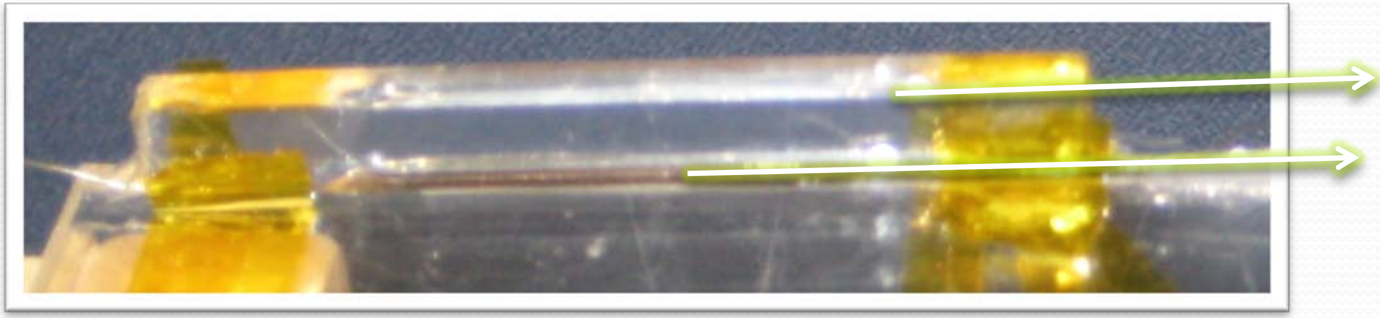
ANNUAL PERFORMANCE MODEL OF CONCENTRATING COMPOUND PARABOLIC CONCENTRATOR INTEGRATED PHOTOVOLTAICS

By
Sneha Sriwastava
&
Prof. John Duffy
U Mass, Lowell



Objective:

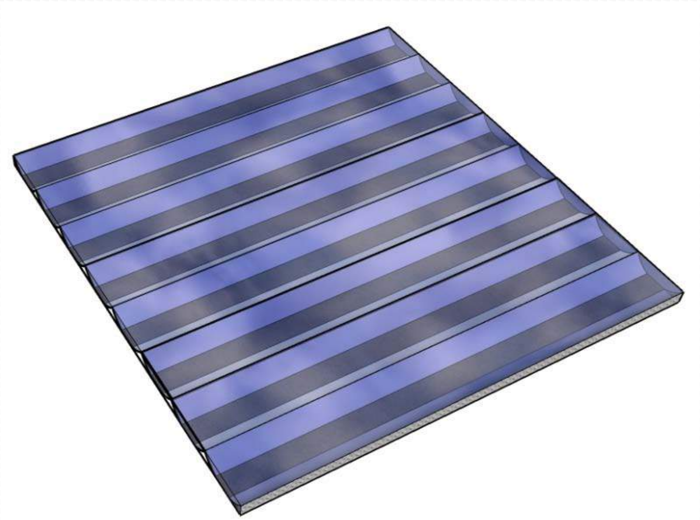
- Developing and testing a methodology to quantify the power produced by a concentrating compound parabolic collector integrated PV (CPV).

- At finding the optimal orientation of the CPV.

Concentrating Photovoltaics (CPV)

- Use less PV material still providing a reasonably high power output.

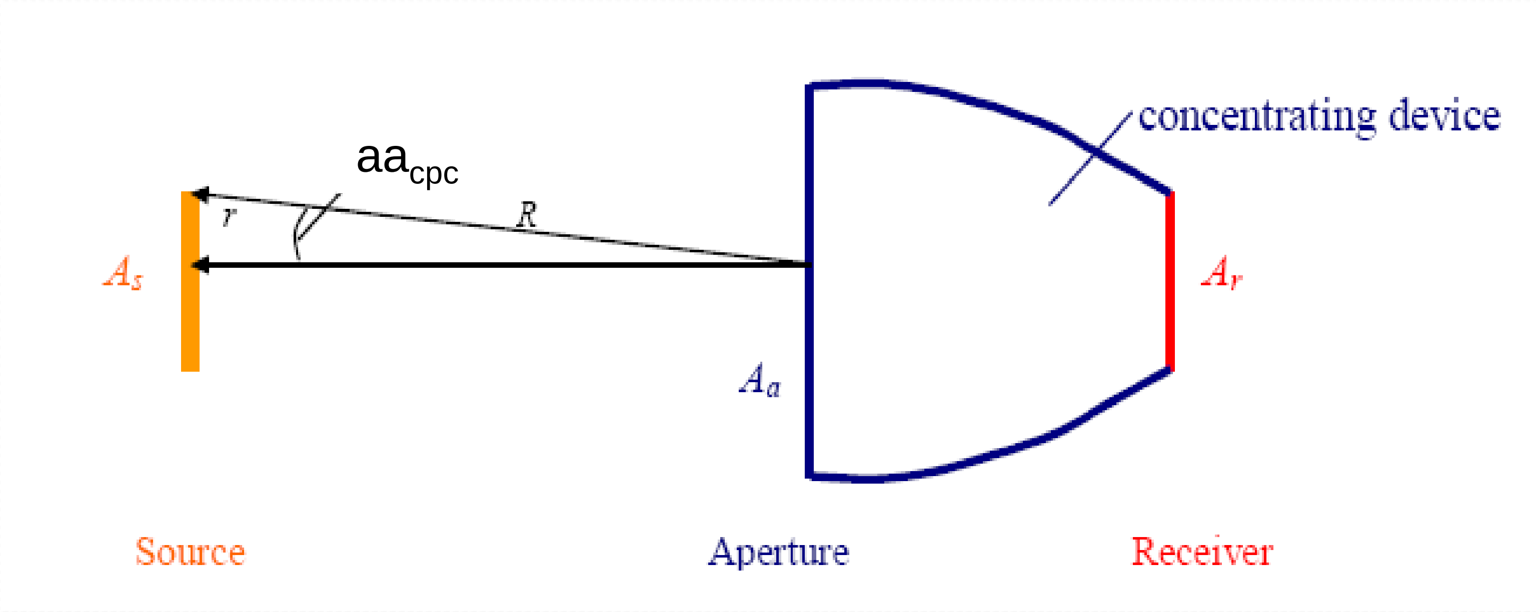
- Cost effective, require lower capital investment, and have the potential for large scale solar power generation.



