1 \\ -0.17 \\ 0 \\ 0.98 \end{bmatrix}$

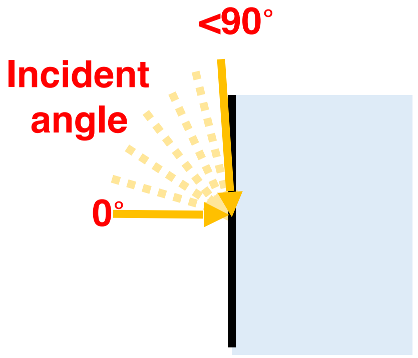
Incident angle = **Normal/Tilt Angle** - **Absolute angle** = 19.9º

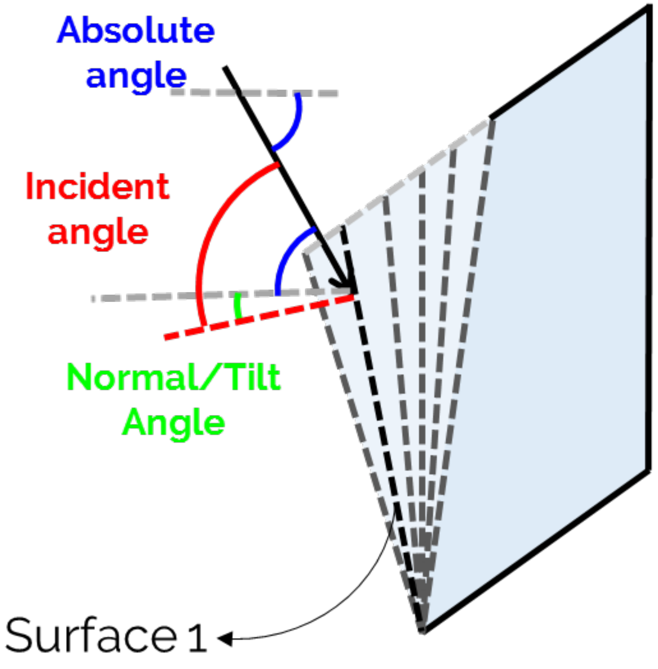
If 0º < incident angle < 90º

Yes: Use Refraction Law

$$\begin{pmatrix} 1 \\ K_x' \\ K_y' \\ K_z' \end{pmatrix} = \mathcal{R} \begin{pmatrix} 1 \\ K_x \\ K_y \\ K_z \end{pmatrix},$$

No: Use another “Normal Surface angle”





Refraction Law

$$\begin{pmatrix} 1 \\ K_x' \\ K_y' \\ K_z' \end{pmatrix} = \mathcal{R} \begin{pmatrix} 1 \\ K_x \\ K_y \\ K_z \end{pmatrix},$$

$$\mathcal{R} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ k_x[\rho' - (n/n')\rho] & n/n' & 0 & 0 \\ k_y[\rho' - (n/n')\rho] & 0 & n/n' & 0 \\ k_z[\rho' - (n/n')\rho] & 0 & 0 & n/n' \end{pmatrix}.$$

$$\rho = \cos I = \sum K_i k_i$$

$$\rho = \cos 19.9 = 0.93$$

$$\rho' = \cos I' = \sqrt{1 - \left[\left(\frac{n}{n'}\right)\sin I\right]^2}$$

$$\rho' = \sqrt{1 - \left[\left(\frac{1.0003}{1.5}\right)\sin 19.9\right]^2} = 0.9737$$

$n' = Refractive\ index\ of\ material = 1.5$

$n \ = Refractive\ index\ of\ air = 1.0003$

$I' = Output\ Incident\ Angle$

$$K' = \begin{bmatrix} 1 \\ 0.05 \\ 0 \\ 1.00 \end{bmatrix} \quad \blacktriangleright \quad 3.15^{o}$$

Scenario 1 – Surface 2

Incident ray vector (Absolute angle)

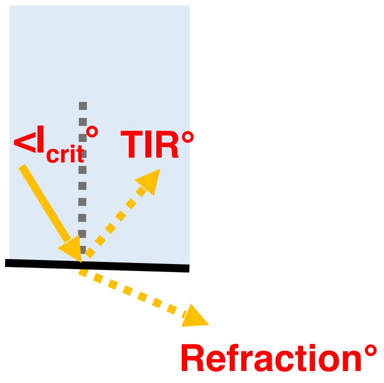
Angle = 3.15° ▶ $Cartesian\ Coord. = K = \begin{bmatrix} 1 \\ 0.05 \\ 0 \\ 1.00 \end{bmatrix}$

Normal Surface Angle

Angle = -74.34 ▶ $k = \begin{bmatrix} 1 \\ 0.96 \\ 0 \\ 0.27 \end{bmatrix}$

Incident angle = **Normal/Tilt Angle** - **Absolute angle** = 71.19°

$I_{crit} = arcsin(n'/n) =$
$arcsin(1.5/1.0003) = 41.68^o$



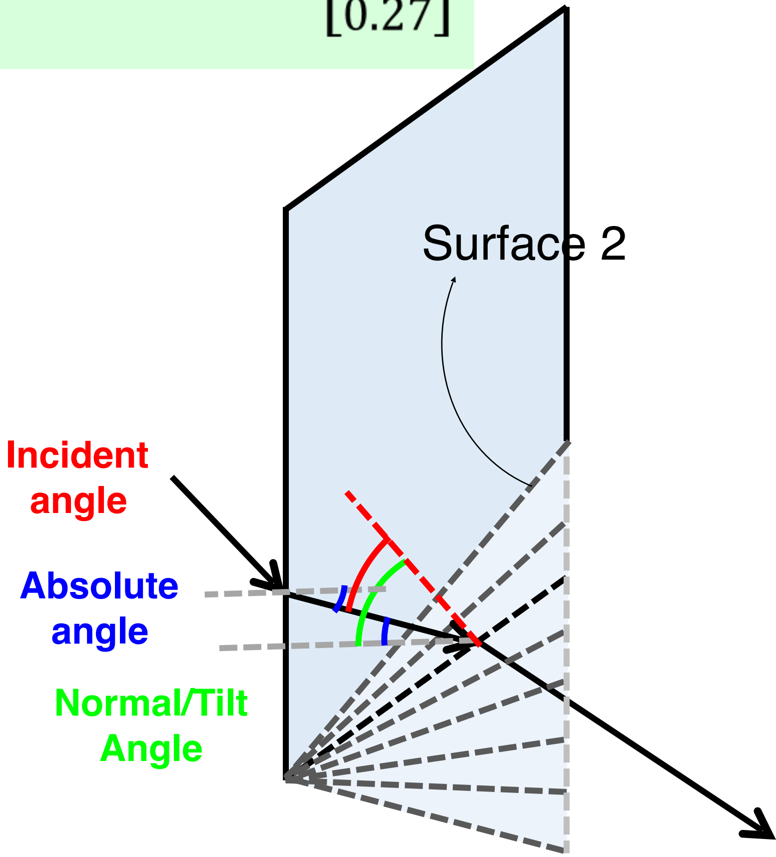
If incident angle < I critical

Yes → Use Refraction Law

$$\begin{pmatrix} 1 \\ K_x' \\ K_y' \\ K_z' \end{pmatrix} = \mathcal{R} \begin{pmatrix} 1 \\ K_x \\ K_y \\ K_z \end{pmatrix},$$

No → Use Reflection Law

$$\begin{pmatrix} 1 \\ K'_x \\ K'_y \\ K'_z \end{pmatrix} = R' \begin{pmatrix} 1 \\ K_x \\ K_y \\ K_z \end{pmatrix}$$



Reflection Matrix

$$\begin{pmatrix} 1 \\ K'_x \\ K'_y \\ K'_z \end{pmatrix} = R' \begin{pmatrix} 1 \\ K_x \\ K_y \\ K_z \end{pmatrix}$$

$$\mathbf{R}' = \begin{pmatrix} 1 & 0 & 0 & 0 \\ -2k_x\rho & 1 & 0 & 0 \\ -2k_y\rho & 0 & 1 & 0 \\ -2k_z\rho & 0 & 0 & 1 \end{pmatrix},$$

$$\rho = \cos I = \sum K_i k_i$$

$$\rho = \cos 71.19 = 0.32$$

$$\begin{pmatrix} 1 \\ K'_x \\ K'_y \\ K'_z \end{pmatrix} = R' \begin{pmatrix} 1 \\ 0.05 \\ 0 \\ 1.00 \end{pmatrix}$$

$$K' = \begin{bmatrix} 1 \\ -0.57 \\ 0 \\ 0.82 \end{bmatrix}$$ ▶ -34.46°

Scenario 1 – Surface 3

Incident ray vector (Absolute angle)

Angle = =34.5° ▶ $Cartesian\ Coord. = K = \begin{bmatrix} 1 \\ -0.57 \\ 0 \\ 0.82 \end{bmatrix}$

Normal Surface Angle

Angle = -33.16 ▶ $k = \begin{bmatrix} 1 \\ -0.55 \\ 0 \\ 0.84 \end{bmatrix}$

Incident angle = **Normal/Tilt Angle** - **Absolute angle** = 1.29°

If incident angle < I critical

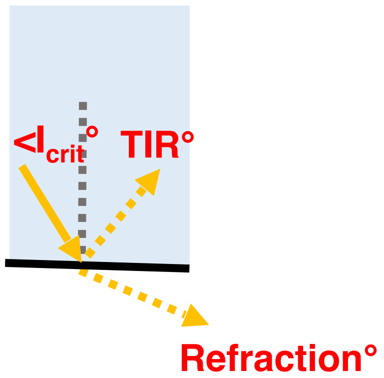
Yes

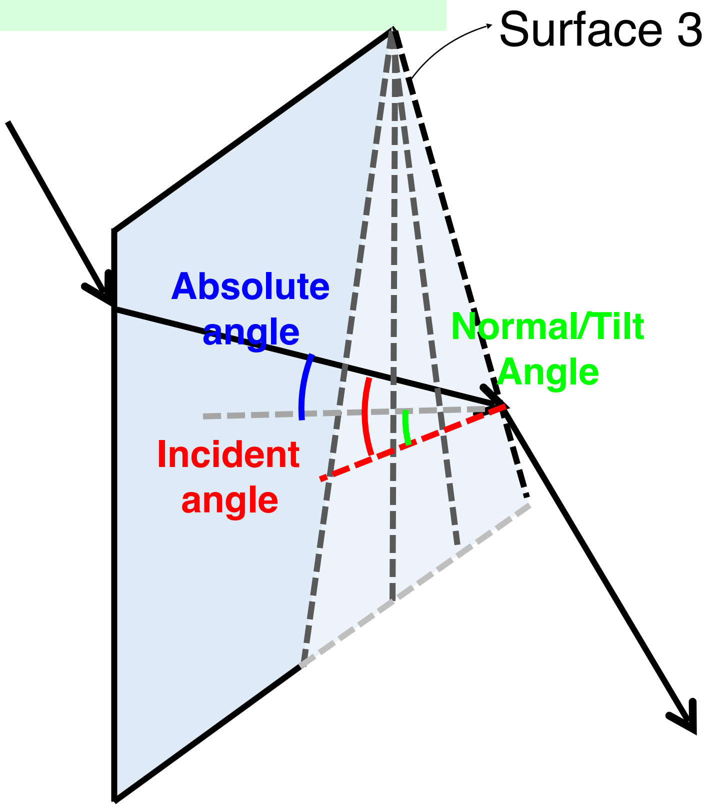
Use Refraction Law

$$\begin{pmatrix} 1 \\ K_x' \\ K_y' \\ K_z' \end{pmatrix} = \mathcal{R} \begin{pmatrix} 1 \\ K_x \\ K_y \\ K_z \end{pmatrix},$$

No

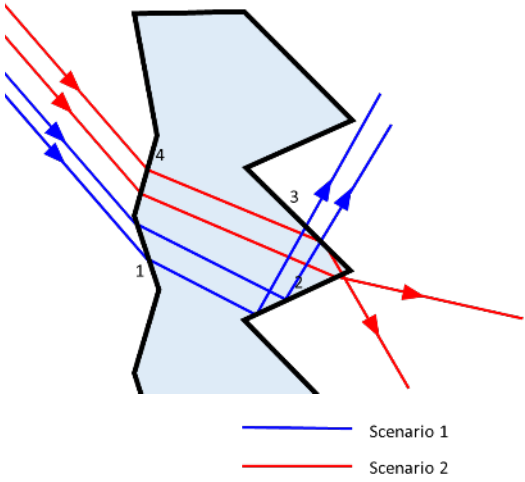
FAILED!!



