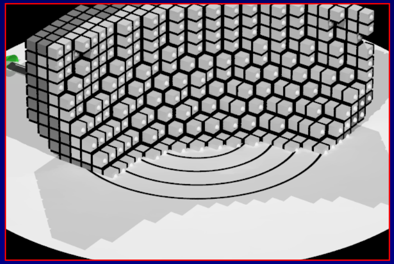
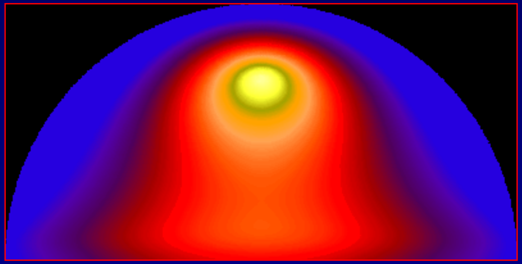
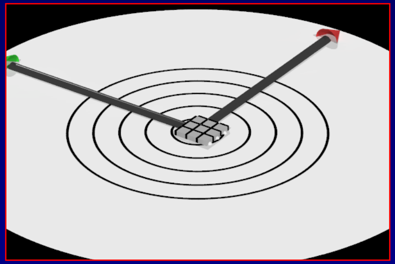
A *Radiance* Evaluation Of Parallax Errors In Sky Simulator Domes







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BACKGROUND

Quantitative daylight modelling is founded on the daylight factor approach which gives a measure of illumination under CIE standard overcast sky conditions.

Mirror-box artificial skies can reproduce reasonable approximations to the standard overcast sky luminance pattern. They provide a controlled luminous environment for daylight factor measurement in scale models.

Although it is the dominant approach, the limitations of the daylight factor paradigm are manifest:

- A single, relatively simple sky luminance pattern.
- Illumination from the sun is not considered.
- Daylight factors are invariant with respect to orientation.

Beyond Daylight Factors: Computer Simulation

Arbitrary sky and sun conditions (e.g. overcast, clear, intermediate, with/without sun, measured patterns) can be accurately modelled using computer simulation (e.g. *Radiance*).

Efficient prediction of time-varying daylight illuminance using *Radiance*-based techniques has been demonstrated by a number of researchers:

- XDAPS (Mardaljevic), end-user version DLS (Cropper).
- DAYSIM (Reinhart).

Typically compute annual time-series of daylight profiles at hour (or shorter) time-step.

Beyond Daylight Factors: Physical Modelling

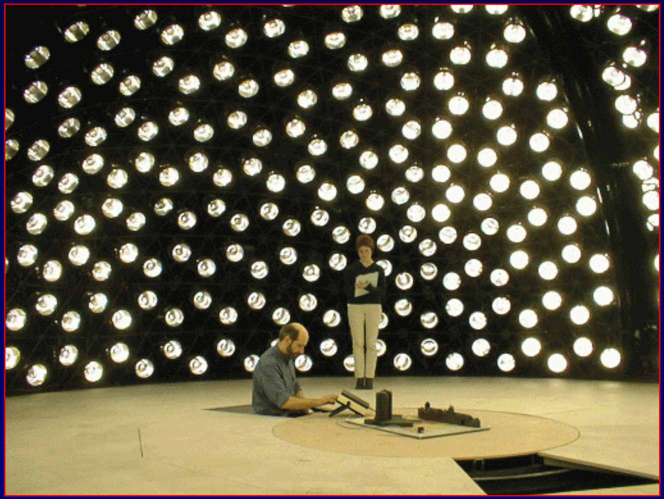
There are now a number of sky simulator domes (SSDs) that are capable, in principle, of modelling any sky luminance distribution. SSDs are typically a large number (several hundred) of independently controlled lamps arranged in a hemi-spherical pattern.

Examples include:

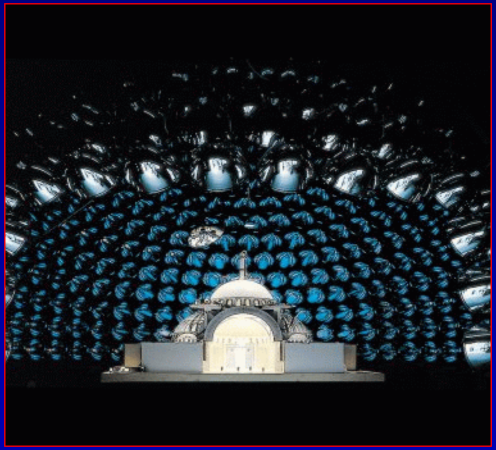
- University College London, UK (270 lamps, 5.4m).
- Cardiff University, UK (640 lamps, 8m).
- EPFL Lausanne, Switzerland (partial dome).
- Seksui Corporation, Japan (unknown).
- Bartenbach LichtLabor, Austria (393 lamps, 6.5m).

PHOTOGRAPHS OF SSDs

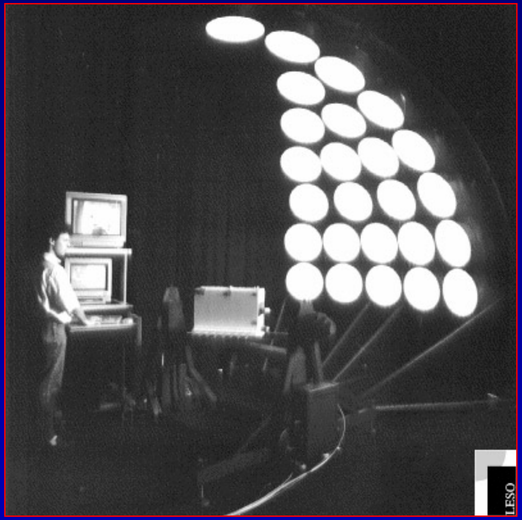
Cardiff



UCL



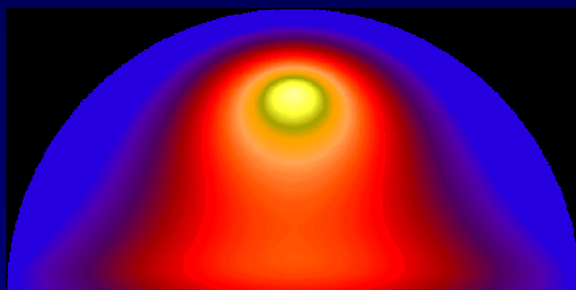
Bartenbach



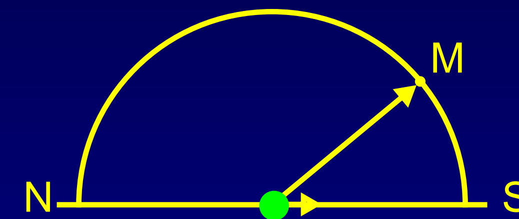
EPFL

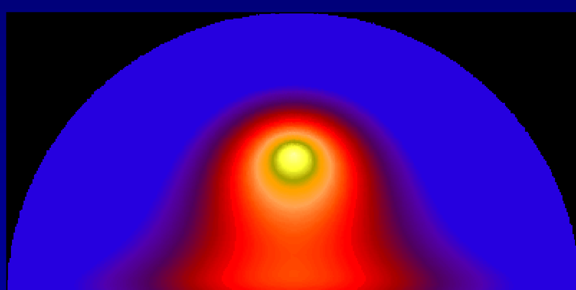
Parallax Errors (Visualization)

The sky luminance distribution is correct **only** at the origin of the (hemi)-sphere - otherwise there is a parallax error.

