Daylighting

MSc Architecture, Energy & Sustainability
Module ADP033
Daylighting & Energy Efficient Artificial Lighting

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2012/13

Structure

I Introduction

II Daylighting Metrics

III UK Regulations

IV Daylight Design

V Dynamic Daylight Simulations

VI Axel's Dissertation

I *Introduction*

What is Daylighting?

“Daylighting is the practice of placing windows, or other transparent media, and reflective surfaces so that, during the day, natural light provides effective internal illumination.

“Within the overall architectural design of a building, particular attention is given to daylighting when the aim is to maximize visual comfort, productivity, or to reduce energy use. Energy savings from daylighting are achieved in two ways--either from the reduced use of electric lighting, or from passive solar heating or cooling.”

Wikipedia

Definitions

- Daylight
- Skylight
- Sunlight
- Natural light

Skylight = Rooflight = Toplight

Natural light = Daylight (or is it?)

Side lighting exists, but sidelights don't (they are called 'windows').

Daylight as opposed to sunlight

BUT

Daylight = sunlight + skylight

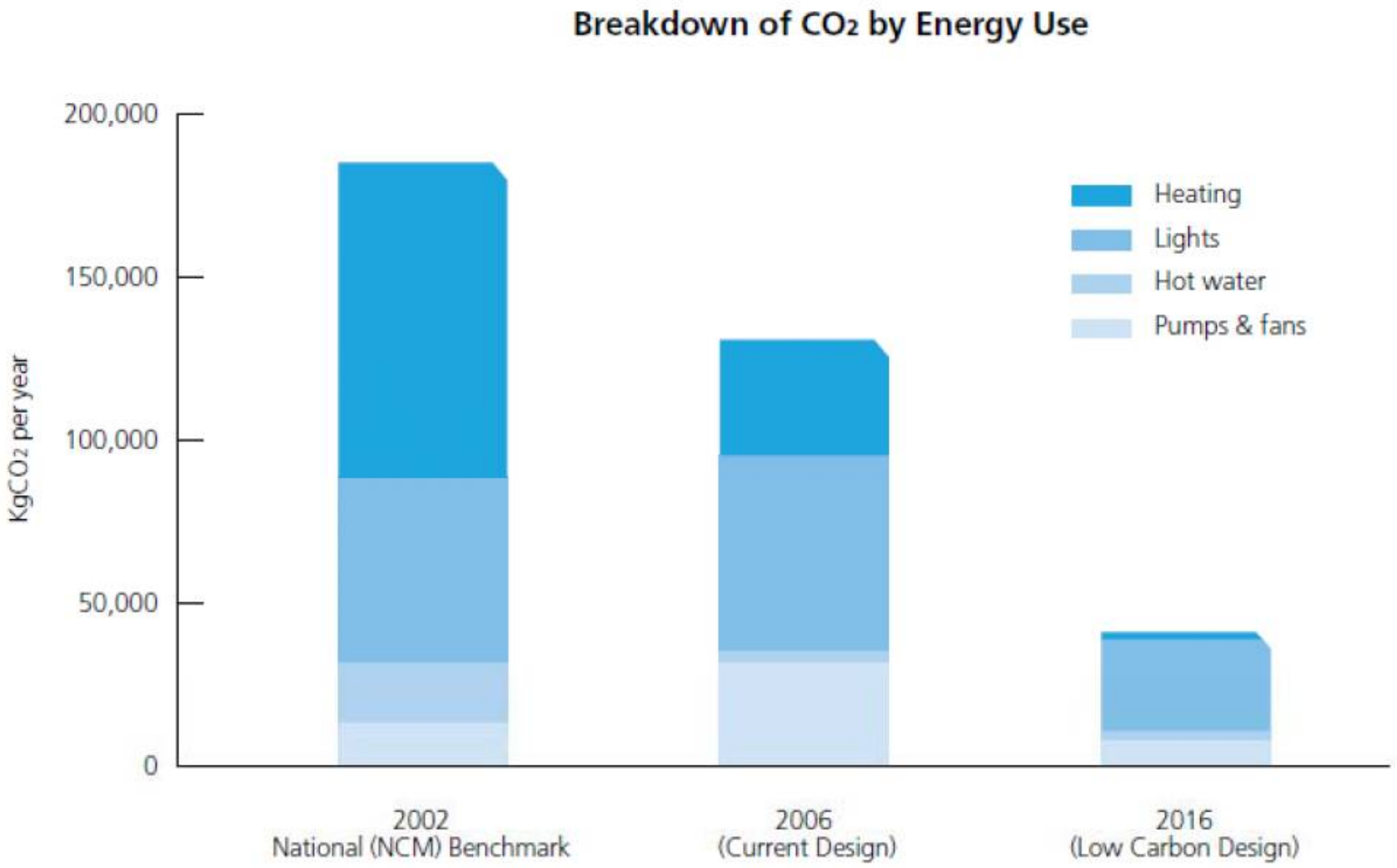
Architects of old knew how...

In this Georgian facade, windows are taller on the lower floors because they are more heavily obstructed and therefore need more glazing to let in the same amount of daylight.

... but then Edison came along.

... but then Edison came along, and the decline of daylighting began. Advances in fluorescent lighting technology meant that starting in the 1940s, buildings could be artificially lit 100% of the time.

Typical Energy Consumption



BBC

Last Updated: Thursday, 29 June 2006, 11:02 GMT 12:02 UK

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Lighting the key to energy saving

By Richard Black
Environment correspondent, BBC News website

A global switch to efficient lighting systems would trim the world's electricity bill by nearly one-tenth.

The technology exists to save energy, the IEA says

That is the conclusion of a study from the International Energy Agency (IEA), which it says is the first global survey of lighting uses and costs.

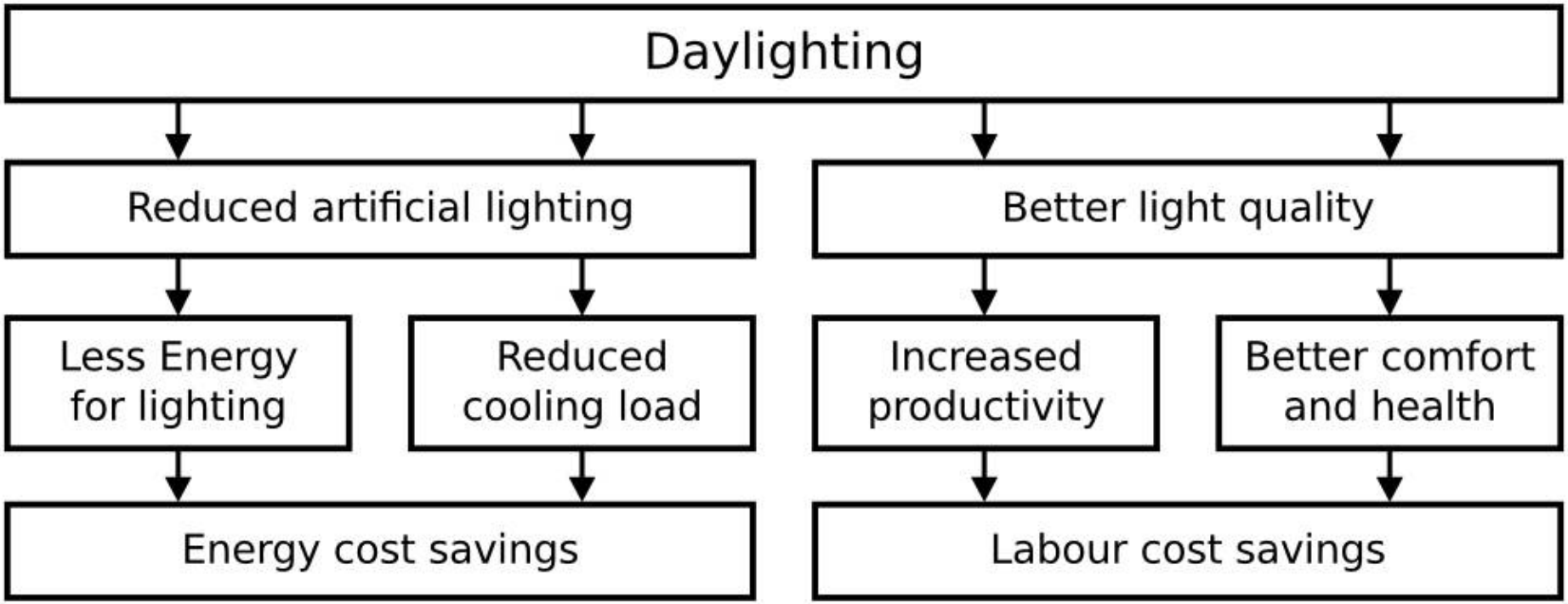
The carbon dioxide emissions saved by such a switch would, it concludes, dwarf cuts so far achieved by adopting wind and solar power.

ENERGY IN THE UK

KEY STORIES

Oil 'bonanza'
Venezuela spreads its wings on the back of high oil prices
Indian demand sparks fears
Chinese energy hunger
Sugar crop fuels Brazil's cars
Fall and rise of Brazil's biofuel
Mining nuclear

Benefits of Daylight



Recent News

FoxNews.com,
4 November 2010

Business of Technology
PLANET EARTH

Town in Perpetual Night Receives Ultimate Night Lights

By Loren Grush
Published November 04, 2010 | FoxNews.com

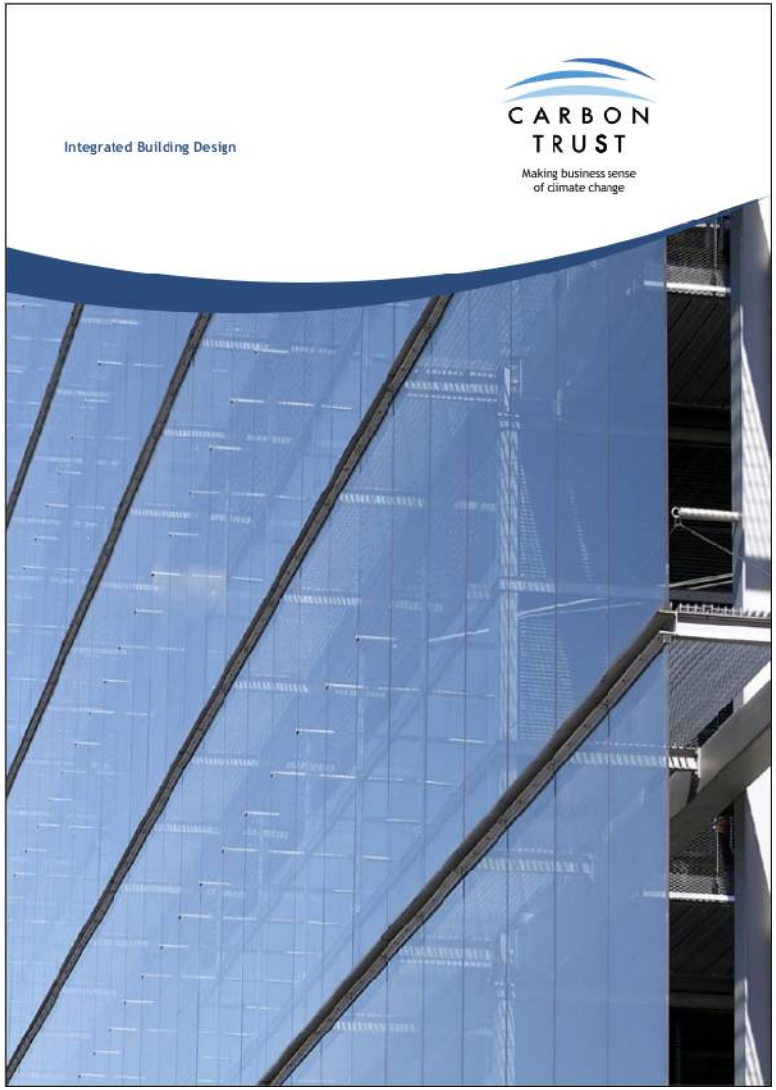
Philips

Longyearbyen, Norway, is the northernmost town on the planet, and consequently experiences four months of darkness each winter.

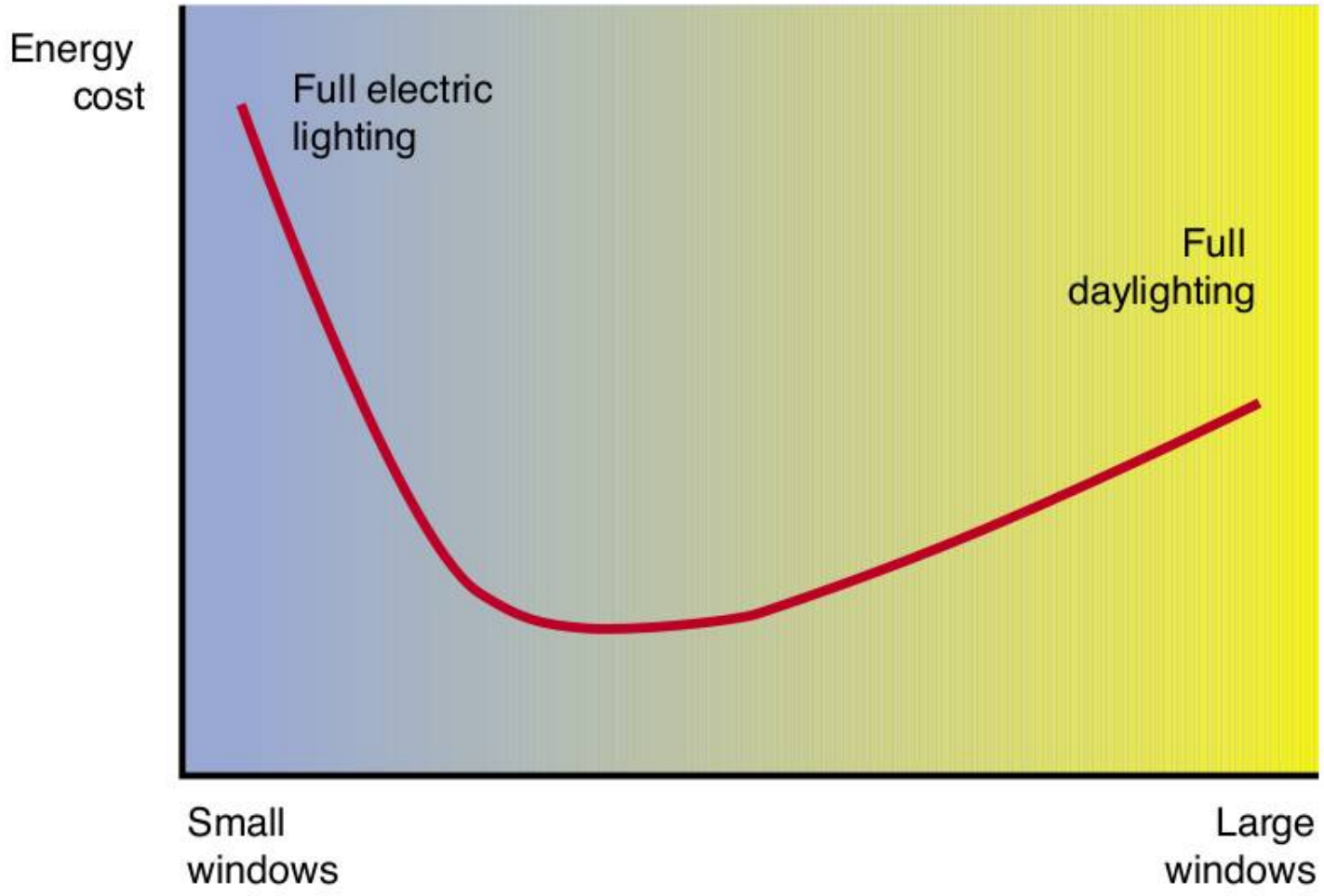
On October 26, 2,000 residents of Earth's northernmost town watched the sun set. The next time they'll see it rise? Sometime in February.

In an attempt to lighten the Norwegian town's mood about the forthcoming four months of night, Philips has launched a science experiment it calls "Wake Up the Town." And anyone who's complained about the brief daylight hours in winter will want to know how it works.