Compound Parabolic Collector

Acceptance angle = $aa_{cpc} = \sin^{-1}\left(\frac{1}{CR}\right)$

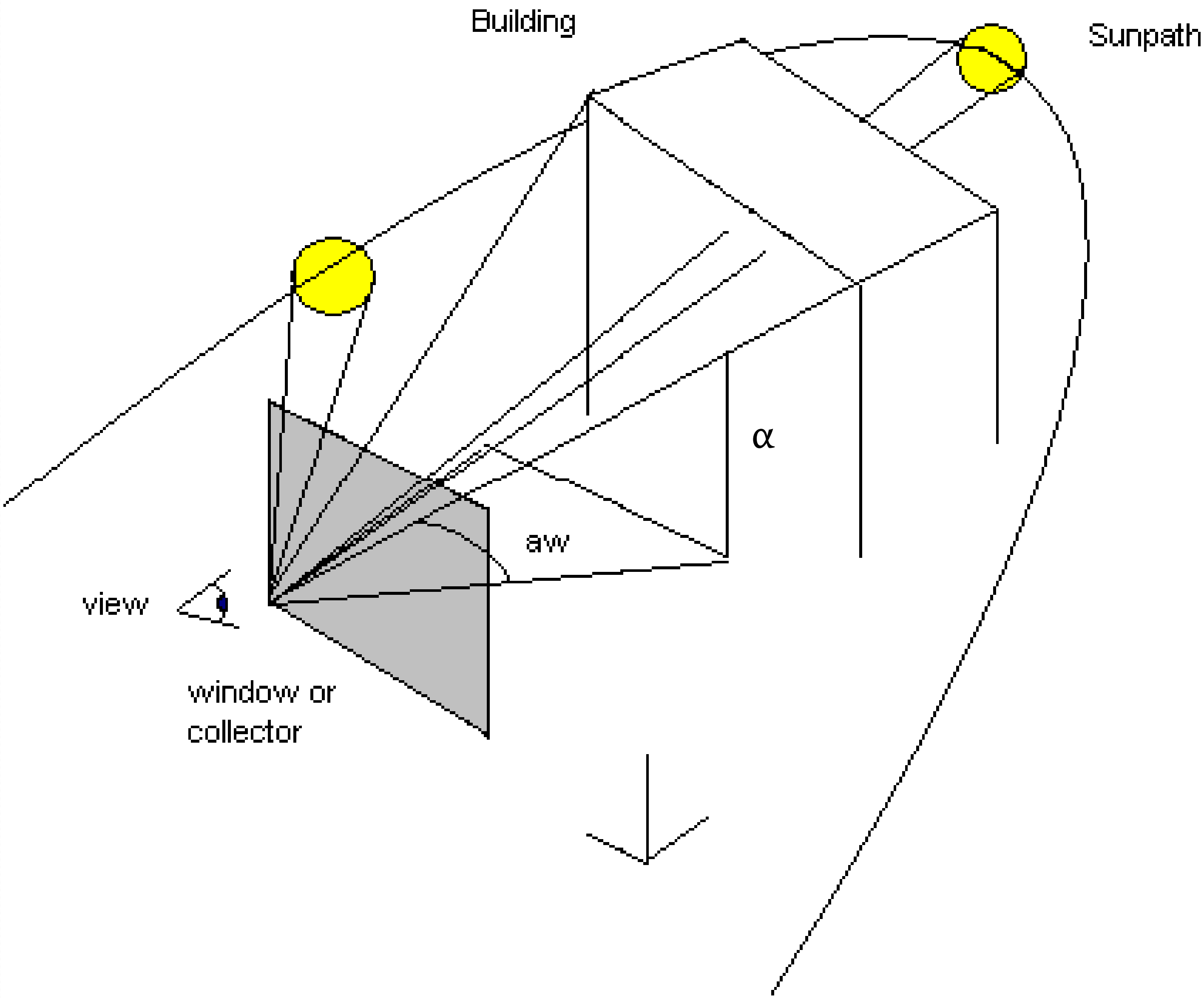
Concentration Ratio = Aa/ Ar



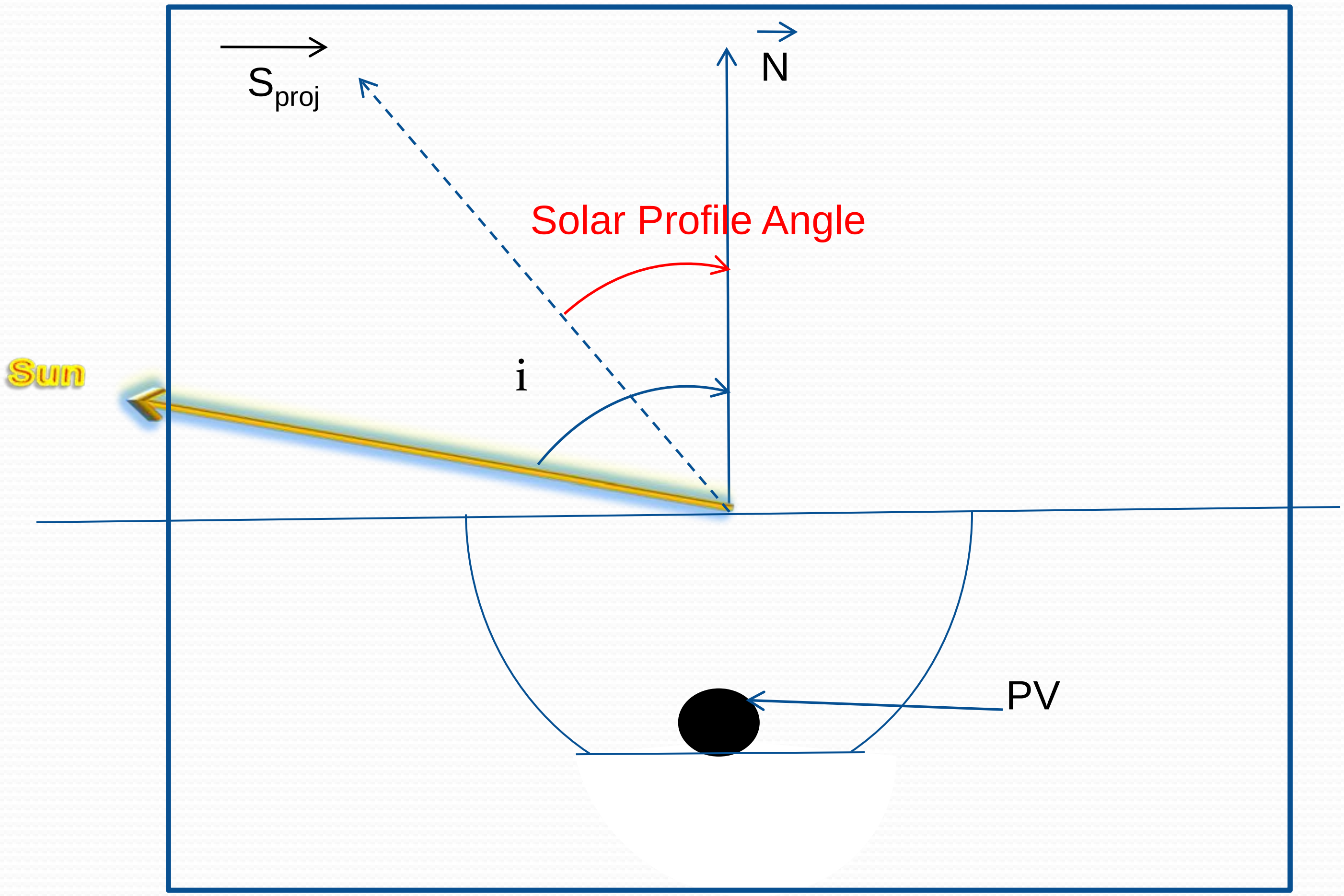
Solar Profile Angle

Solar profile angle of the incident beam radiation on a receiver plane is the projection of