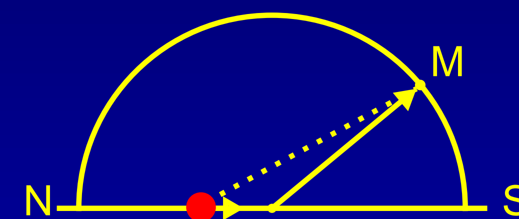


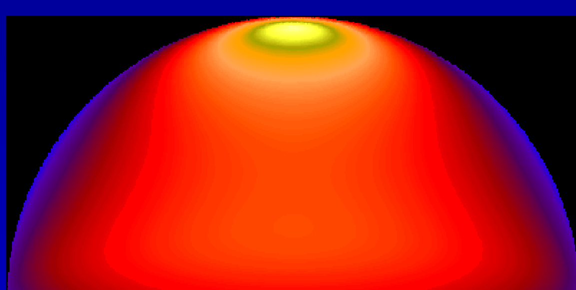
✓ ‘Correct’ luminance distribution



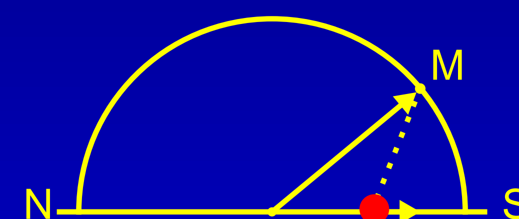


✗ Parallax error



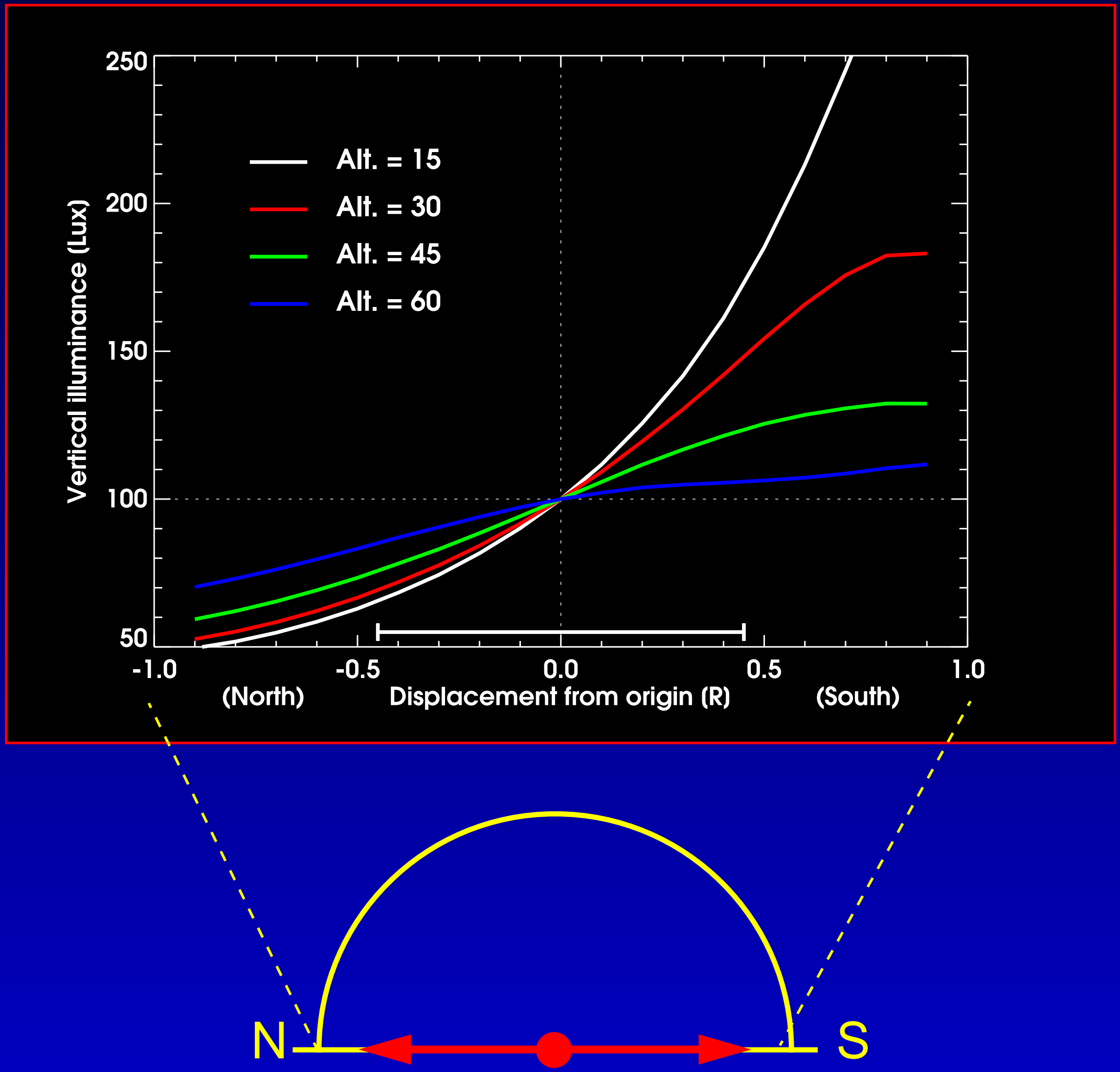


✗ Parallax error



Parallax Errors (Quantification)

Error in illuminance with displacement along N-S diameter.



Evaluation of Parallax Errors Based on 'Design Goal' for SSDs

The magnitude of the parallax error will depend on the particular luminance pattern. As an infinite number of patterns are conceivable, the following credible 'design goal' was devised:

- 'Accurate' prediction of vertical south illuminance under CIE clear sky conditions for a number of sun positions.
- Sun positions based on the annual distribution for a given locale.

The illuminance effect of the CIE clear sky only is considered - the sun position provides the locus for the clear sky luminance pattern.

RATIONALE FOR THE DESIGN GOAL

- Vast majority of building designs have vertical glazing.
- South-facing surface ‘sees’ to the circumsolar region.
- Clear sky conditions can occur for any sun position - the SSD should perform well for all of these.
- If external vertical illuminance cannot be accurately predicted, then internal illuminances will be in error.

The aim therefore was to determine, subject only to parallax errors, what volume of space in the SSD gave ‘accurate’ values of VS illuminance for all the CIE clear skies - this space would contain the scale model.

This space is called the **Parallax-Bounded Volume** (PBV).

The extent of the PBV was determined for three accuracy bands: high (±10%), medium (±25%) and low (±50%).