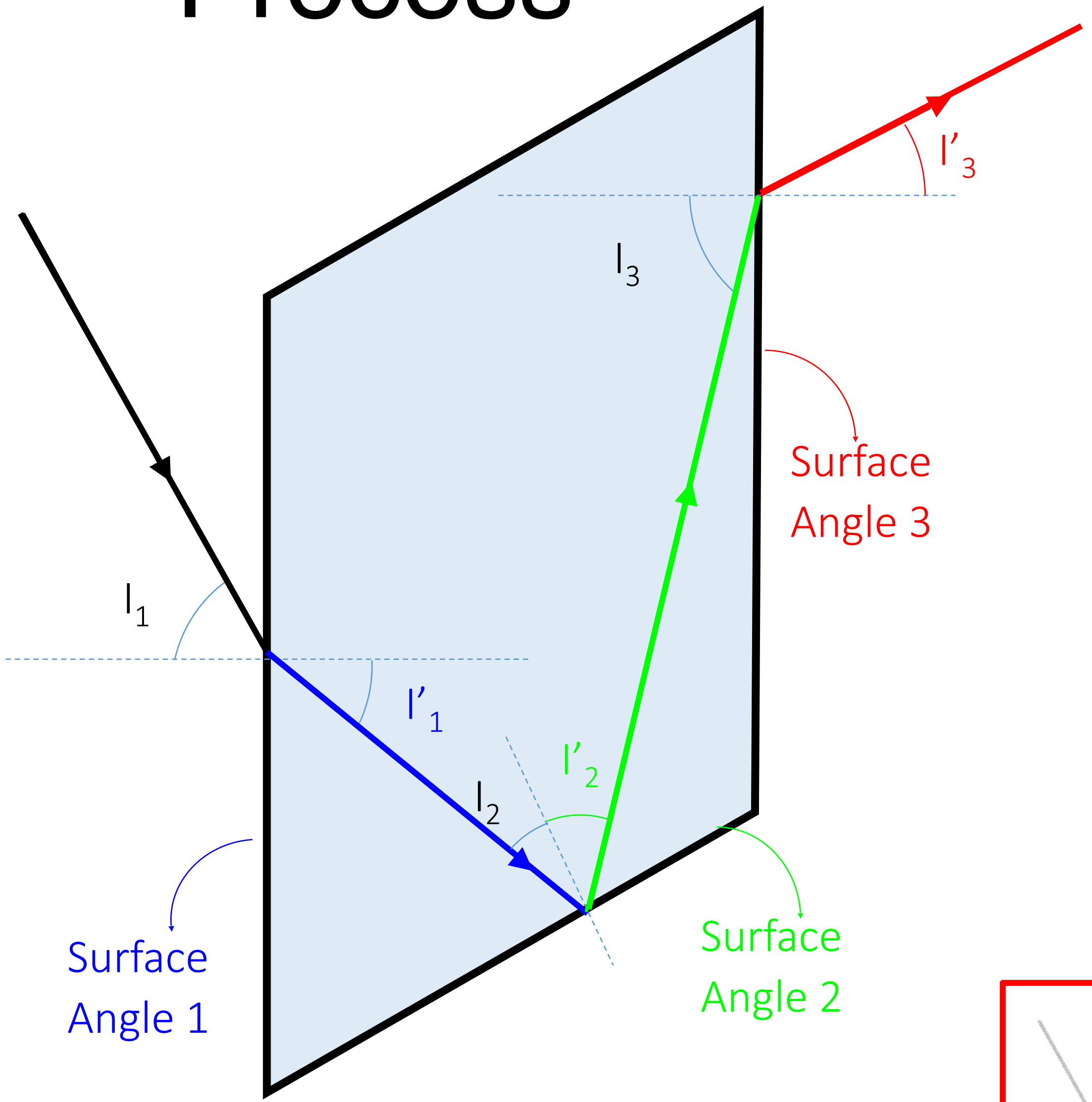


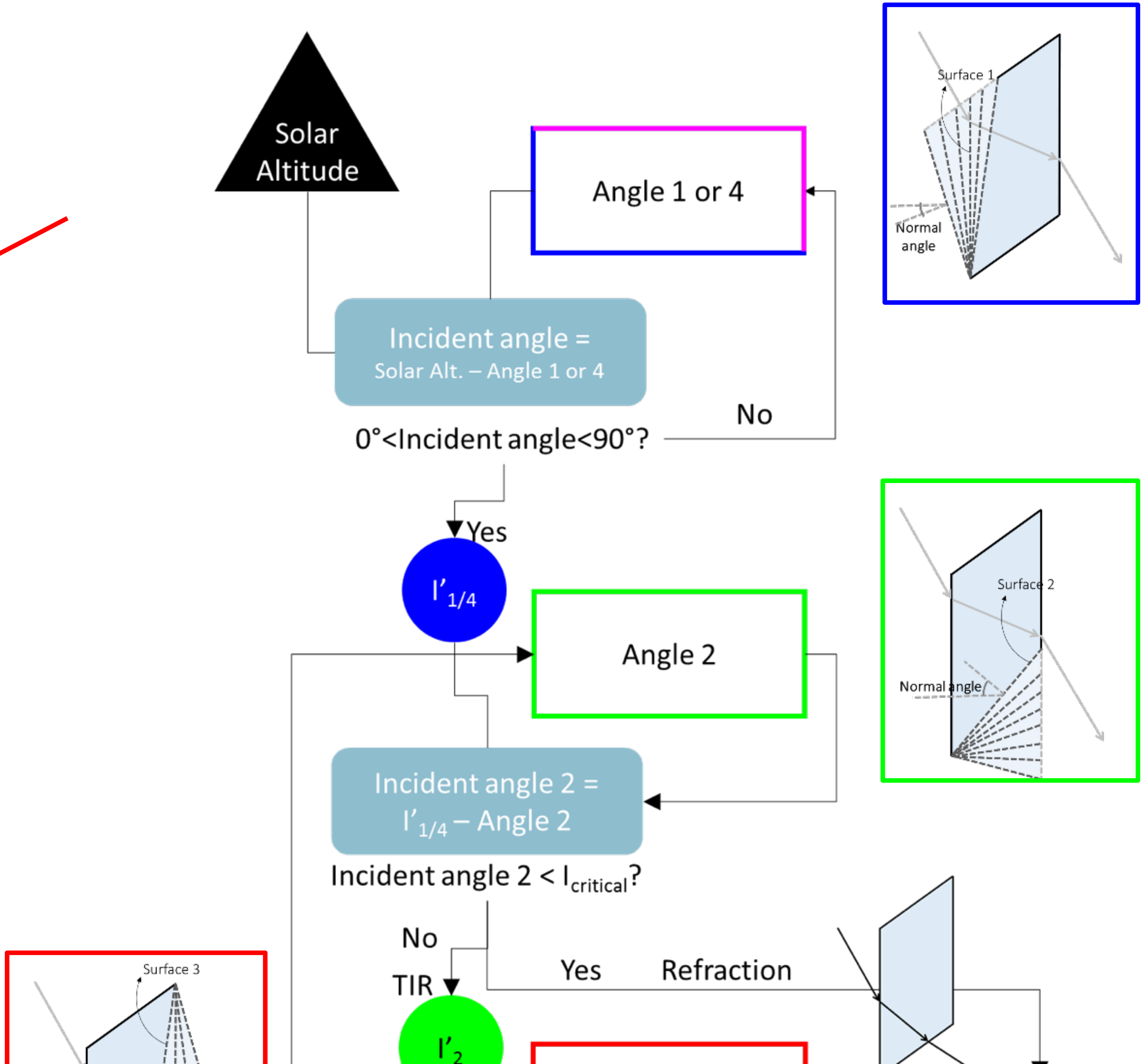
Scenario 1 : Final Table

Solar Altitude		Surface 1	Surface 2	Surface 3	Final Exiting Ray
		-9.99	74.34	-33.17	
10	Absolute	3.15	-34.46	35.11	35.11
	Incident	20.00	71.19	1.29	
20	Absolute	9.42	-40.74	44.41	44.41
	Incident	30.00	64.92	7.57	
30	Absolute	15.31	-46.63	52.67	52.67
	Incident	40.00	59.03	13.46	
40	Absolute	20.63	-51.95	59.52	59.52
	Incident	50.00	53.71	18.78	
50	Absolute	25.17	-56.48	64.84	64.84
	Incident	60.00	49.17	23.31	
60	Absolute	28.68	-60.00	68.60	68.60
	Incident	70.00	45.66	26.83	
70	Absolute	30.92	-62.23	70.83	70.83
	Incident	80.00	43.42	29.06	
80	Absolute	31.69	-63.01	71.57	71.57
	Incident	90.00	42.65	29.84	



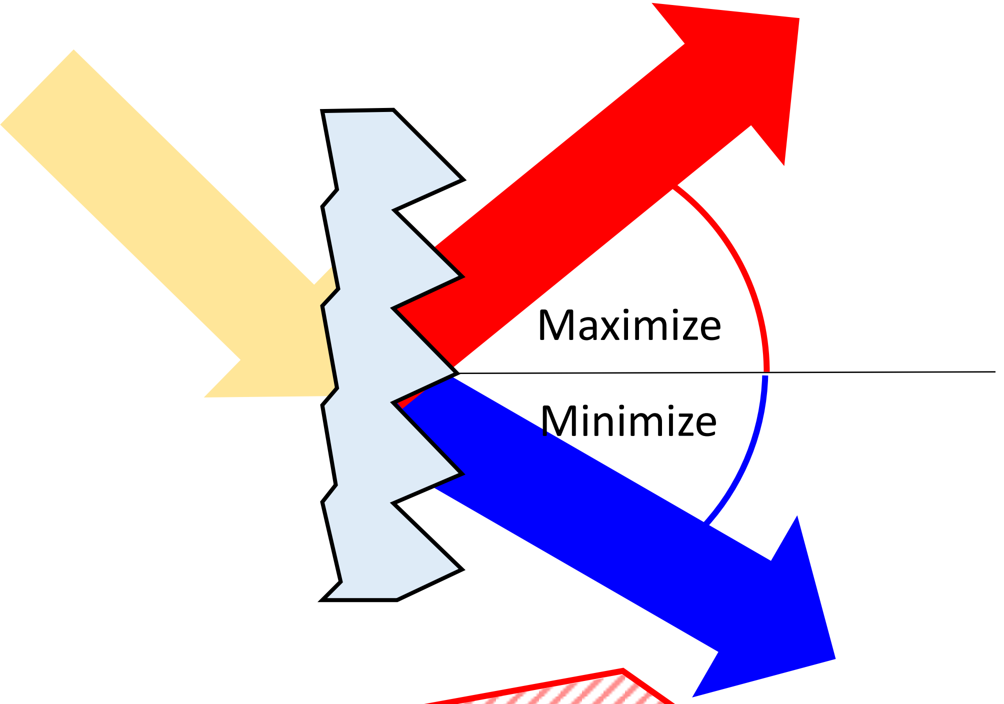
Optimization Process

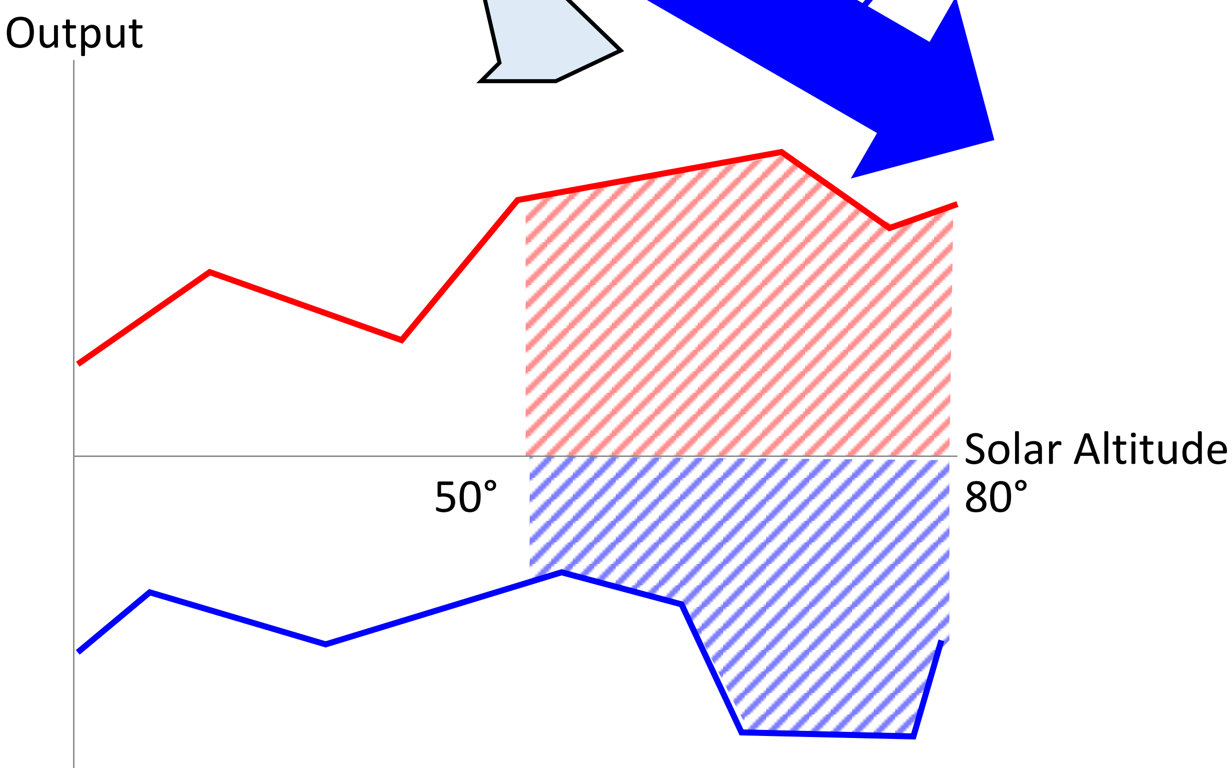


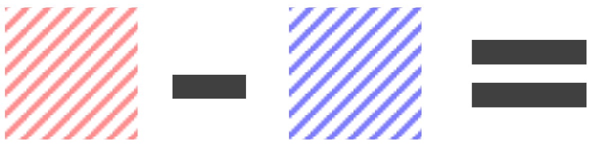


Objective Function

- **Maximizing** the output angle that is directed **upwards** and **minimizing** the output angle that is directed **downwards** at high solar altitudes (from 50° to 80°)