the solar altitude angle on a vertical plane perpendicular to the plane in question.

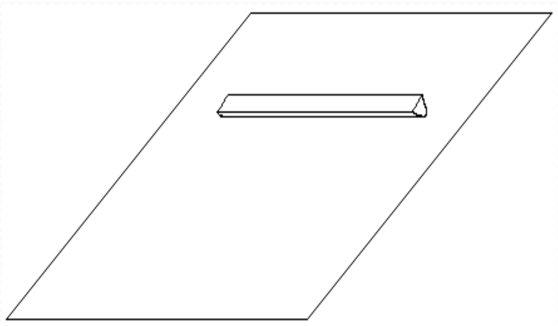
$$\theta p1 = \ tan^{-1}(\tan(z) * \cos(as - aw))$$


Building
Sunpath
α
aw
view
window or
collector

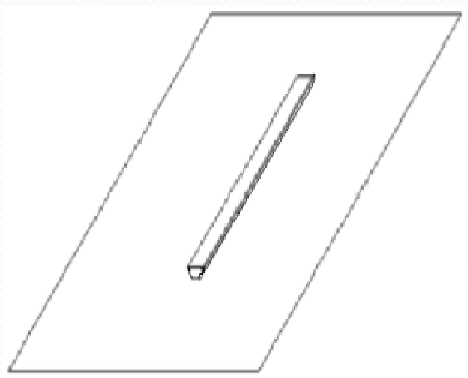
Solar Profile Angle & CPV



A tale of 2 directions..