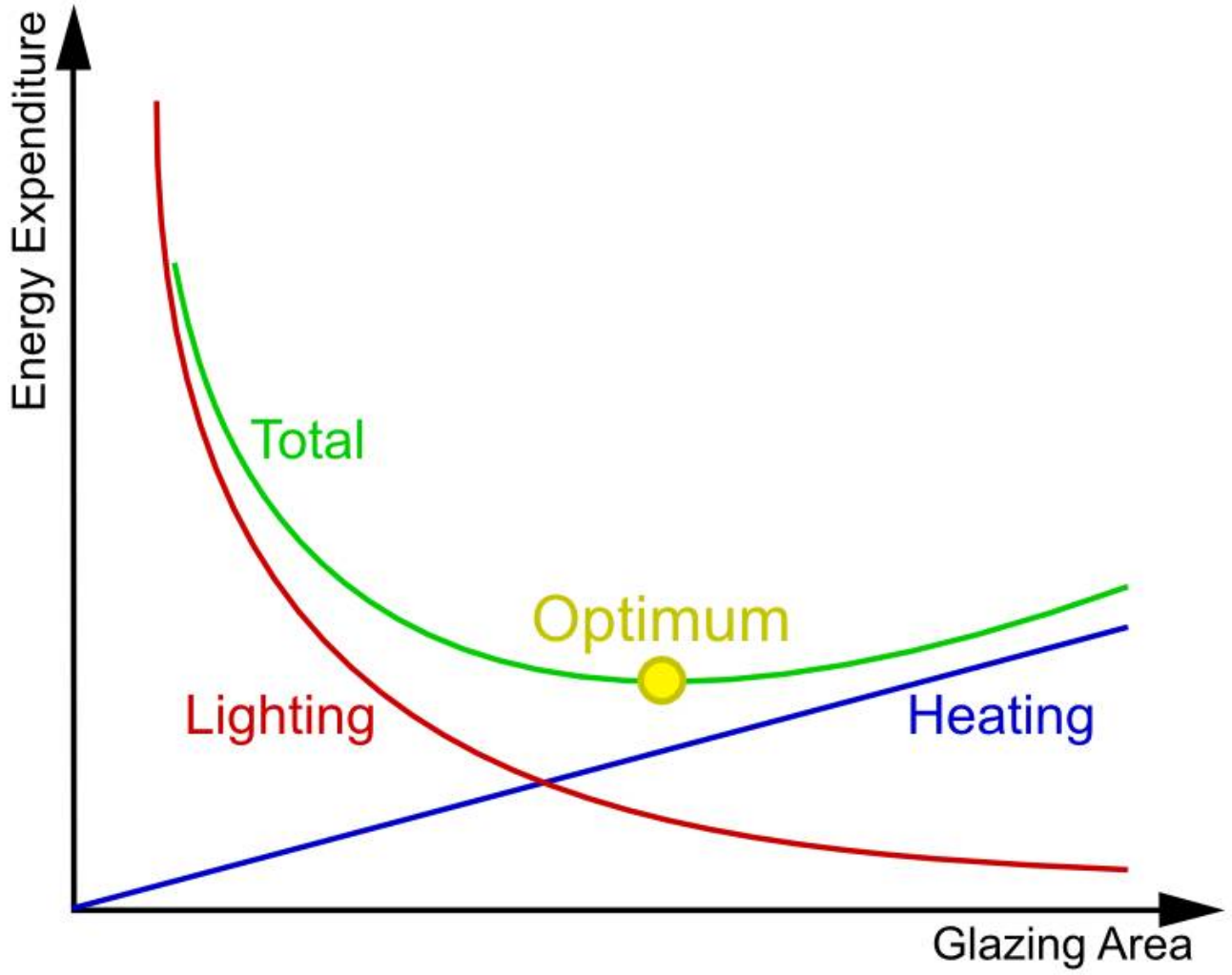
RIBA Web Site



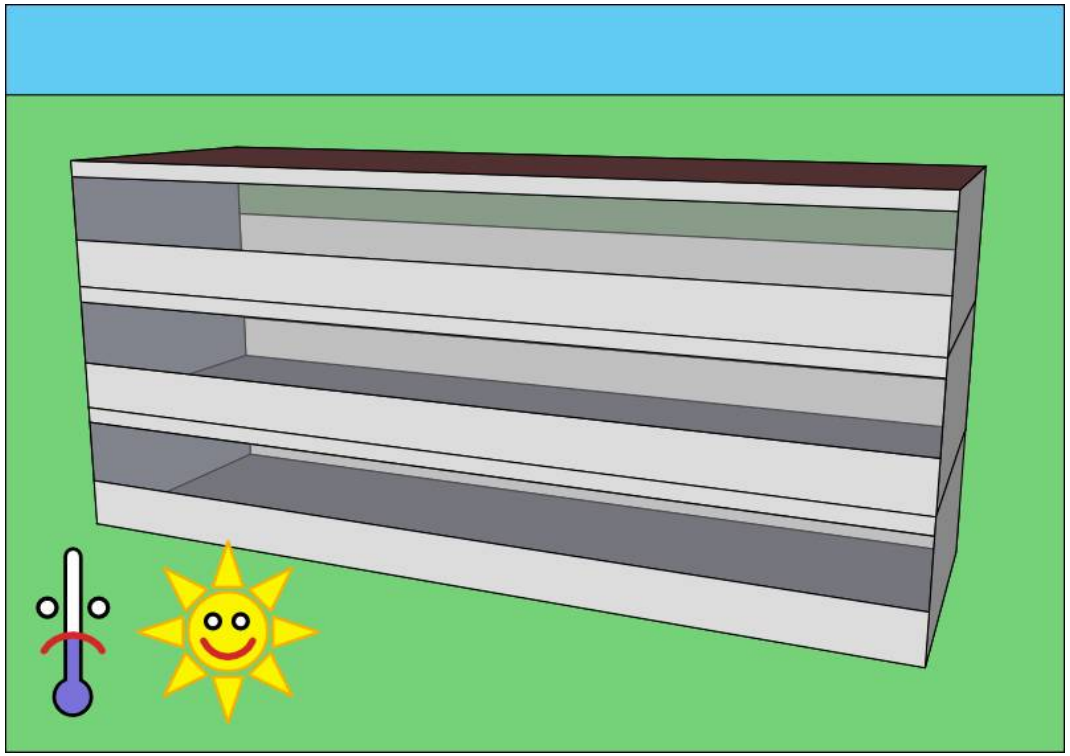
From RIBA "Daylighting"



Here's why

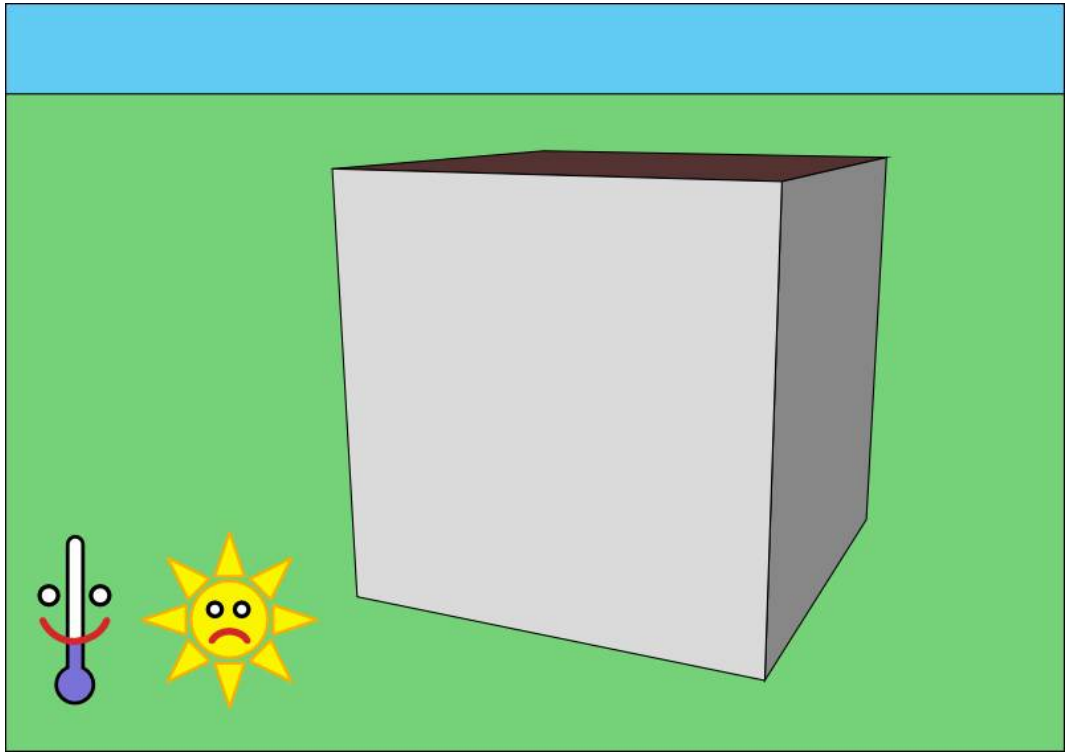

Energy Expenditure
Total
Optimum
Lighting
Heating
Glazing Area

How a Daylighting Designer Would Design a Building



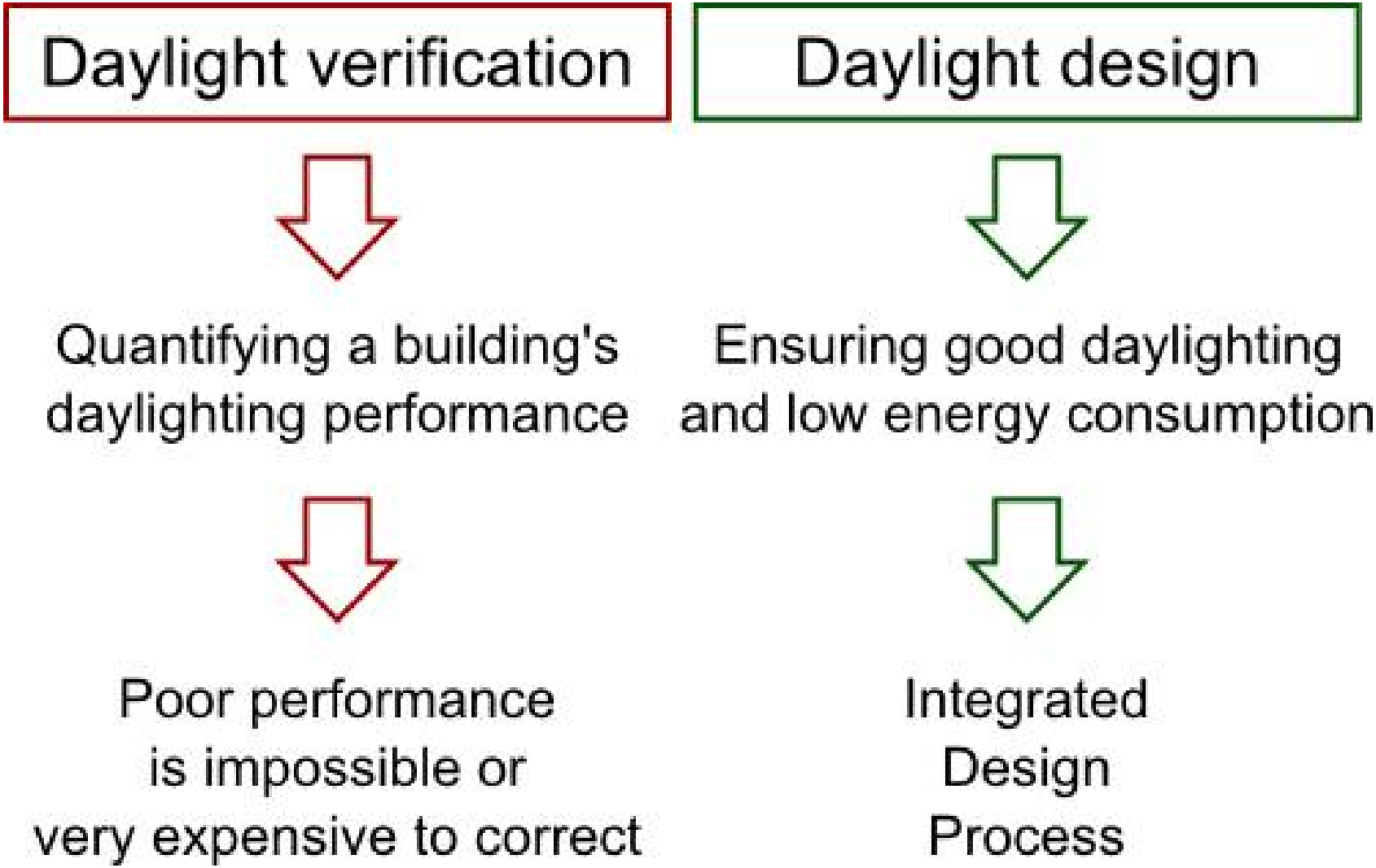
Generously sized windows could provide sufficient daylight for most of the working year...

How a Building Engineer Would Design a Building



... but Part L is all about heat losses and U-values. Good daylighting is discouraged.

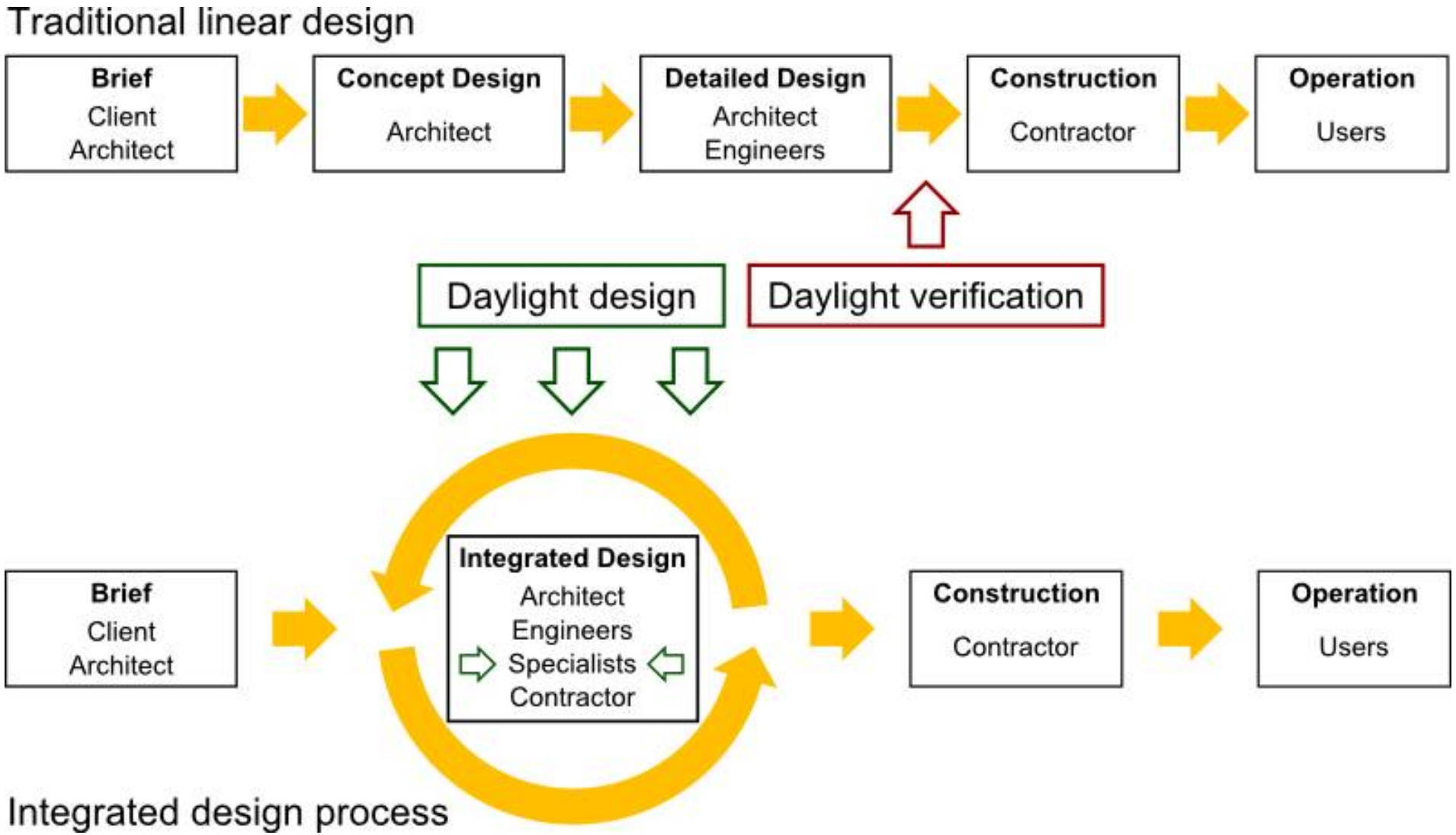
DL Design v DL Verification



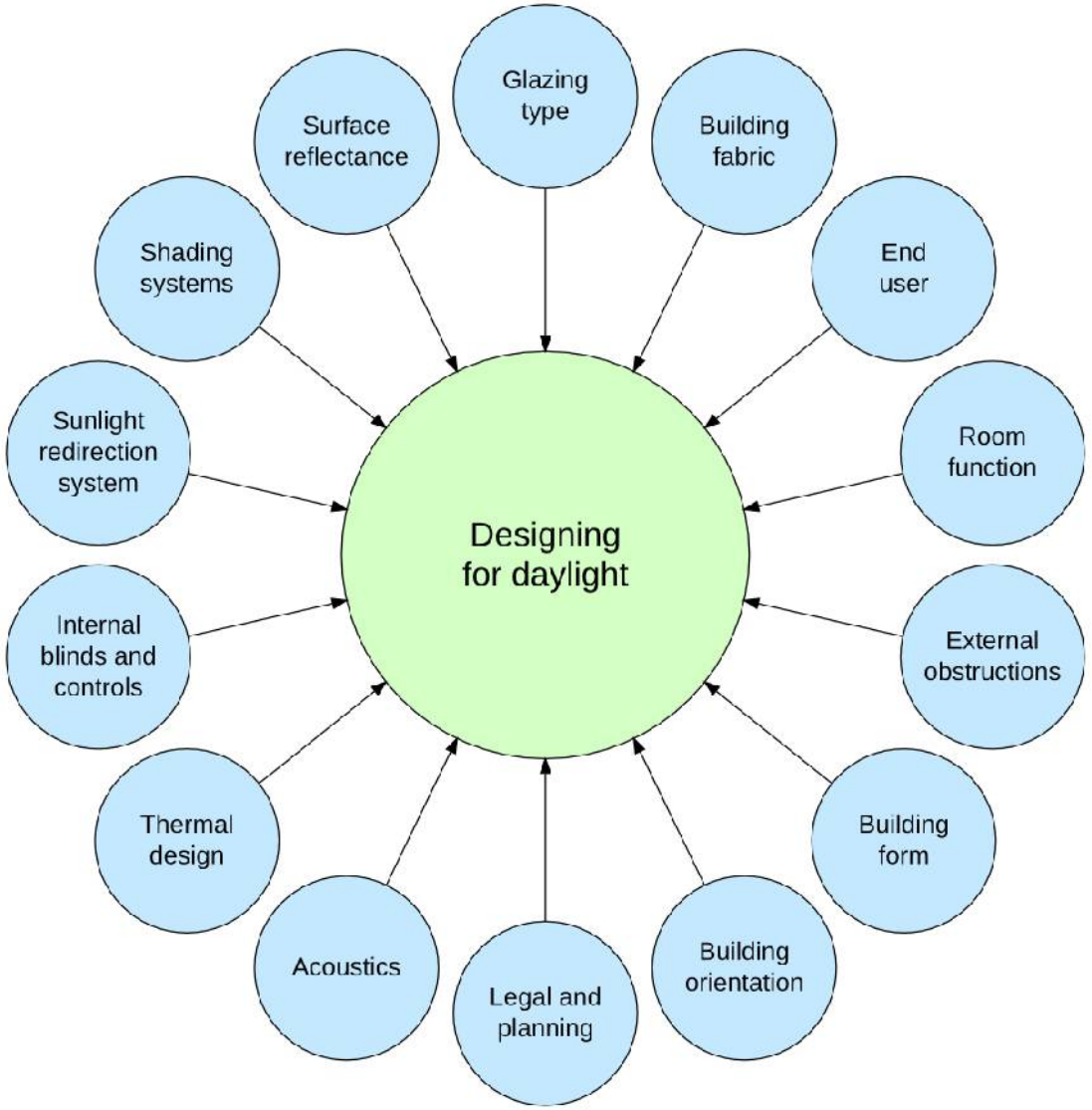
Multi-disciplinary Challenge

“Daylighting is a systems integration challenge for a multi-disciplinary design team. It must involve the participation and cooperation of the owner/tenant, architect, electrical and lighting engineer, mechanical systems engineer, interior designer, operation and maintenance staff and the construction team.” [2]