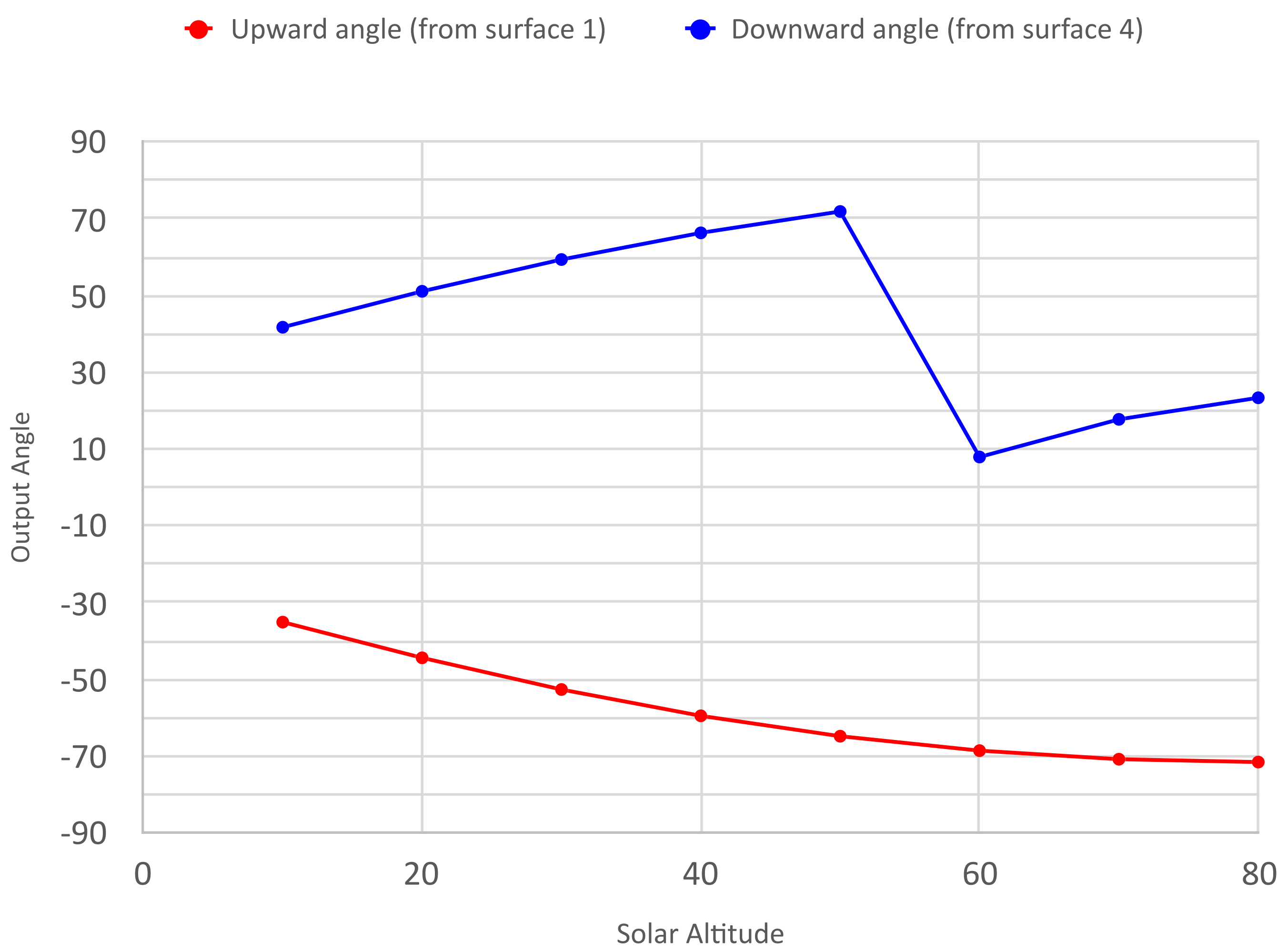


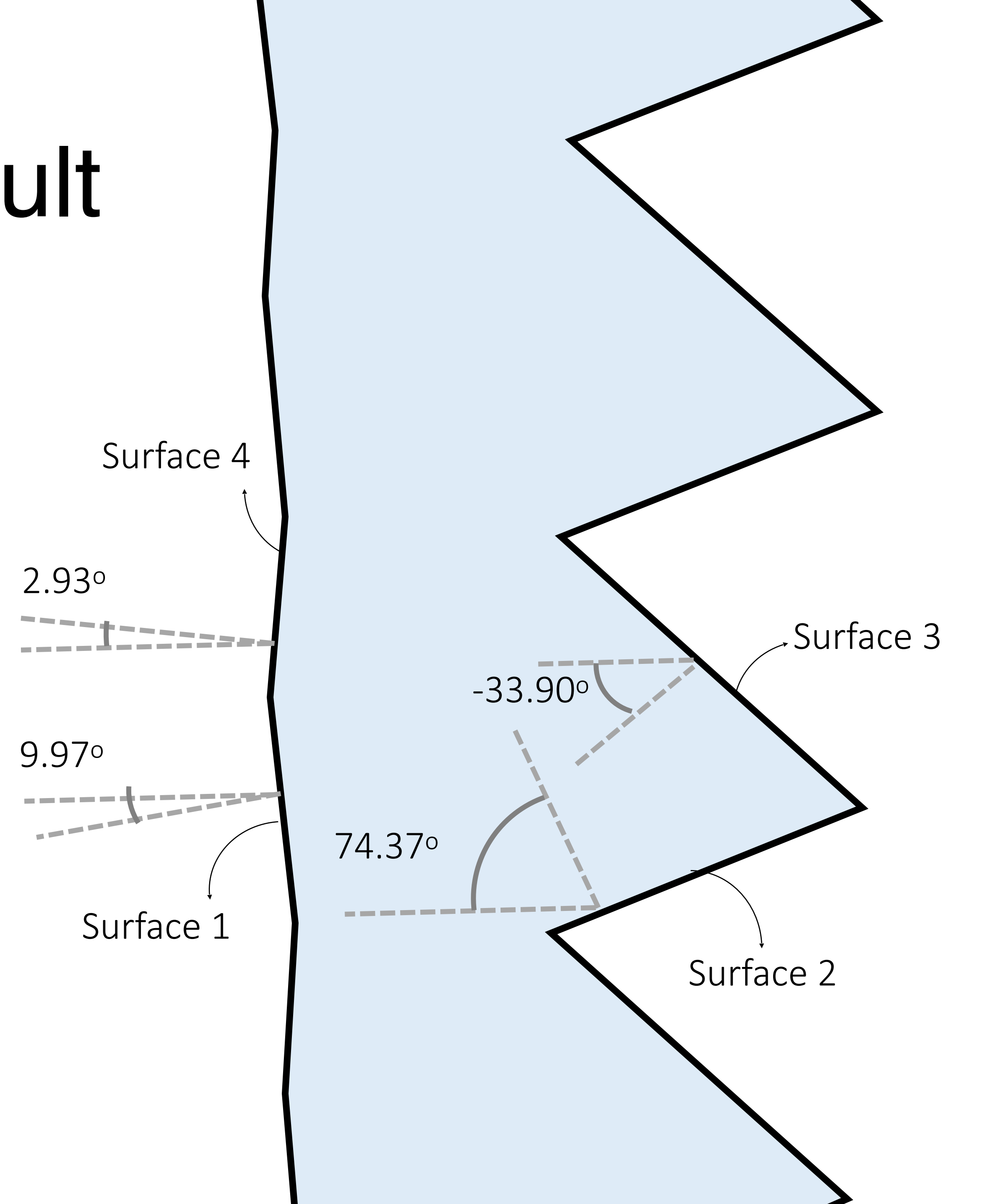




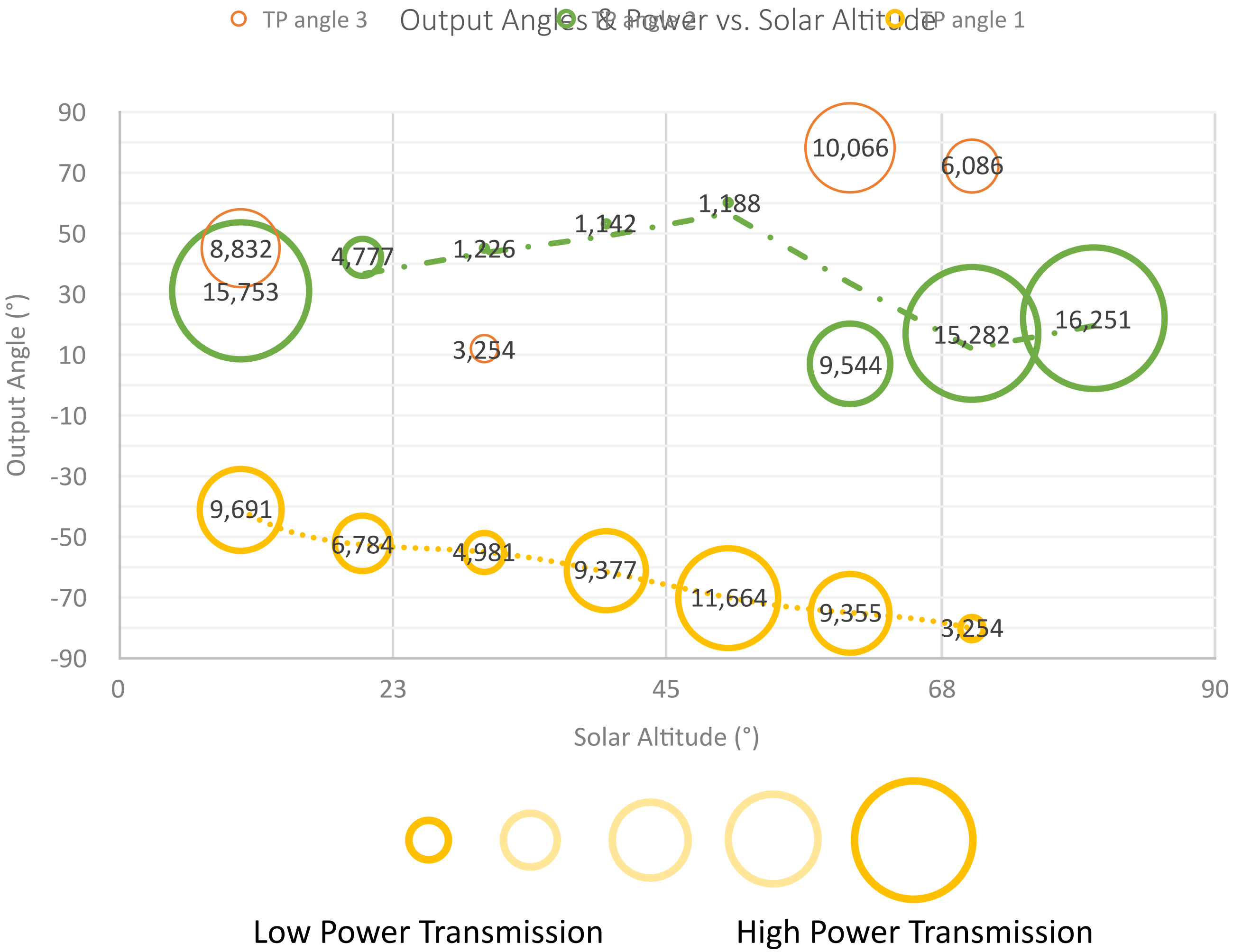
Objective Function Value

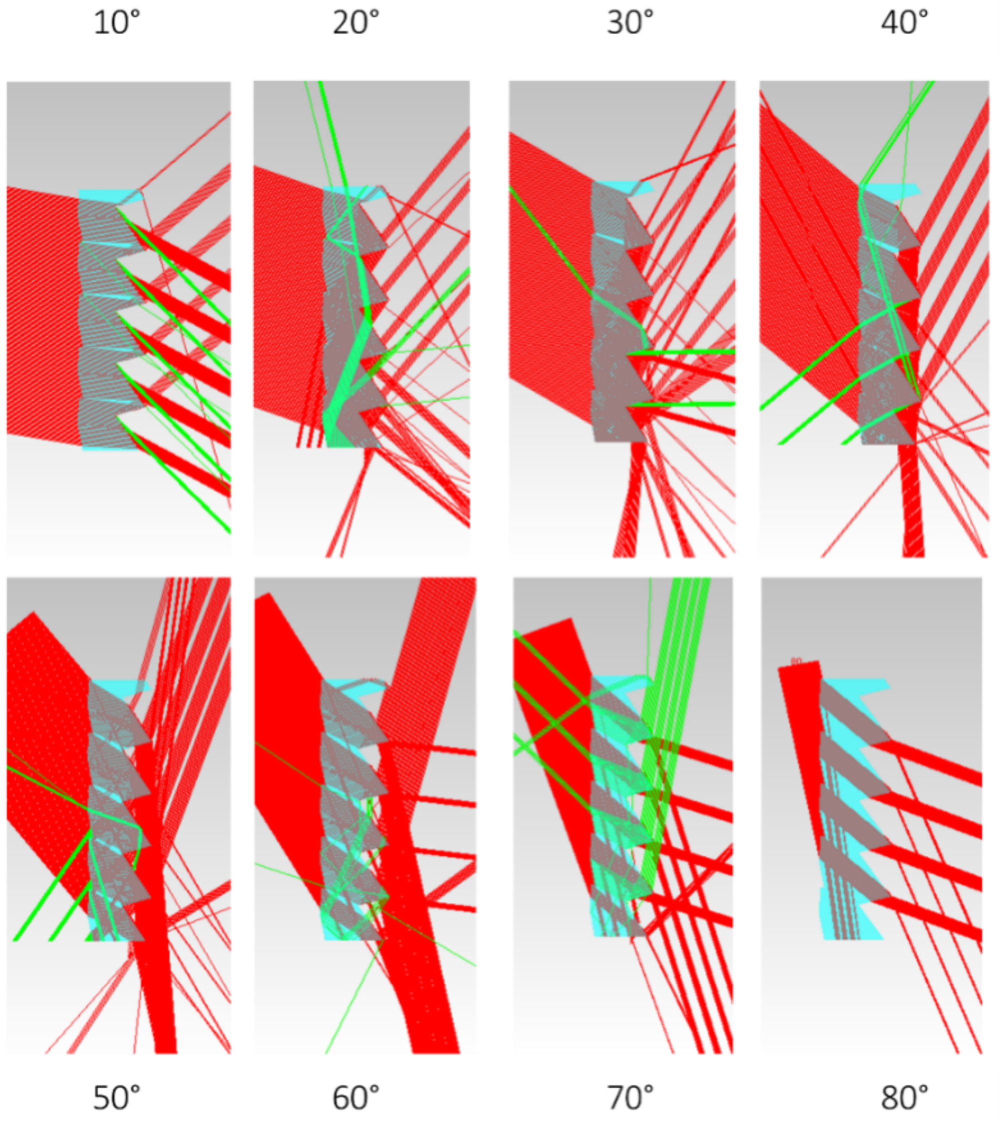
Final Optimization Result



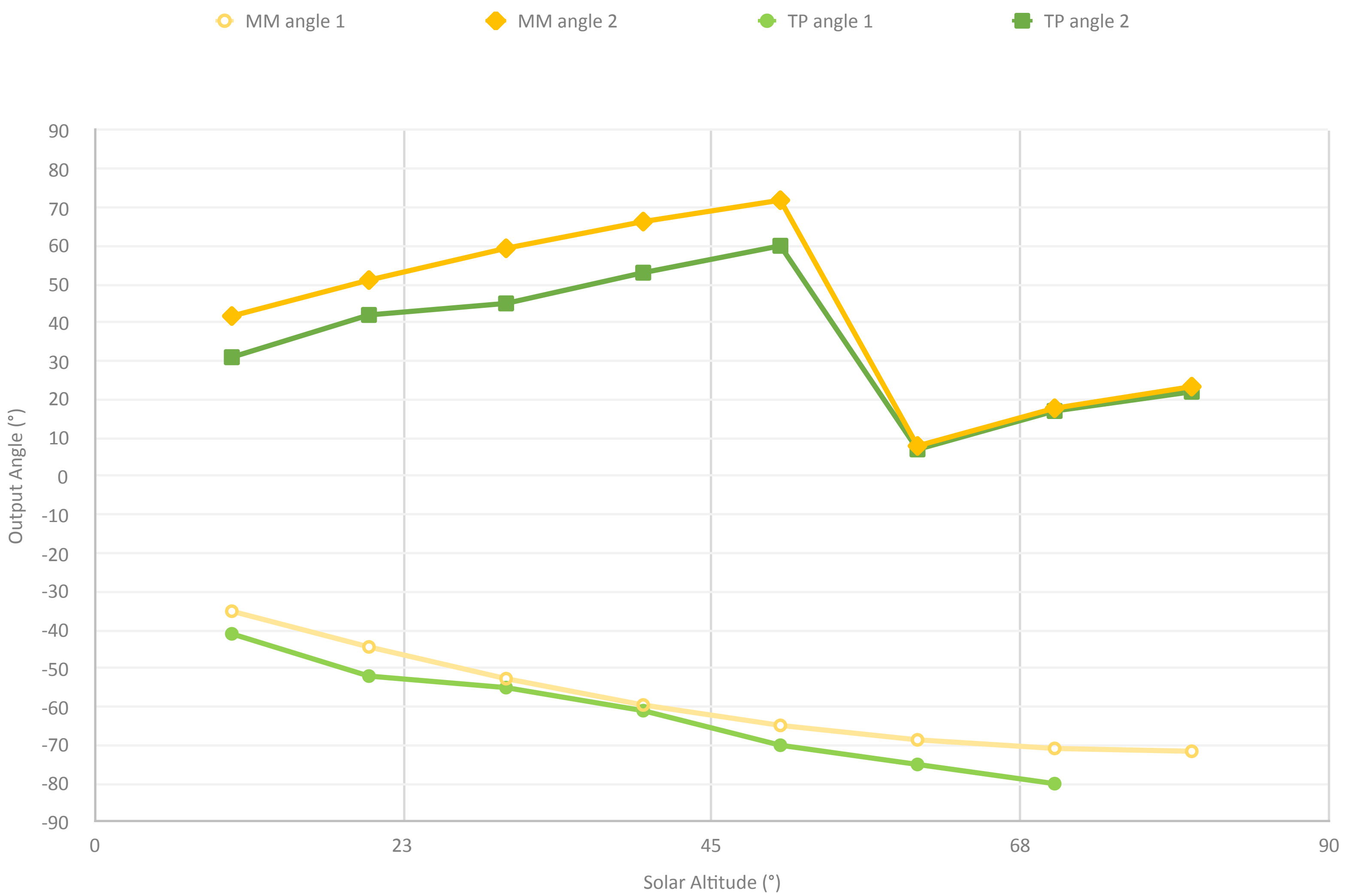


Validation Against TracePro®





Validation Against TracePro®

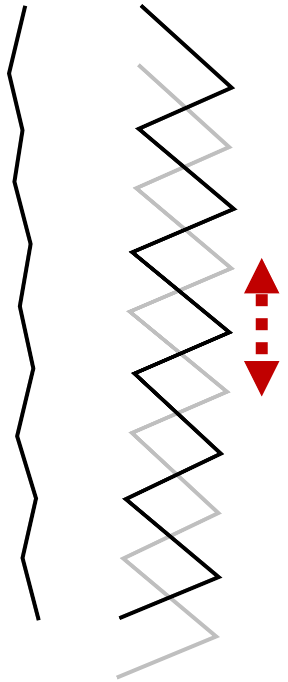


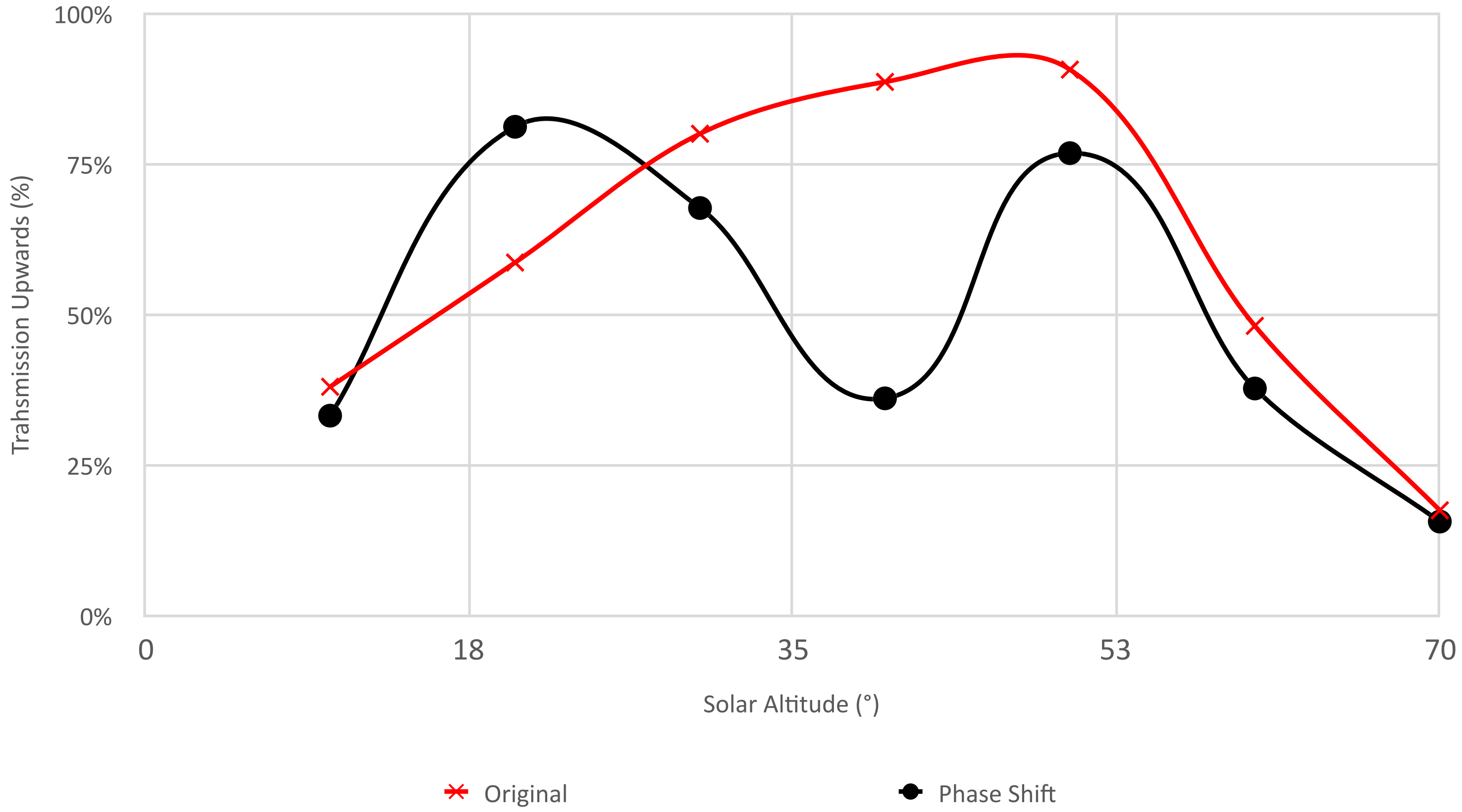
<u>The standard error of the mean</u>

Upwards = ±1.03°

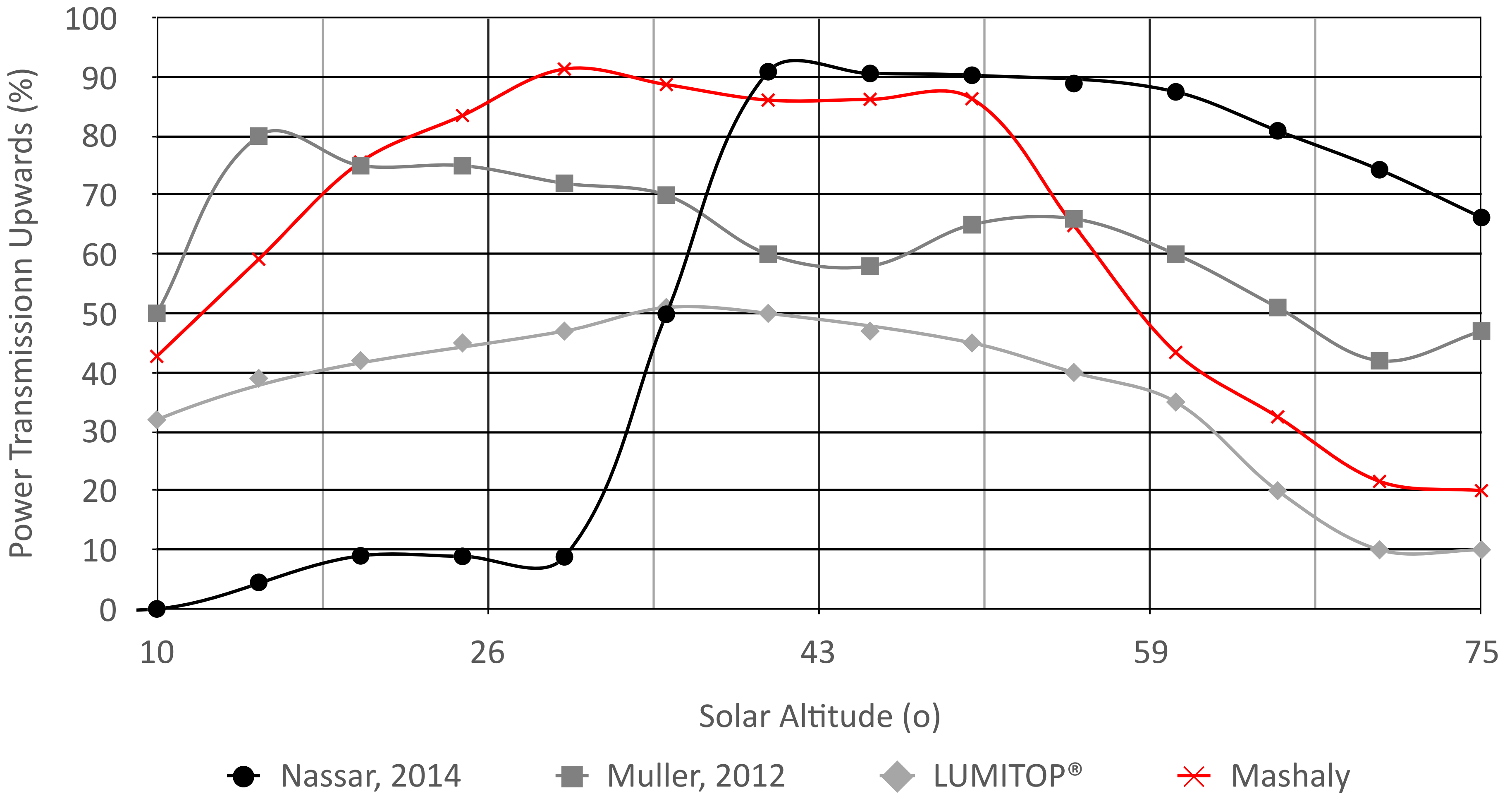
Downwards = ± 2.47°

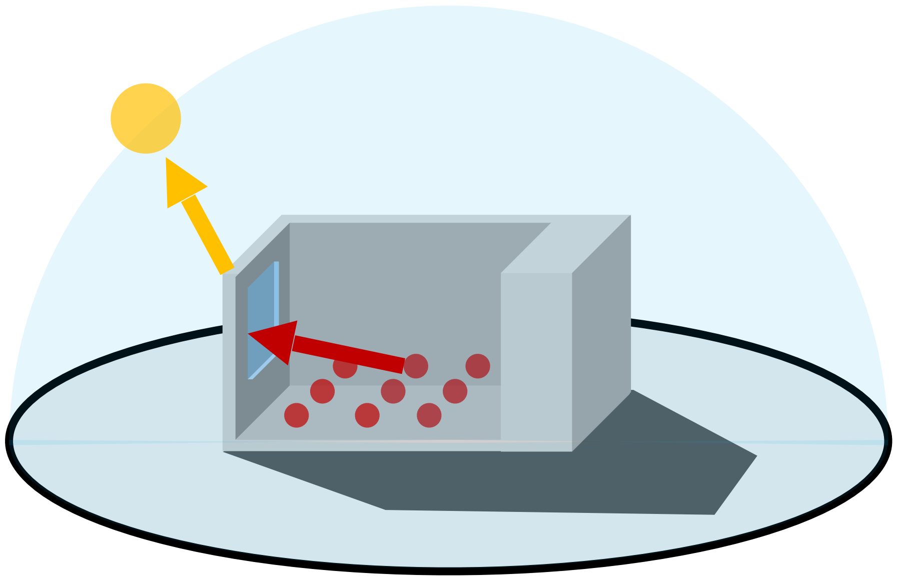
Phase Shift effect





Comparison with other research





