The quantification of shading for the built environment in South Africa

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Presentation Content

- Aim of research
- Climate maps
- Passive design
- Solar movement
- Solar protection
- Toolkit
- Conclusions

Photographs: D.C.U. Conradie, CSIR
Heating Degree Days and Cooling Degree Days

\[
D_h = \frac{\sum_{j=1}^{8760} \left( \theta_{o,j} - \theta_b \right) \left( \theta_{o,j} - \theta_b > 0 \right)}{24}
\]

\[
D_c = \frac{\sum_{j=1}^{8760} \left( \theta_b - \theta_{o,j} \right) \left( \theta_b - \theta_{o,j} > 0 \right)}{24}
\]

Where:

- \(D_h\) is the heating degree-days for a year
- \(D_c\) is the cooling degree-days for a year
- \(\theta_b\) is the base temperature. 18 °C is used.
- \(\theta_{o,j}\) is the outdoor temperature in hour \(j\)

Source: D.C.U. Conradie, CSIR
Bioclimatic design approaches (Watson & Labs)

### Identification of climate control strategies on the Building Bioclimatic Chart

**BIOCLIMATIC NEEDS ANALYSIS**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Zone(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating</td>
<td>(&lt; 19.72 °C)</td>
</tr>
<tr>
<td>Cooling</td>
<td>(&gt; 25.56 ET*)</td>
</tr>
<tr>
<td>Comfort</td>
<td>(19.72 °C – 25.56 °C ET*, 5 mm Hg – 80% RH)</td>
</tr>
<tr>
<td>Dehumidification</td>
<td>(&gt; 17 mm Hg or 80% RH)</td>
</tr>
<tr>
<td>Humidification</td>
<td>(&lt; 5 mm Hg)</td>
</tr>
</tbody>
</table>

### STRATEGIES OF CLIMATE CONTROL

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Example Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Restrict conduction</td>
<td>1-5; 9-11, 15-17</td>
</tr>
<tr>
<td>Restrict infiltration</td>
<td>1-5; 16-17</td>
</tr>
<tr>
<td>Promote solar gain</td>
<td>1-5</td>
</tr>
<tr>
<td>Restrict solar gain</td>
<td>6-17</td>
</tr>
<tr>
<td>Promote ventilation</td>
<td>9-11</td>
</tr>
<tr>
<td>Promote evaporative cooling</td>
<td>6B, 11, 13, 14A, 14B</td>
</tr>
<tr>
<td>Promote radiant cooling</td>
<td>10-13</td>
</tr>
<tr>
<td>Mechanical cooling</td>
<td>17</td>
</tr>
<tr>
<td>Mechanical cooling and dehumidification</td>
<td>15-16</td>
</tr>
</tbody>
</table>

**Victor Olgyay (1910-1970)**

"Design with Climate: Bioclimatic Approach to Architectural Regionalism”
Bioclimatic design approaches (*Climate Consultant*)

**Shading Line**
- 23.8 °C dry bulb, 315.5 Wh/m² Global Horizontal Radiation
Aim, Climate Maps, Passive Design, **Solar Movement**, Solar Protection, Toolkit, Conclusions
## Direct incident solar gain per surface

<table>
<thead>
<tr>
<th>City/Town</th>
<th>Total kWh/m² annum per building surface</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>East</td>
<td>West</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>P</td>
</tr>
<tr>
<td>Bloemfontein</td>
<td>884</td>
<td>400</td>
</tr>
<tr>
<td>Cape Town</td>
<td>776</td>
<td>350</td>
</tr>
<tr>
<td>Durban</td>
<td>493</td>
<td>219</td>
</tr>
<tr>
<td>East London</td>
<td>554</td>
<td>249</td>
</tr>
<tr>
<td>George</td>
<td>672</td>
<td>301</td>
</tr>
<tr>
<td>Johannesburg</td>
<td>759</td>
<td>340</td>
</tr>
<tr>
<td>Kimberley</td>
<td>840</td>
<td>382</td>
</tr>
<tr>
<td>Port Elizabeth</td>
<td>649</td>
<td>292</td>
</tr>
<tr>
<td>Pretoria</td>
<td>786</td>
<td>333</td>
</tr>
<tr>
<td>Forum</td>
<td>786</td>
<td>353</td>
</tr>
<tr>
<td>Pretoria Irene</td>
<td>775</td>
<td>348</td>
</tr>
<tr>
<td>Roodeplaat</td>
<td>949</td>
<td>435</td>
</tr>
<tr>
<td>Upington</td>
<td>780</td>
<td>360</td>
</tr>
<tr>
<td>Polokwane (Pietersburg)</td>
<td>780</td>
<td>360</td>
</tr>
</tbody>
</table>

The values in column **U** is for unprotected surfaces and in column **P** for correctly engineered protected surfaces.