Design v Verification

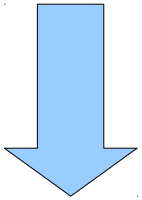


Integrated Design Process



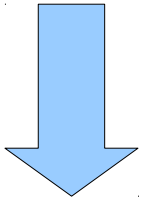
Daylighting Techniques

Simple, effective,
little to no extra cost



Site layout
Building orientation
Massing
Appropriate window areas
Simple shading

Sophisticated,
state-of-the art



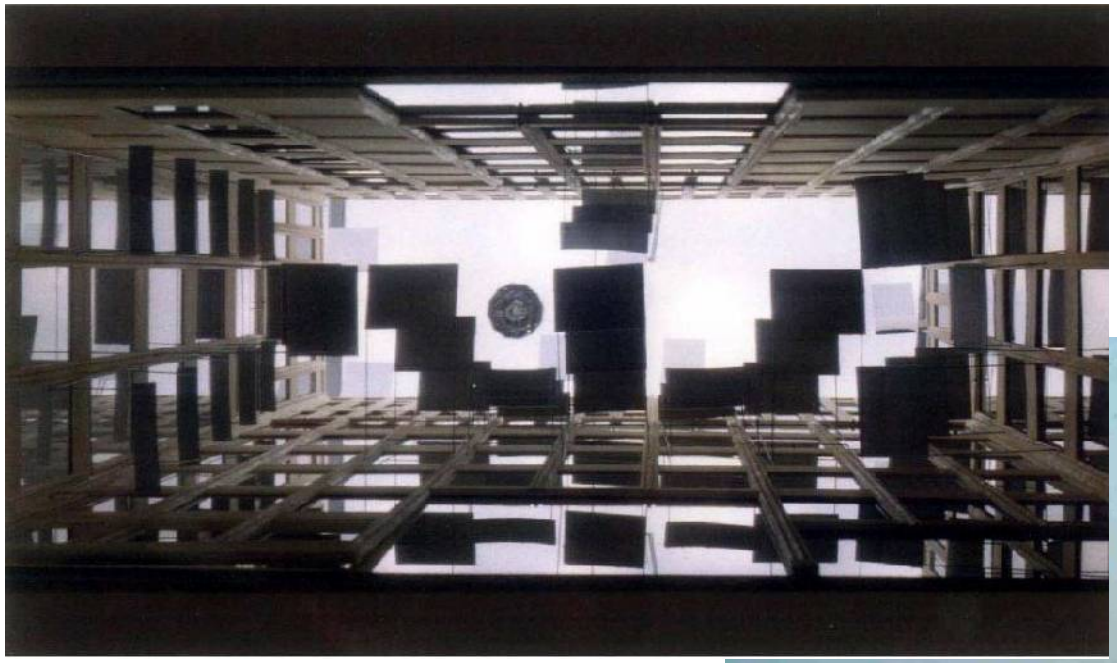
Heliostats
Moveable reflectors
Fibre-optics
Light guides
Fancy shading

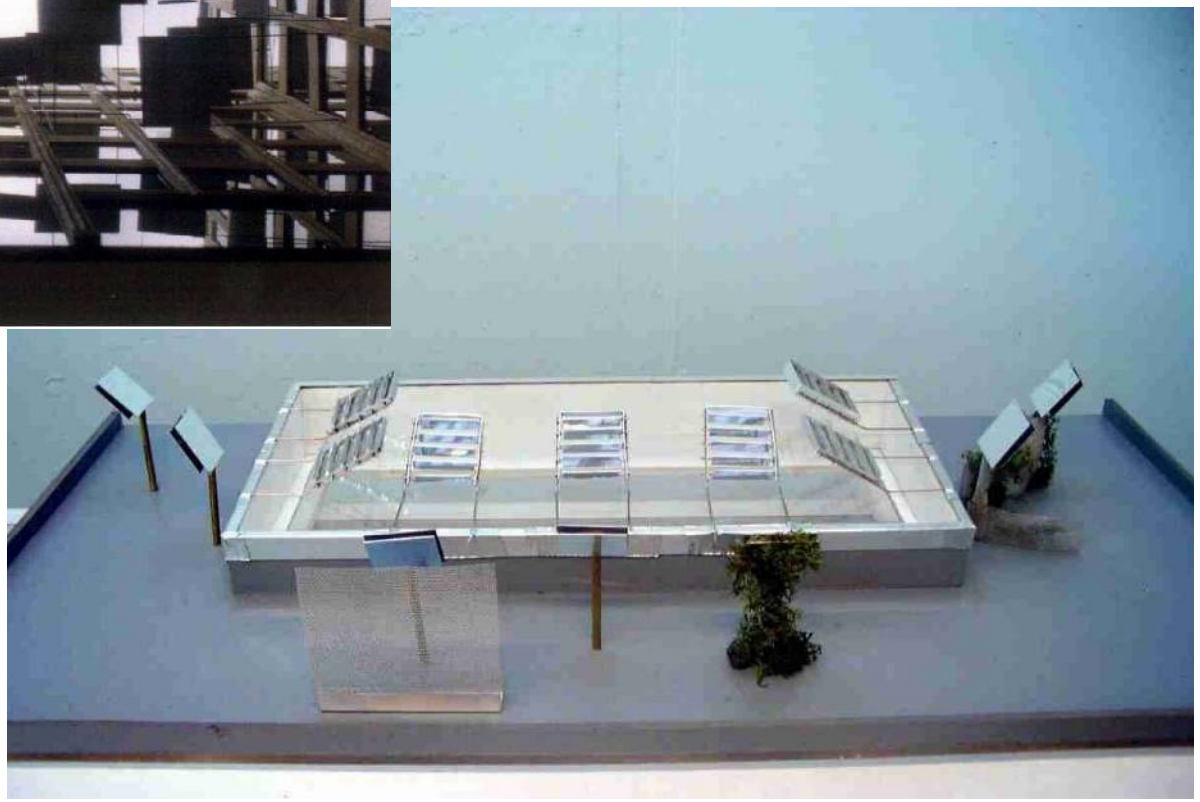
Daylighting doesn't need to be expensive.

State-of-the Art Example

Courtyard with heliostats in Karl-Scharnagl-Ring in Munich
Concept and design by Bartenbach LichtLabor, Austria

State-of-the Art Example (contd.)

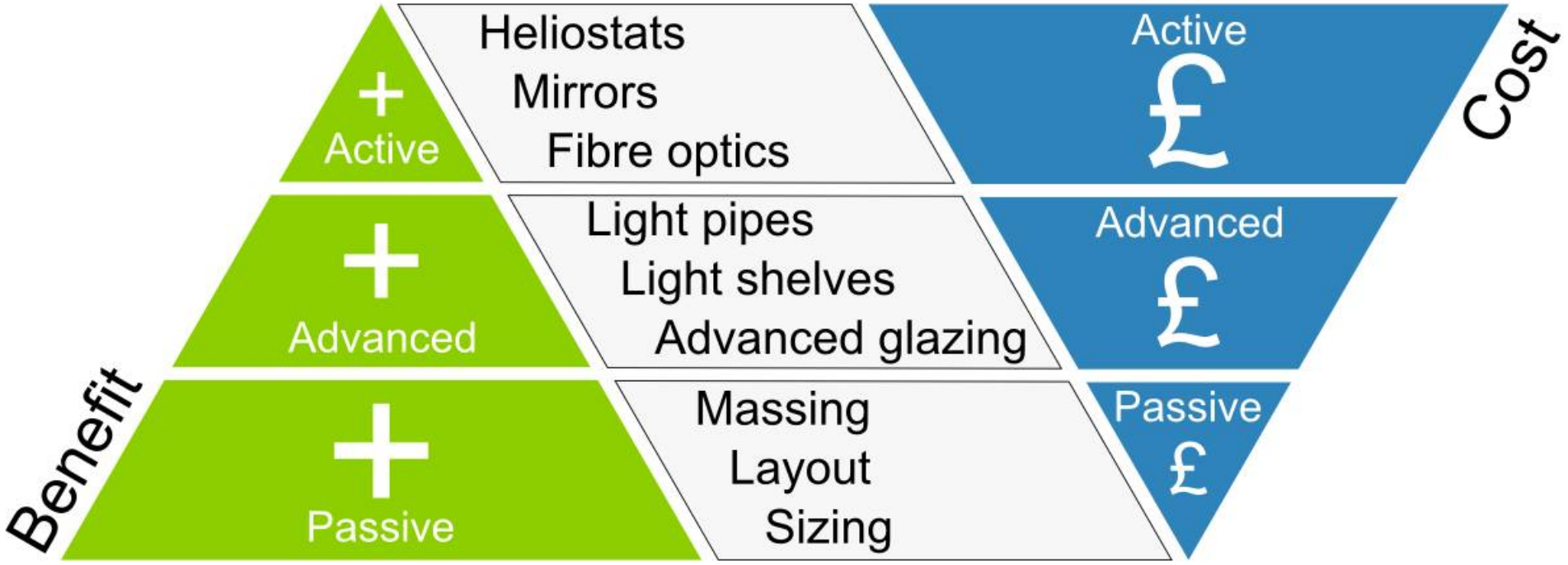




KISS

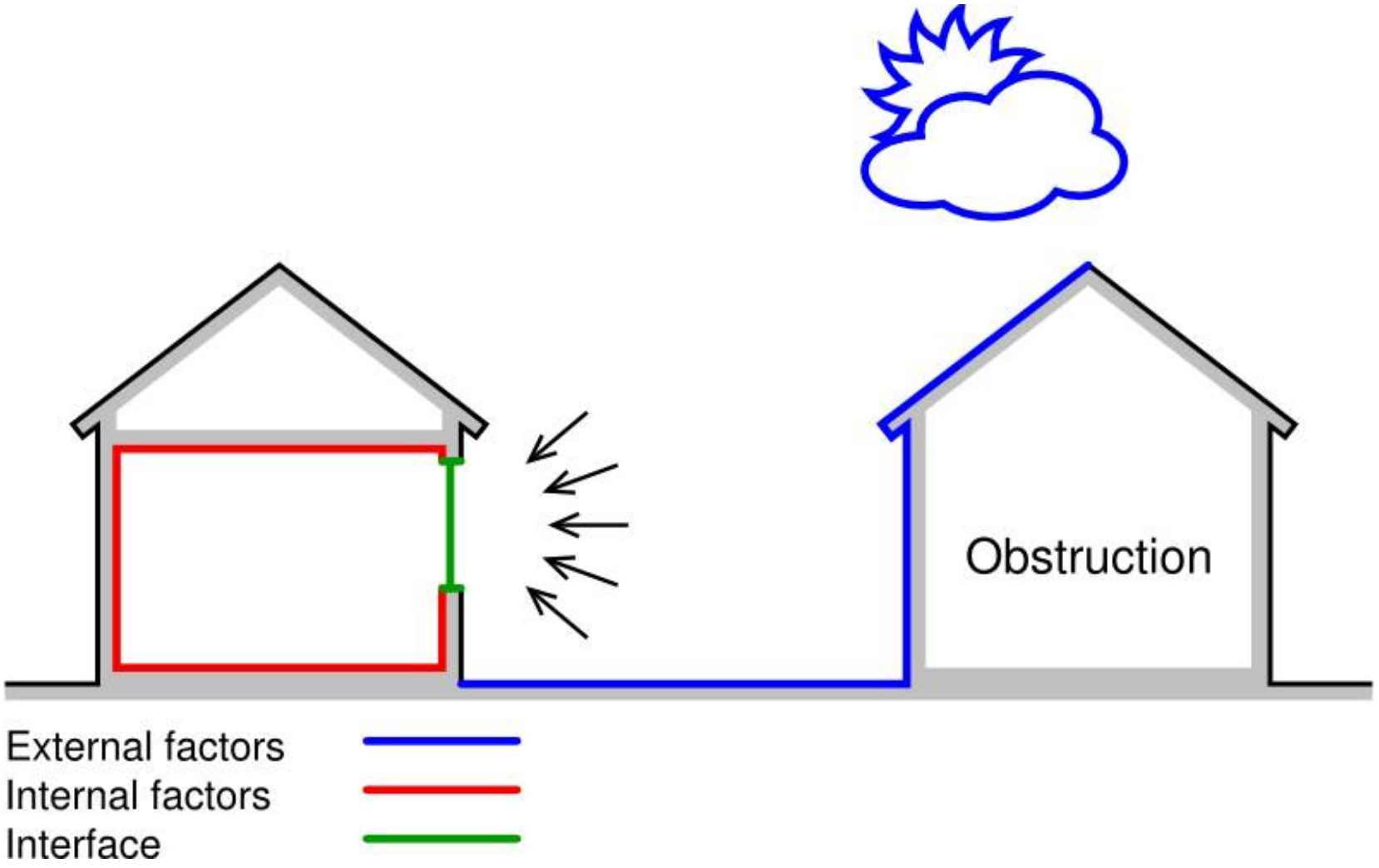
Keep It Simple, Stupid!

Design Hierarchy



II *Daylighting Metrics*

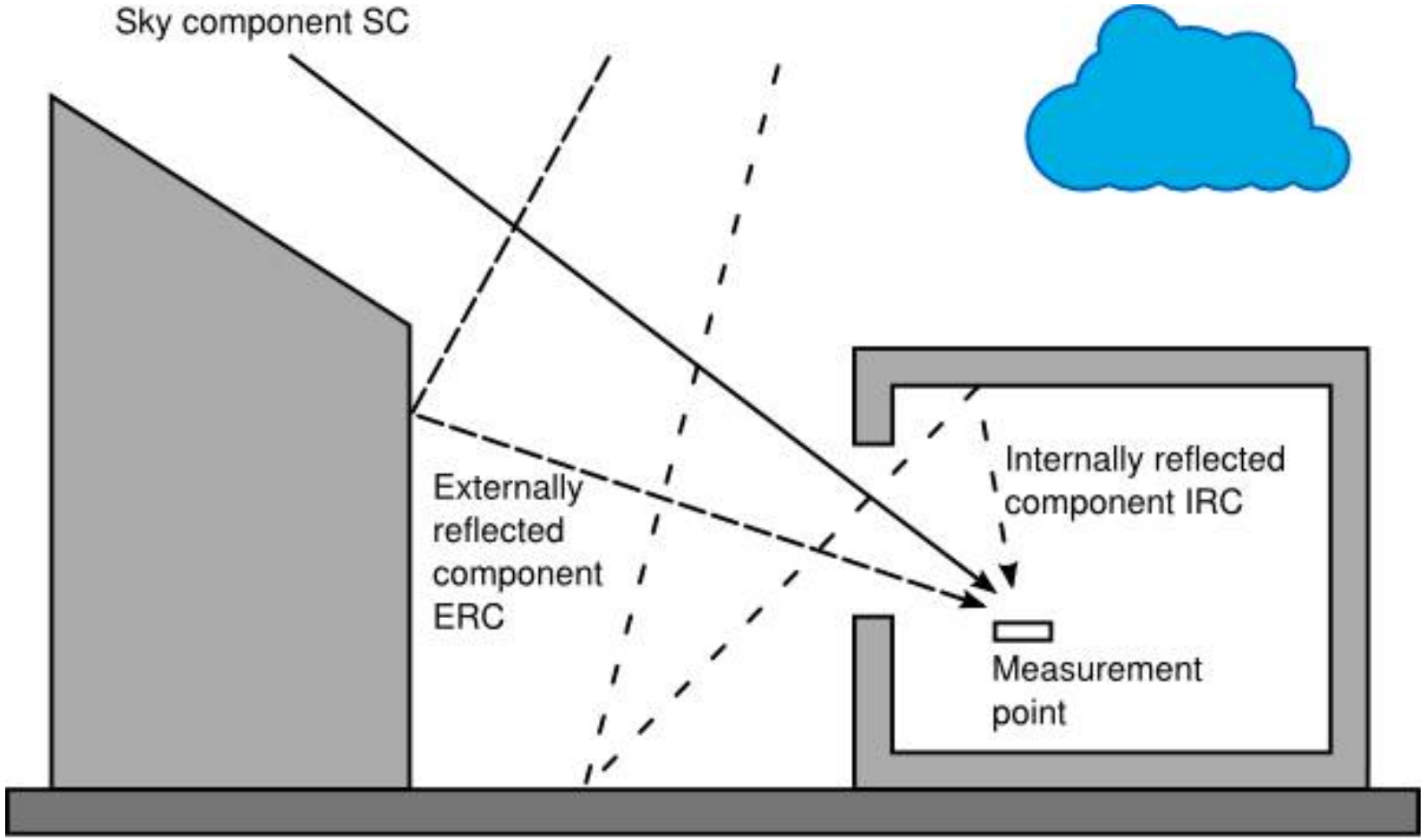
Daylight in a Room



Criteria and Metrics

- Daylight Factor (Point DF and ADF)
- No-sky line
- Obstruction Angle
- Vertical Sky Component
- Probable Sunshine Hours
- (Illuminance)
- Dynamic metrics

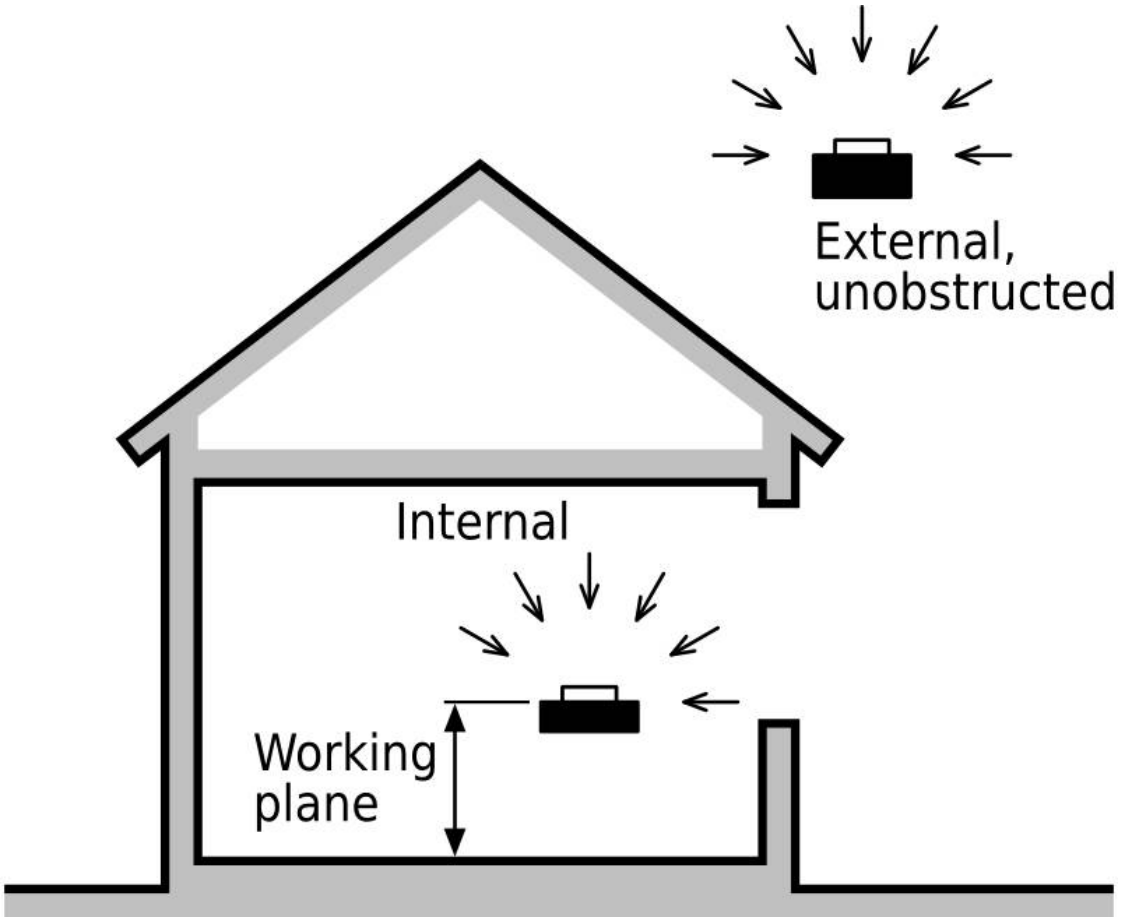
Components of Daylight and DF



Daylight Factor DF = SC + ERC + IRC

Daylight Factor

- Internal illuminance divided by unobstructed external illuminance in [%]
- DF only defined for overcast skies!