Daylight Simulation of CFS using 5 phase method

25%	29%	29%	28%	26%
32%	35%	37%	35%	36%
46%	50%	47%	46%	46%
63%	65%	67%	66%	64%
73%	74%	74%	73%	74%
80%	81%	81%	81%	80%
84%	84%	84%	84%	83%
86%	87%	87%	87%	85%
86%	90%	91%	90%	85%

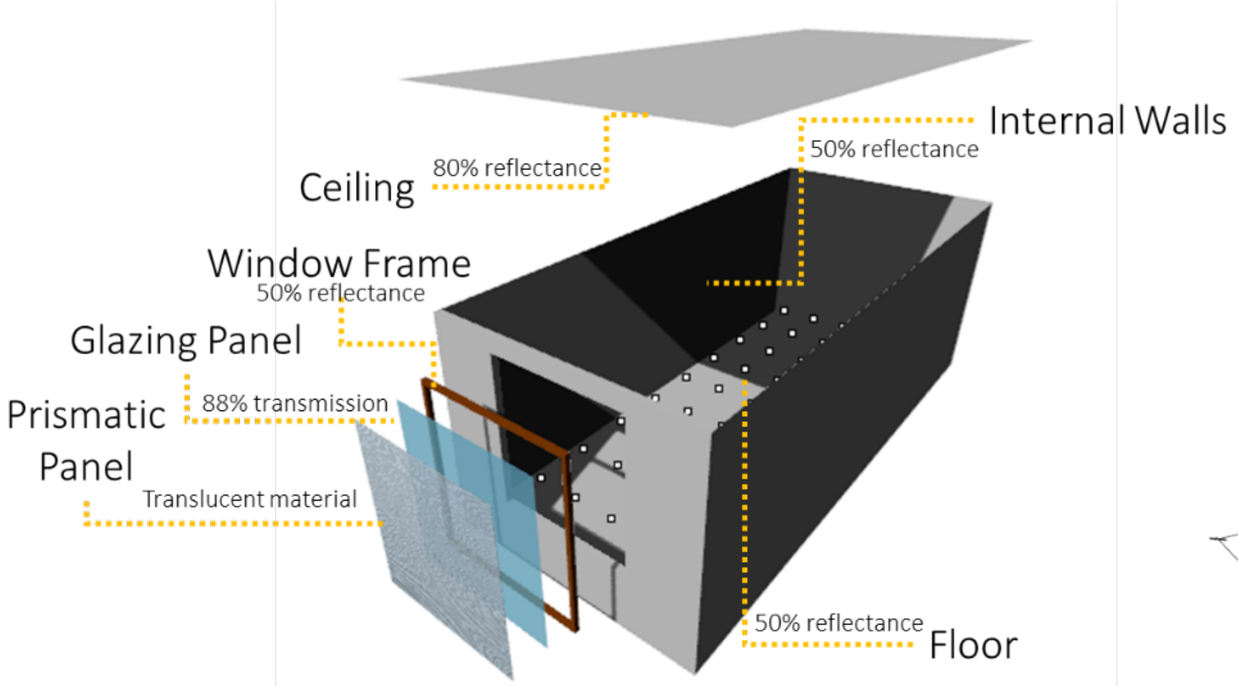
Lighting Simulation Methods

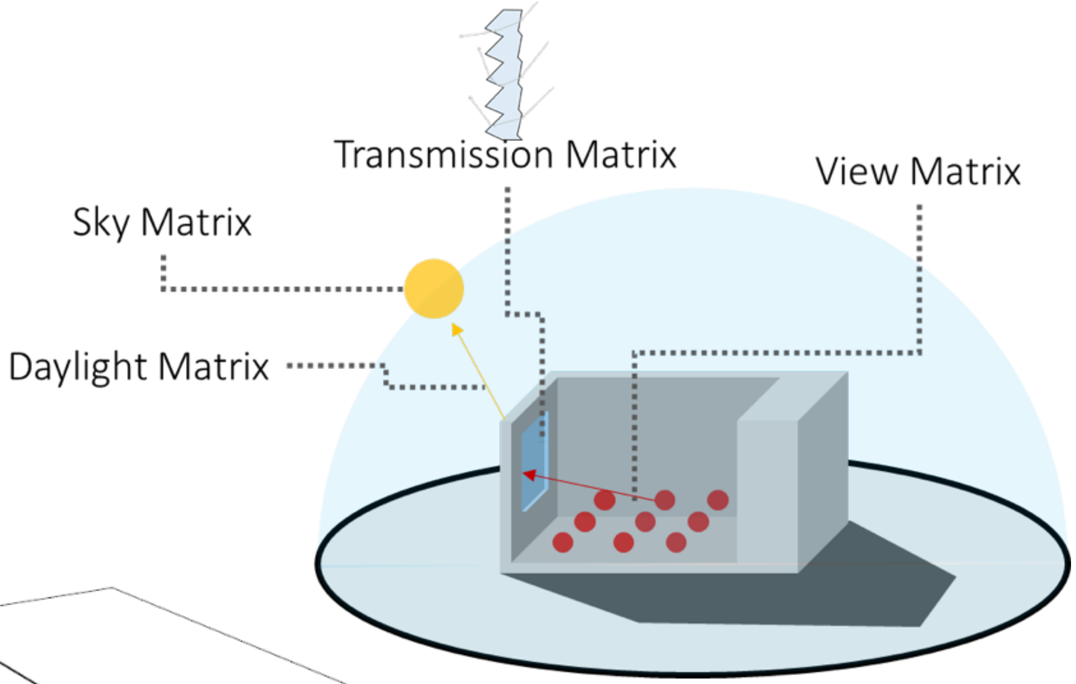
Lighting Simulation

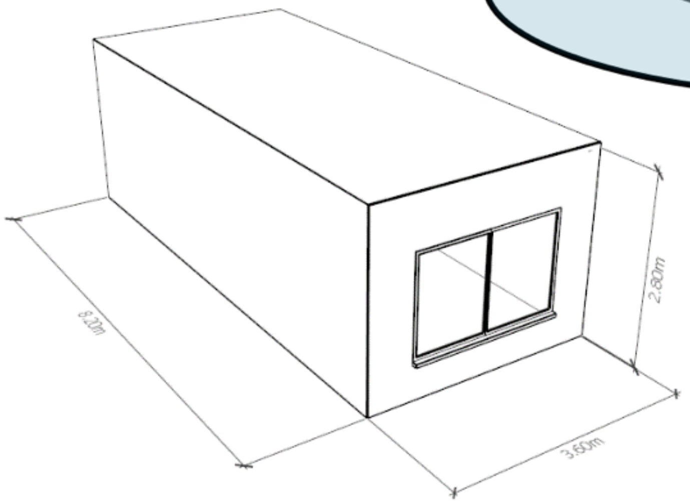
- Photorealistic

Validation of proposed system using Radiance

- Three and five Phase Method



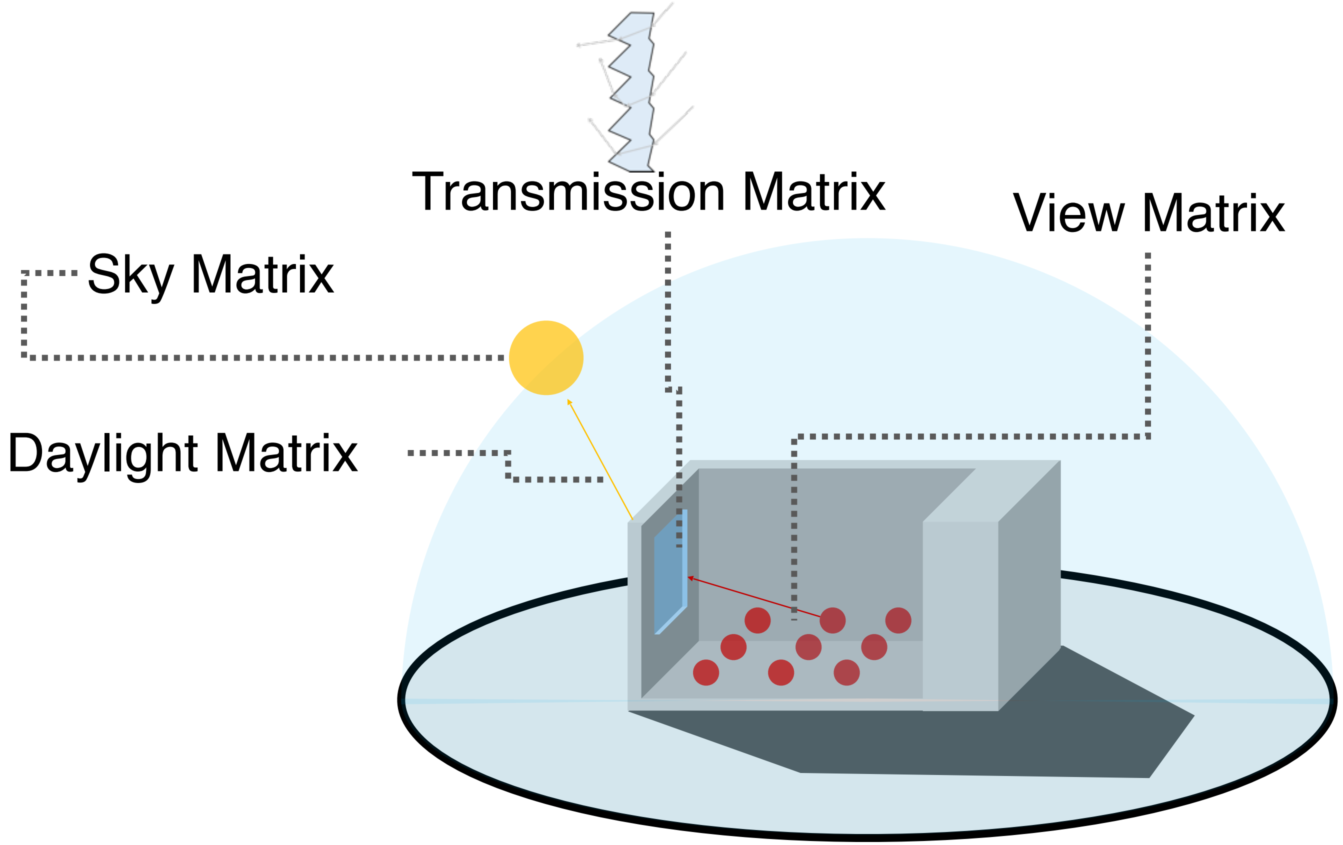




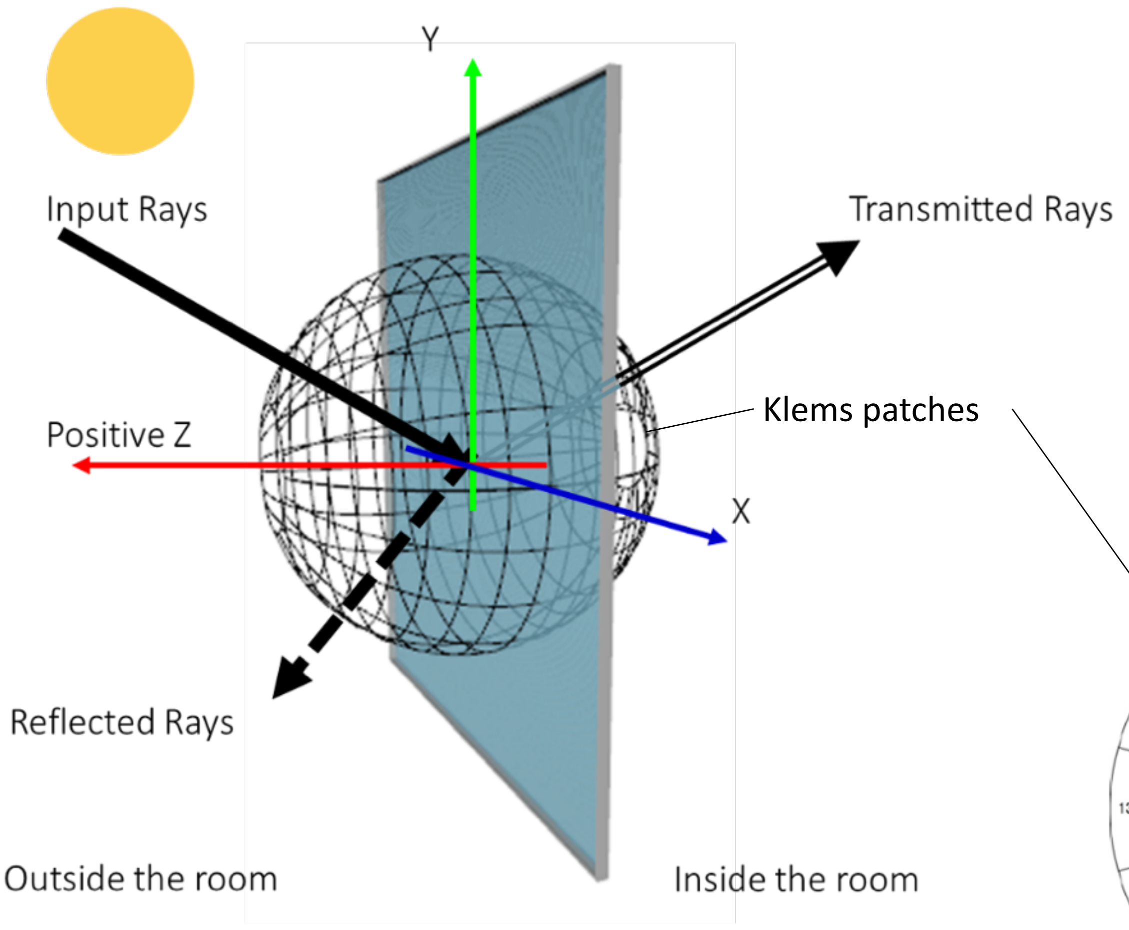
Why 5 phase method?