Evaluation Of The PBV

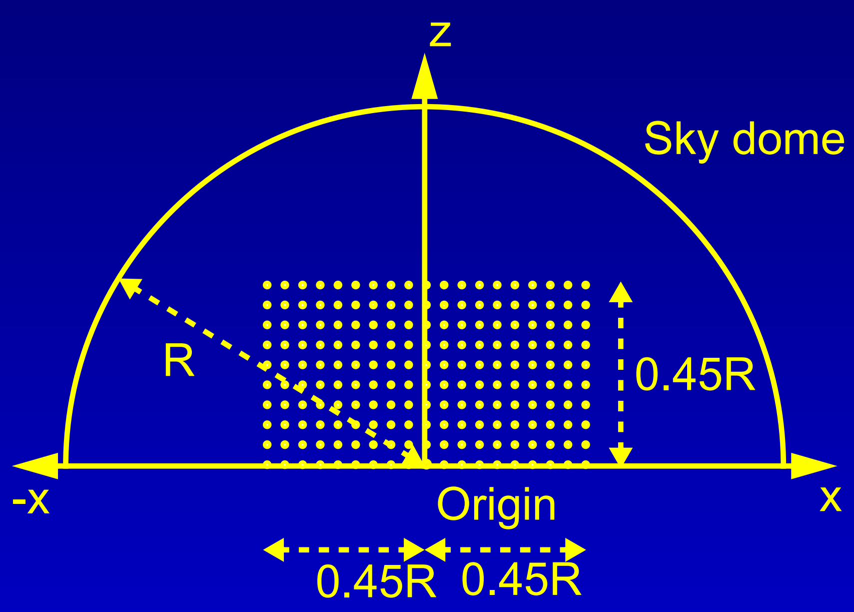
The PBV was accurately determined using computer simulation (the *Radiance* system). In fact, it could well be impossible to do this using measurements in an actual SSD because of confounding factors, principally:

- Incomplete coverage of the sky dome.
- Stability of the luminous output of the lamps.

In contrast, with simulation it was possible to specify the luminous environment - geometry and sky luminance pattern - with exact precision and compute the illuminances to an accuracy better than ±1%. Thus the PBV delineates the theoretical limits of performance of SSDs in general. The particular characteristics of an actual dome are likely to introduce other errors.

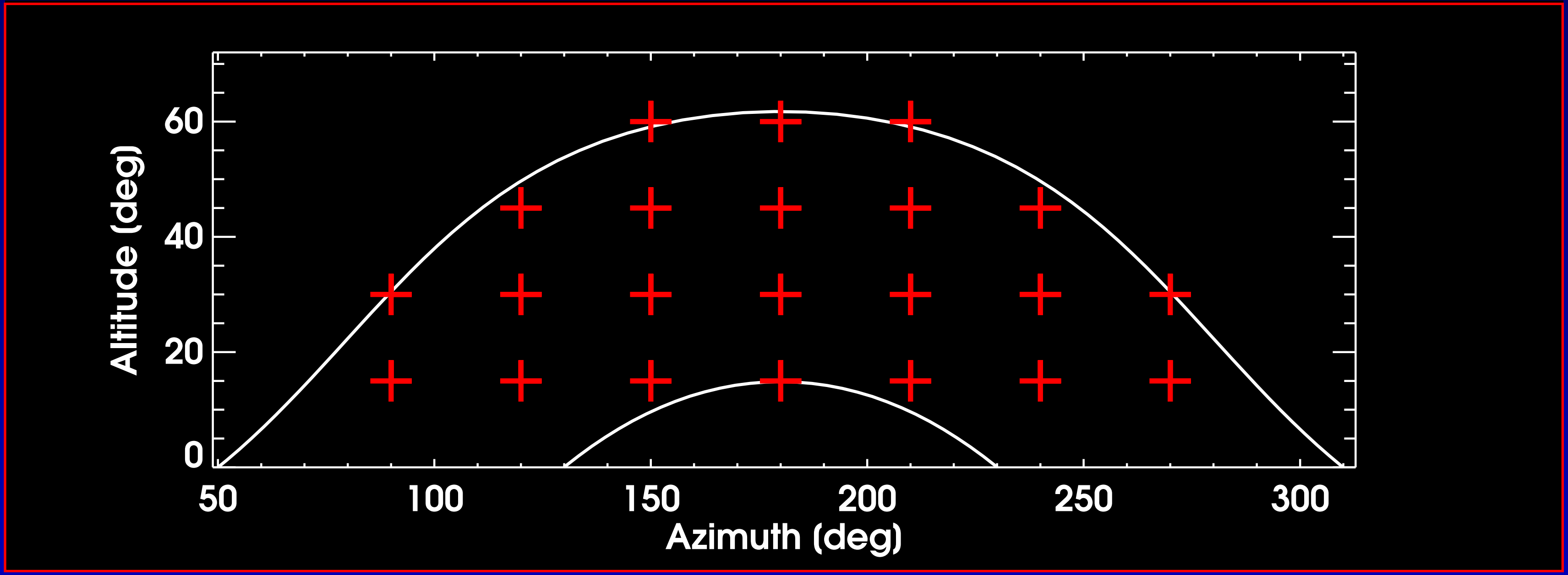
Test Volume of the SSD

The test volume was a ‘block’ that encompassed the space of the SSD tested for parallax. The dimensions were 0.9R by 0.9R by 0.45R. The base was centred on the origin and the block occupies ~17% of the hemisphere’s volume. The block was used to locate a 3D array of (3610) calculation points that were equally spaced in the x y z directions with a separation of 0.05R.



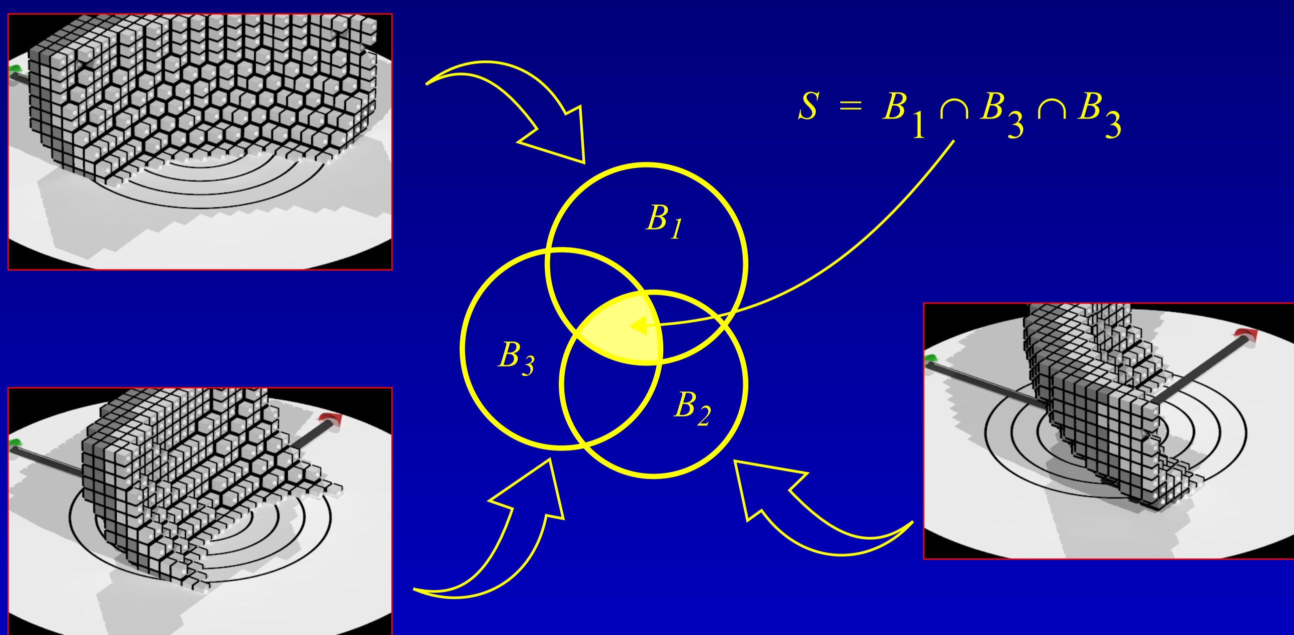
Distribution in Sun Position

The sun positions were based on the range that occur throughout the year for the Midlands (UK). A grid of 22 points that span a major part of the distribution were selected (+ symbols). These were the sun-position loci for each of the 22 CIE clear sky configurations evaluated.