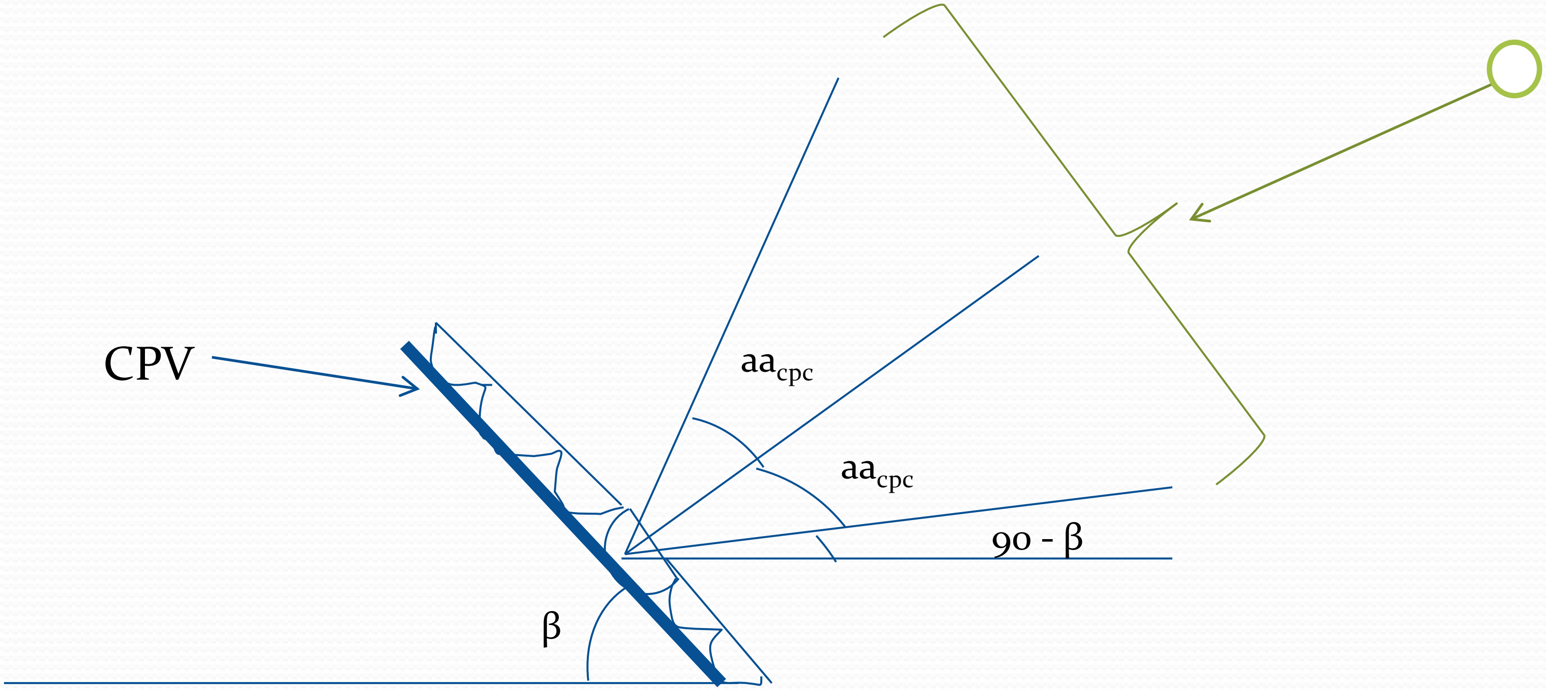


Orientation-1 (east-west)



Orientation-2 (north-south)

Orientation-1 (East-West)