- **Dynamic** Analysis for **complex fenestration systems**
- **Radiance** can deal with “Bi-directional Scattering Distribution Function” **BSDF data**
- **Annual Hourly Illumination** for flexibility in daylight measures

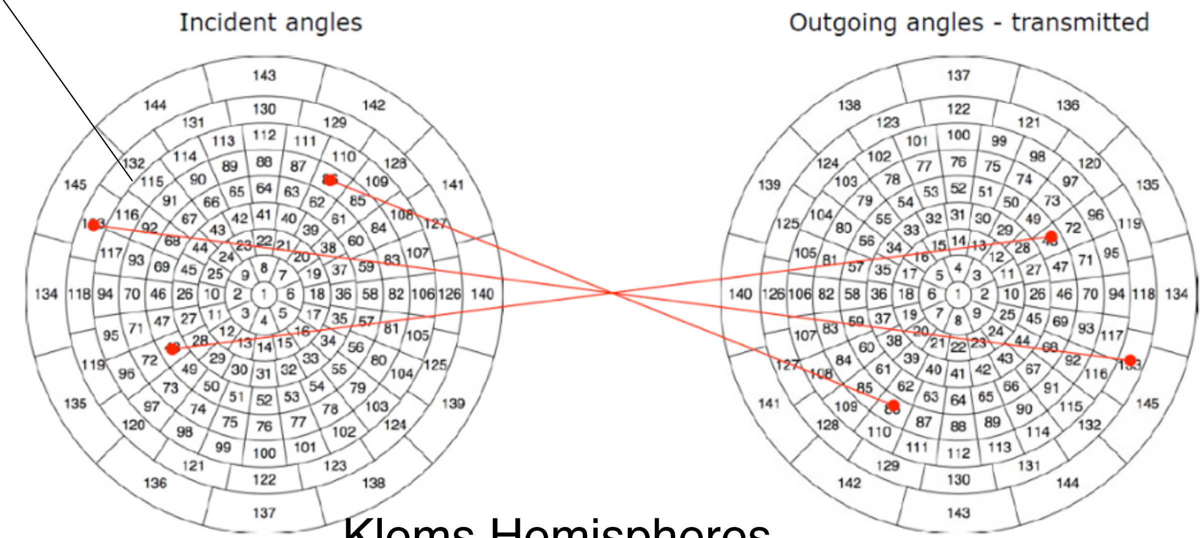
5 phase method



Transmission Matrix

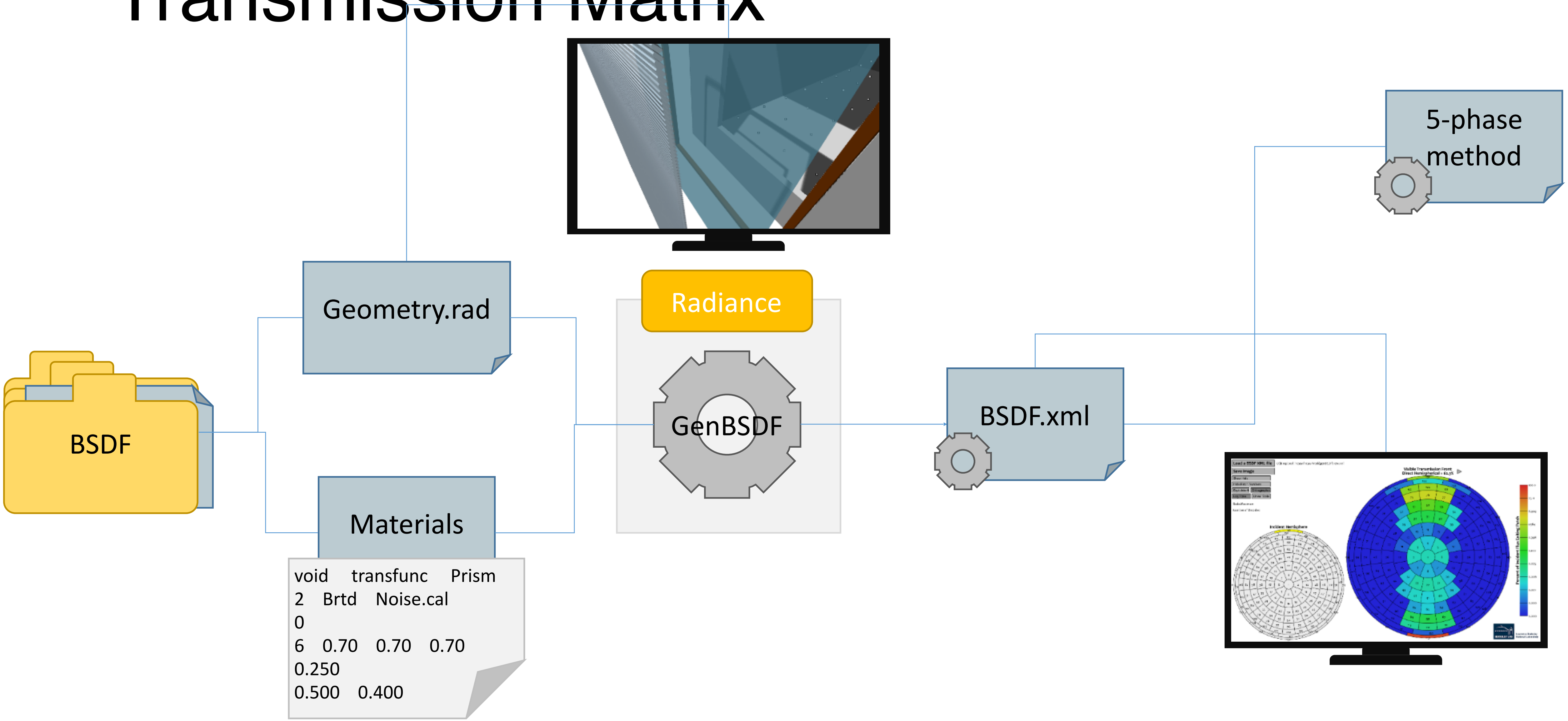


1. Model the prism geometry as per window's dimensions
2. Export geometry to be run with genBSDF (a Radiance command)
3. Add material to geometry*
4. genBSDF generates input rays in every direction to the window through (145 Klems patches)
5. The output according to the prism design is presented on 145 Klems patches also with the direction and power



Klems Hemispheres

Transmission Matrix



Material Definition for acrylic

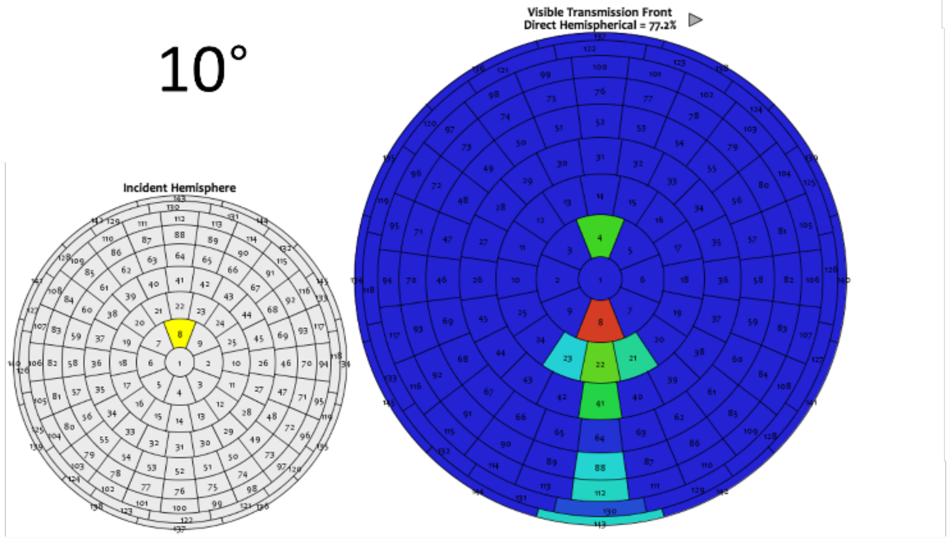
modifierglass		identifier			
Ø					
Ø					
4	**R**	**G**	**B**	◀	(Colour)
n				◀	(Refractive index)
void	glass	**Acrylic_Panel**			
Ø					
Ø					
4	**0.96**	**0.96**	**0.96**	**1.49**	

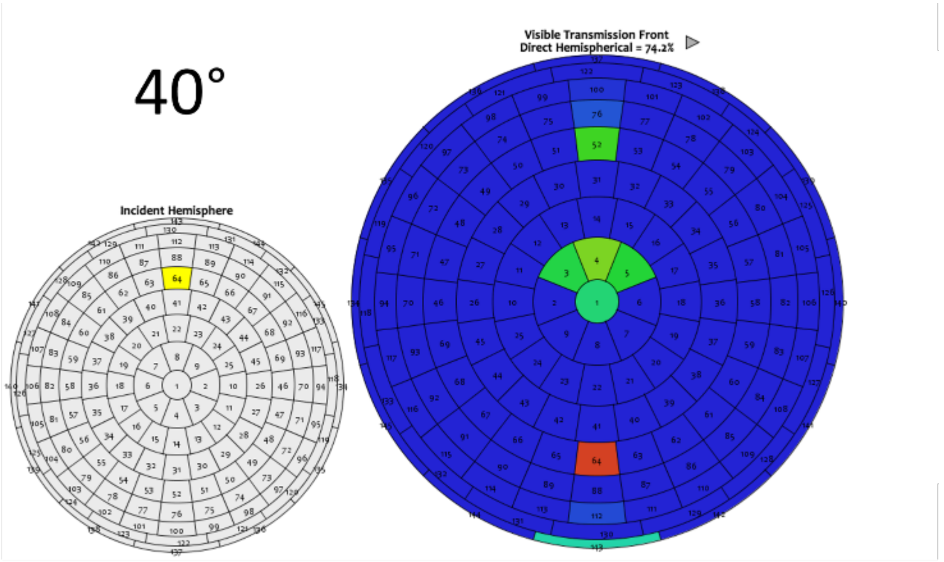
Material Definition for recycled plastic

modifier	transfunc		identifier		
2+	brtd		funcfile		
Ø					
6	R	G	B	◀	(Colour)
rspec				◀	(specularity)
trans		tspec		◀	(transmission & transmitted specularity)

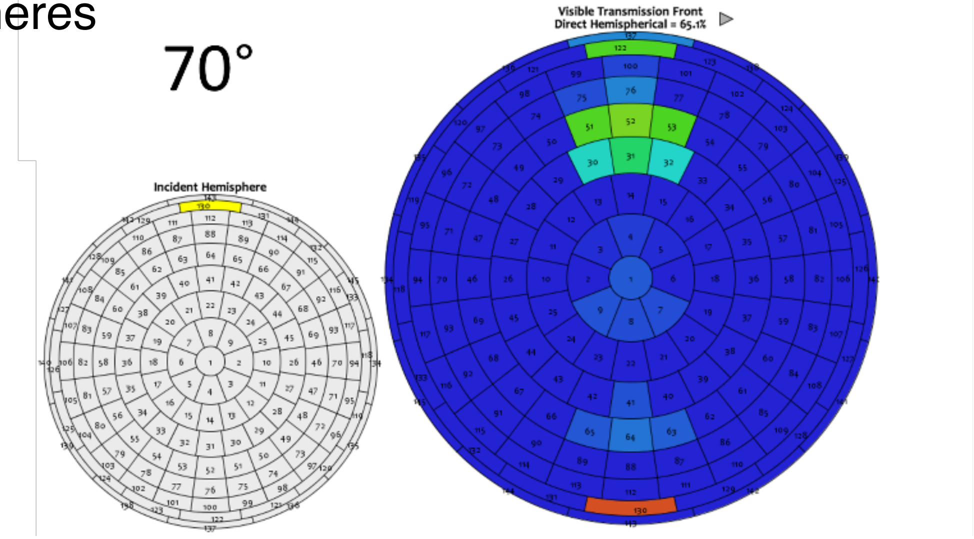
void transfunc Prismatic_Panel			
2	brtd	Noise.cal	
0			
6	0.70	0.70	0.70
0.250			
0.500	0.400		