Procedure

- Compute vertical south illuminance at each of the 3610 points of the test volume.
- Repeat for each of the 22 clear sky configurations.
- Determine, for each of the accuracy bands, the set of points that gave ‘accurate’ predictions for all sky configurations, i.e. a volume of intersection.



Simple and Compound Parallax Errors

SSD illuminance measurements need to be normalized using a simultaneous measurement of unobstructed horizontal illuminance.

The lamps are programmed to reproduce a particular luminance distribution (e.g. CIE clear sky) - no attempt is made to achieve a specific horizontal illuminance level.

Thus, for each sky modelled in a SSD, the horizontal illuminance that it produces is not known *a priori* and must be measured.

This measurement is called the normalization illuminance and it is applied as a factor to all the other illuminances measured in the model.

Simple and Compound Parallax Errors (cont'd)

Typically, the normalization illuminance (i.e. unobstructed horizontal illuminance) is taken simultaneously with the illuminance measurements for the scale-model.

The most practical way to achieve this is to place a photocell on top of the scale model.

If measured anywhere other than the origin, which is likely to be the case when a scale model is present, the horizontal illuminance will be subject to its own parallax error.

This will add to the already present (i.e. simple) parallax error (SPE) in the vertical illuminance giving what is referred to here as the compound parallax error (CPE).

Recap: Simple and Compound Parallax Errors

The simple parallax error (SPE) results from the difference in vertical south illuminance between the zero parallax value (i.e. at the origin) and that measured elsewhere in the dome.

The compound parallax error (CPE) is the same as the SPE, but it includes the effect of the parallax error in the measurement of the normalization illuminance.

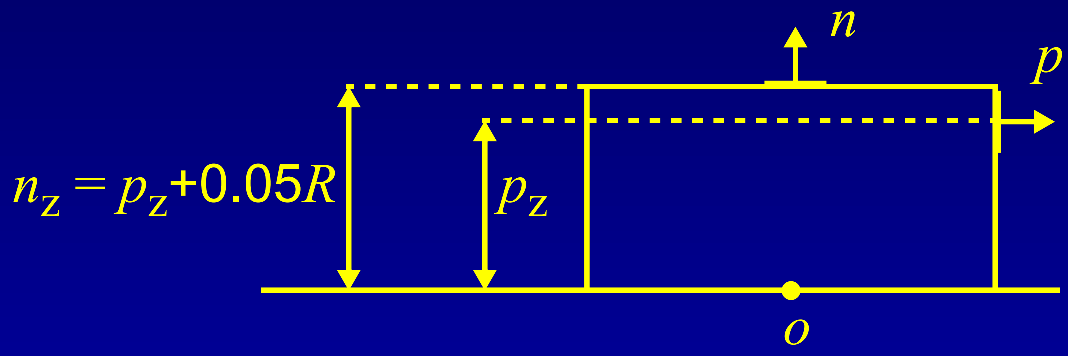
The normalization illuminance was evaluated above the origin (i.e. along the z-axis, no displacement in x-y plane).

The parallax bounded volume was determined for both the simple parallax error and the compound parallax error on the basis of the design goal.

Locating Strategies for Evaluating the CPE

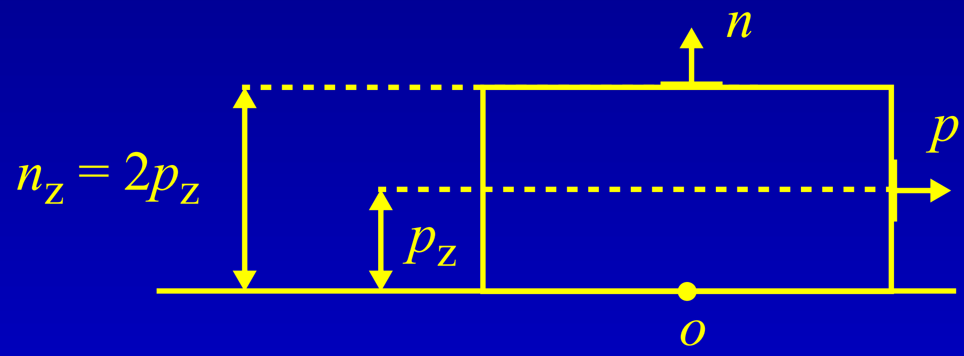
The magnitude of the CPE will depend on relative positions of the measurement points for the vertical south (p) and normalization (n) illuminances.