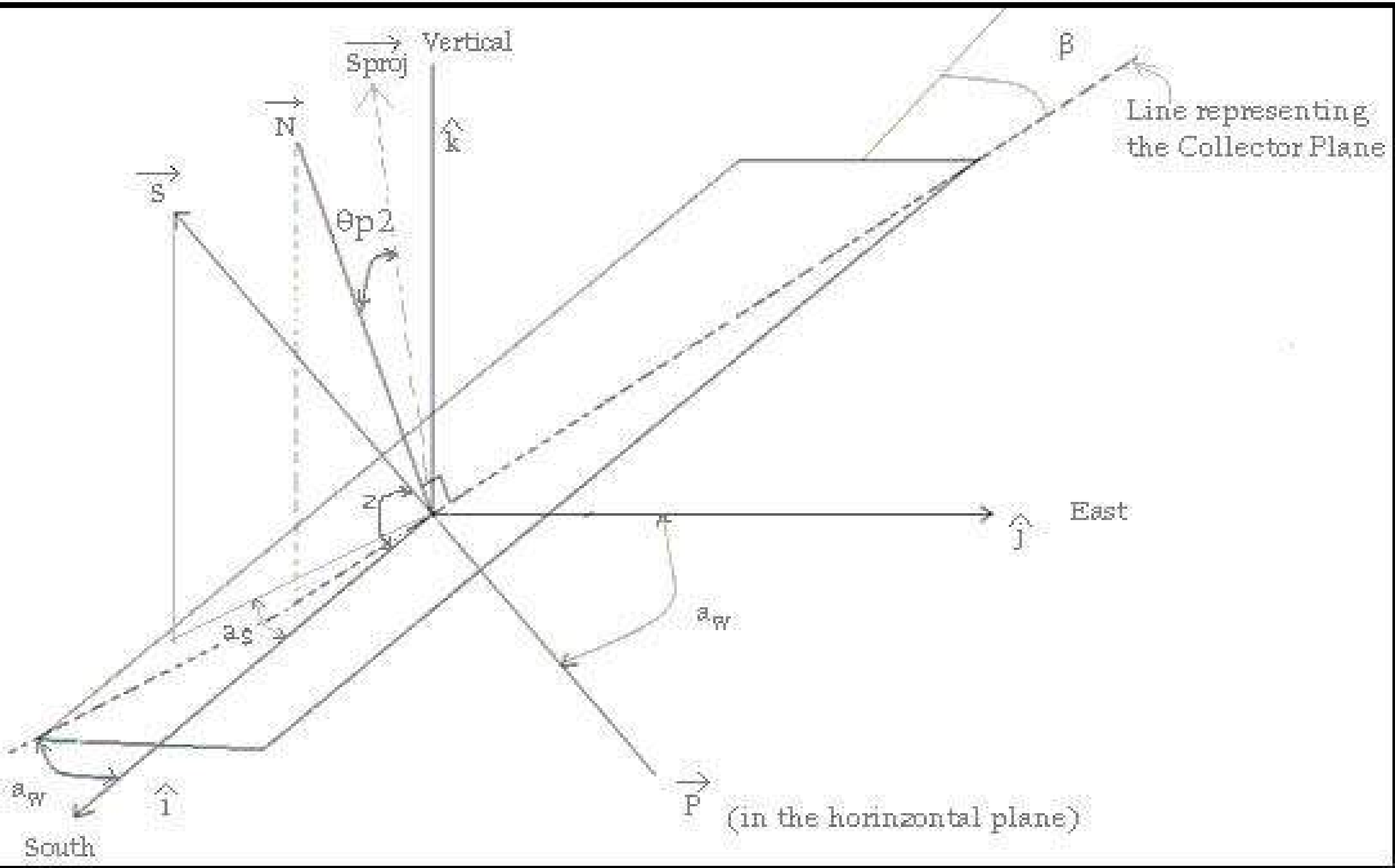


If, $\alpha > 0$

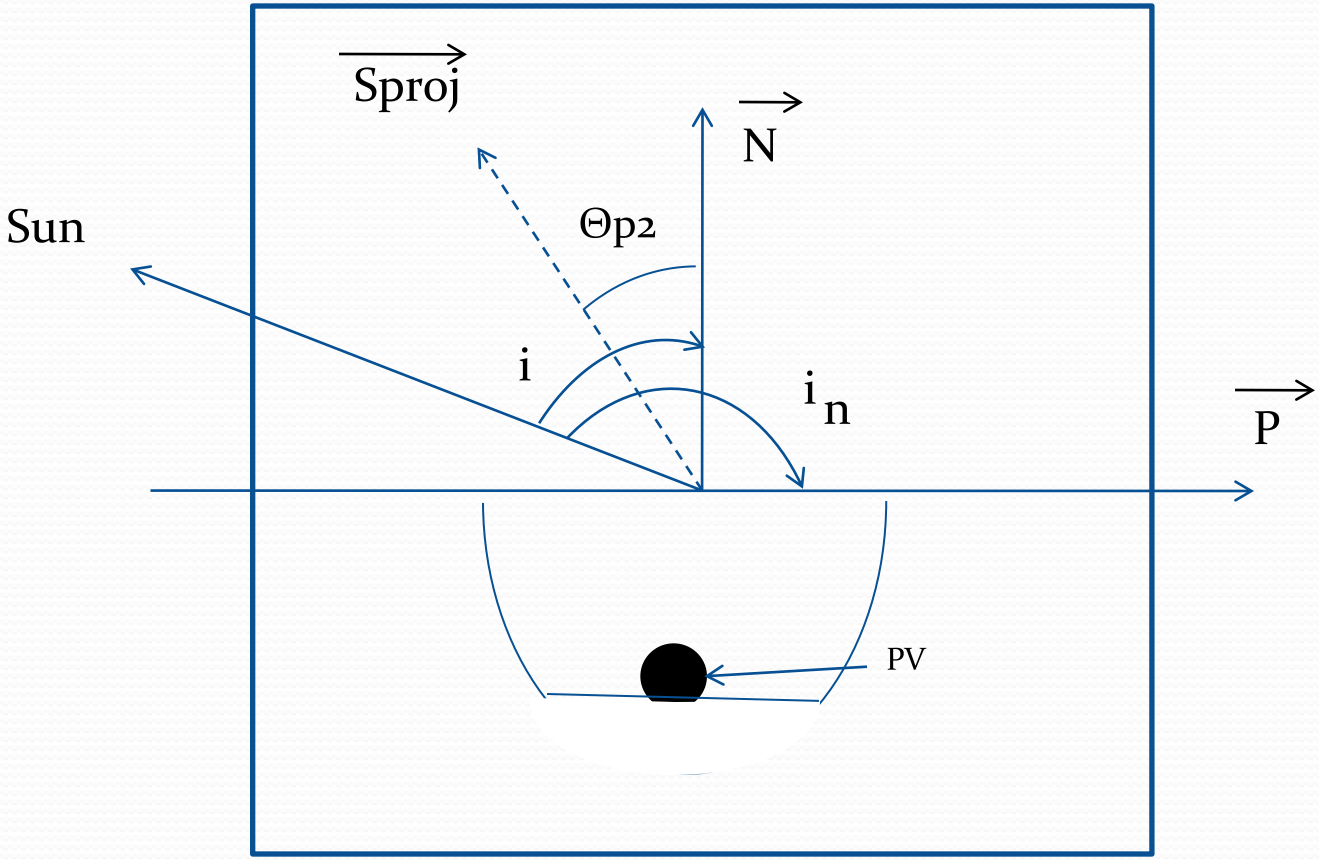
$$(90 - \beta - 2 * aa_{cpc}) < \theta p1 < (90 - \beta + 2 * aa_{cpc})$$