BSDF viewer

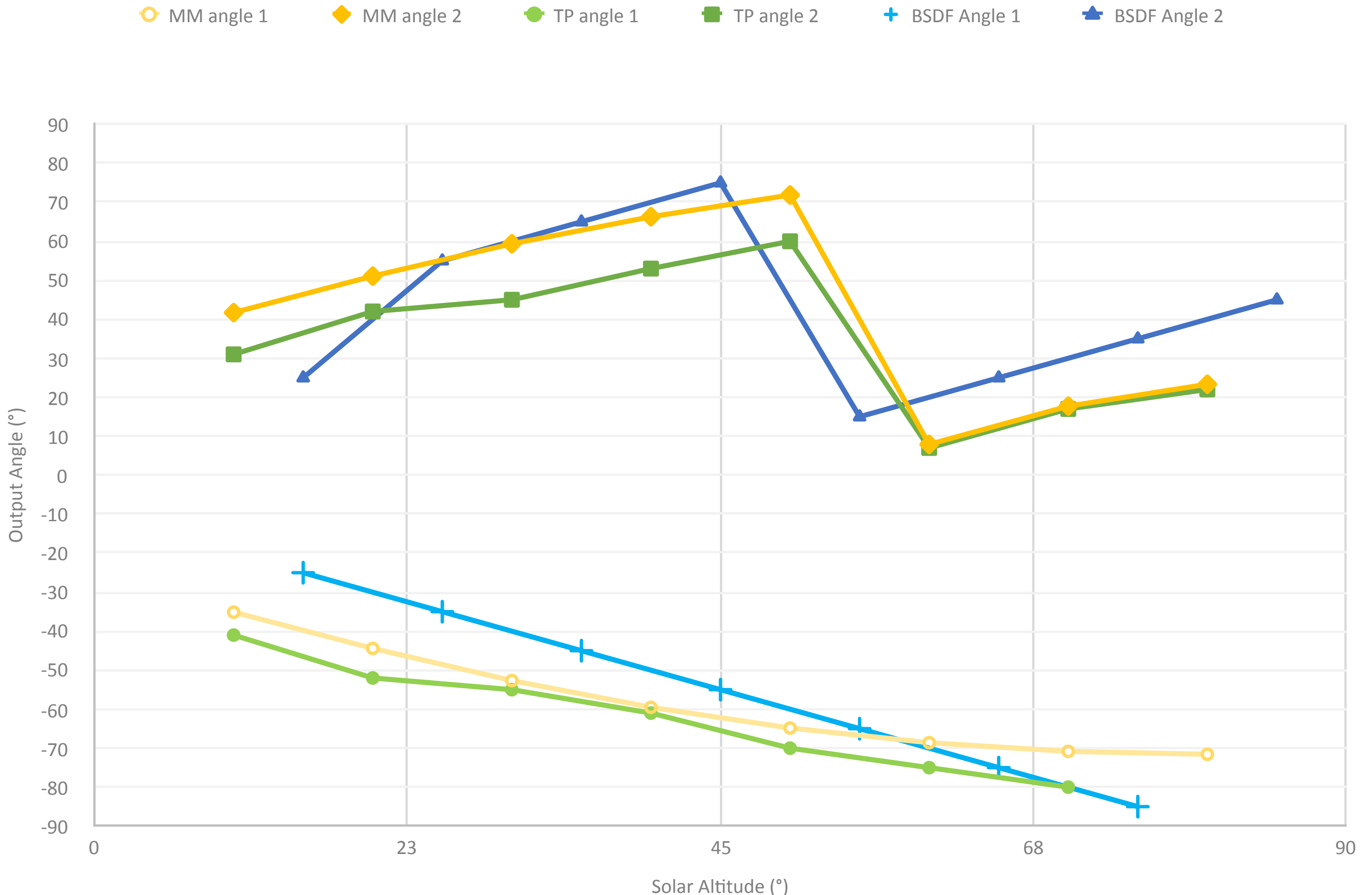




Klems Hemispheres



Verification of BSDF with Mathematical Model

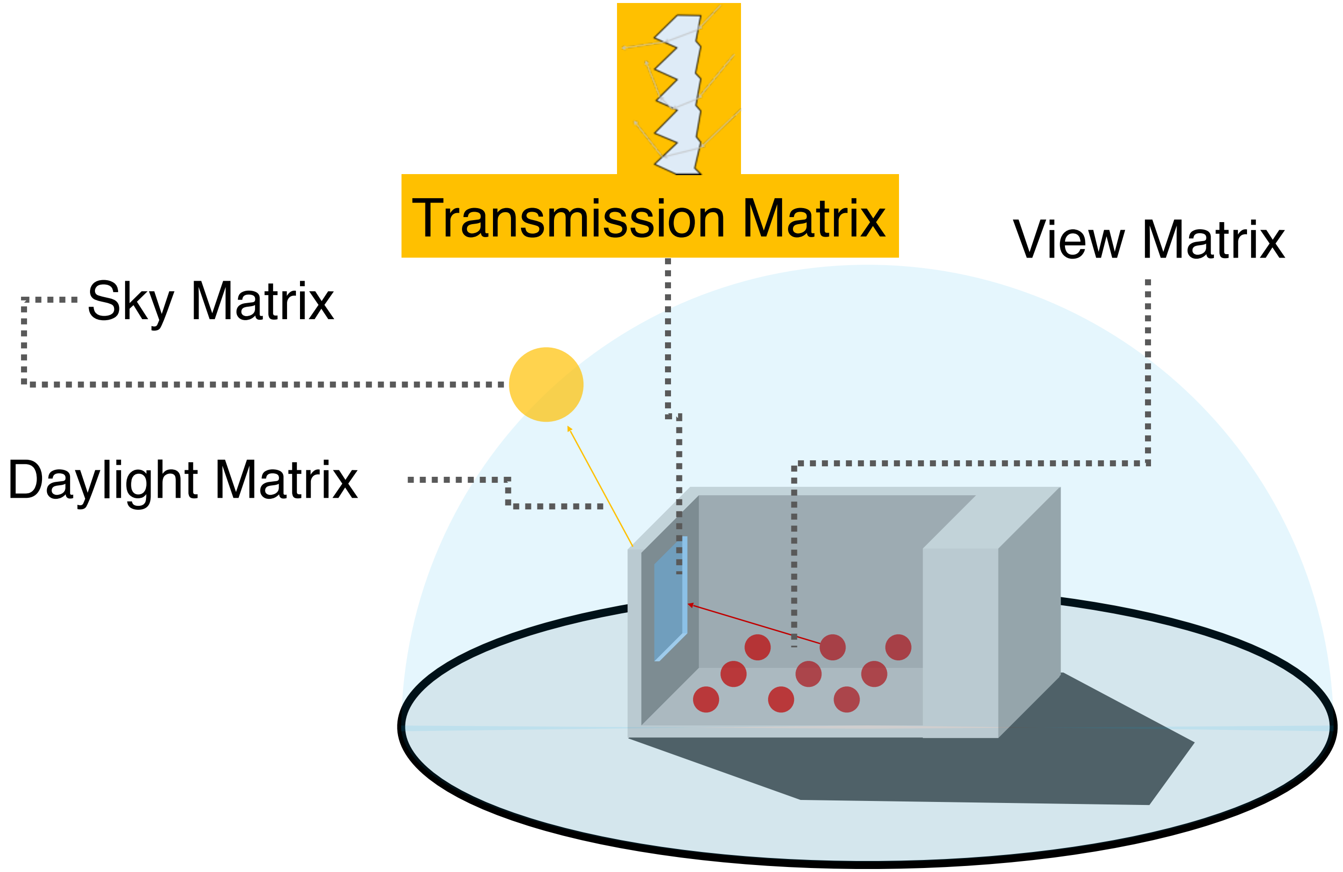


The standard error of the mean

Upwards = ±3.70°

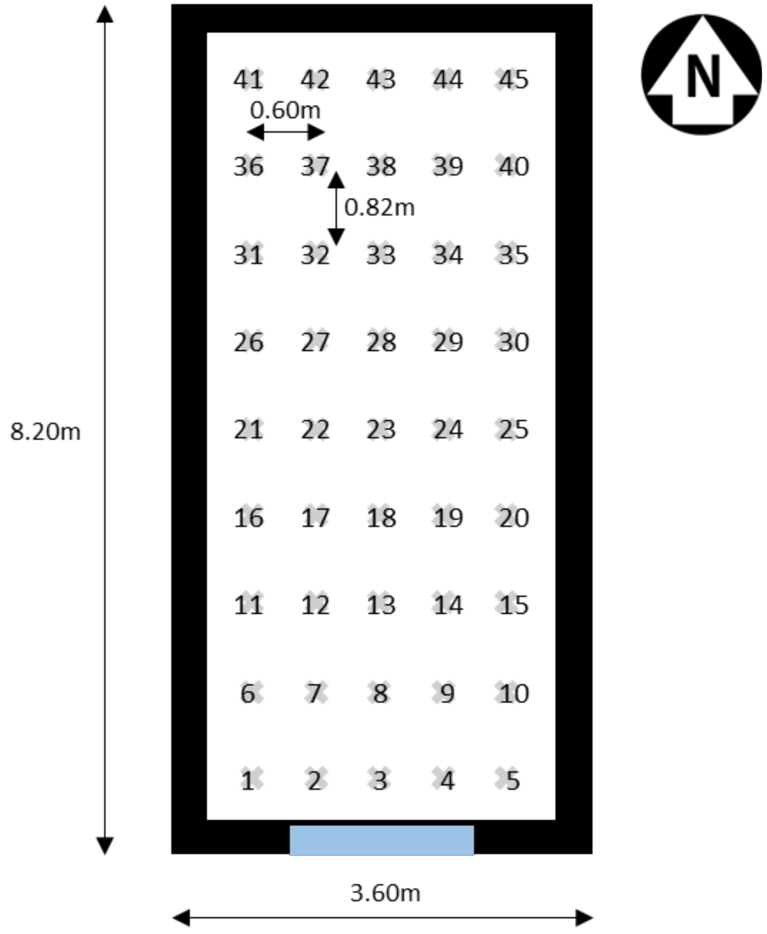
Downwards = ± 5.83°

5 phase method (cont.)



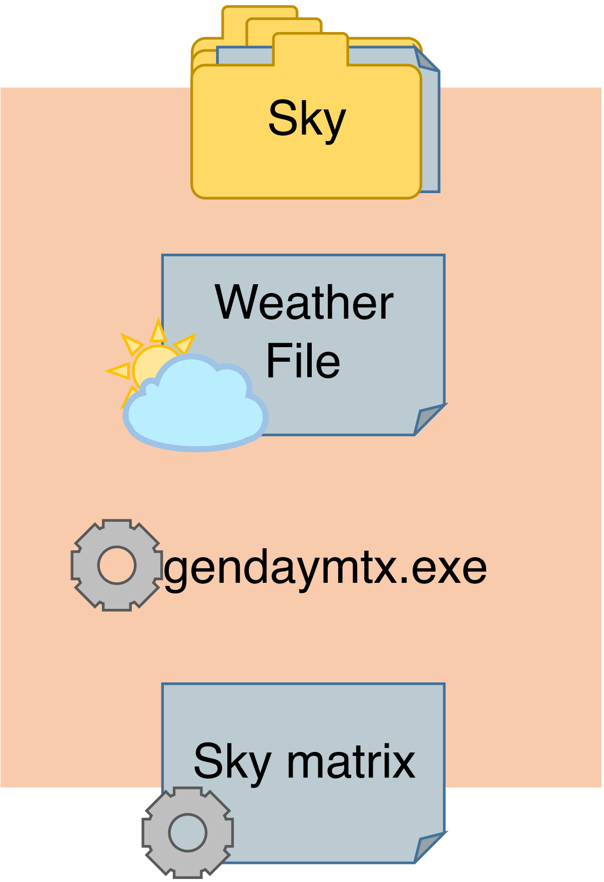
Parameters for simulation

Interior Room Surface	Parameter	Value
Interior Walls	Reflectance (%)	0.50
Floor		0.50
Ceiling		0.80
Window Frame		0.50
Internal Glazing	Transmission (%)	0.88
	SHGC	0.64
Window to wall ratio	Ratio (%)	0.20
Windows Dimensions	Length x Width (m)	2.0 x 1.8
Shading Device	Y/N	No
Illuminance sensor point	Height (m)	0.75
	Distance in-between (m)	0.50
	Number of points	45
	Distribution (L x W)	8 x 5
Sky Condition	Clear/Overcast/uniform	Clear Sky



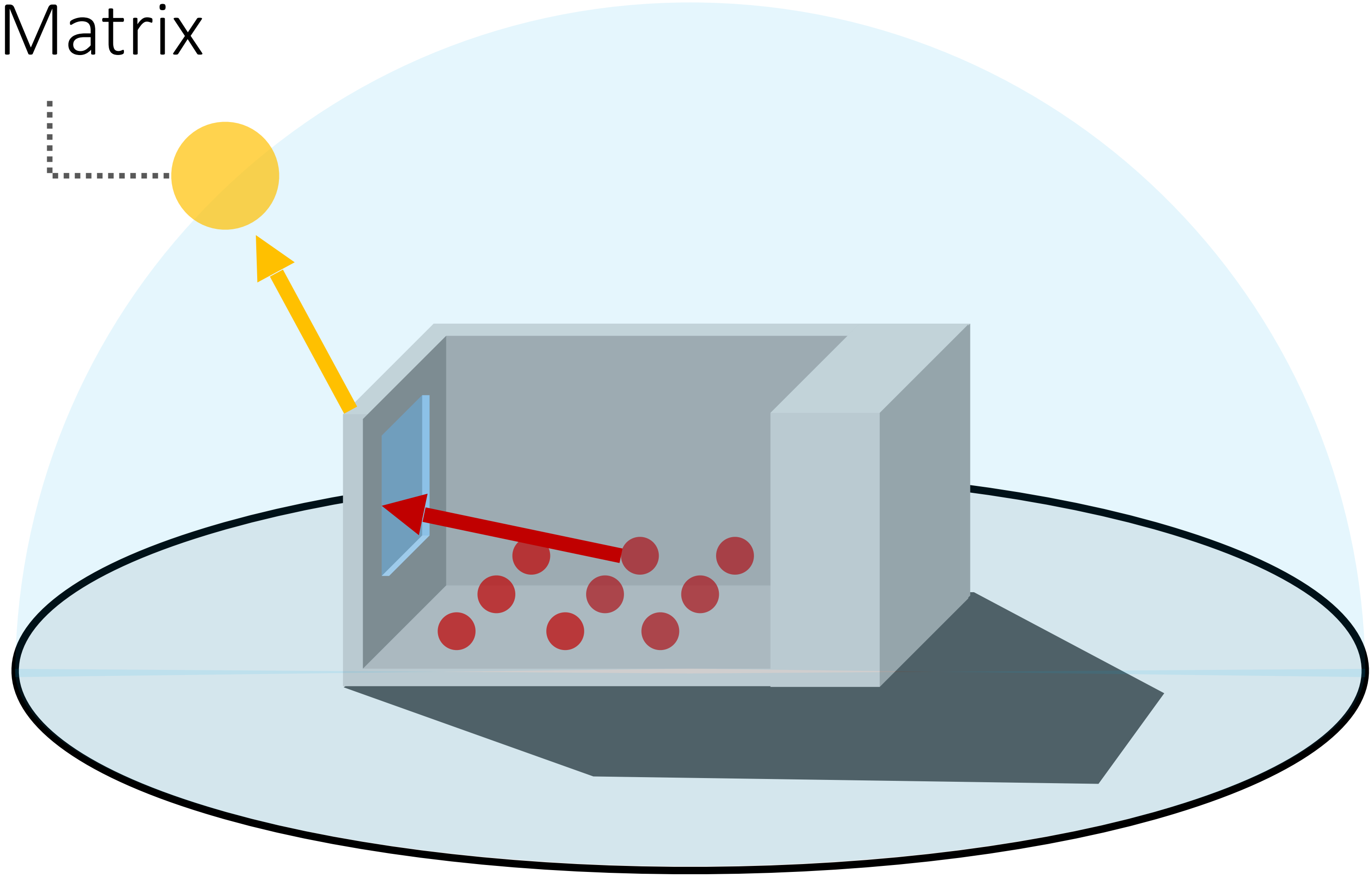
Reinhart, C., Jakubiec, J., & Ibarra, D. (2013). Definition of a Reference Office for Standardized Evaluations of Dynamic Façade and Lighting Technologies. *13th Conference of International Building Performance Simulation Association.* Chambéry

5 phase method

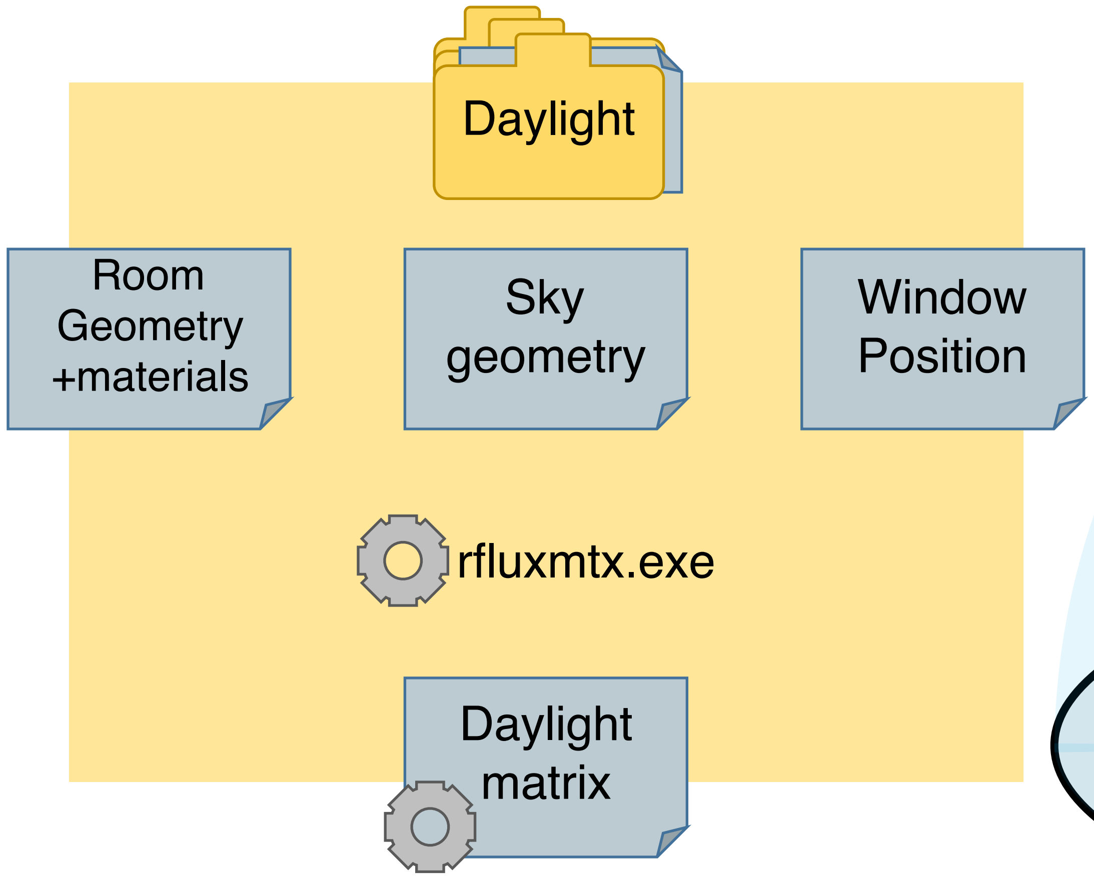


$$\begin{pmatrix} n & \cdots & n \\ \vdots & \ddots & \vdots \\ n & \cdots & n \end{pmatrix}$$

Sky Matrix

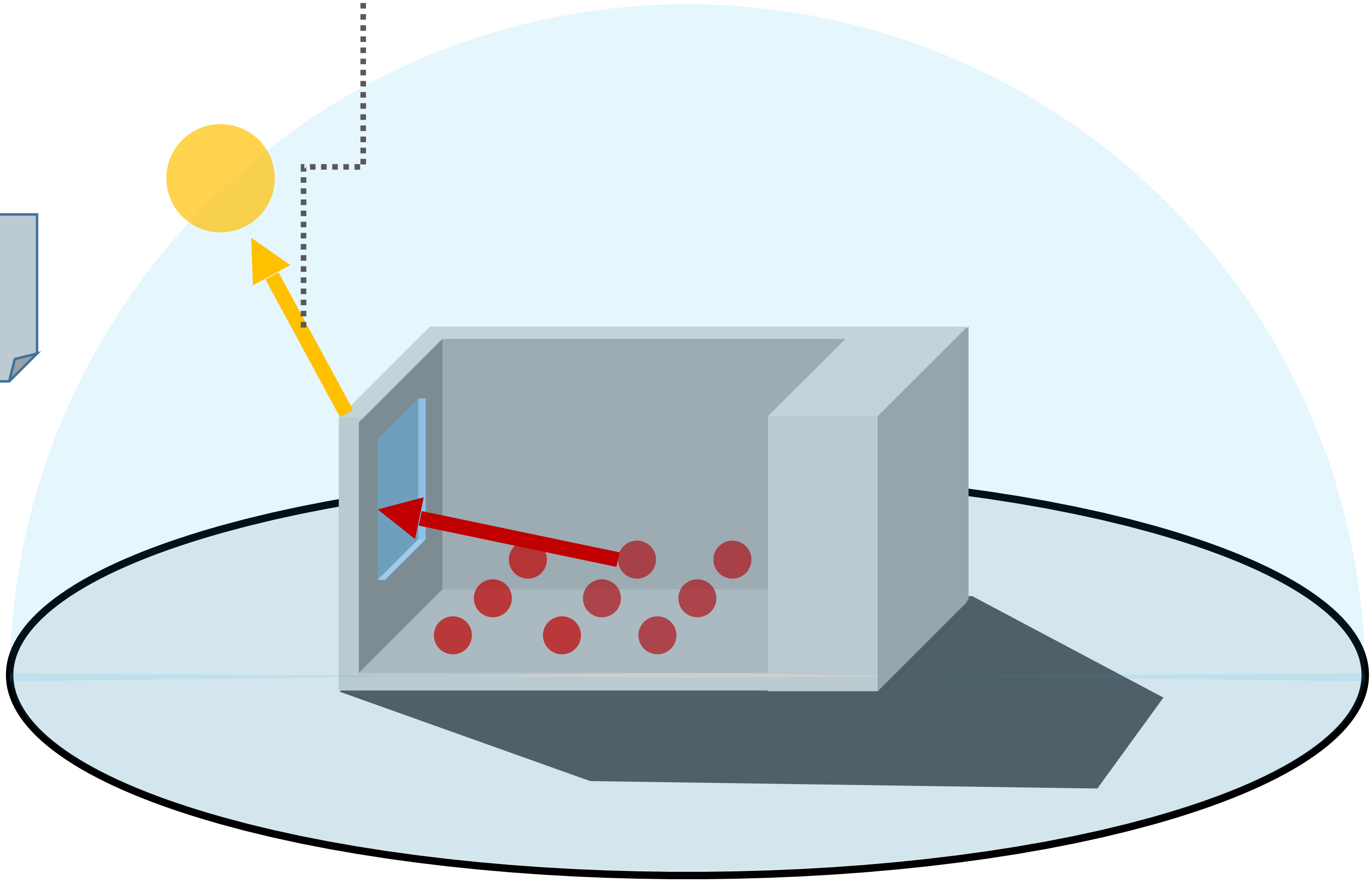


5 phase method

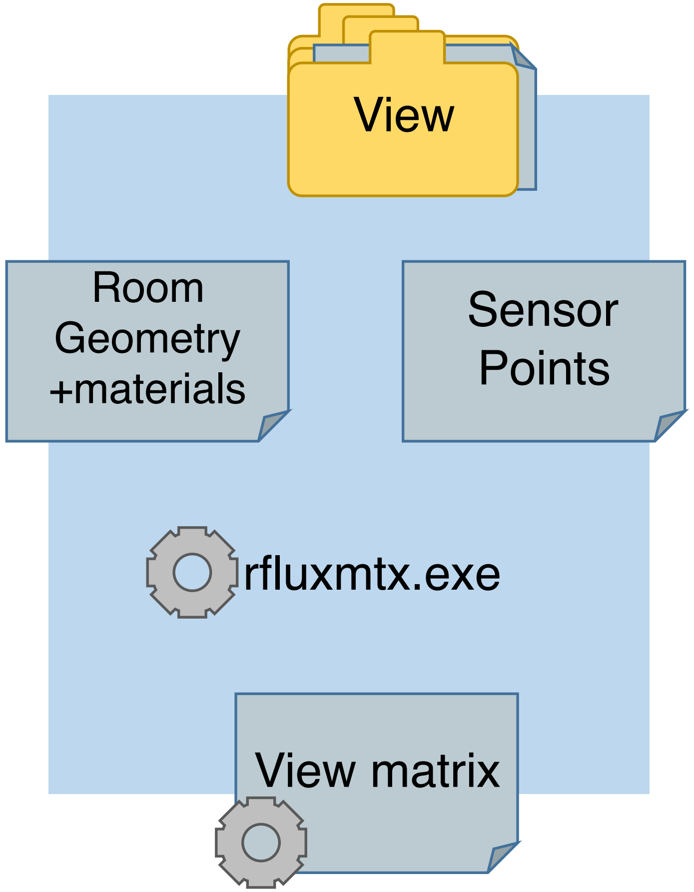


$$\begin{pmatrix} n & \cdots & n \\ \vdots & \ddots & \vdots \\ n & \cdots & n \end{pmatrix}$$