A



'Just above' *p*

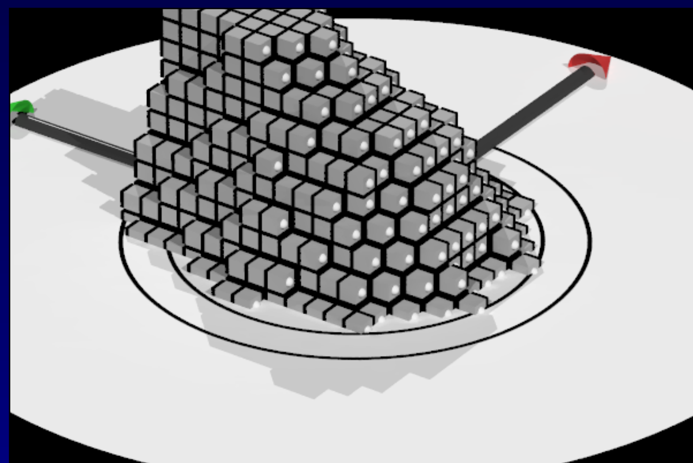
B



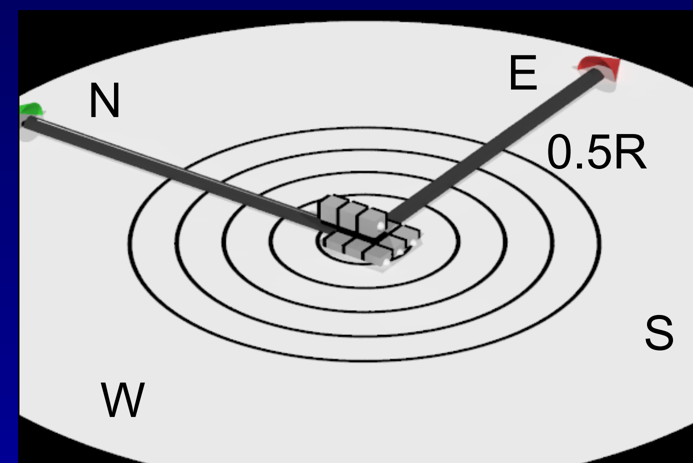
At twice the height of *p*

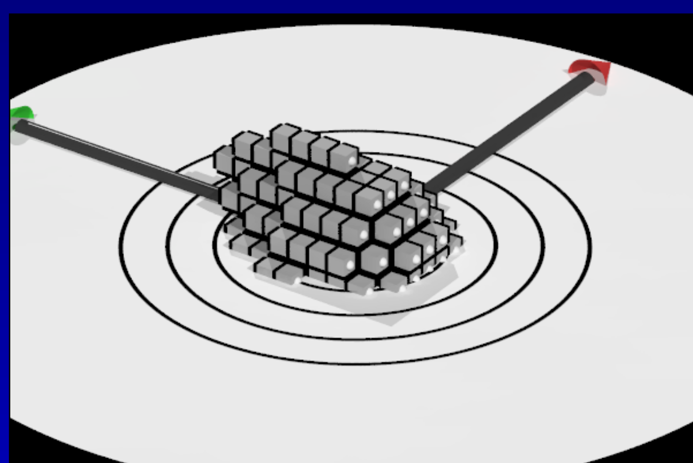
Results - Simple Parallax Error

Low ≤ 50%



High ≤ 10%

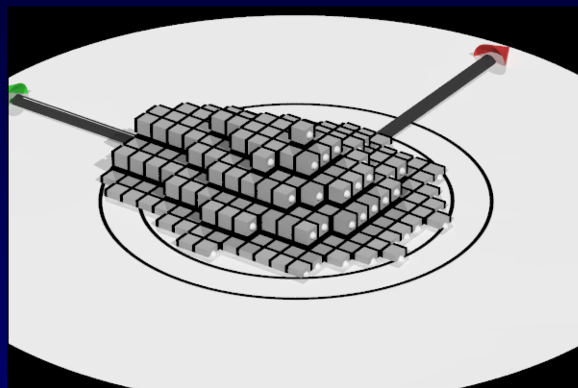
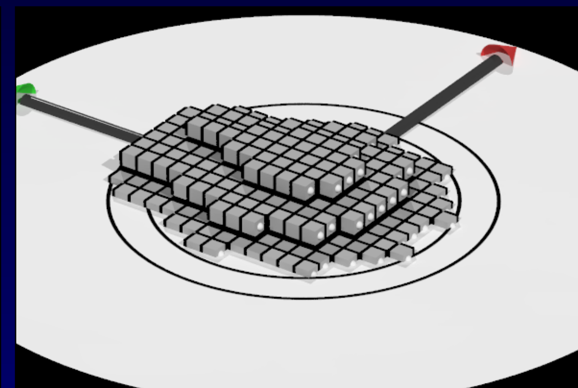




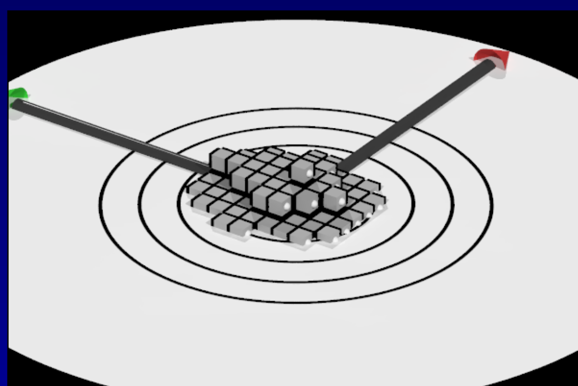
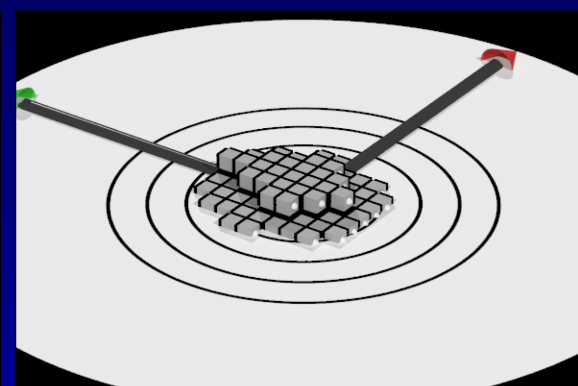
Medium ≤ 25%

Points in the plane of the base are not useable

RESULTS - COMPOUND PARALLAX ERROR

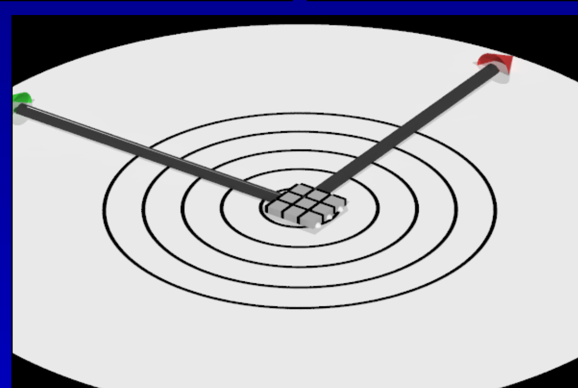
A   B

Low ≤ 50%

A   B

Medium ≤ 25%

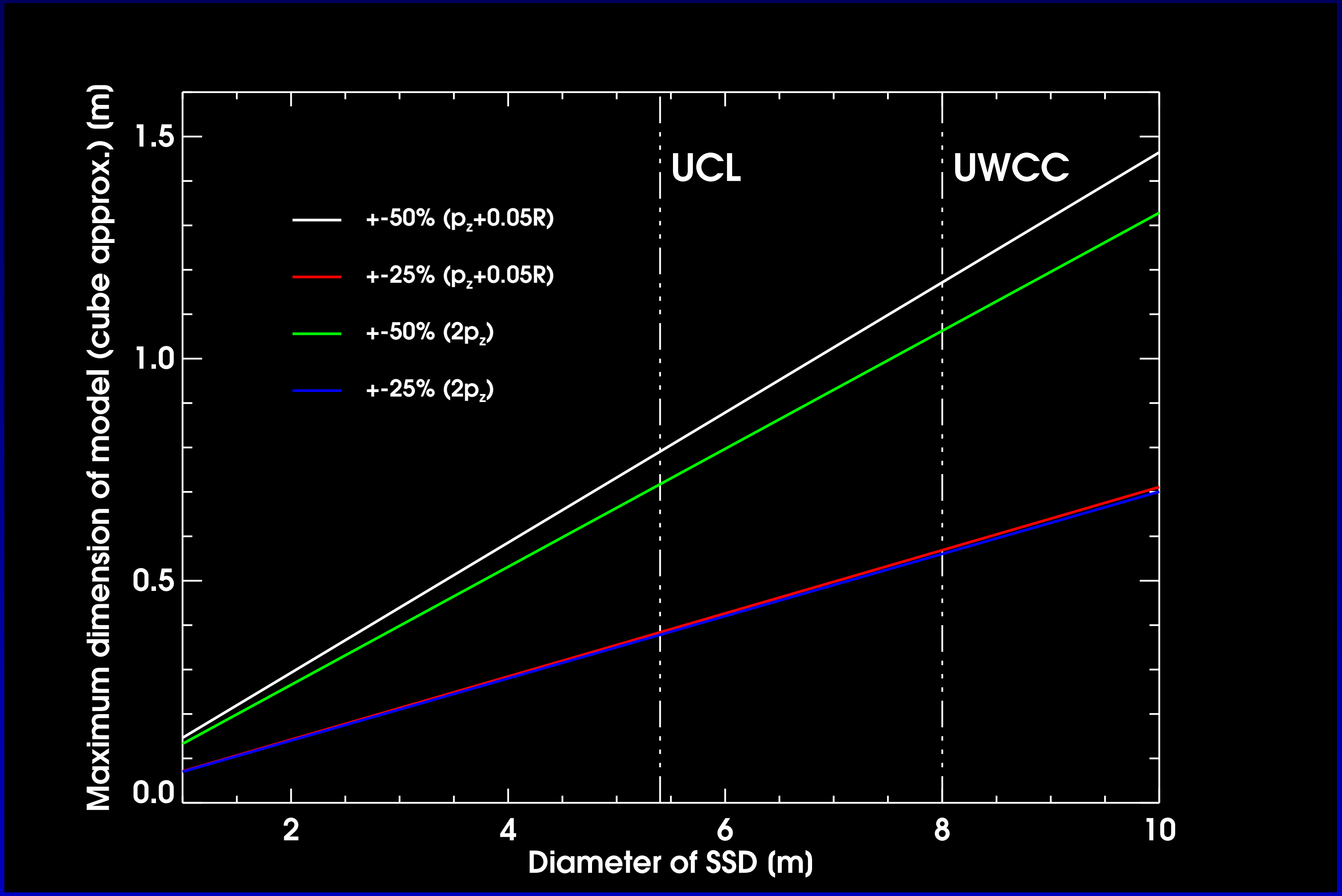
***No** points above the plane of the base*