Source: D.C.U. Conradie, CSIR
Annual and Diurnal Solar movement

Vernal and Autumnal equinox (23 September and 21 March)

Winter Solstice (21 June)

Summer Solstice (21 December)

α = azimuth clockwise from 0° (north)
γ = elevation (or altitude) in degrees above horizon.

Source: D.C.U. Conradie, CSIR
Calculate solstices and equinoxes (vertical plane at noon)

True Obliquity ($\varepsilon$) = $23^\circ 26' 17.986'' = 23.438329544^\circ$

Convert degrees, minutes seconds to decimal degrees:
$23^\circ + 26'/60 + 17.986''/3600 = 23.438^\circ$

Convert decimal degrees to degrees, minutes, seconds:
$23.438^\circ = 23^\circ + 26.28 [.438 \times 60] + 16.8 [.28 \times 60] = 23^\circ 26' 16.8''$

Source: D.C.U. Conradie, CSIR
Types of solar shading

- **Fixed**
- **Moveable (manual/automatic)**
- **Other types**
  - **External**
  - **Intermediate**
  - **Internal**
Types of solar shading


Source: D.C.U. Conradie, CSIR
Geometry of shading devices (Pretoria Forum)

Shading angles for a northern wall at latitude of $25^\circ 44' 57.11''$ S at Pretoria Forum

Source: D.C.U. Conradie, CSIR
Methodology

1) Generated typical meteorological weather files by means of *Meteonorm* for current climate and for an A2 climate change scenario by year 2100.

2) Developed a software parser to read weather files (8 760 records, 18 essential fields)

3) Calculated solar azimuth and elevation angles for each of the 8 760 hours and merged with weather file data (Large number of formulas based on NOAA and Jean Meeus algorithms)

4) The initial dataset was interpolated to a set of 35 037 points (15 minute intervals) to produce a smooth set.

5) Algorithms were developed to calculate a recommended elevation and set of azimuth angles. (Used *K-means clustering* and *Harmonic means* to achieve this)
**K-Means Clustering and Harmonic Mean**

\[ J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^{(j)} - c_j \right\|^2 \]

Where:
- \( J \) is an objective function.
- \( k \) is the number of clusters where \( k \) is predefined.
- \( n \) is the number of cases or hot points in the weather file being analysed as defined above.
- \( \left\| x_i^{(j)} - c_j \right\|^2 \) is a function to determine the Euclidian distance between case \( i \) and the centroid for cluster \( j \).

\[ H = \frac{n}{\frac{1}{x_1} + \frac{1}{x_2} + \ldots + \frac{1}{x_n}} = \frac{n}{\sum_{i=1}^{n} \frac{1}{x_i}} \left( \sum_{i=1}^{n} x_i^{-1} \right)^{-1} \]  

Where:
- \( H \) is the harmonic mean.
- \( n \) is the number of cluster points (7 has been used for the elevation and two pairs of 4 for the azimuth).
- \( x_1 \ldots x_n \) are the elevation and azimuth cluster points used in the various solar angle calculations.

Source: D.C.U. Conradie, CSIR
Structure of solar chart

- **Summer Solstice**
- **Equinoxes**
- **Analemma shapes (15 min intervals)**
- **Winter Solstice**

**Cold (Blue):**
- Drybulb temperature $\leq 18 \, ^\circ C$

**Comfortable (green):**
- Drybulb temperature $> 18 \, ^\circ C$ and Drybulb temperature $< 23.8 \, ^\circ C$

**Warm (Magenta):**
- Drybulb temperature $\geq 23.8 \, ^\circ C$ and Global Horizontal Irradiation $< 315.5 \text{ Wh/m}^2$

**Hot (Red):**
- Drybulb temperature $\geq 23.8 \, ^\circ C$ and Global Horizontal Irradiation $\geq 315.5 \text{ Wh/m}^2$
Solar charts for Kimberley

Source: D.C.U. Conradie, CSIR
Elevation and azimuth protection angles for Kimberley
Solar charts for Addis Ababa

Source: D.C.U. Conradie, CSIR
Conclusions

- South Africa has significant unrealized passive design potential.
- Solar protection/ utilisation is the single most important measure/ opportunity in South African climatic zones.
- The toolkit enables a designer during the early stages of design to quantify and recommend solar protection angles for the different facades of a building turned at any bearing (elevation and azimuth solar angles). This can be developed further by means of detailed energy simulation software (200 types known).
- The software works in the tropical band as well (Addis Ababa).
- The software has been tested in the Cofimvaba, Beaufort West Hillside Clinic and Gautrain project.
“Isti mirant stella”

These [people] look in wonder at the star
(Bayeux tapestry, circa 1070)

Thank you!