Daylight Matrix

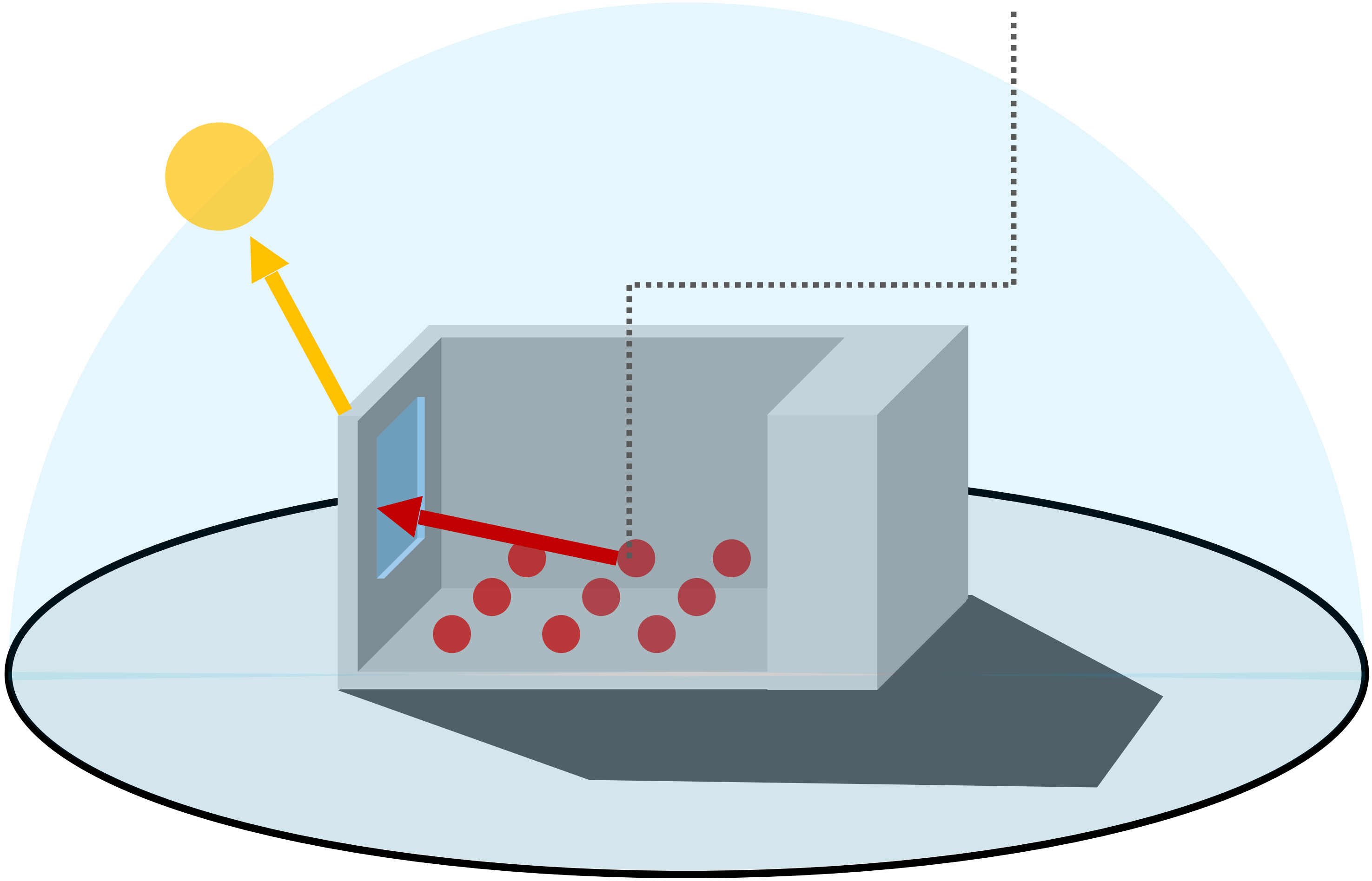


5 phase method



$$\begin{pmatrix} n & \cdots & n \\ \vdots & \ddots & \vdots \\ n & \cdots & n \end{pmatrix}$$

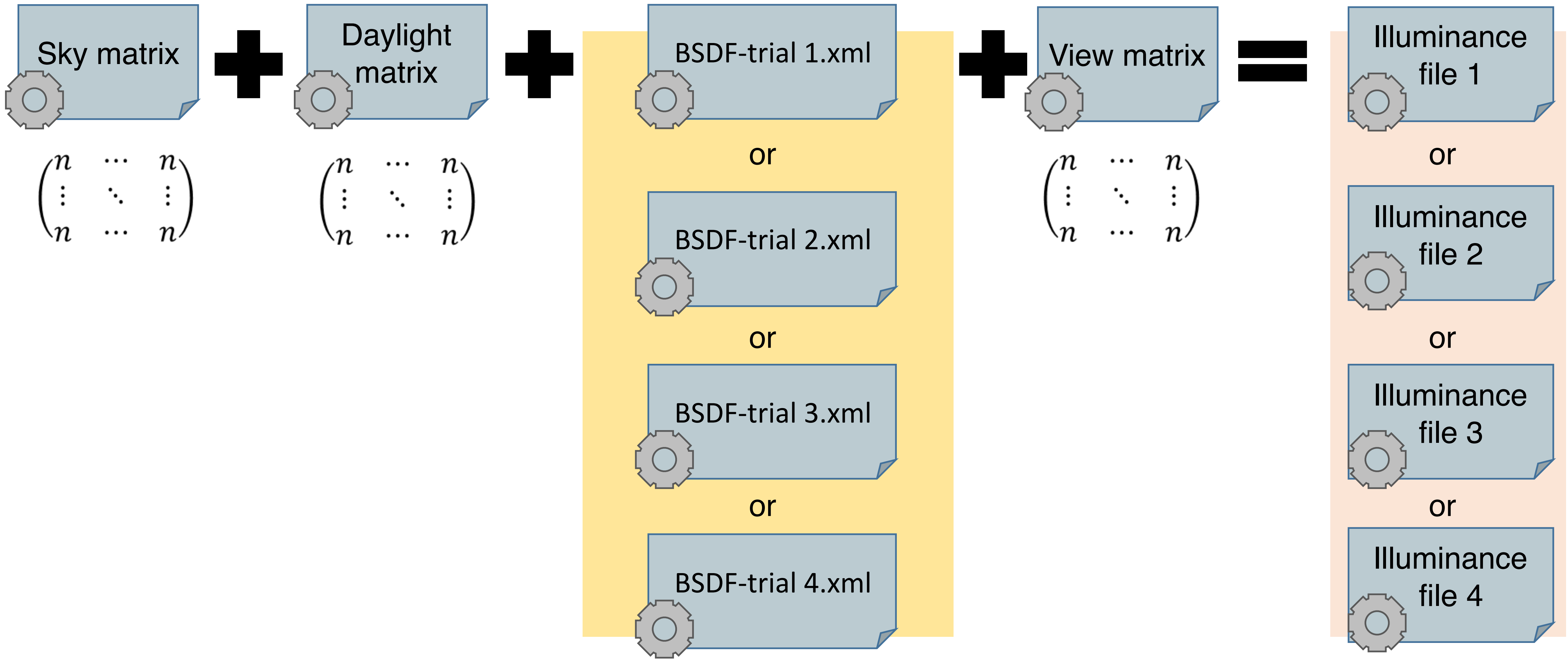
View Matrix



Trials

Trial No.	BSDF used	Accuracy (number of samples per patch in the BSDF file)
Glass	-	2000
1	Acrylic transparent panel	2000
2	Full frame & transparent panel	2000
3	Full frame & translucent prism	100
4	Full frame & translucent prism	2000

5 phase method workflow



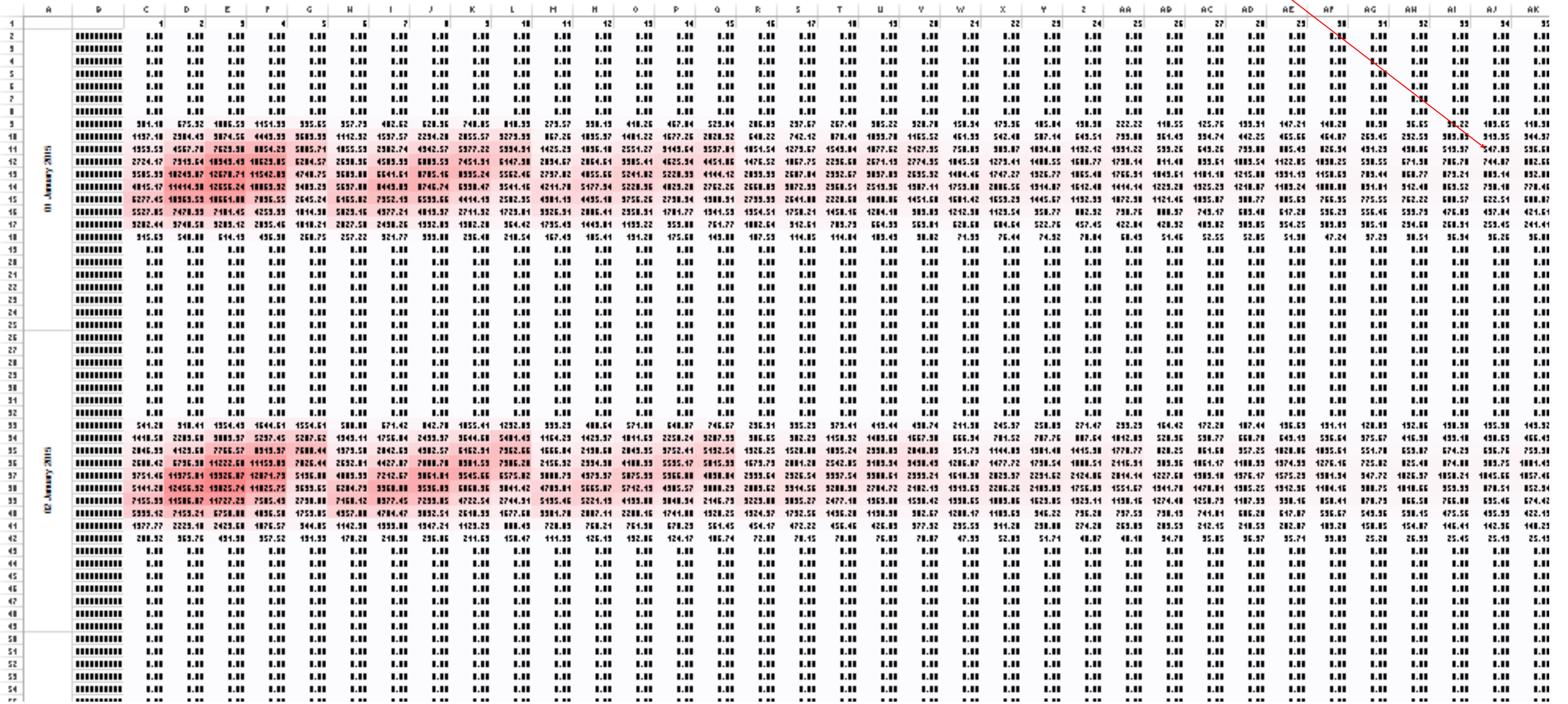
Output file

Illuminance file 1

Illumination value (lux)

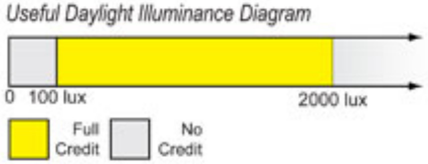
45 sensor points

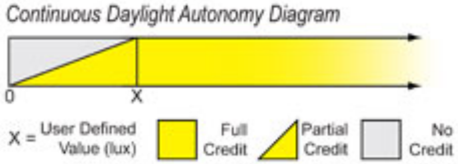
8760 Hours

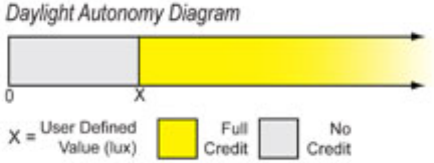


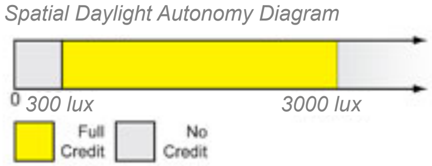
Daylight Measures

Abbrv.	DF	UDI	DA	DA_{con}	sDA	ASE
Measure	Daylight Factor	Useful Daylight Illuminance	Daylight Autonomy	Continuous Daylight Autonomy	Spatial Daylight Autonomy	Annual Sunlight Exposure
Creation Year	1900s	2005	1989	2006	2013	2013
Value	Internal / External Illuminance (%)	100 to 2000 lux	>certain set point for 50% of daytime hours	Introduction of partial credit	300 to 3000 lux for 50% of occupied hours	>1000 lux for 250 hours per year









The Natural and Artificial Lighting of Buildings, The Journal of the Royal Institute of British Architects, Vol. XXXII, No. 13, pp. 405-426 and 441-446)
Reinhart, C. F., & Walkenhorst, O. (2001). Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds. Energy and Buildings, 33(7), 683-697.
Nabil A, & Mardaljevic J. (2005a). Useful Daylight Illuminance: A New Paradigm to Access Daylight in Buildings. Lighting Research & Technology, 37(1), 41-59.
Reinhart, C., Mardaljevic, J., & Rogers, Z. (2006). Dynamic Daylight Performance Metrics for Sustainable Building Design. Leukos, 3(1), 7-31.