Then, Beam Irradiation enters the CPV. Otherwise, it does not!

Orientation-2 (North-South)



Profile View in Orientation–2 (North-South)



Vector geometry to the rescue!

$$\tan \theta p2 = \frac{\vec{S}.\vec{N}}{\vec{S}.\vec{P}} = \frac{\cos i}{\cos i_N}$$

$$\theta p2 = \tan^{-1}\left(\frac{\cos i}{\cos i_N}\right)$$

$$\cos i_N = \cos a_z \sin z \sin a_W + \cos a_W \sin a_z \sin z$$

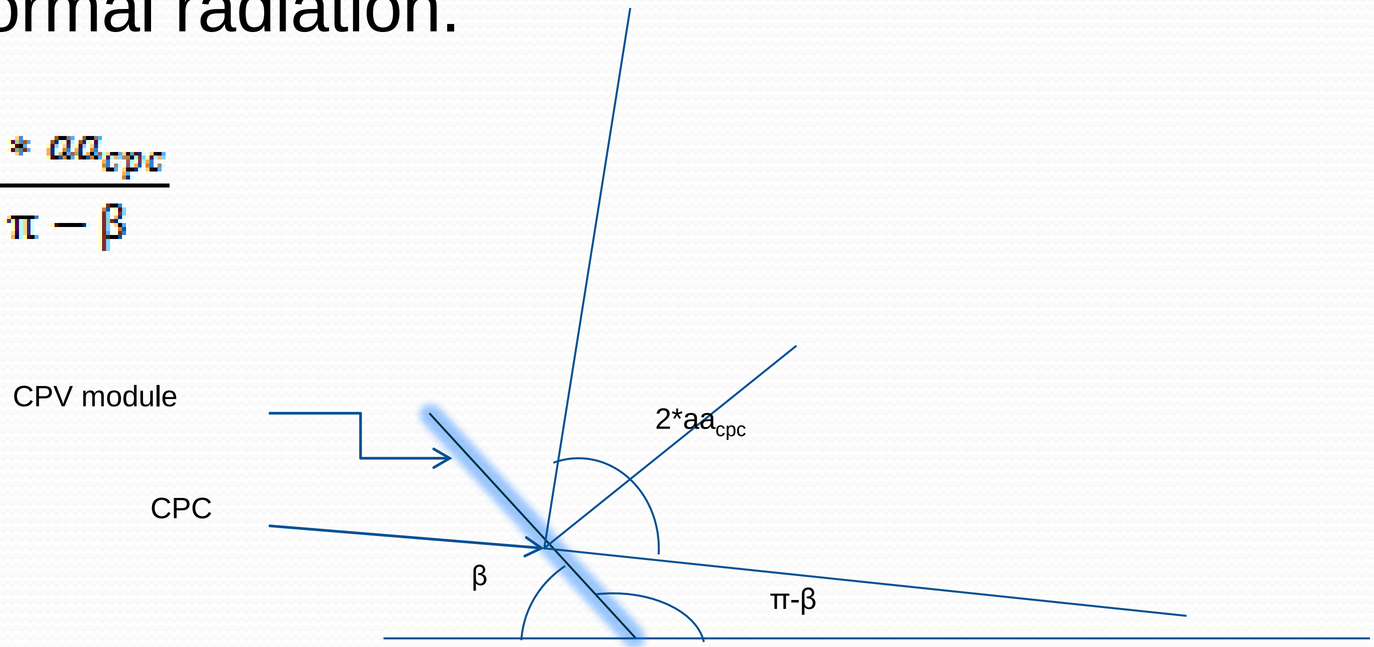
If, $\theta p2 > aa_{cpc}$ ⟹ Beam irradiation hits the PV at the bottom;

Else, No Beam irradiation entering the CPV!