Average Daylight Factor

- BRE simplified formula for ADF allows for sizing of window areas

$$ADF = \frac{A_g \, \theta \, T \, M}{A \, (1-R^2)}$$

T	visible transmittance of the glazing, including corrections for dirt, curtains and blinds. http://www.jaloxa.eu/resources/radiance/lg10_glazing.shtml
A_g	net glazed area of the window [m^2];
A	total area of the room surfaces;
R	average reflectance of the room surfaces;
θ	angle of visible sky [degrees].

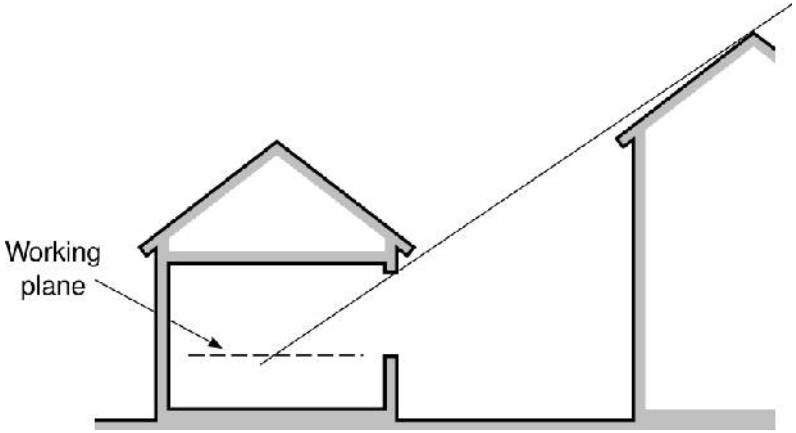
See BS 8206:2-2008 on how to deal with glazing below working plane.

Average Daylight Factors

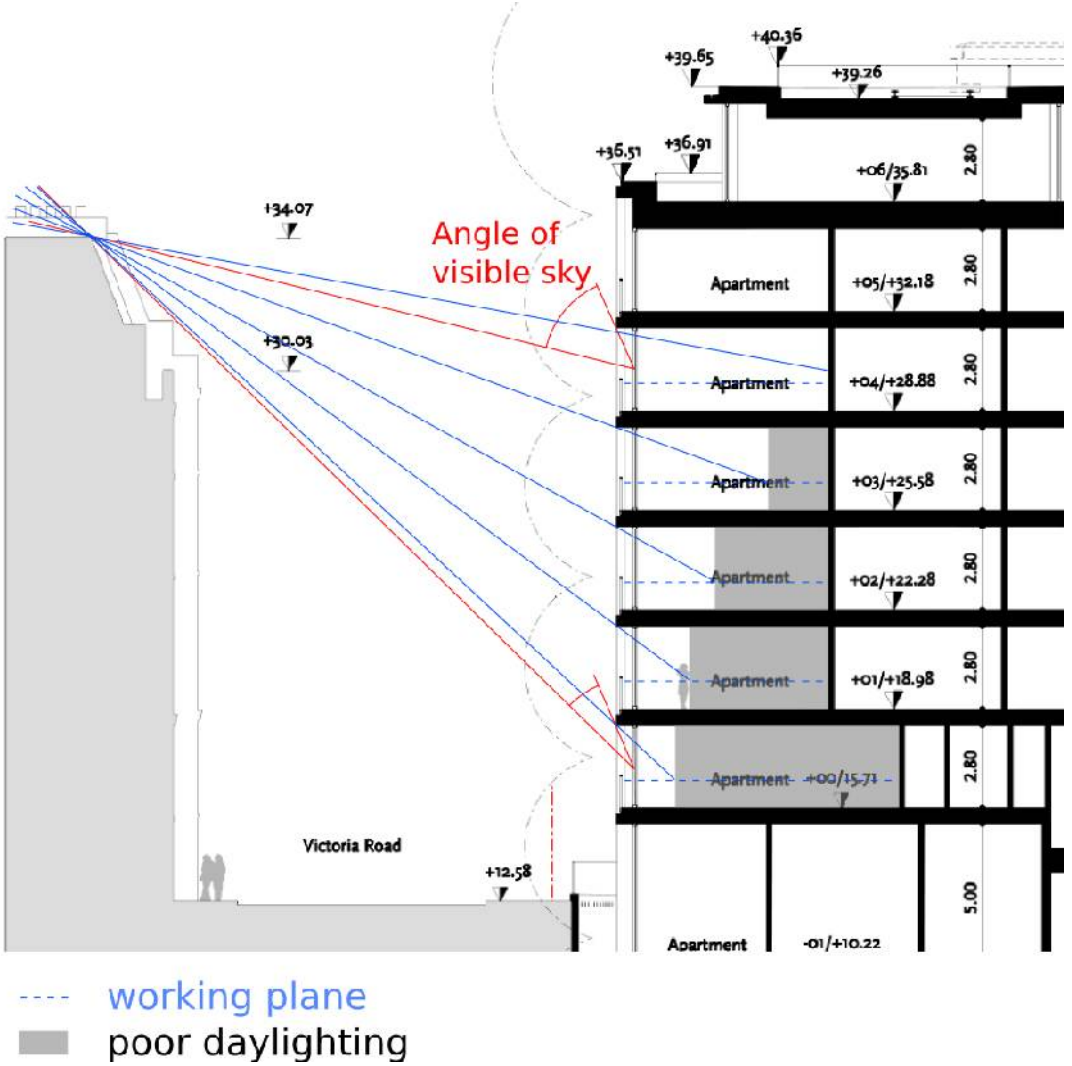
ADF	Appearance	Energy Implications
< 2%	Room looks gloomy	Electric lighting needed most of the day
2% to 5%	Predominantly daylit appearance, but supplementary artificial lighting is needed	Good balance between lighting and thermal aspects
> 5%	Room appears strongly daylit	Daytime electric lighting rarely needed, but potential for thermal problems due to overheating in summer and heat losses in winter

Rooms with an ADF above 2% are considered daylit. However, a room is only perceived as well daylit when the ADF is above 5%.

No-sky Line



"Areas beyond the no-sky line, since they receive no direct daylight, usually look dark and gloomy compared with the rest of the room, however bright it is outside." [SLP]



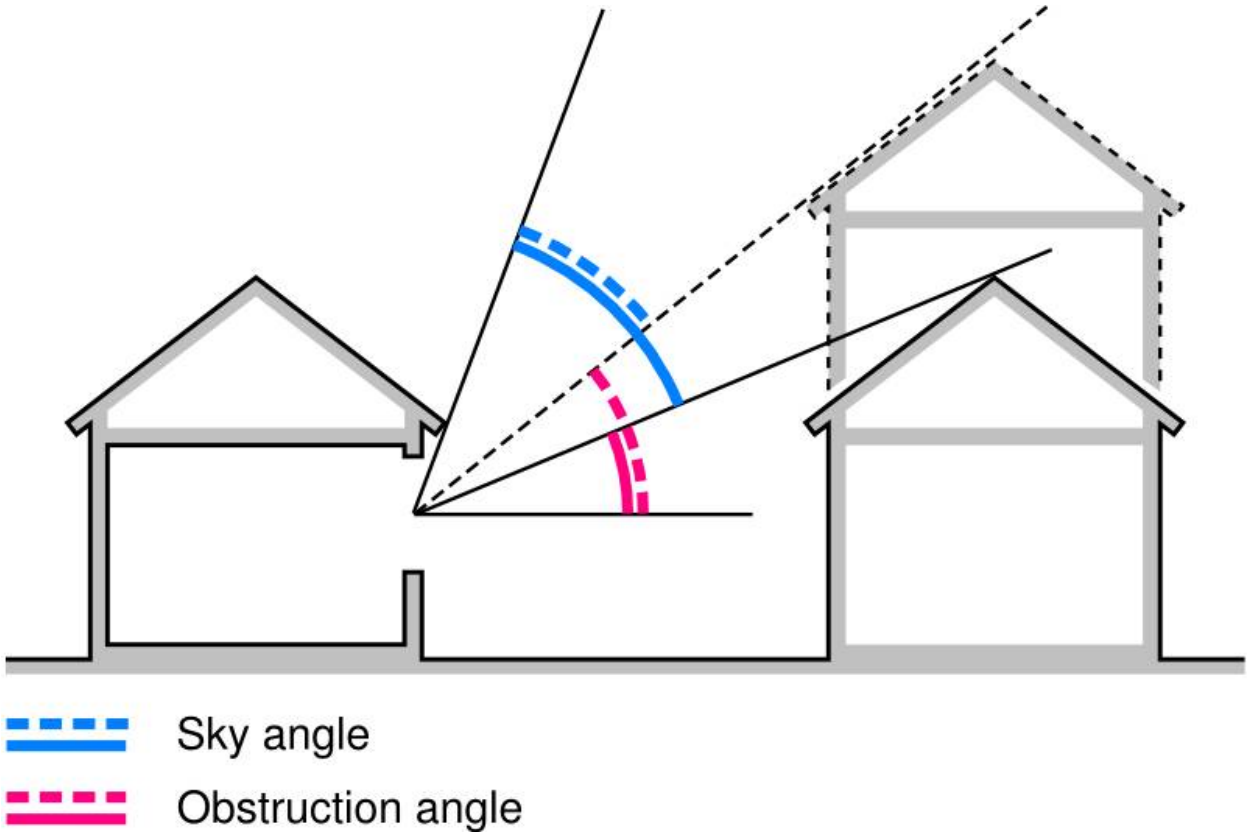
Limiting Room Depth

$$\frac{L}{W}+\frac{L}{H}\leq\frac{2}{(1-R_b)}$$

L length (depth) of room;
W width of room;
H room height;
R_b average reflectance in the back half of the room.

Criterion for uniformity

Sky Angle, Obstruction Angle



Criterion for daylight availability, strictly speaking only valid for long, parallel obstructions. For irregular obstructions, those angles may be derived from VSC (table in BR209 – *Site Layout Planning*).

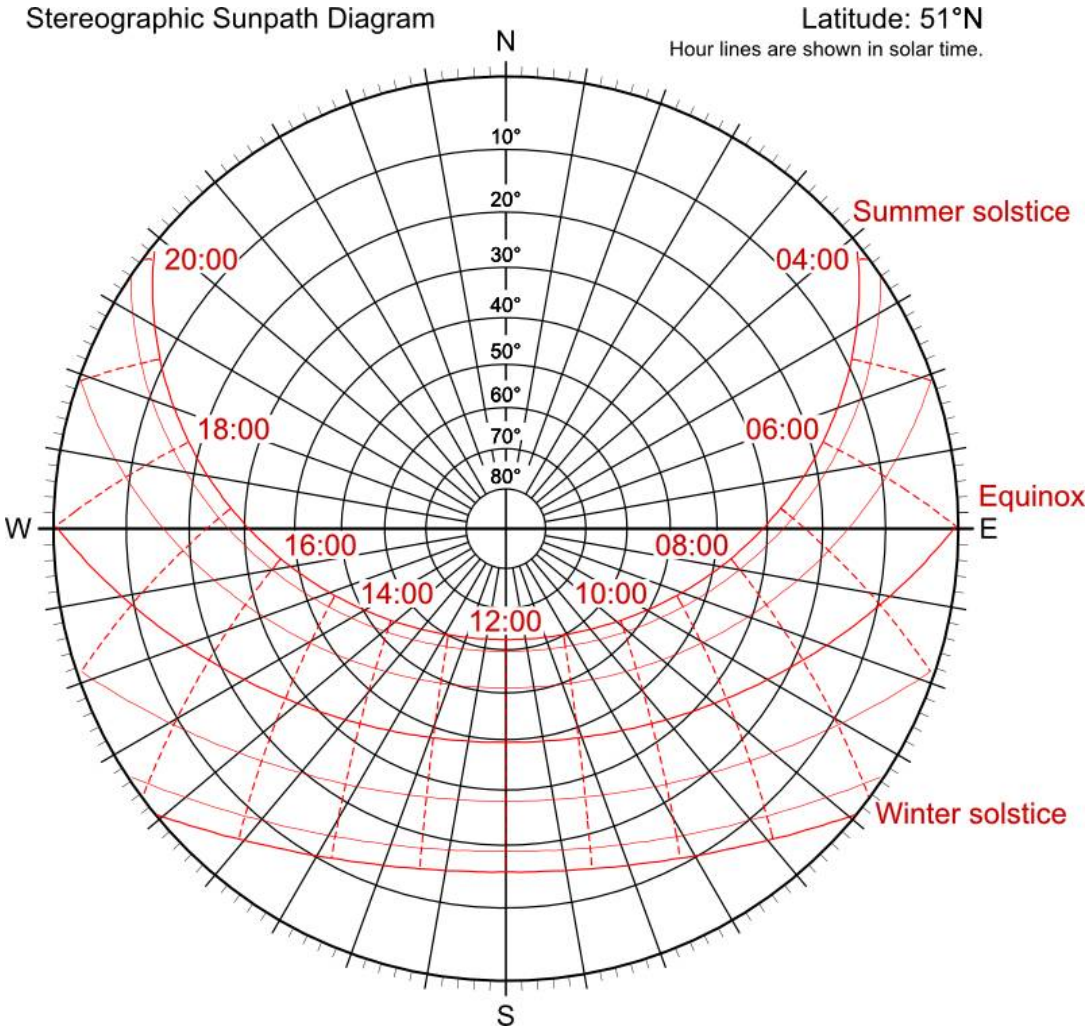
Vertical Sky Component

“The amount of skylight falling on a vertical wall or window can be quantified as the vertical sky component. This is the ratio of the direct sky illuminance falling on the vertical wall at a reference point, to the simultaneous horizontal illuminance under an unobstructed sky.
“The maximum value is almost 40% for a completely unobstructed vertical wall. The vertical sky component on a window can be related to the average daylight factor in a room.” [BR209]

Obstruction Angle v VSC

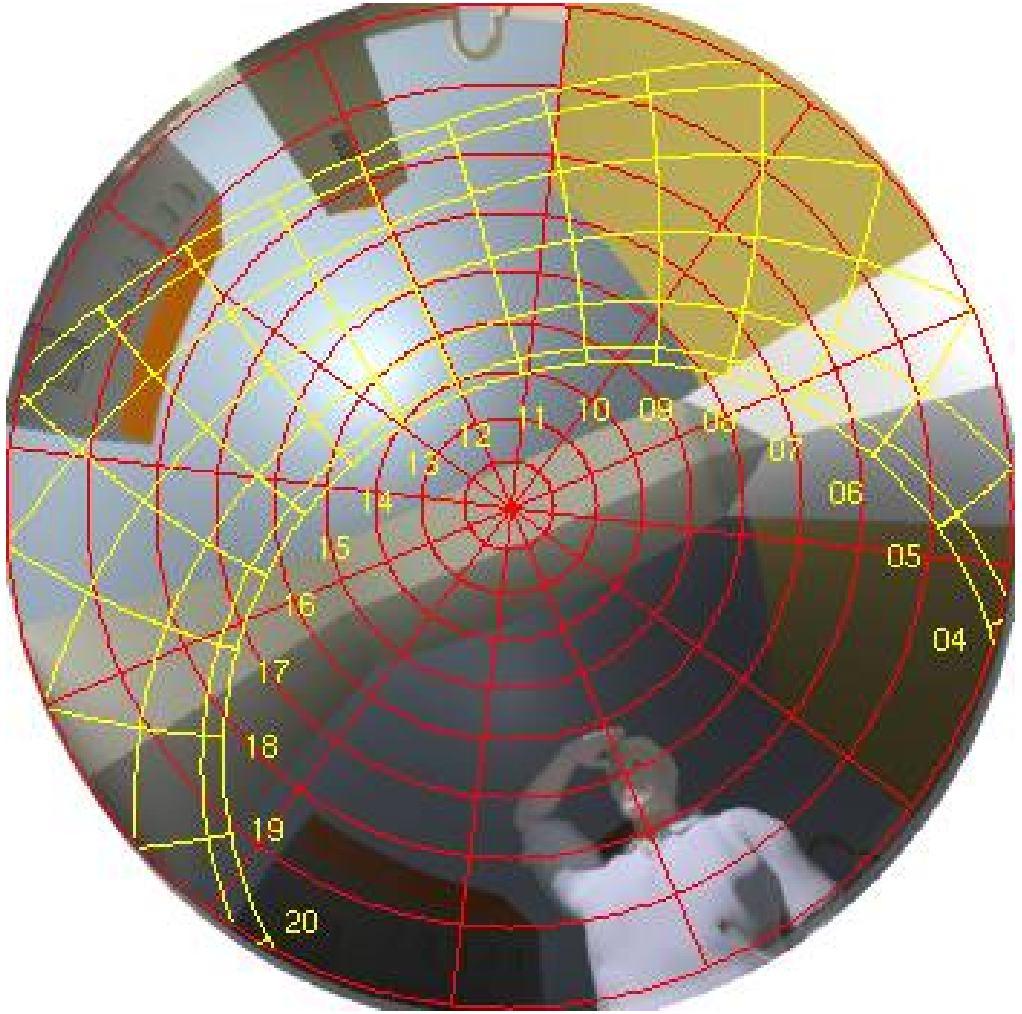
Obstruction angle (° from horizontal)	Vertical sky component at centre of window (%)	Value of θ in average daylight factor equation
0	40	90
5	38	85
10	35	80
15	33	75
20	30	70
25	27	65
30	24	60
35	21	55
40	18	50
45	15	45
50	13	40
55	10	35

Sunpath Diagrams



http://www.jaloxa.eu/resources/daylighting/sunpath.shtml

Sunpath Diagrams (contd.)



http://www.jaloxa.eu/resources/radiance/sp_overlay.shtml

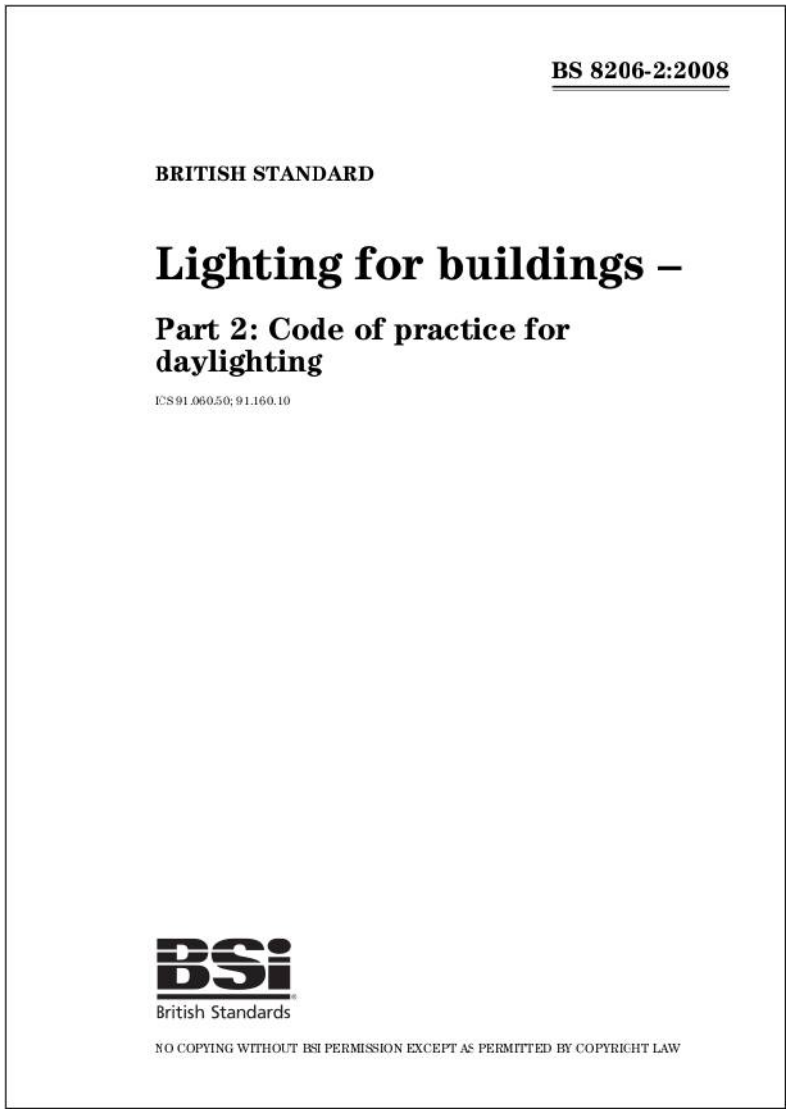
III *UK Regulations*

Daylighting Codes of Practice

- BS 8206:2-2008 Lighting for Buildings, Part 2: *Code of practice for daylighting* [BS]
- BRE, P J Littlefair: *Site layout planning for daylight and sunlight* 2nd edition, 2011 [BR209]
- BREEAM
- Code for Sustainable Homes [CSH]
- Building Bulletins [BB]
- CIBSE Lighting Guides
- (Rights of Light, Ancient Lights)

Note the absence of Part L from this list!

