Multi-Scale Climate-Based Daylight Modelling

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“Now in the houses with a south aspect, the Sun’s rays penetrate into the porticoes in the winter, but in summer the path of the Sun is right over our heads and above the roof so that there is shade.”

Quoted by Xenophon in *Memorabilia Socrates*
Units + Measurements → Standards
The daylight factor

\[ DF = \frac{E_{in}}{E_{out}} \times 100\% \]
North-facing in St. Petersburg or South-facing in Miami?

For a given design you get the same daylight factor either way
Daylight factor

Shadow pattern

Incompatible methodologies - often giving contradictory advice
Climate-based daylight modelling (CBDM)
Why climate-based daylight modelling?

- Absolute values of luminous quantities, e.g. illuminance, luminance, etc.
- Realistic sky and sun conditions
- Founded on standardised climate files
- Allows ‘holistic’ evaluation of daylighting combined with solar shading
CIBSE standard climate file for Nottingham

Diffuse Horizontal Illuminance

Direct Normal Illuminance

CIBSE standard climate file for Nottingham
Realistic sky model patterns derived from climate data
Validation
145 measurements 11° acceptance angle
Multi-Scale Modelling

Climate-based daylight modelling (CBDM) was originally conceived as a means to predict realistic measures of daylight in buildings.

The simulation approach proved to be highly scaleable and CBDM has found applicability for a wide range of urban design issues operating across all relevant architectural scales from individual window details to entire 3D city models.
IESD projects where CBDM has been applied:

• Art Students League (New York) daylight injury study.

• Hermitage Museum (St. Petersburg) daylighting design and long-term exposure of art works.

• New York Times HQ Buildings evaluation and calibration of active daylighting systems.

• Performance of Serraglaze light redirecting material.

• Residential study for VELUX (multi-climate).

• Daylighting performance of school buildings.
Solar access study: the Arts Students League, New York

Founded in 1875, the ASL boasts an alumni list that is a veritable Who's Who in American art, from Winslow Homer and Georgia O'Keeffe to Mark Rothko, Jackson Pollock and Louise Nevelson.
The ASL artists, teachers and students, both past and present, have all placed great value in the daylight afforded by the skylights.
Proposed
Solution: Assess daylight in terms of ‘real’ illumination

Total annual illumination (TAI) is a measure of all the visible daylight energy incident on a surface.

The prediction of TAI is founded on standard climate data recorded at/near the site (NYC).

The simulation accounts for overcast and clear sky conditions, the sun and inter-reflection.
Predict total annual illumination:

(a) For existing situation.

(b) With proposed tower reflectance = 0%.

(c) With proposed tower reflectance = 50%.

Highly detailed 3D model of New York was used for the area around the ASL.
Existing

- Direct sun
- Direct sky
- Total sun
- Total sky
- Total sun + sky

KLUX h

Values:
- Direct sun: 9418
- Direct sky: 29907
- Total sun: 33774
- Total sky: 39327
- Total sun + sky: 36946
## Results

<table>
<thead>
<tr>
<th>Case</th>
<th>TAI klux-hrs</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td>36,946</td>
<td>-</td>
</tr>
<tr>
<td>Prop. (0% refl)</td>
<td>23,455</td>
<td>-36.5%</td>
</tr>
<tr>
<td>Prop. (50% refl)</td>
<td>29,972</td>
<td>-18.9%</td>
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</tbody>
</table>
Outcomes / Issues

• First (only?) example where measures predicted using CBDM have formed part of the legal agreement governing an urban development.

• Similar technique can be used to determine impact on BIPV performance due to overshadowing.

Issues such as these will come to the fore as solar-dependant technologies become more common in urban settings. Investors in these technologies will need assurance that there are reliable procedures in place to determine a just measure of financial compensation should the performance of, say, a BIPV array be degraded by later building developments.
New York Times HQ Building
Spatio-temporal dynamics of solar exposure - south facade

Temporal Map at Point X

Hours sun exposure at X: 2029hrs (59%)
Unobstructed at X: 3446hrs (100%)
Surface normal at X: altitude=0; azimuth=209

Spatial Map

Hours sun exposure at X: 3415hrs (99%)
Unobstructed at X: 3446hrs (100%)
Surface normal at X: altitude=0; azimuth=209

Temporal Map at Point X
Floor 26, South facade, view wc01

No shades
99745 fully down

Dynamic shades
ML(nits) Up Down

Illuminance station 1

Illuminance station 2

Illuminance station 3

Illuminance station 4

Hours per day equivalent [hrs]

Median illuminance [lux]

Mean luminance in the field of view [cd/m²]

ML(nits) Up Down
1E3 695 3667
2E3 1179 3184
3E3 1624 2738
4E3 2062 2300
5E3 2438 1924
Facade height available for PV: 1.75m

Glazing/ECG: 1.95m

Floor void: 0.75m

EC control point

Core workplane area

0.5m

Luminaires

2.7m

6m

Sill

ECG

FPV

Luminaires

Floor void

FPV

ECG
The ‘well-tempered’ daylit environment

[a] ‘Active’ facade

[b]

[c]

[d]

[e] ‘Passive’ facade

[f]
Strategic assessment of the potential for deployment of solar-dependant retrofit technologies
SolaVeil in Operation

| Oxford County Hall |

Pre-SolaVeil Office Environment
Window Blinds Closed, Energy Consuming Dark Environment

SolaVeil Treated Office Environment
Cool, Glare Free, Natural Daylight - Minimum Energy Requirement

Lighting Energy Savings 65%
Table 1. Facade area (m²) graded for total annual irradiation and height above ground level for the San Francisco model (see Figure 5 for image).

<table>
<thead>
<tr>
<th>Height range (m)</th>
<th>4E5 to 6E5</th>
<th>6E5 to 8E5</th>
<th>8E5 to 1.0E6</th>
<th>&gt; 1.0E6</th>
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</thead>
<tbody>
<tr>
<td>3 to 25</td>
<td>1.04E+05</td>
<td>4.96E+04</td>
<td>3.73E+04</td>
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<td>25 to 50</td>
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<td>7.68E+04</td>
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<td>50 to 75</td>
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<td>75 to 100</td>
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<td>100 to 125</td>
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<td>3.82E+03</td>
<td>6.80E+03</td>
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<tr>
<td>&gt;200m</td>
<td>2.13E+03</td>
<td>3.36E+03</td>
<td>7.01E+03</td>
<td>3.17E+03</td>
</tr>
</tbody>
</table>
Urban Climate Applications?

“The effect of geometry on the radiation balance is a key to understanding the energy balance of an urban area.”

Harman, Best & Belcher

Irradiation mapping may have application to some of the more traditional areas of urban climate research, e.g. urban heat island (UHI).
Radiation Trapping

The trapping of radiation between buildings is a major factor in the generation of the UHI.

Many radiation trapping models account for visible and longwave, but assume idealised geometries, e.g. an ‘infinite’ linear canyon.
Can Irradiation Mapping Help?

Irradiation mapping may offer the means to gain insight into radiation trapping effects for realistic urban forms.

Although IM is not able to deal explicitly with longwave exchange, this limitation might be compensated for by the capacity to elucidate factors significant for radiation trapping across large scale urban settings using the full complexity of available 3D city models.
3D London

Model supplied by Infoterra
340k polygons
Total annual irradiation
Thank you