A  B

High ≤ 10%

SCALE MODEL SIZE AND SSD DIAMETER

The maximum (linear) dimension of a scale model is related to the diameter of an actual SSD by approximating the PBV to a cube.



SUMMARY

Given the likely mode in operation of a SSD, it would appear that the PBVs for compound parallax error best describe the theoretical performance limit of SSDs. These findings have implications for the use and operation of SSDs and raise a number of issues:

- High accuracy (±10%) predictions are practically unattainable on the basis of parallax errors alone.
- The PBVs for medium accuracy (±25%) place severe limitations on scale-model dimensions, even for 8m dome at UWCC.
- Any expansion of the design goal is likely to result in further diminution of the PBV.

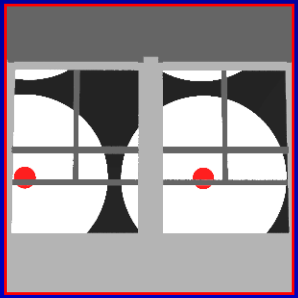
Summary (cont'd)

- Practical operation of a SSD will introduce a number of other factors that will add to the uncertainty of measurements taken from scale models. For example, less than exact reproduction of clear sky luminance patterns, incomplete sky coverage, and of course, inaccuracies in scale-model construction.
- The sky was modelled as a diffuse emitting hemisphere whereas actual SSDs are comprised of a large number of luminaires providing directional illumination. The light-field in an actual SSD therefore is likely to be more complex than that modelled here. The parallax characteristics of a particular SSD, based on luminaire photometry, could be modelled using lighting simulation if the data were available.

Special Cases

There may be instances, say for models with low internal reflectance, where the accuracy of internal illuminance measurements is more dependent on the directly visible luminance through the window than the vertical illuminance at the plane of the window.

For these special circumstances, the effective PBVs may be larger than those evaluated here. However, errors resulting from incomplete sky coverage could be quite significant when the 'view' through the window happens to include a large patch of 'black' sky between the luminaires.



'View' of incomplete sky from inside office space.

Conclusion

The theoretical limits of performance of SSDs, based on parallax errors alone, are sufficient to bring into question the practicality of SSDs as an instrument for producing benchmark, high-accuracy illuminance data under clear sky conditions. It would appear that no-better than medium-accuracy (±25%) is attainable, and that other confounding factors may make that difficult to achieve.

The accuracy of illuminance modelling in SSDs cannot be readily assumed and needs to be proven.

Note - the simulation of annual illuminance profiles using SSDs has yet to be demonstrated.

POSTSCRIPT: SIMULATION VERSUS SSDs

There are a number of other application areas where simulation-based approaches excel over scale modelling. For example, modelling irradiation in dense urban environments.

Example shows qualitative assessment of solar access using a state-of-the-art sky simulator and physical model.

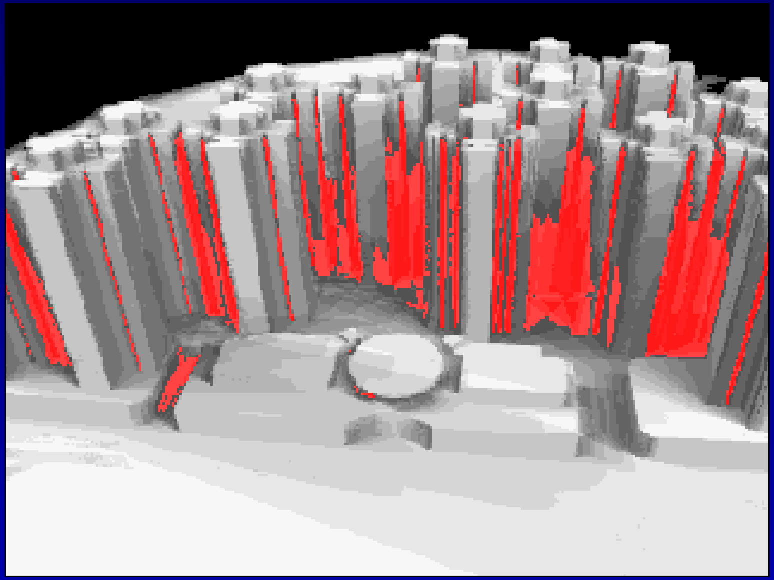
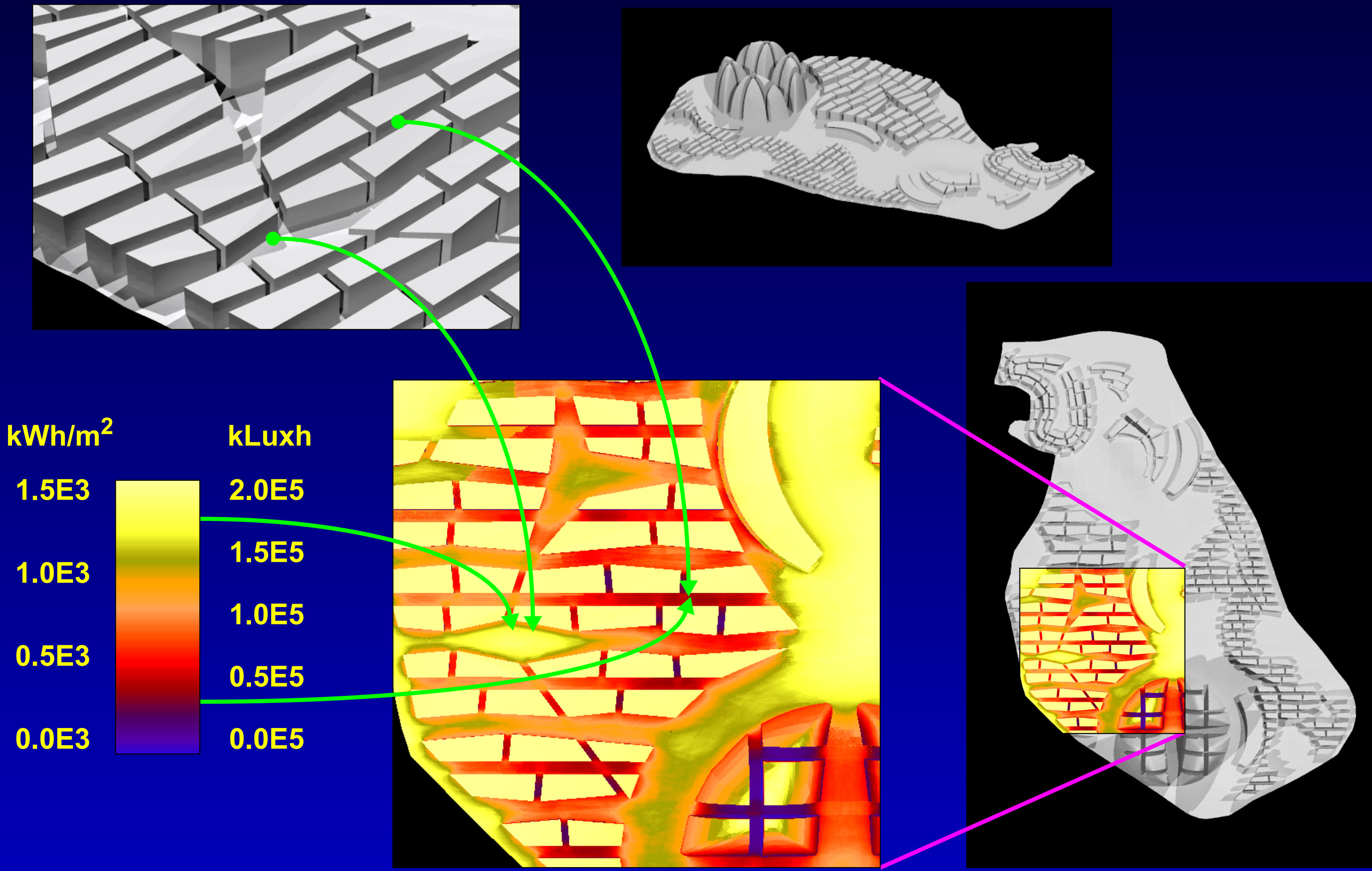