BS 8206:2



BS 8206-2:2008

BRITISH STANDARD

Lighting for buildings –

Part 2: Code of practice for daylighting

ICS 91.060.50; 91.160.10

BSi
British Standards

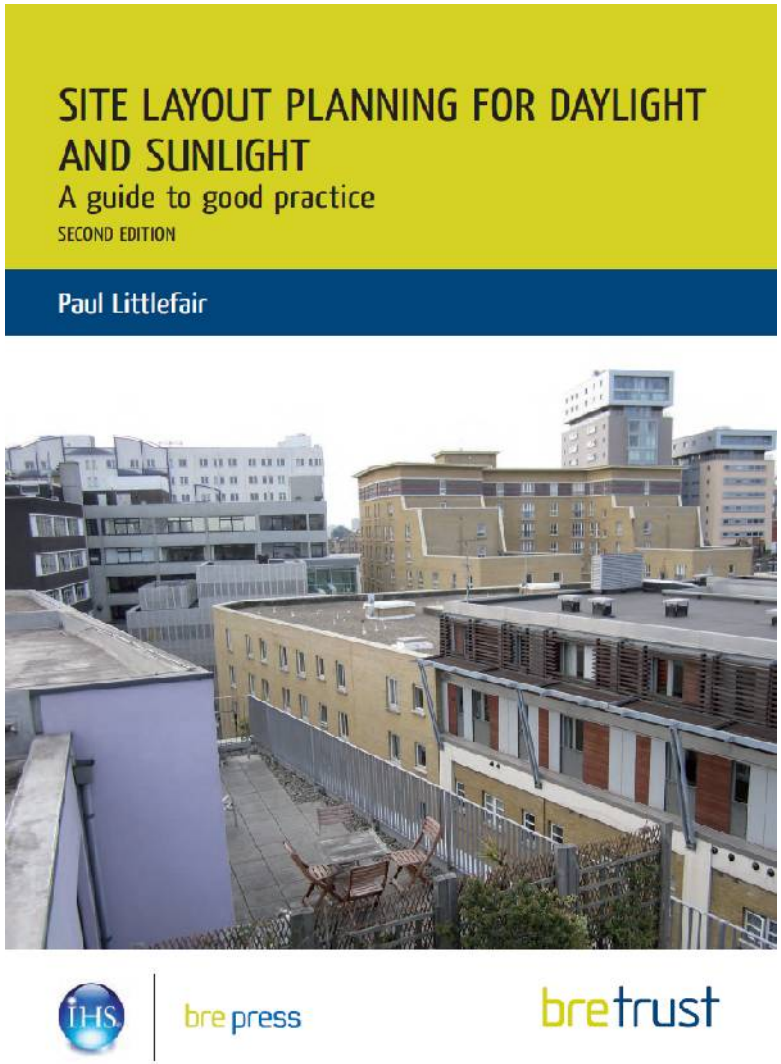
British Standard 8206 is split into two parts:

- Part 1: Artificial lighting
- Part 2: Daylighting

Part 1 is superseded by
BS EN 12464
Lighting of indoor work places

Part 2 was last revised in 2008.

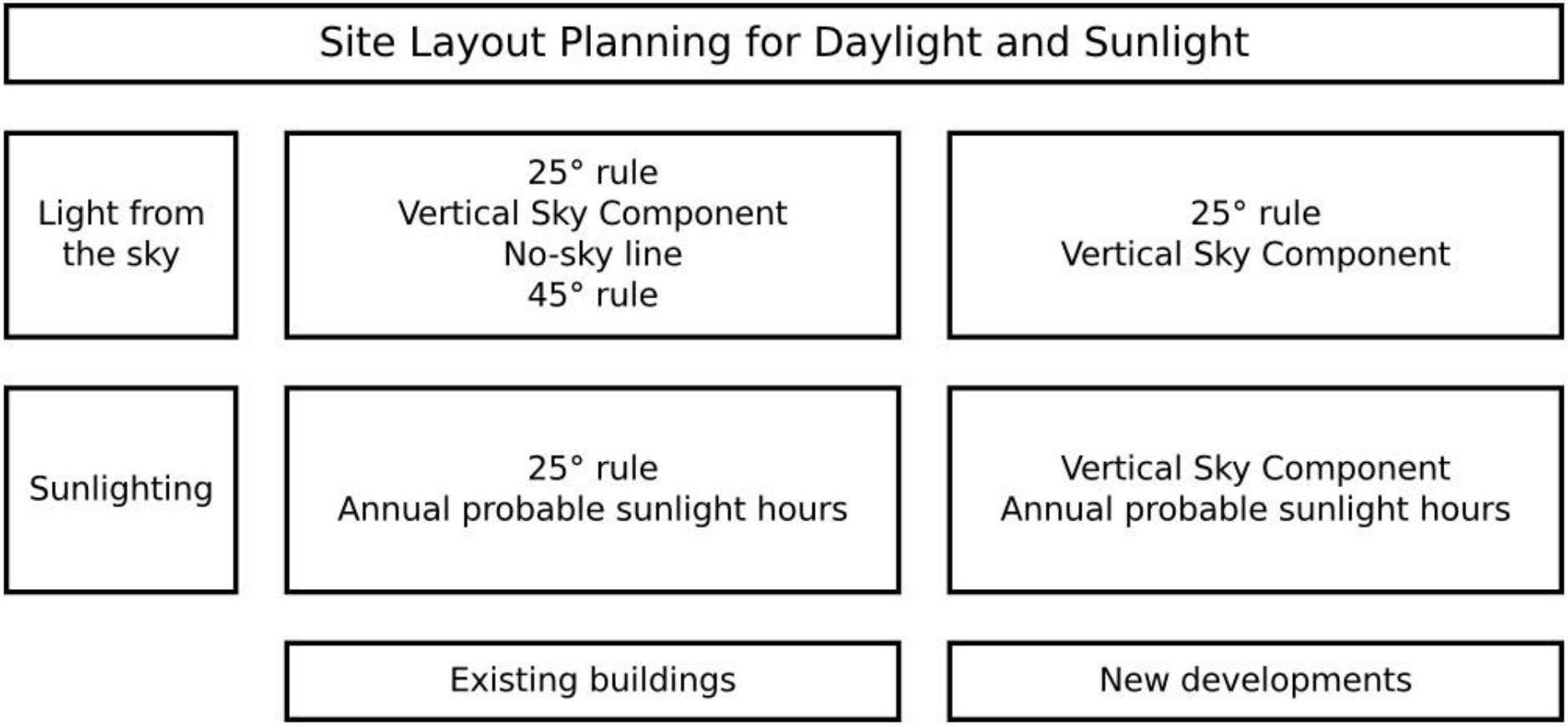
BR209



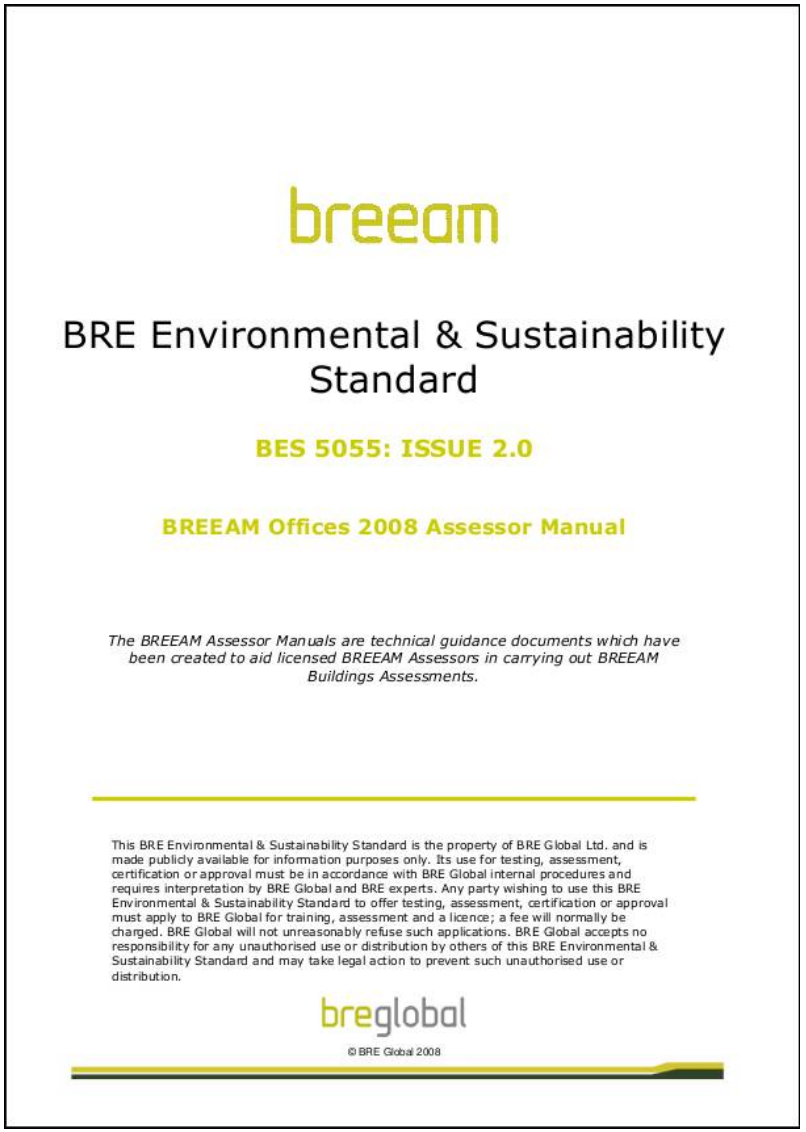
BRE publication *Site layout planning for daylight and sunlight - A guide to good practice*
by Paul Littlefair

The second edition of this guide was released in autumn 2011.

BR209


Site Layout Planning for Daylight and Sunlight
Light from the sky
25° rule
Vertical Sky Component
No-sky line
45° rule
25° rule
Vertical Sky Component
Sunlighting
25° rule
Annual probable sunlight hours
Vertical Sky Component
Annual probable sunlight hours
Existing buildings
New developments

BREEAM



breeam

BRE Environmental & Sustainability Standard

BES 5055: ISSUE 2.0

BREEAM Offices 2008 Assessor Manual

The BREEAM Assessor Manuals are technical guidance documents which have been created to aid licensed BREEAM Assessors in carrying out BREEAM Buildings Assessments.

breglobal

BRE Environmental Assessment Method

Used to be separate documents for Offices, Education, Health care, Retail, Prisons etc. (2008)

New 2011 BREEAM *New Construction* is much more unified and consistent (single document)

Also by BRE is

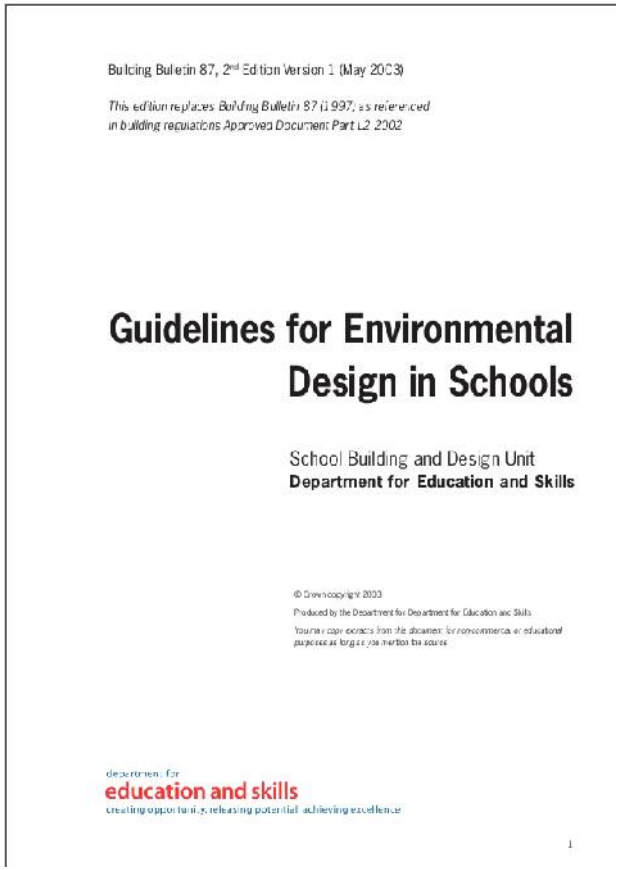
Code for Sustainable Homes, formerly EcoHomes

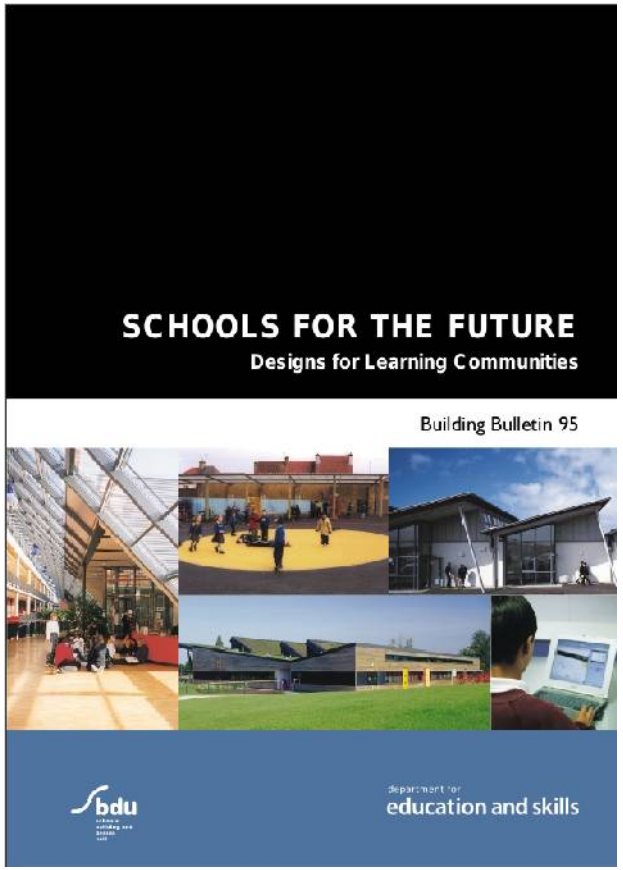
Building Bulletins

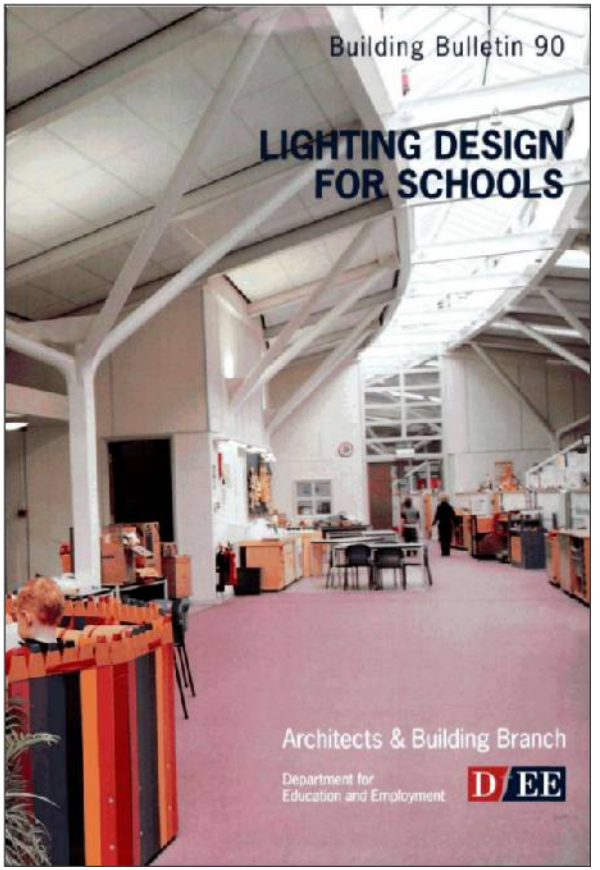
BB 87: Environmental Design in Schools

BB 90: Lighting Design for Schools

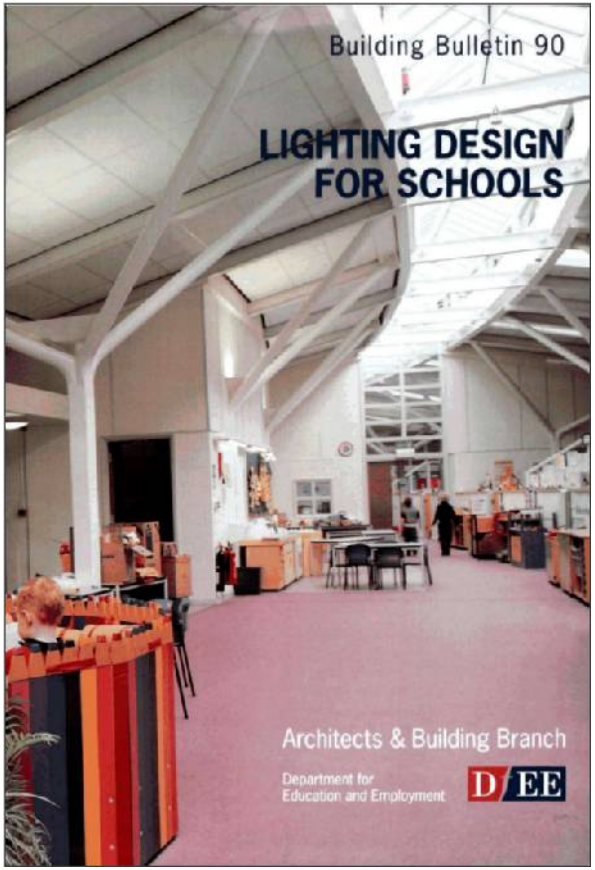
BB 95: Schools for the Future







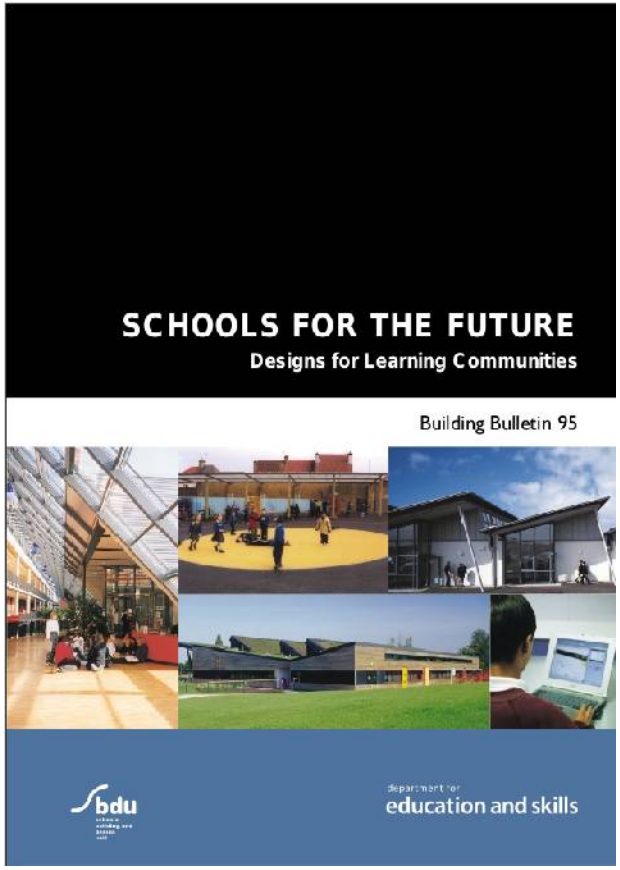
BB 90



”Unless there are over-riding educational reasons for not doing so in certain rooms, the school designer should assume that daylight will be the prime means of lighting when it is available. This is both because of the unique quality of natural light and the link with the external environment which windows of all types provide.

