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Project Summary

Objectives:

Our objective is to find the tilt angle and orientation which allow a fixed solar cell to reach maximum input throughout the year in different cities. We will further proceed to find the relationship between the optimum tilt angle and latitude, and to explore other methods of maximizing the power input of a solar panel.

Literature Review:

Bucciarelli gave this formula of calculating monthly average daily radiation,

$$H_{ext}(\beta) = \frac{24}{\pi}\phi_{ext}\cos\delta\cos(\lambda-\beta)[\sin\omega'_{ss} - \omega'_{ss}\cos\omega'_{ss}]$$

Wang gave the formula of calculating the daily solar insolation on a tilted surface,

$$H_{0(\beta,d)} = \frac{24}{\pi}E_{sc}(\frac{r_0}{r})^2\left[\frac{\pi}{180\tau'_s}\sin\delta\sin(\lambda-\beta) + \cos\delta\cos(\lambda-\beta)\sin\tau'_s\right]$$

Klein developed the formula of daily solar insolation,

$$H_0 = \frac{24}{\pi}\left[1 + 0.033\cos\left(\frac{2\pi n}{365}\right)\right][\cos(\lambda-\beta)\cos\delta\,\sin\omega'_{ss} + \omega'_{ss}\sin(\lambda-\beta)\,sin\delta]$$

Where,

$$\delta = 23.45° \cdot \sin(360° \cdot \frac{284+n}{365})$$

$$\omega'_{ss} = \min\{cos^{-1}[-\tan\delta\tan\lambda], cos^{-1}[-\tan\delta\tan(\lambda-\beta)]\}$$

$$\theta = \frac{2\pi(n-79.7)}{365.242}$$

$$\left(\frac{r_0}{r}\right)^2 = E_K = 0.032359\sin(\theta) + 0.000086\sin(2\theta)$$
$$-0.008349\cos(\theta) + 0.000115\cos(2\theta) + 1.00042$$

However, after trying these three formulas and actually calculating with them, we found out Klein's formula is the most legitimate one, and we will further use his formula in our methodology.

Methodology:

Using the Klein formula and substituting in variables such as declination, latitude and hour angle of the sun, a polynomial is obtained with only β, the panel tilt angle and n, the number of the day left unknown.

Adding up the the sum, as n goes from 1 to 365, of the polynomial, the expression of annual solar radiation is obtained. Using the idea of differentiation, the vertex of the function can be calculated. However, as the polynomial is too long for manual calculation, we used software to help us with the solution.

Findings:

Fixed solar panel:

	latitude	Tilt angle
Sapporo	43.1°	41.0°
Tokyo	35.7°	33.7°
Aomori	40.8°	38.3°
Sendai	38.3°	36.4°
Moscow	55.8°	51.7°
Beijing	40.0°	38.26°
Guangzhou	23.1°	22.5°
Kuala Lumpur	3.1°	3.5°

Adjust twice a year：

Latitude: 40°N, 7.5% more solar power input

<table>
<tr><th></th><th>Once</th><th>Twice</th></tr>
<tr><td rowspan="2">Tilt angle</td><td rowspan="2">38.26°</td><td>15.5°</td></tr>
<tr><td>59.9°</td></tr>
<tr><td>Yearly insolation/unit</td><td>344.22</td><td>370.23</td></tr>
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Considering ground reflection:

City	Latitude	Tilt angle
Sapporo	43.1°	52.3°
Tokyo	35.7°	46.4°
Aomori	40.8°	50.5°
Sendai	38.3°	48.6°
Moscow	55.8°	60.5°
Beijing	40.0°	49.9°
Guangzhou	23.1°	34.2°
Kuala Lumpur	3.1°	6.7°

Conclusion:

Given the latitude of the location, the theoretical optimum panel tilt can be calculated. Other than a fixed solar panel, it is feasible to adjust the tilt angle twice a year which will result in increase of solar power input. When considering ground reflection, the calculated panel tilt increases compared with considering beam radiation only.