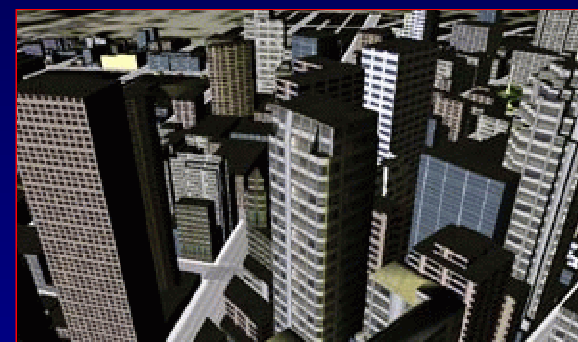
Image taken from Welsh School of Architecture website: http://www.cf.ac.uk/archi/research/envlab/skexmpl3.html

SIMULATION EXAMPLES FROM ICUE



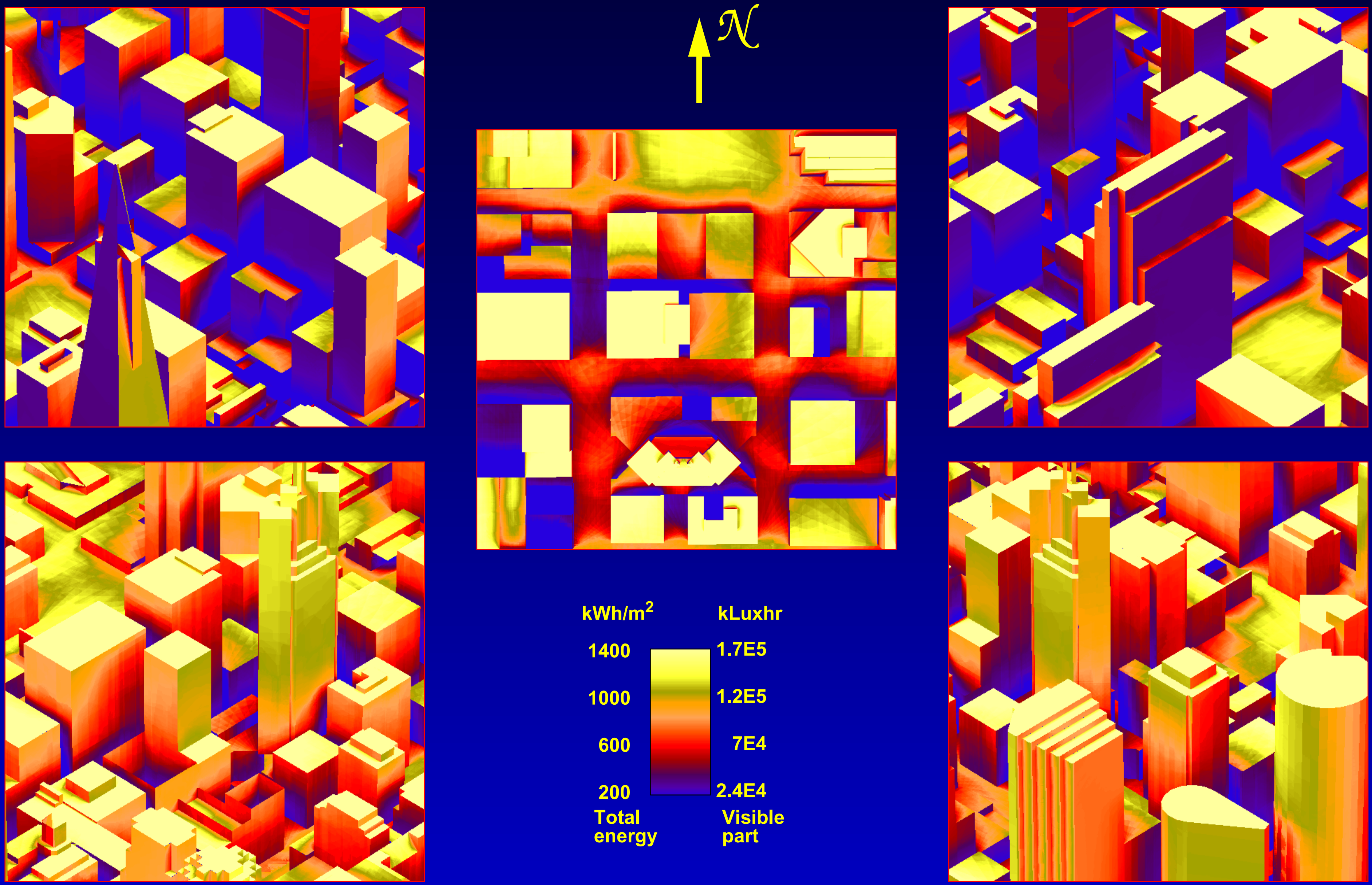
San Francisco - A Complex City Model

Dense urban environments provide the greatest challenge for simulation tools.