”Windows can also have an effect on other environmental factors, particularly thermal comfort, fresh air supply, energy efficiency and noise intrusion. It can be seen therefore that windows are a complex part of building design and need careful consideration for maximum benefit and pleasure together with minimum dissatisfaction.”

BB 95

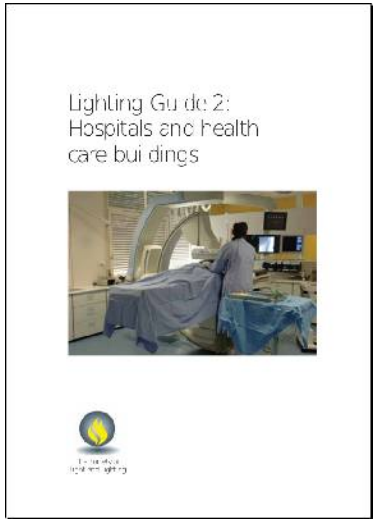


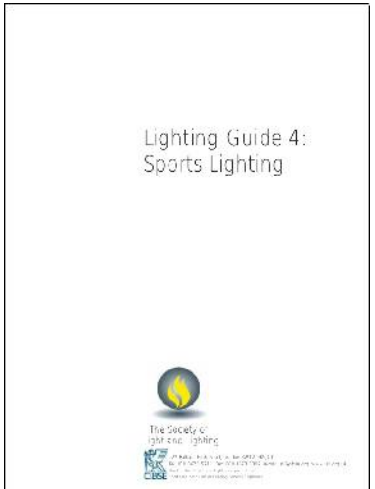
”Daylight should be the principle means of illumination where possible...”

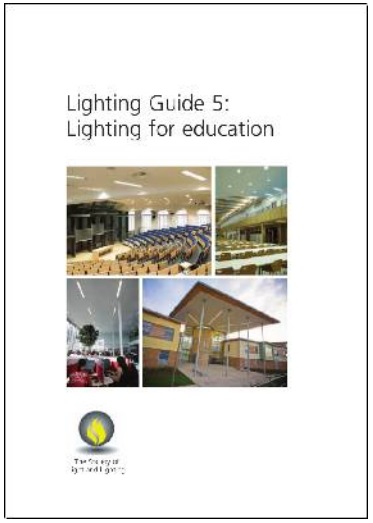
”A space can be considered well daylit if it has an average daylight factor of 4-5% and a uniformity ratio of 0.3-0.4. Key factors in achieving this are the position and area of glazing, ceiling height and depth of space. Daylighting should therefore be considered at the earliest planning stage. Consider, for example, the difficulty of getting daylight to the back of rooms over 6m deep if there are windows on only one side; the use of courtyards to bring daylight (and ventilation) into deep plan building; avoidance of narrow gaps between buildings which can reduce available daylight.”

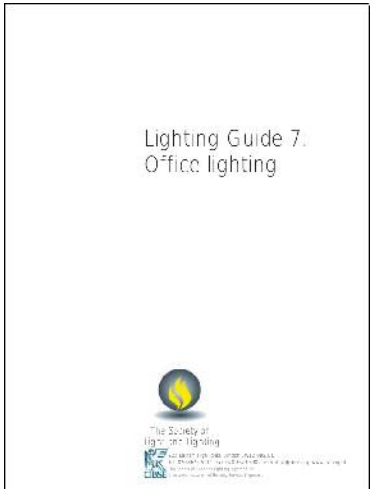
CIBSE Lighting Guides

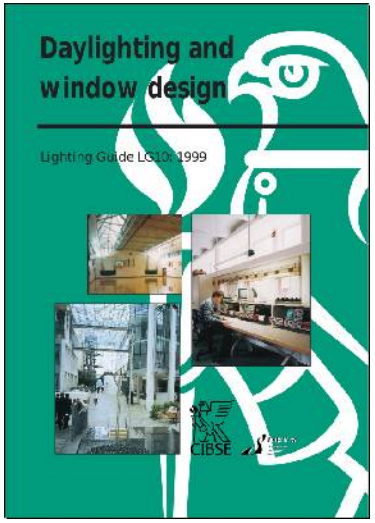
LG2: Hospitals and Health Care Buildings
LG4: Sports
LG5: Lighting for Education
LG7: Office Lighting
LG10: Daylighting and window design



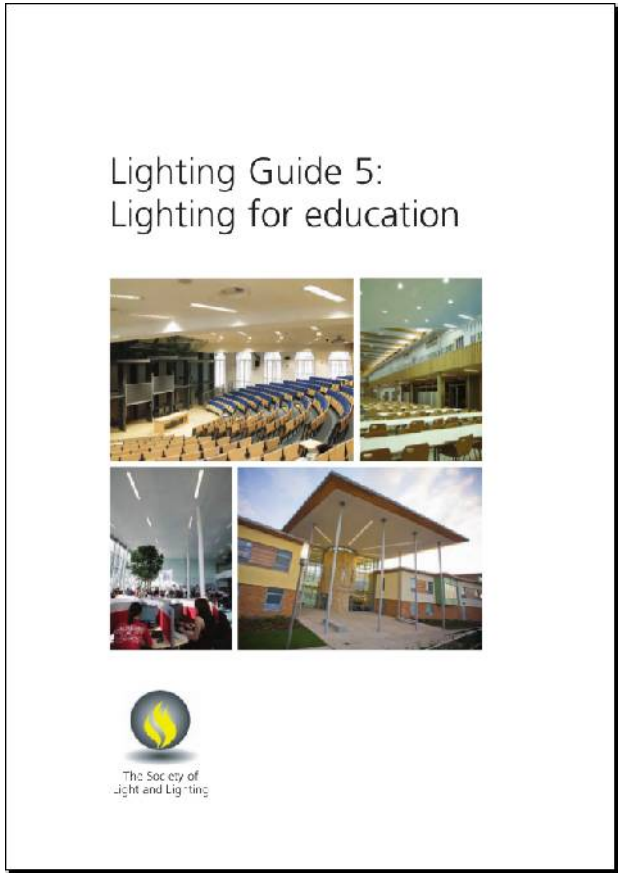








LG 5



"... with the essential drive to design low, or zero carbon buildings, the strategy for all schools and colleges must be to use daylight as the primary light source and the building design process should be informed from the outset as to how that can be achieved."

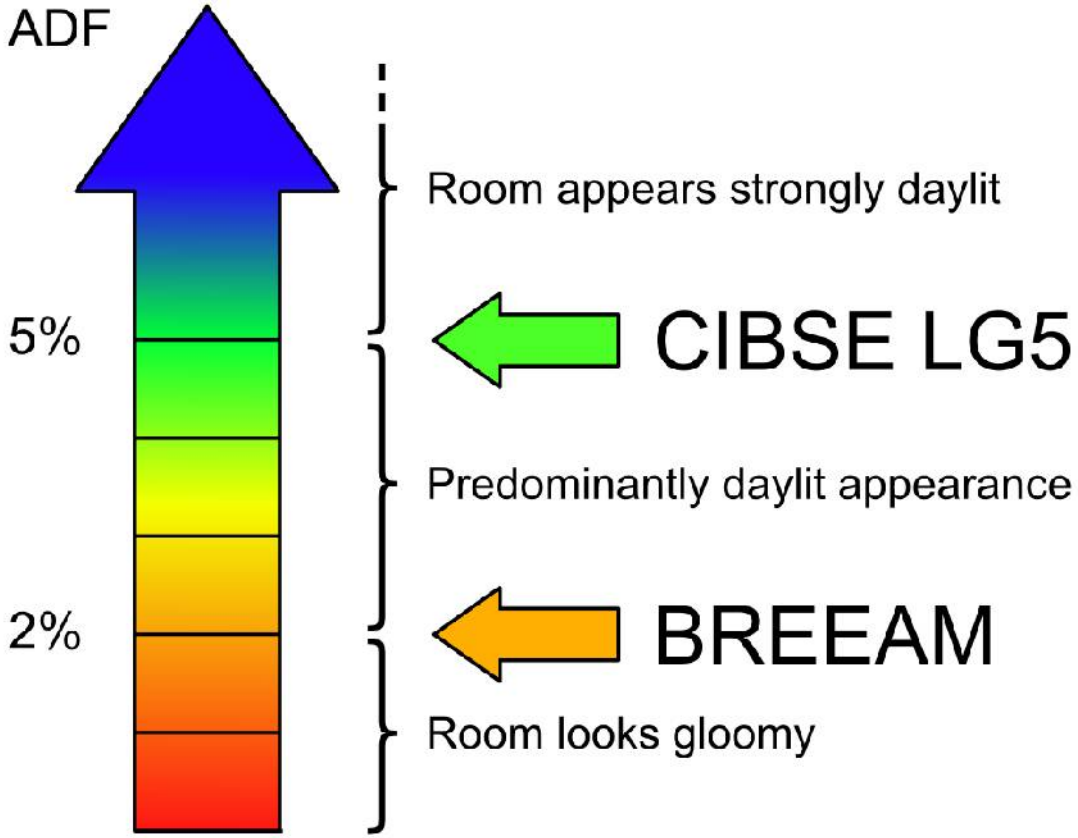
"The use of daylight as the main means of lighting is recommended and should not be compromised in a learning environment, except in circumstances outside the designer's control."

LG 5 (contd.)

“The strategy should be to create spaces that are daylit to improve learning rates and reduce energy consumption. Therefore good practice would be to achieve 5% average daylight factor and a minimum point daylight factor of 2%.”

“The importance of the uniformity cannot be underestimated. Too high a contrast and a space will look gloomy from some positions and viewpoints and be visually uncomfortable or distracting. Controlling uniformity requires the access of daylight and distribution of daylight within the room to be balanced. Measures that easily identify if this will be achieved include the ‘no sky line’ and room depth criteria. Calculating the daylight factors throughout the space, either manually or by computer, is also appropriate.”

BREEAM vs LG5



BREEAM and BR209 define minimum requirements.
CIBSE Guides are Good Practice.

Good Daylighting – New Buildings

Some examples from
UK regulations

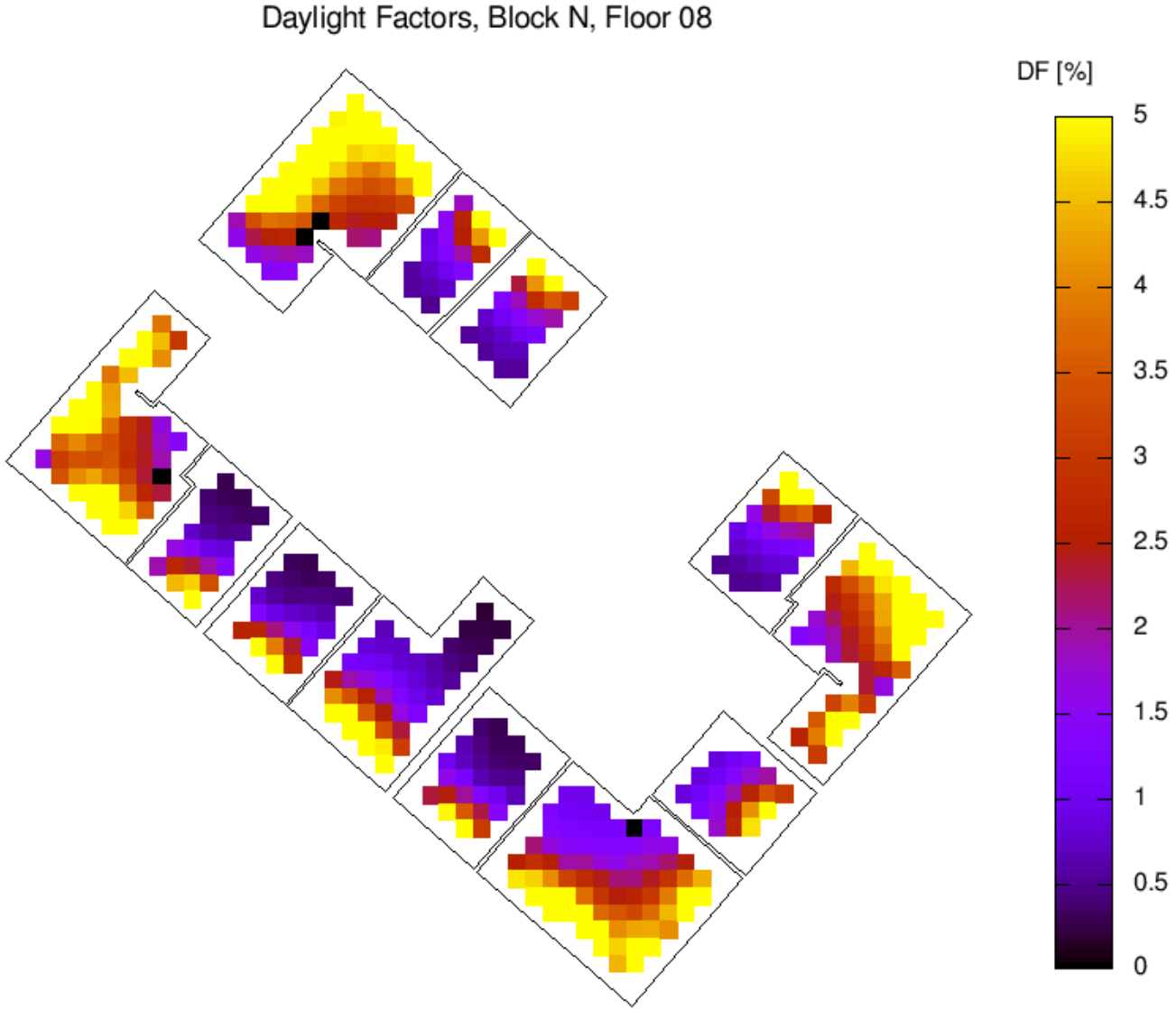
BS8206:2, BR209

Room Type	Minimum ADF
Kitchens	2.0%
Living rooms	1.5%
Bedrooms	1.0%

The uniformity of daylight is considered to be unsatisfactory if:

a) a significant part of the working plane (normally more than 20%) lies behind the no-sky line; or
b) in a room lit by windows in one wall only, the depth of the room is too large in comparison with the height and the width of the windows.

Example: ADF for Planning Permission



BREEAM Offices 2008

"At least 80% of net lettable floor area in each occupied space is adequately daylit as follows:

(a) ADF of 2% or more plus b or (c and d):

(b) a uniformity ratio at least 0.4, or a minimum DF of at least 0.8% (spaces with glazed roofs: 0.7, or 1.4%)

(c) a view of the sky from desk height (0.7 m) is achieved

(d) the room depth criterion is satisfied.”

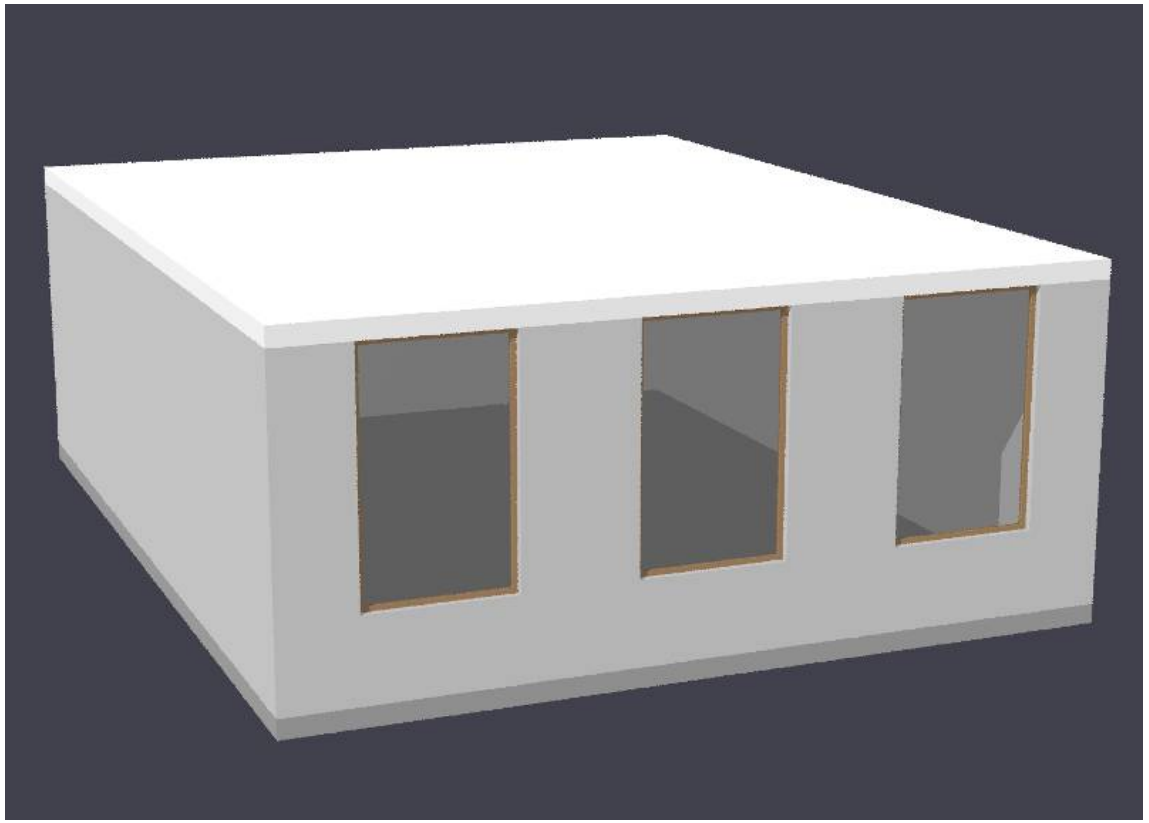
BR209

“Note that all three of the criteria (ADF, RDC, NSL) need to be satisfied if the whole of a room is to look adequately daylit.
“Even if the amount of daylight in a room (given by the average daylight factor) is sufficient, the overall daylit appearance will be impaired if its distribution is poor.”