Diffuse radiation

We quantified it to be a fraction of the global diffuse radiation and the ground reflected component of the beam normal radiation.

$$\text{fraction} = \frac{2 * aa_{cpc}}{\pi - \beta}$$



This is geometrically valid for slopes less than 90 degrees, which seems reasonable.

Methodology

Database of hourly irradiation was taken from NSRDB, TMY3 records for Concord, NH

Beam Incident Irradiation is estimated by using the following equation,

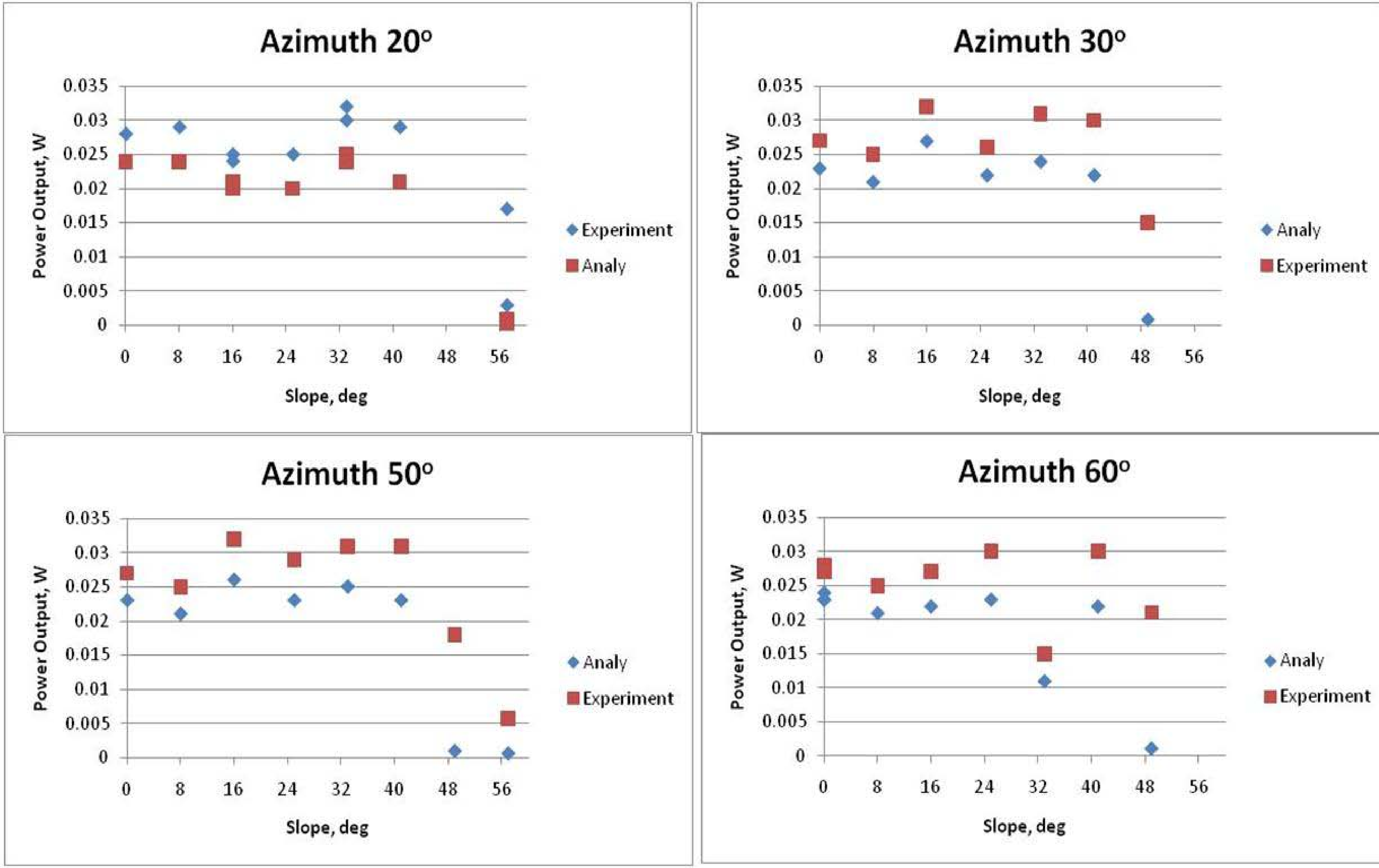
$$I_{cpv} = I_{beam} + [\overline{R_d} \cdot I_D + \overline{R_r} \cdot I_{beam}] \cdot fraction$$

Where, $\overline{R_d} = \left(\frac{1 + \cos\beta}{2}\right)$ $\overline{R_r} = \rho_{g} \cdot \left(\frac{1 - \cos\beta}{2}\right)$