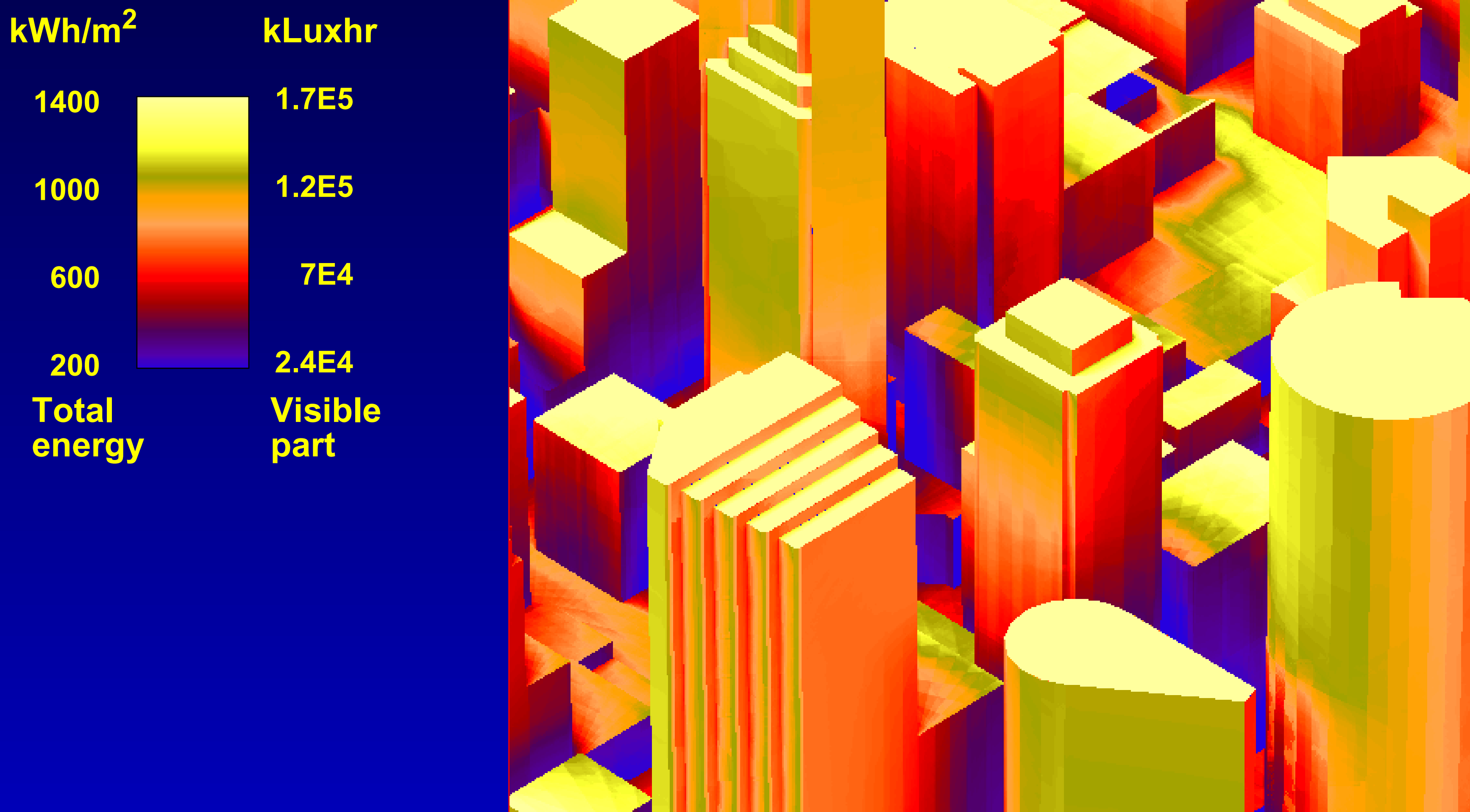


Texture mapped images of 3D city model

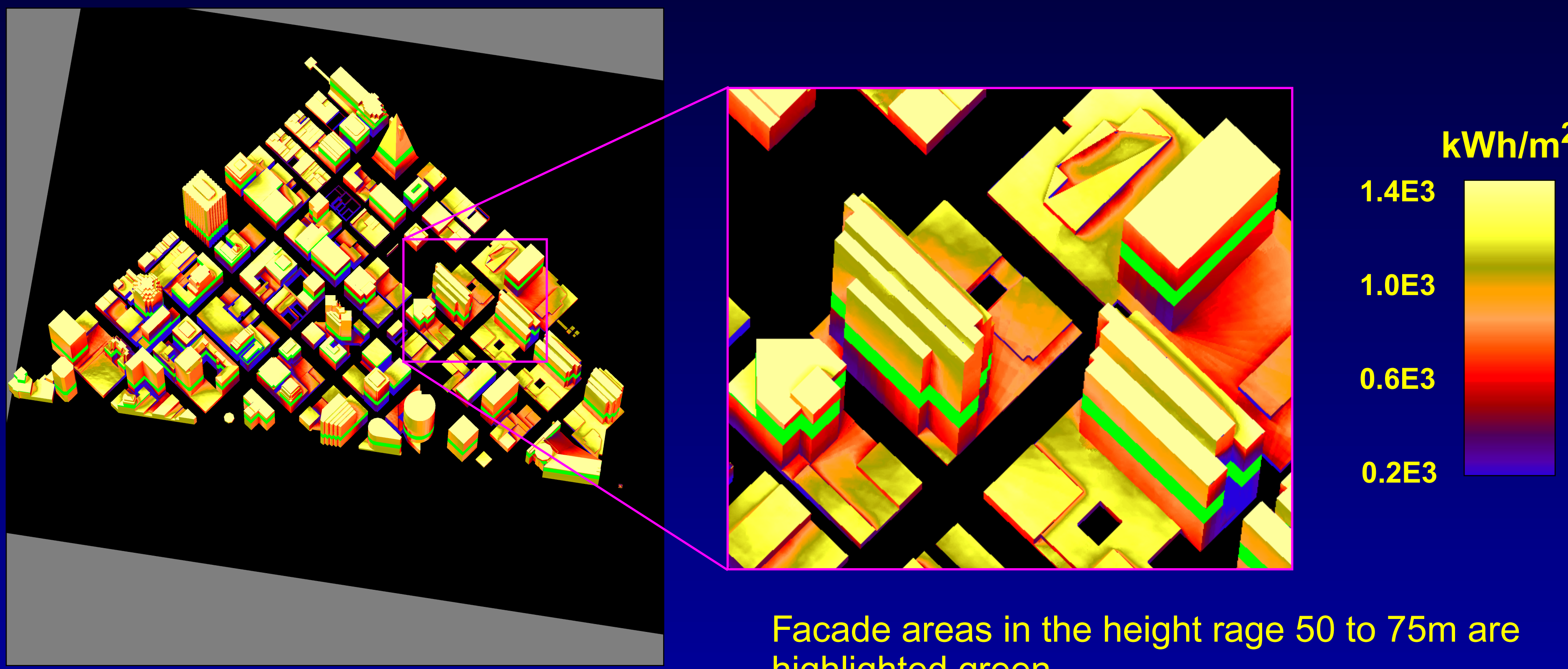
SOLAR ACCESS REVEALED



Steep gradients in solar access



Solar Access Quantified



Facade areas in the height rage 50 to 75m are highlighted green

Facade area graded for total annual irradiation and height above ground level

A Role For SSDs?

SSDs could be employed for validation exercises where they would be used to provide a controlled luminous environment rather than attempting to mimic a realistic sky luminous pattern.

The rationale here is that *Radiance* can do a better job of modelling the actual SSD (individual lamps, finite scale, etc.) than the SSD can do of modelling realistic skies.

Thus measurements in an SSD could be used to test *Radiance* models of light transmission for complex glazing materials.

(Could someone mention daylight coefficients and SSDs).