Code for Sustainable Homes

(a) ADF in kitchens 2%
(b) All living rooms, dining rooms and studies must achieve a minimum ADF of at least 1.5%
(c) 80% of the working plane in each kitchen, living room, dining room and study must receive direct light from the sky.

Example – Room Depth



Ceiling height: 3.3 m

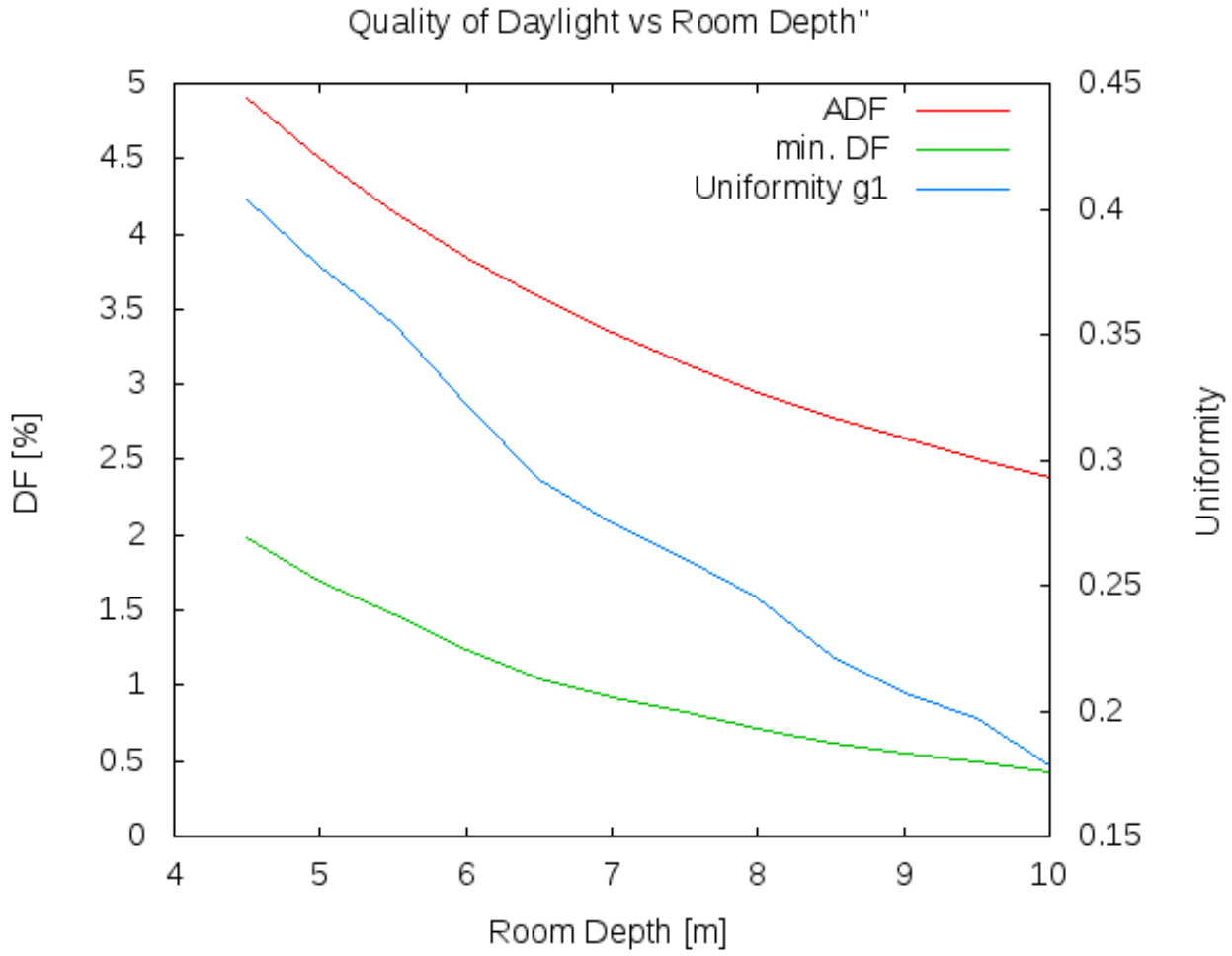
Typical room in new school building, window sizes and positions already decided upon.

Q: How deep can the classrooms be to achieve certain ADF and Uniformity targets?

Example – Room Depth

room depth [m]	glazed facade [%]	glazing to floor [%]	RDC pass?	ADF [%]
4.0	42.3%	34.9%	TRUE	5.60
5.0	42.3%	27.9%	TRUE	4.84
6.0	42.3%	23.3%	TRUE	4.26
7.0	42.3%	19.9%	TRUE	3.80
8.0	42.3%	17.4%	TRUE	3.43
9.0	42.3%	15.5%	TRUE	3.13
10.0	42.3%	14.0%	FALSE	2.87

Example – Room Depth



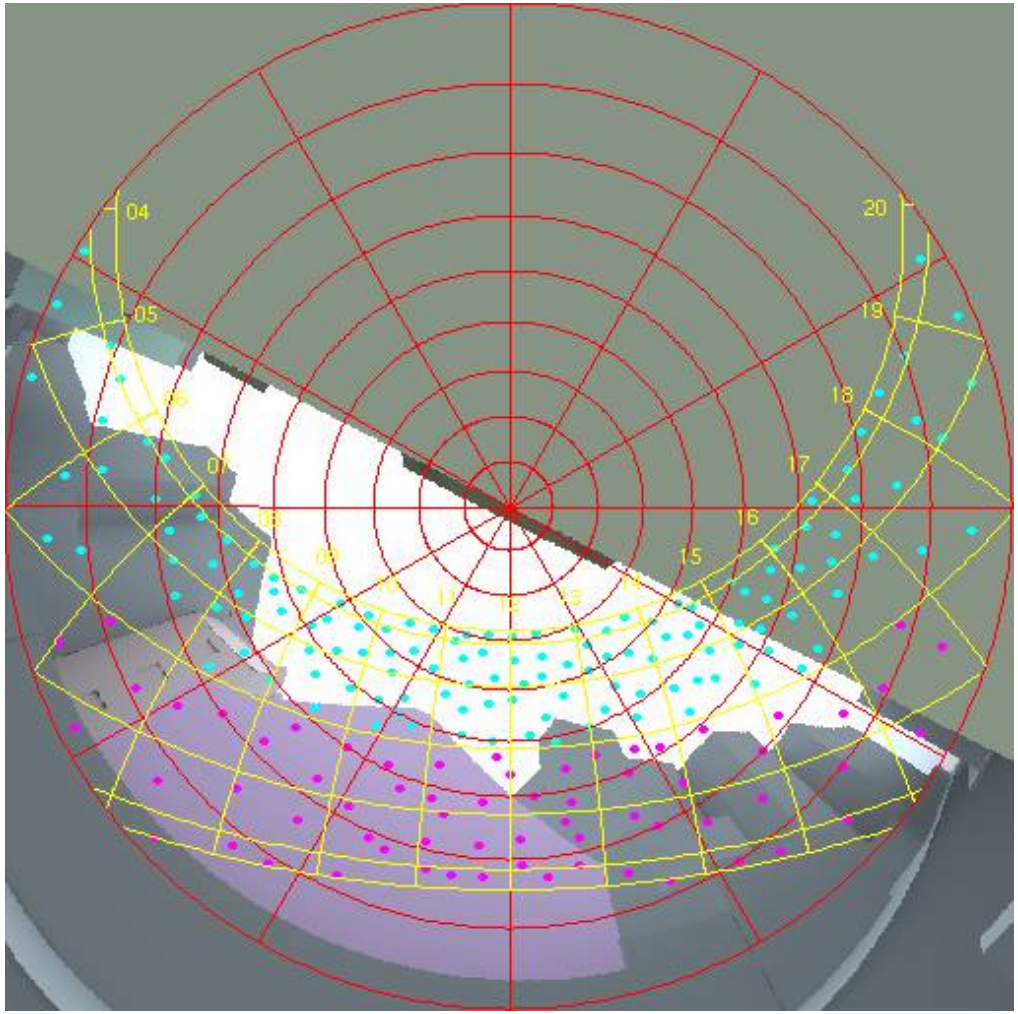
Radiance parametric study

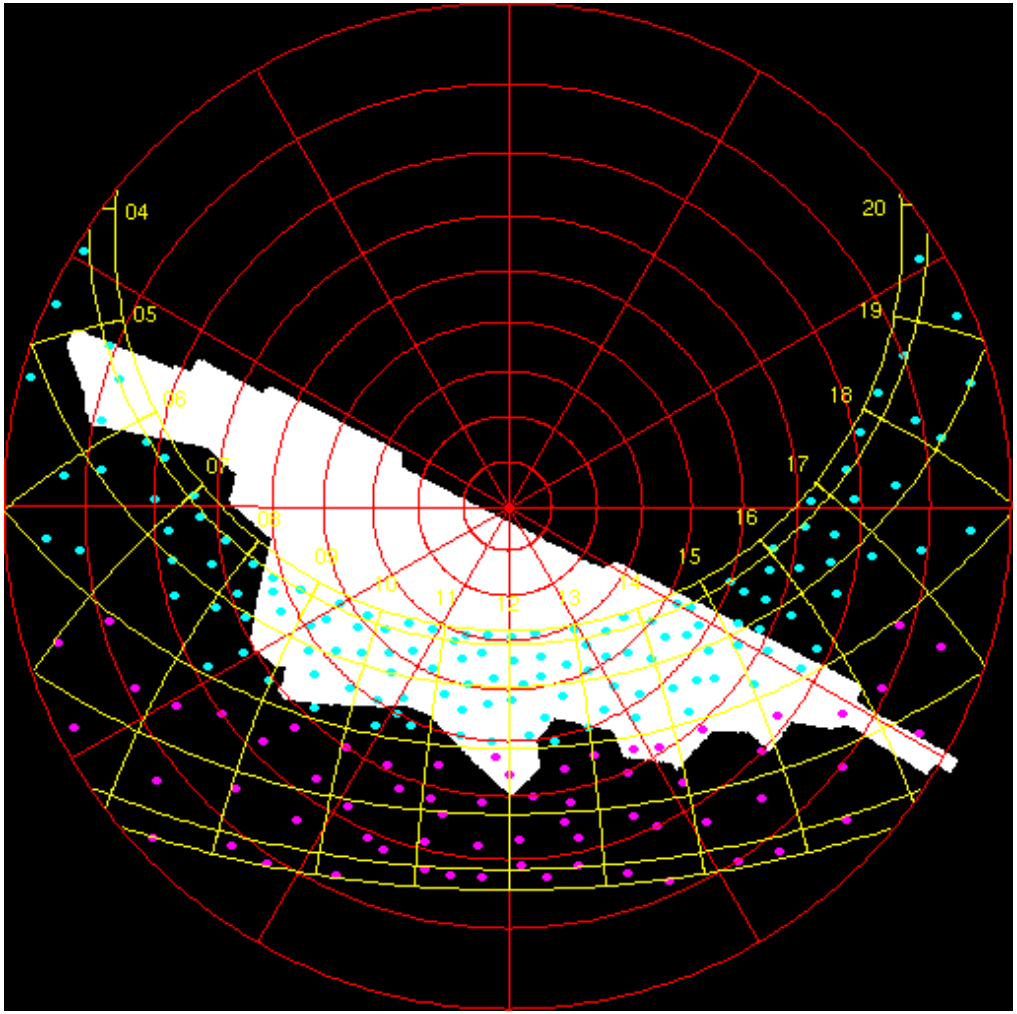
BS 8206:2, SLP

5.3 Sunlight Duration

"Interiors in which occupants have a reasonable expectation of direct sunlight should receive at least 25% of probably sunlight hours. At least 5% of probable sunlight hours should be received during the winter months, between 23rd September and 21st March."

Sunlighting Example: Sunlight Availability





Good Daylighting – Existing Buildings

Thou shalt not obstruct
thy neighbour's daylight

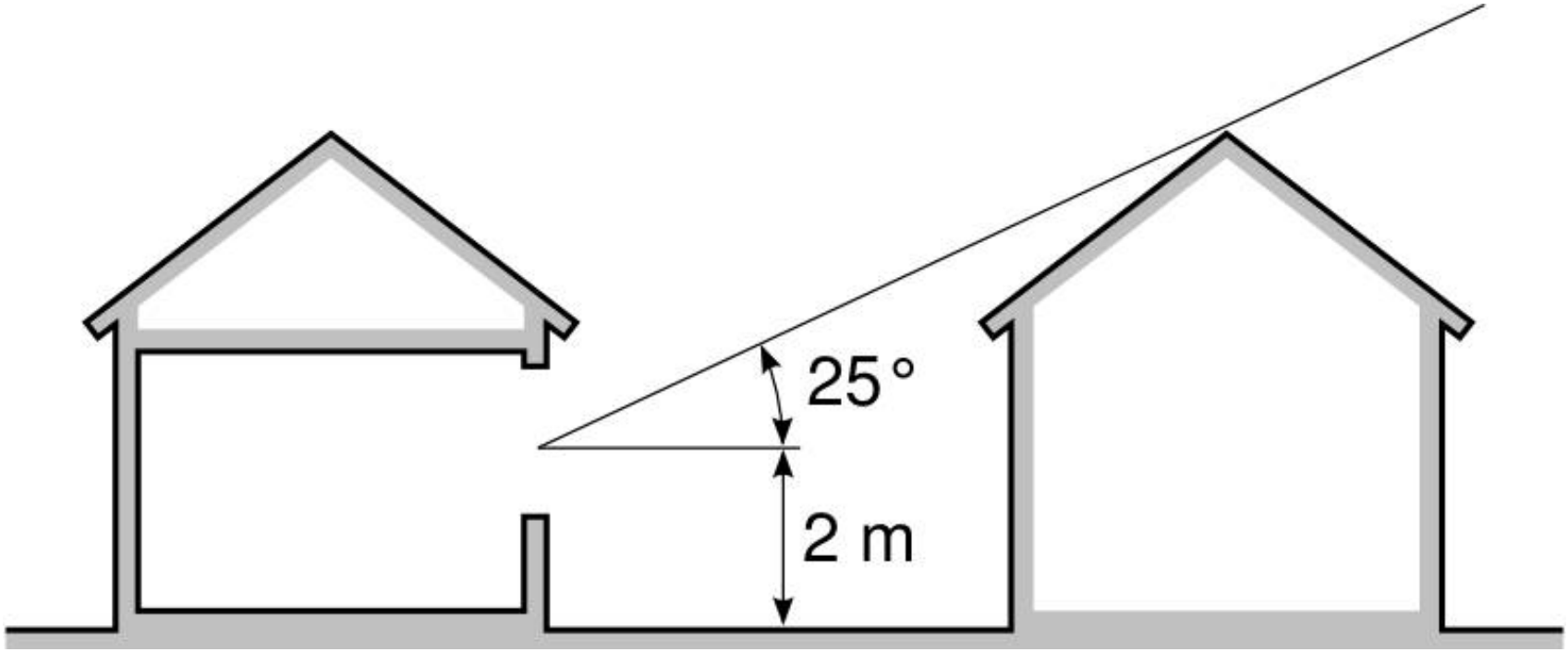
BR209

“If, following construction of a new development, the no-sky line moves so that the area of the existing room which does receive direct skylight is reduced to less than 0.8 times its former value, then this will be noticeable to the occupants, and more of the room will appear poorly lit.”

BR209

“If the vertical sky component, with the new development in place, is both less than 27% and less than 0.8 times its former value, then occupants of the existing building will notice the reduction in the amount of skylight. The area lit by the window is likely to appear more gloomy, and electric lighting will be needed more of the time.”

BR209 – Obstruction Angle



BR209 – Obstruction Angle (contd.)

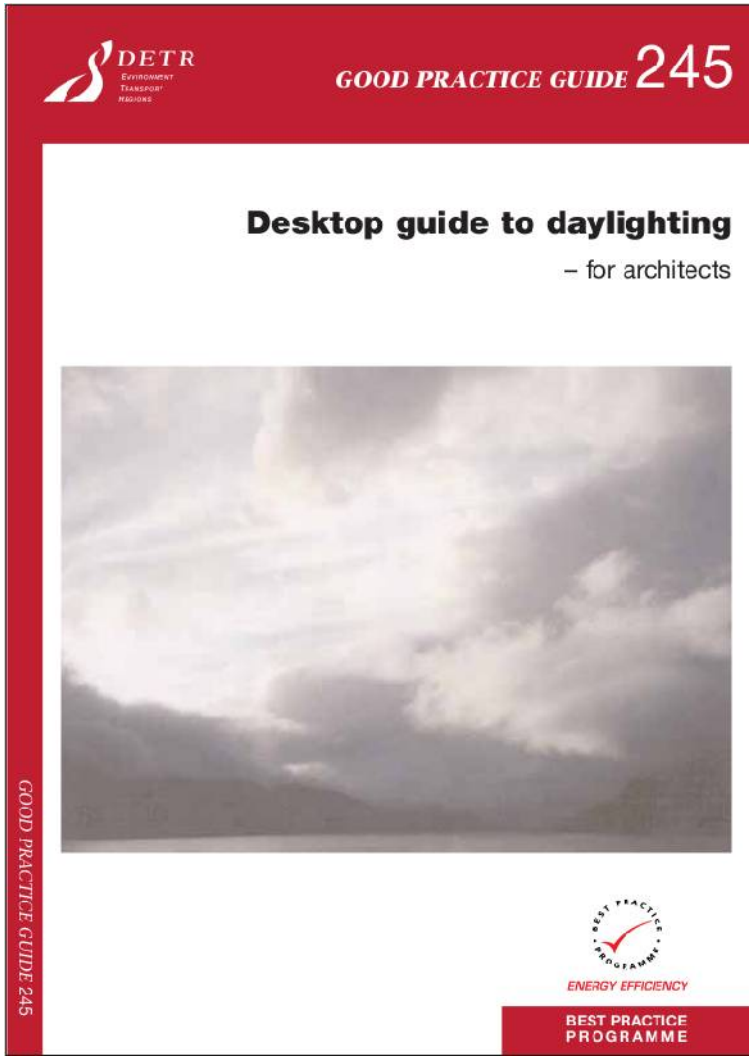
“If this angle is less than 25° for the whole of the development then it is unlikely to have a substantial effect on the diffuse skylight enjoyed by the existing building.