Power output is estimated by, $P = I_{cpv} \cdot A_{lens} \cdot \eta \cdot \tau \cdot (1 + \Delta P)$

Temperature effects were considered, $\Delta P = \Delta Tc \cdot \Delta P\%$

Experimental Verification



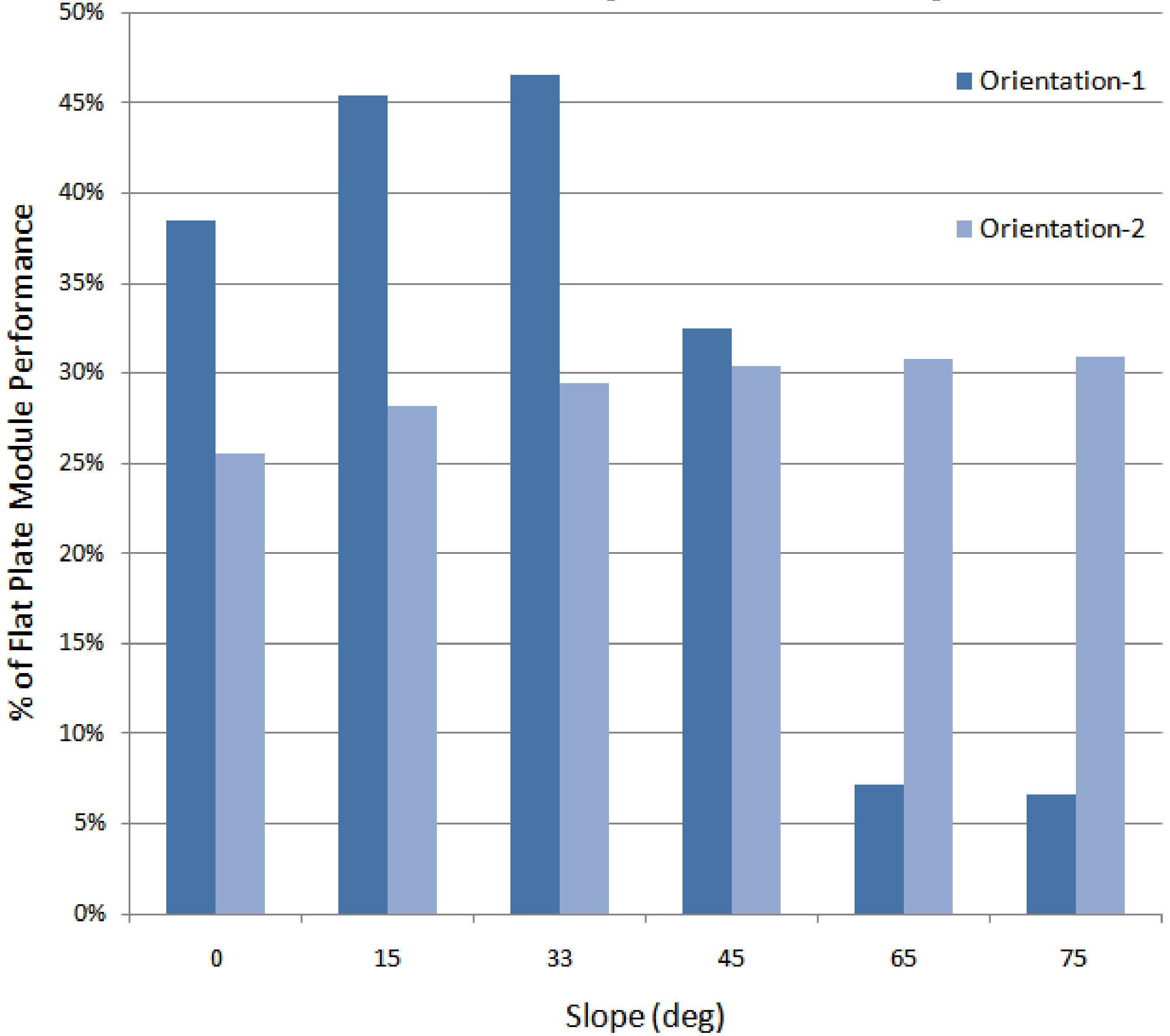
Difference b/w Analytical & Experimental Results

- Discretization uncertainty, due to the very small current output from the experimental module.

- Moreover, at higher collector slopes where the profile angle is outside of the acceptance range, the current produced is extremely small resulting in higher discretization uncertainty.

- Irradiation entering from the side of the CPC has not been considered.

Annual Power Output Comparison



Note: Assuming equal aperture area of Flat Plate Module and the CPV

In Conclusion..

The annual model demonstrates that optimal performance is attained at low roof slopes while the CPV is aligned “east-west” in orientation-1.

At higher collector slopes as required in building elements, CPV aligned “north-south” in Orientation-2 offers better performance.

Recommendations

- Incorporating the irradiation that enters through the side of the CPC.
- A module could be built and tested instead of a cell, for less discretization error.
- More tests could be conducted on the orientation-2.
- Field tests for prolonged periods of time could provide useful data on temperature effects.
- Transmittance as a function of incidence angle could be investigated.

Thank You for your attention!

Any questions?