Investigating the Impact of Ground Albedo on the Performance of PV Systems

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Background Research

- UK PV installed cumulative capacity reached up to 5 GW.

- Facilities for electricity generation from solar PV in U.K
  - Domestic
  - Building mounted
  - Ground mounted
  - Building Integrated Photovoltaic's (BIPV)

- Planning and design of solar PV system
  - type of PV modules
  - ground albedo (ground reflectance)
  - building azimuth
Earth naturally reflects 8% of total solar radiation received from Sun

White surface has an albedo of 1
Black surface has an albedo of 0

Usual approach
- 0.2 for temperate and humid tropical localities
- 0.5 for dry tropical localities
In some locations, ground reflected radiation may reach up to 100W/m².

Researchers proved that a constant value of 0.2 is too high and unsatisfactory. Should be abandoned.

Accurate estimation of ground reflected radiation is essential with a good knowledge of foreground.

<table>
<thead>
<tr>
<th>Surface</th>
<th>Albedo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrugated roof</td>
<td>0.1 - 0.15</td>
</tr>
<tr>
<td>Colored paint</td>
<td>0.15 - 0.35</td>
</tr>
<tr>
<td>Trees</td>
<td>0.15 - 0.18</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.05 - 0.2</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.25 - 0.7</td>
</tr>
<tr>
<td>Grass</td>
<td>0.25 - 0.3</td>
</tr>
<tr>
<td>Ice</td>
<td>0.3 - 0.5</td>
</tr>
<tr>
<td>Red/Brown roof tiles</td>
<td>0.1 - 0.35</td>
</tr>
<tr>
<td>Brick/Stone</td>
<td>0.2 - 0.4</td>
</tr>
<tr>
<td>Oceans</td>
<td>0.05 - 0.1</td>
</tr>
<tr>
<td>Old snow</td>
<td>0.65 - 0.81</td>
</tr>
<tr>
<td>White paint</td>
<td>0.5 - 0.9</td>
</tr>
<tr>
<td>Fresh Snow</td>
<td>0.81 - 0.88</td>
</tr>
</tbody>
</table>

Albedo values of different kind of surfaces.
Radiation Exchange

1. Black body radiation

\[
\frac{q_{\text{net exchange}}}{A} = \sigma F_{1-2}(T_1^4 - T_2^4)
\]

2. Perpendicular surfaces

\[
F_{1-2} = \frac{1}{\pi L} \left[ L \tan^{-1}\left(\frac{1}{L}\right) + N \tan^{-1}\left(\frac{1}{N}\right) - \sqrt{N^2 + L^2} \tan^{-1}\left(\frac{1}{\sqrt{N^2 + L^2}}\right) \right]
+ \frac{1}{4} \ln \left[ \frac{(1+L^2)(1+N^2)}{1+L^2+N^2} \right] + L^2 \ln \left[ \frac{L^2(1+N^2+L^2)}{(1+L^2)(1+N^2)} \right] + N^2 \ln \left[ \frac{N^2(1+N^2+L^2)}{(1+N^2)(N^2+L^2)} \right]
\]

where, \( N = \frac{c}{b} \) and \( L = \frac{a}{b} \)

- Restriction:
  - ground horizon and PV module are perpendicular to each other
  - surface share a common edge
3. Inclined/tilted surfaces

\[
F_{1-2} = -\frac{\sin 2\Phi}{4\pi B} \left[ AB \sin \Phi + \left( \frac{\pi}{2} - \Phi \right) \left( A^2 + B^2 \right) + B^2 \tan^{-1} \left( \frac{A - B \cos \Phi}{B \sin \Phi} \right) + A^2 \tan^{-1} \left( \frac{B - A \cos \Phi}{A \sin \Phi} \right) \right]
\]
\[
+ \frac{\sin^2 \Phi}{4\pi B} \left( \frac{2}{\sin^2 \Phi} - 1 \right) \ln \left[ \frac{(1 + A^2)(1 + B^2)}{1 + C} \right] + B^2 \ln \left[ \frac{B^2(1 + C)}{C(1 + B^2)} \right] + A^2 \ln \left[ \frac{A^2(1 + A^2)^{\cos^2 \Phi}}{C(1 + C)^{\cos^2 \Phi}} \right]
\]
\[
+ \frac{1}{\pi} \tan^{-1} \left( \frac{1}{B} \right) + \frac{A}{\pi B} \tan^{-1} \left( \frac{1}{A} \right) - \frac{\sqrt{C}}{\pi B} \tan^{-1} \left( \frac{1}{\sqrt{C}} \right) + \frac{\sin \Phi \sin 2\Phi}{2\pi B} AD \left[ \tan^{-1} \left( \frac{A \cos \Phi}{D} \right) + \tan^{-1} \left( \frac{B - A \cos \Phi}{D} \right) \right]
\]
\[
+ \frac{\cos \Phi}{\pi B} \int_0^B \sqrt{1 + z^2} \sin^2 \Phi \left[ \tan^{-1} \left( \frac{z \cos \Phi}{\sqrt{1 + z^2} \sin^2 \Phi} \right) + \tan^{-1} \left( \frac{A - z \cos \Phi}{\sqrt{1 + z^2} \sin^2 \Phi} \right) \right] dz
\]

- **Restriction:**
  - last part of the equation is unsolvable integral
  - surface share a common edge

- **Only solution to solve this equation by partial analytical and partial numerical.**
Methodology

Case study: PV facade of Edinburgh Napier University’s Merchiston campus building.
- Google earth software.
- Various type of ground surfaces (road, grass, tree-tops and roof).
- Eye altitude of 250m.
- Total selected land area 14,692m² (road area 3041m², roof area 3766m², and grass and tree-top area 7885m²).
- Number of surface patches, each having its own albedo value.

- Numerical approach incorporated to obtain the amount of reflected-radiation from ground to PV facade.

- VBA code was written within an MS-Excel environment.
Liu and Jordan proposed daily reflected irradiation from ground = $\rho G \sin^2(\beta/2)$

The horizontal irradiation is assumed as 800 W/m²

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Conditions</th>
<th>Radiation Exchange</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$\rho = 0.2$ constant for complete PV façade area i.e. 14682m²</td>
<td>45.2W/m²</td>
</tr>
<tr>
<td>2</td>
<td>Actual values of $\rho$, (grass 0.24, road 0.2 and red/brown roof tiles as 0.35)</td>
<td>61.8W/m²</td>
</tr>
<tr>
<td>3</td>
<td>Roof tops are painted with white cool paint $\rho = 0.7$</td>
<td>92W/m²</td>
</tr>
</tbody>
</table>
Researchers also proved that,

- White elastomeric coatings of 0.72 albedo value can be 45°C cooler than black coatings and 20°C cooler than grey and silver paints with albedo of 0.3 and 0.5.

- White painted roads have albedo 0.55 while unpainted road exhibited an albedo of 0.15.

- Cool painted tiles can also have high solar reflectance.

Such paints or high reflective building materials applied to surfaces in close visual proximity of the PV façade may thus be used effectively to enhance ground-reflected radiation.
Applying white paint to 25% of total ground area, will generate an excess 626 kWh/annum of solar electricity.

Considering cost of electricity £0.12/kWh, will provide an extra income of £75/annum.

Life-time cost of paint will be £393. Applying paint will result in profit of £454.

Over the 20-year life of the PV plant the extra energy generated will be 12.5 MWh.

Future work may be undertaken to explore the potential of application of such highly-reflective paints and/or building materials.
Thank You...