Comparison between Glass and Prismatic design

21,March

8.0%	8.8%	14.7%	14.1%	18.1%
4.8%	7.2%	11.1%	10.3%	10.7%
2.0%	2.8%	4.8%	2.6%	5.1%
-1.4%	-0.9%	-0.3%	0.1%	0.8%
-4.5%	-3.7%	-3.5%	-3.4%	-2.6%
-7.7%	-6.9%	-6.7%	-6.4%	-7.0%
-10.0%	-10.3%	-10.6%	-10.5%	-10.7%
-13.5%	-14.6%	-17.9%	-18.3%	-17.9%
-17.3%	-21.5%	-22.8%	-24.8%	-22.4%

21,June

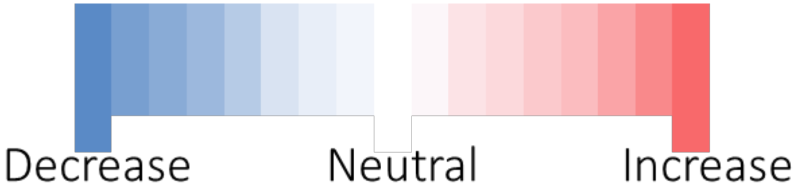
-0.4%	-0.2%	0.3%	0.2%	0.8%
-1.2%	-0.1%	-0.7%	-0.4%	-1.2%
-1.5%	-0.8%	-0.8%	-1.6%	-0.9%
-1.7%	-1.8%	-1.5%	-1.8%	-1.9%
-3.2%	-2.5%	-2.1%	-2.6%	-2.8%
-4.9%	-4.2%	-4.0%	-4.0%	-4.5%
-7.3%	-7.0%	-7.1%	-6.6%	-7.2%
-11.5%	-11.8%	-12.4%	-12.2%	-12.3%
-17.9%	-19.3%	-20.0%	-20.2%	-20.4%

21,September

31.5%	21.0%	20.8%	9.4%	12.0%
24.6%	23.4%	13.7%	10.6%	5.4%
15.8%	16.3%	9.8%	9.8%	8.3%
9.7%	10.4%	7.3%	2.4%	3.3%
3.4%	2.3%	3.3%	0.9%	-1.0%
-3.5%	-1.1%	-2.4%	-3.1%	-4.2%
-3.7%	-5.5%	-8.3%	-6.3%	-5.7%
-16.6%	-16.2%	-20.7%	-7.6%	-7.9%
-23.0%	-26.6%	-28.5%	-20.3%	-8.9%

21,December

4.0%	3.4%	7.0%	9.1%	7.1%
-2.8%	-2.5%	-2.5%	-2.0%	-0.9%
-7.1%	-6.7%	-6.5%	-6.1%	-4.1%
-7.3%	-8.5%	-3.2%	-9.6%	-4.9%
-9.7%	-10.3%	-9.9%	-8.6%	-8.2%
-11.8%	-10.6%	-10.9%	-10.9%	-11.2%
-11.8%	-14.1%	-16.9%	-13.2%	-14.2%
-12.7%	-18.0%	-17.1%	-20.8%	-13.9%
-12.3%	-18.5%	-15.9%	-20.2%	-13.4%



Comparison between Glass and Prismatic design

Plain Window (Glass)

$sDA_{300/50\%}$

25%	29%	29%	28%	26%
32%	35%	37%	35%	36%
46%	50%	47%	46%	46%
63%	65%	67%	66%	64%
73%	74%	74%	73%	74%
80%	81%	81%	81%	80%
84%	84%	84%	84%	83%
86%	87%	87%	87%	85%
86%	90%	91%	90%	85%

67%

$ASE_{1000/250}$

0%	0%	0%	0%	0%
0%	0%	0%	0%	0%
1%	2%	2%	1%	1%
8%	9%	9%	10%	8%
16%	20%	20%	18%	19%
33%	36%	37%	37%	34%
54%	58%	62%	59%	54%
69%	74%	75%	75%	68%
71%	81%	83%	81%	69%

67%

Plain Window (Glass)

Prismatic Array panel (translucent)

$sDA_{300/50\%}$

26%	30%	30%	29%	28%
34%	36%	37%	35%	36%
50%	51%	50%	50%	50%
62%	62%	63%	63%	61%
72%	73%	73%	72%	72%
78%	79%	79%	79%	78%
83%	83%	84%	83%	83%
85%	86%	86%	86%	84%
86%	89%	89%	89%	85%

76%

$ASE_{1000/250}$

0%	0%	0%	0%	0%
0%	0%	0%	0%	0%
1%	1%	1%	0%	1%
4%	7%	7%	7%	5%
16%	20%	20%	18%	18%
32%	36%	37%	37%	33%
54%	58%	60%	58%	53%
68%	73%	74%	73%	68%
72%	79%	82%	80%	70%

56%

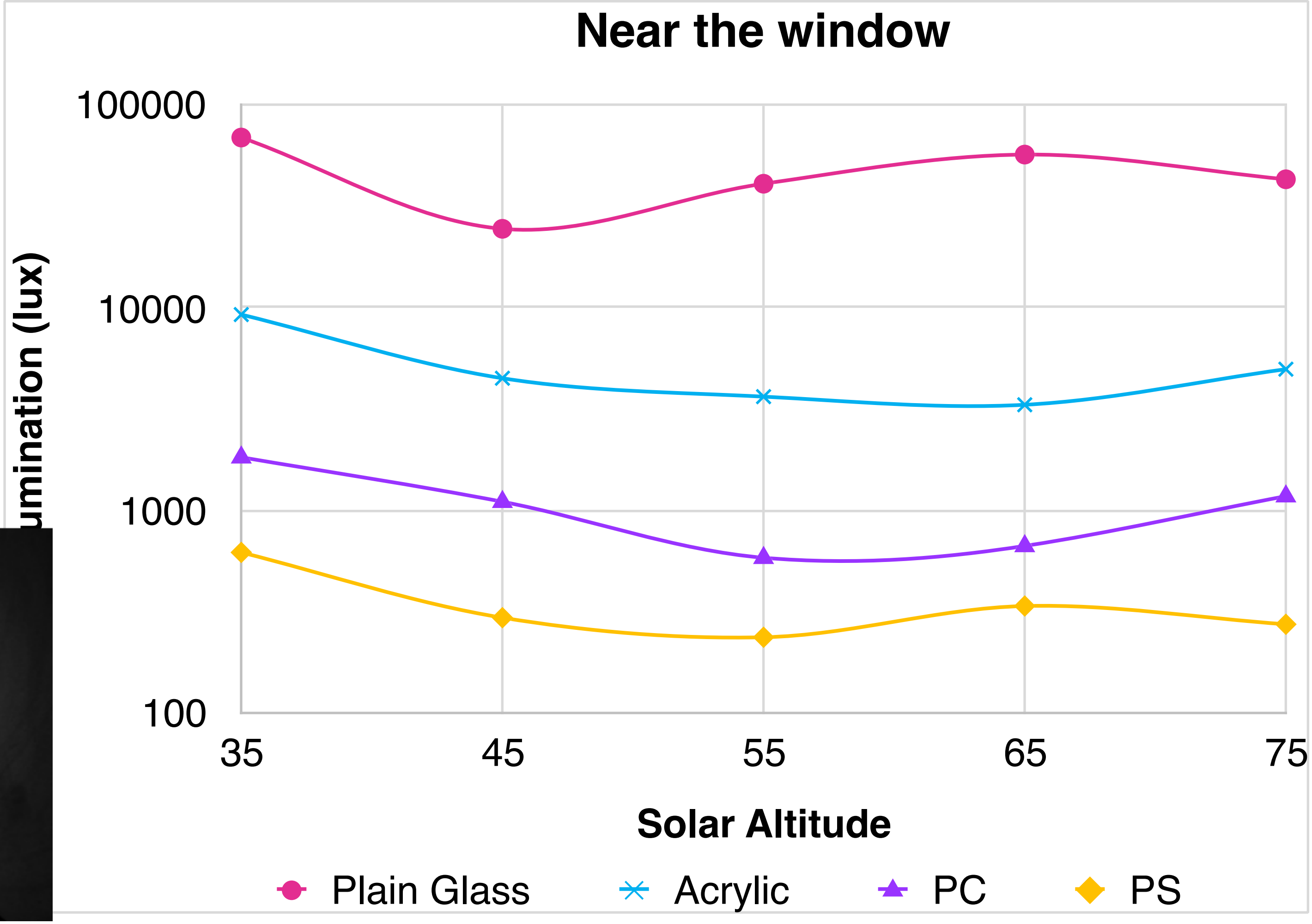
Prismatic Array panel (translucent)

Physical Model

Near the window

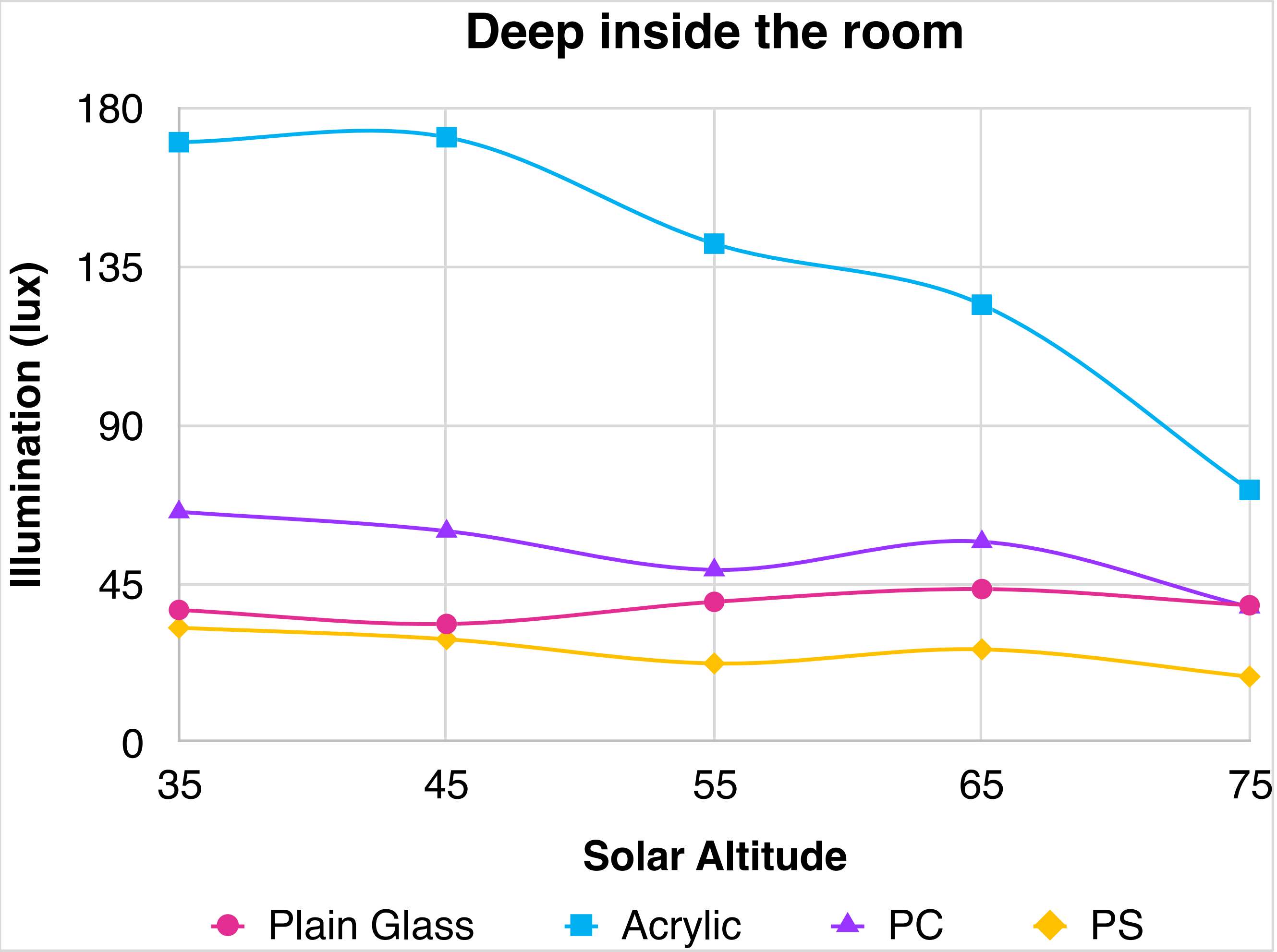
- All panels managed to decrease daylight under 10,000 lux

Acrylic   Plain Glass



Illumination inside the room

- Performance decrease with higher solar altitudes
- Polystyrene (PS) failed to improve daylight inside the room
- Acrylic highly improved daylighting inside the room



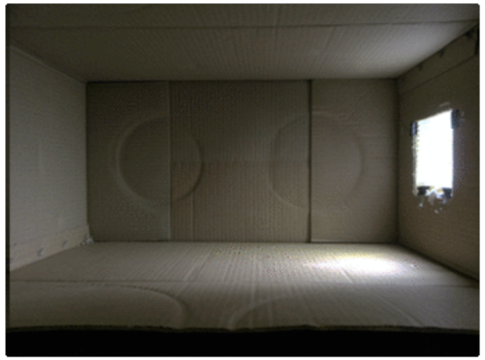
Plain Glass vs. Acrylic (Animation)

Incident Angles

80°

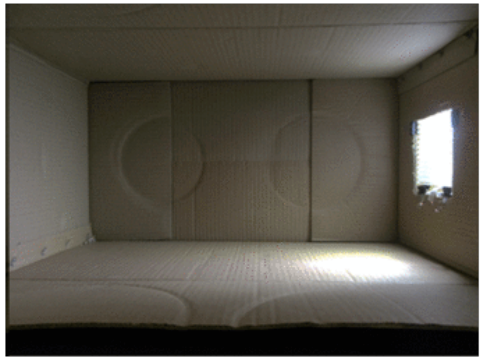
70°

60°

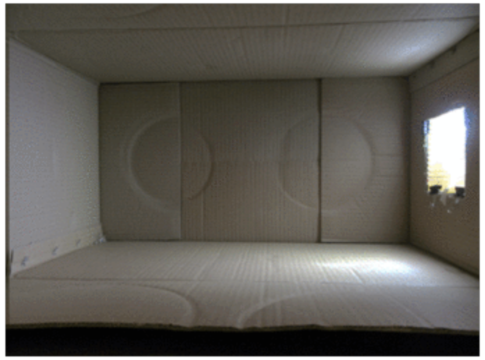


Incident Angles

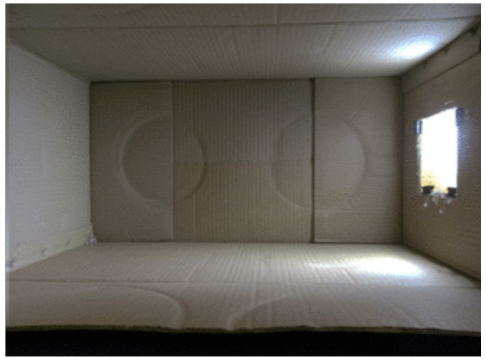
50°



40°



30°



Conclusions

General Conclusions

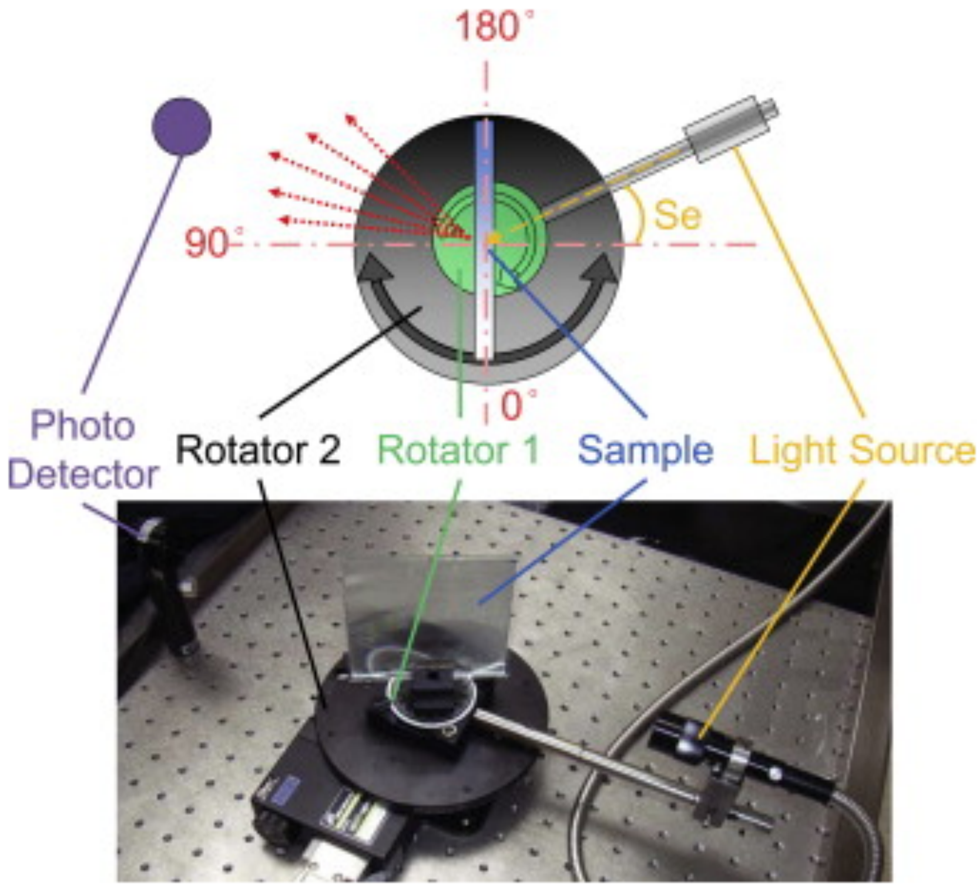
- The Proposed design **improved** daylighting by eliminating the **cave effect**.
- Proposed design has **high** performance at **lower** solar altitudes and **moderate** performance at **higher** solar altitudes.
- The mathematical model constructed is validated against TracePro and Radiance (genBSDF).
- Some **recycled plastics** have the **potential** of replacing glass.
- The proposed design can **compete** with other prismatic structures in the **market.**

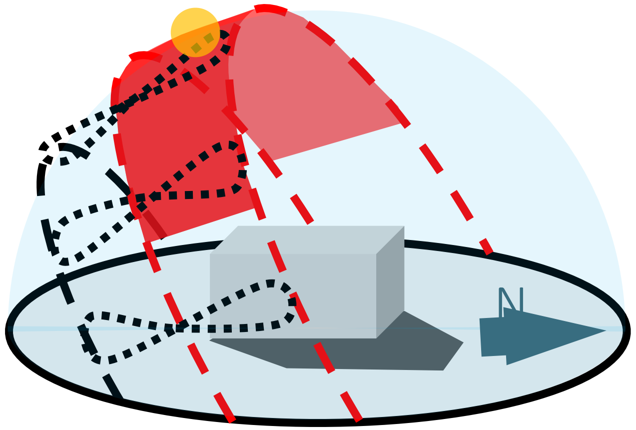
Specific Conclusions

- **Polypropylene** failed to achieve minimum translucency with the simple pressing and heating technique.
- **Heat gain/loss** was not **directly** measured, however a measure like the **ASE** can give an indication of the amount of heat lost/gained
- **Physical measurements** should have considered the effect of **external ground reflection** on the room's illumination

Limitations and Future Research

- View Blockage / Aesthetics
- Glare Analysis
- Thermal Analysis
- Advanced Optical Measurement
- Physical Model Limitations:
  - **Time** Constraint
  - **Full** scale model
  - Limited no. of **Sensor** points





Thank You