“If, for any part of the new development, this angle is more than 25°, a more detailed check is needed to find the loss of skylight to the existing building. Both the total amount of skylight and its distribution within the building are important.”

Note: There is also a 'site obstruction angle' (43°-rule)

IV *Daylighting Design*

Rules of Thumb



DETR Good Practice Guide 245:
Desktop guide to daylighting - *for architects*
by Peter Tregenza

This is a must-read!

Rules of Thumb (contd.)

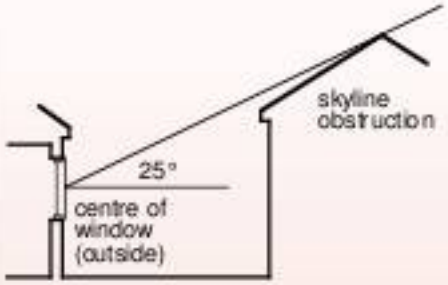
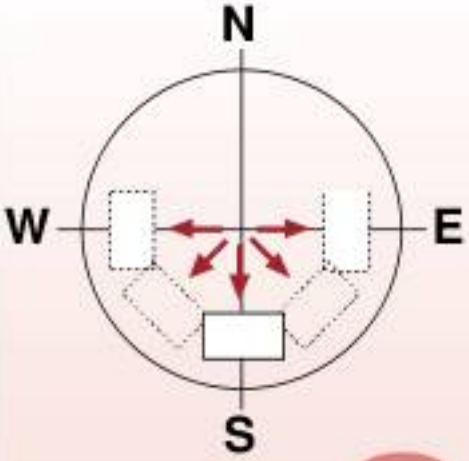


Figure 1 Angle of obstruction above the horizon

1

Rule of thumb

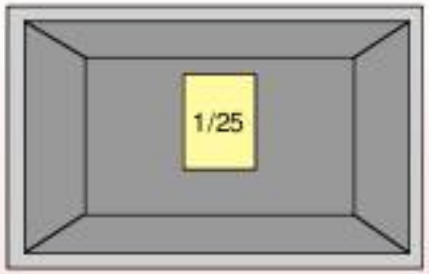
When a window is to be used as a main source of light, external obstructions should not be higher than 25° above the horizon.



2

Rule of thumb

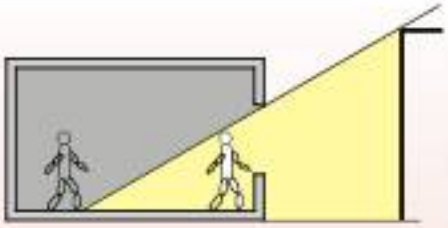
When a window is to be used to provide sunlight in a room, it should face within 90° of south and external obstructions should not be higher than 25° above the horizon.



3

Rule of thumb

A room can have a daylit appearance if the area of glazing is at least 1/25th of the total room area.

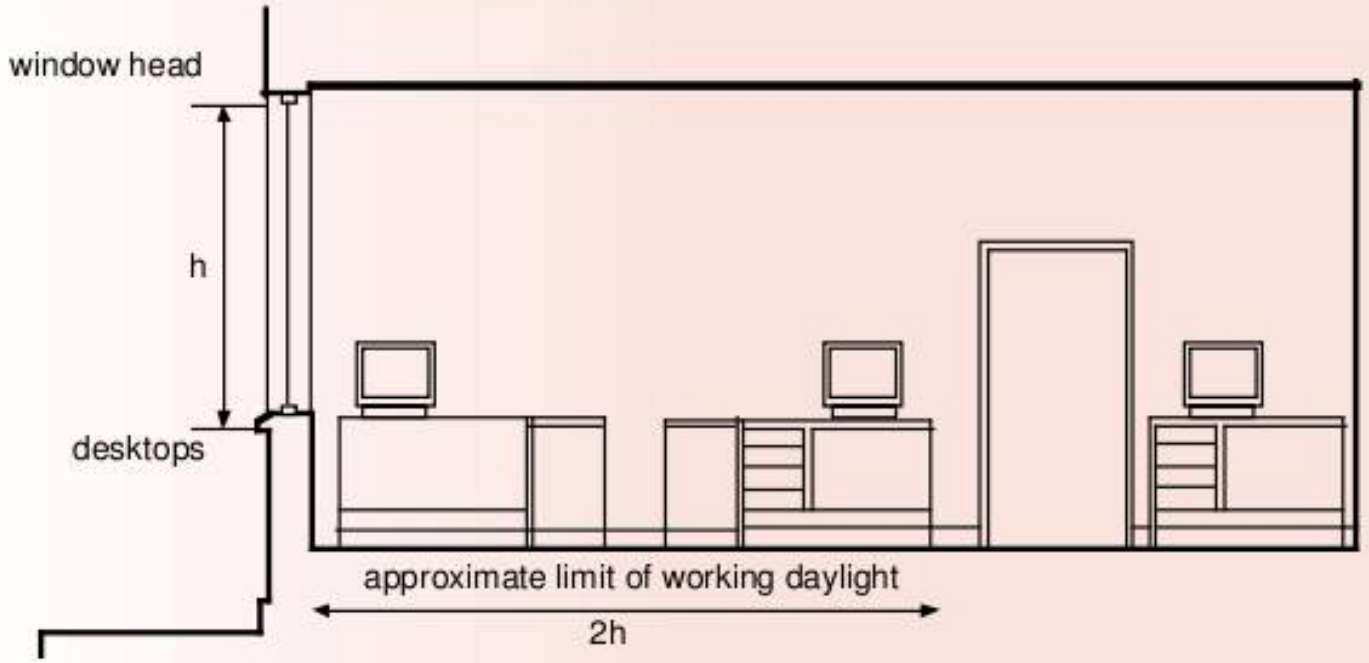


4

Rule of thumb

Areas of the room from which there is no direct view of the sky have a low level of daylight.

Rules of Thumb (contd.)



5

Rule of thumb

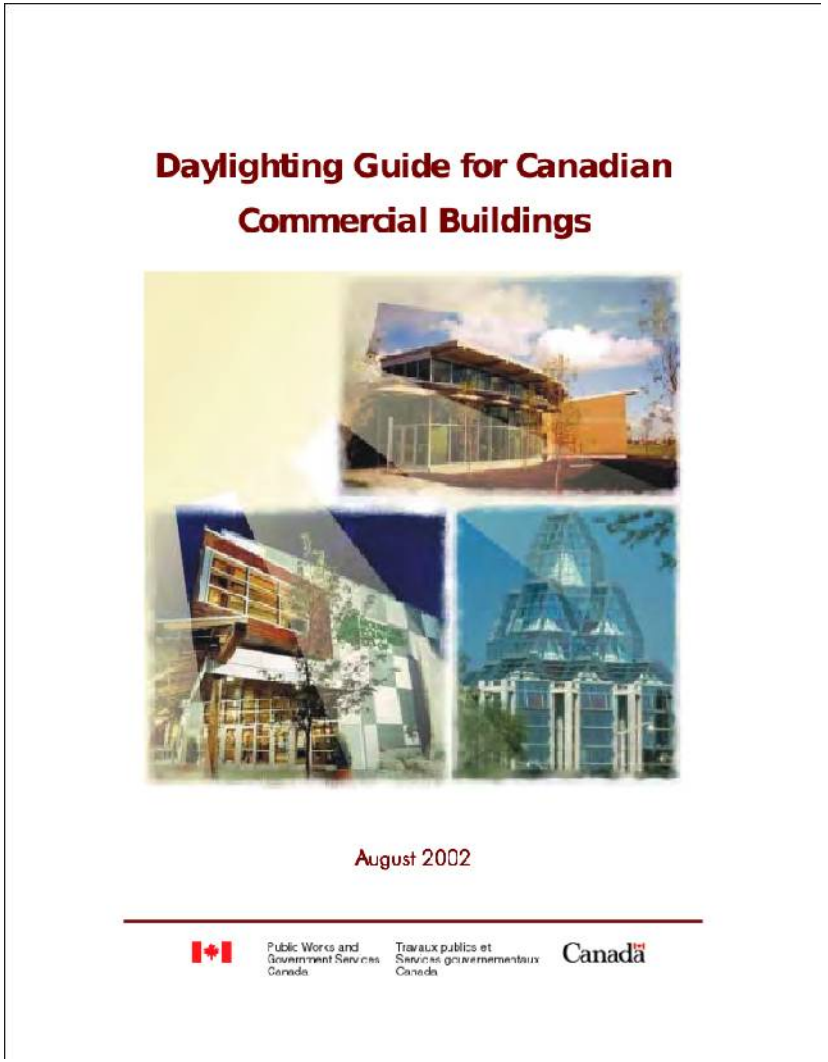
Surfaces that are closer to a window than twice the height (2h) of the window head above desktop level, receive adequate daylight for tasks for most of the working year (see figure 5).

Figure 5 Zone of strong daylight

Please DO read this guide to learn about the other rules-of-thumb!

10-step Design Process

1) Design Basis
2) Building Orientation, Form
3) Daylighting the Perimeter
4) Daylighting the Core
5) Window and Glazing
6) Shading and Visual Comfort
7) Optimising
8) Mechanical Coordination
9) Artificial Lighting Integrations
10) Commissioning



1/10: Design Basis

- Determine spaces that benefit most from daylight

Daylighting Opportunity for Common Building Spaces

Space Function	Light Level	Acceptable Variability	Daylighting Ease
Hospitals, health care	High	Low	Low
Computer work, office	Medium	Medium	Medium
Corridor, washroom, eating area	Low	High	High
Retail (grocery, stores)	High	High	High

- Where is daylight not suitable?
- Set up integrated design team

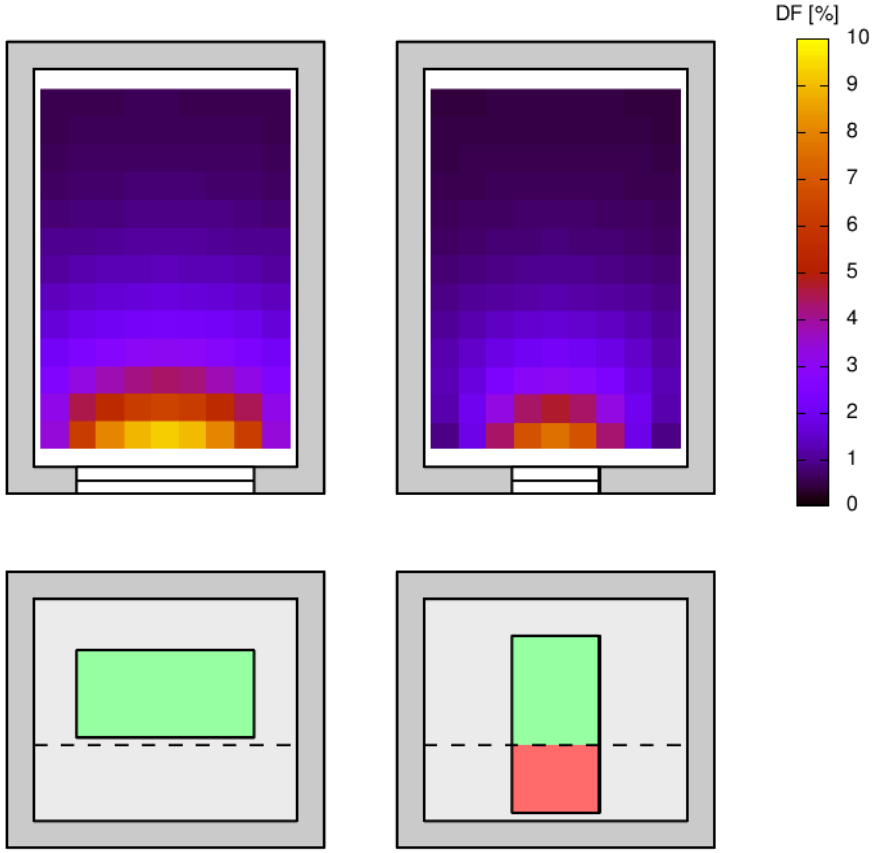
2/10: Building Orientation, Form

- Site layout to optimise DL availability:
  Obstruction angles (BR209)
- Face south (easy shading) or north (no shading required).
  Avoid east and west facing facades.
- Prefer narrow footprints (smaller core area).
- What can go in the core areas?
- Select light coloured materials
- Used glazed atria for core daylighting
- Prefer low-rise over high-rise
- Ensure windows on both sides for deep rooms

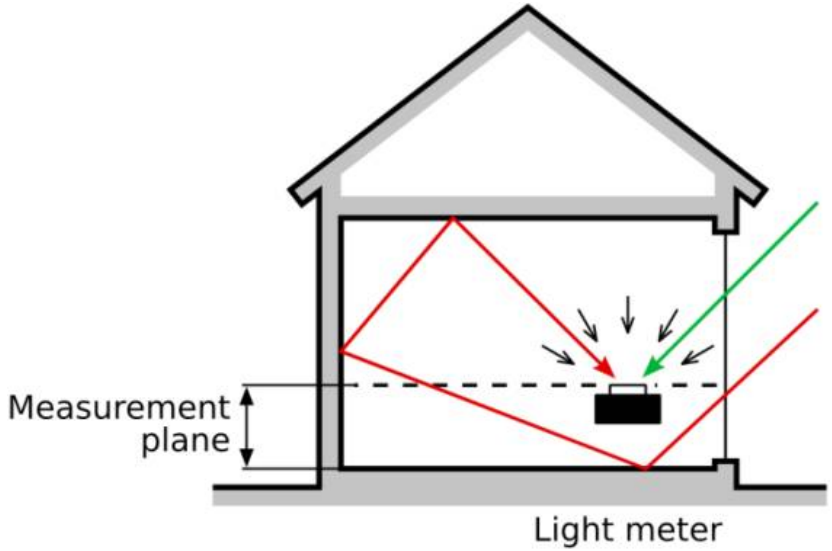
3/10: Daylighting the Perimeter

- Obstruction angle is usually given. Use ADF formula to estimate required glazing area.
- Use software for more complicated cases and to double-check.
- Glazing below working plane is wasted and only adds to thermal problems.
- Consider separate openings for view and daylight.
- High ceilings allow for better uniformity.

3/10: Daylighting the Perimeter (contd.)



Window	ADF	Uniformity
Wide	2.0%	0.25
Tall	1.3%	0.32



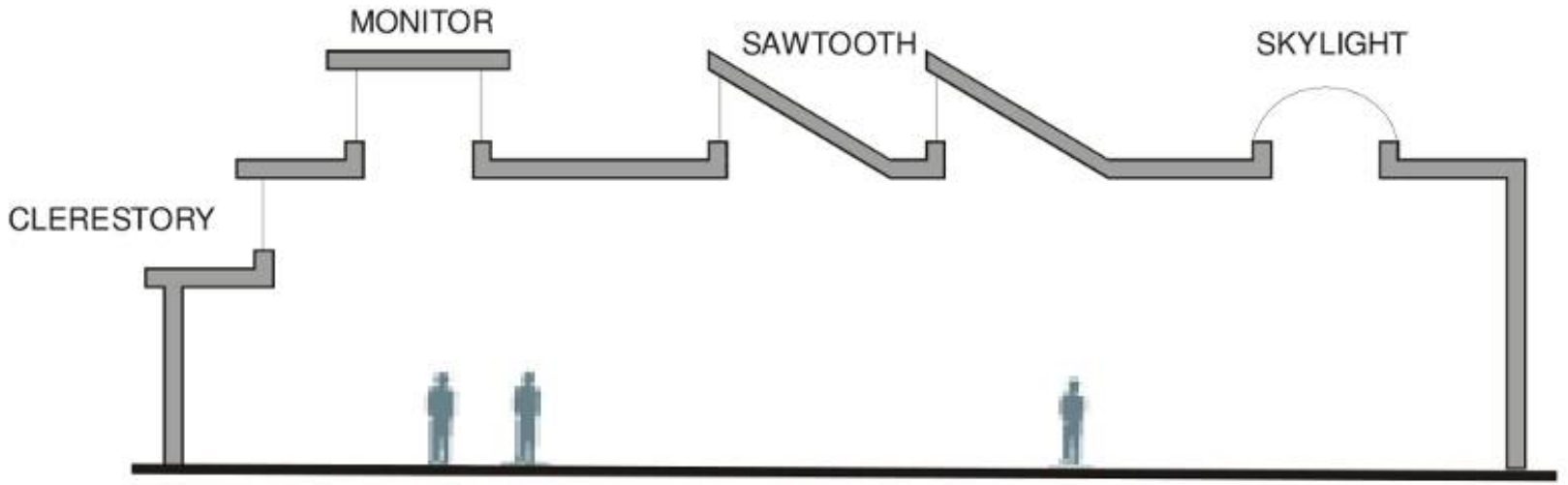
Glazing area below the working plane is nice for a view out, but useless for daylight on the working plane.

3/10: Daylighting the Perimeter (contd.)

- Use light coloured carpets, paints and furniture
- Ensure furniture doesn't obstruct natural light
- Careful with dividers and partitions. Place at right angle to the windows, if possible.
- Choose matt over specular finishes.
- Place computer screens away from windows, or at least parallel to facade.

4/10: Daylighting the Core

- Toplighting can bring natural light to the core area, but only at the top floor.



Example of Toplighting Strategies

- Danger of glare and overheating.

4/10: Daylighting the Core (contd.)

- Paint ceilings white to reduce contrasts
- Make sure work places don't receive direct sunlight.
- Use shades and reflectors.

5/10: Selecting Windows and Glazing

- Define required U-value (Part L)
- Triple glazing, inert gas filled, low-e coating
- Non-metal frames, e.g. wood, plastic, fibre glass
- Be aware of tinted glazing. Clear glazing, combined with external shading is usually better.
- UV or non-UV?

5/10: Selecting Windows and Glazing (contd.)

6/10: Shading and Visual Comfort

- Exterior shading devices to control solar heat gain.
- Internal, movable blinds against glare.
- Deciduous vegetation may act as seasonal shading.
- Horizontal devices such as overhangs or bris-soleil work best with south facing windows.
- North facing windows generally don't require solar shading

6/10: Shading and Visual Comfort (contd.)

- Vertical fins for east and west. Those orientations are difficult to shade effectively, so avoid having windows facing those directions.
- Movable external shading is most effective, but expensive and high-maintenance.
- Consider light shelves instead of simple overhangs.

7/10: Building Simulation

- Carry out a full building simulation to verify the daylight and thermal performance of the building.
- Make sure you understand all assumptions and simplifications that are made by you or by the software.
- Our Building Simulation module:
  - Radiance for daylighting
  - EnergyPlus for thermal simulations

8/10: Mechanical Coordination

- Adjust size and type of HVAC system
- HVAC can be down-sized:
  - Lower peak cooling load in summer due to efficient shading
  - Lower cooling load due to reduced artificial lighting
  - Lower heating load due to high U-value glazing
- Allow for higher internal gains. Future use might result in more occupants or more equipment gains.

9/10: Artificial Lighting Integration

- Don't compromise lighting quality for energy efficiency
- Make sure the lighting control system is adequate and functions properly.
- Don't patronise the users: Allow for manual overwrite.
- Don't trust an electrical engineer with the lighting
- More in our previous lecture
  “Energy efficient artificial lighting”

10/10: Commissioning and Maintenance

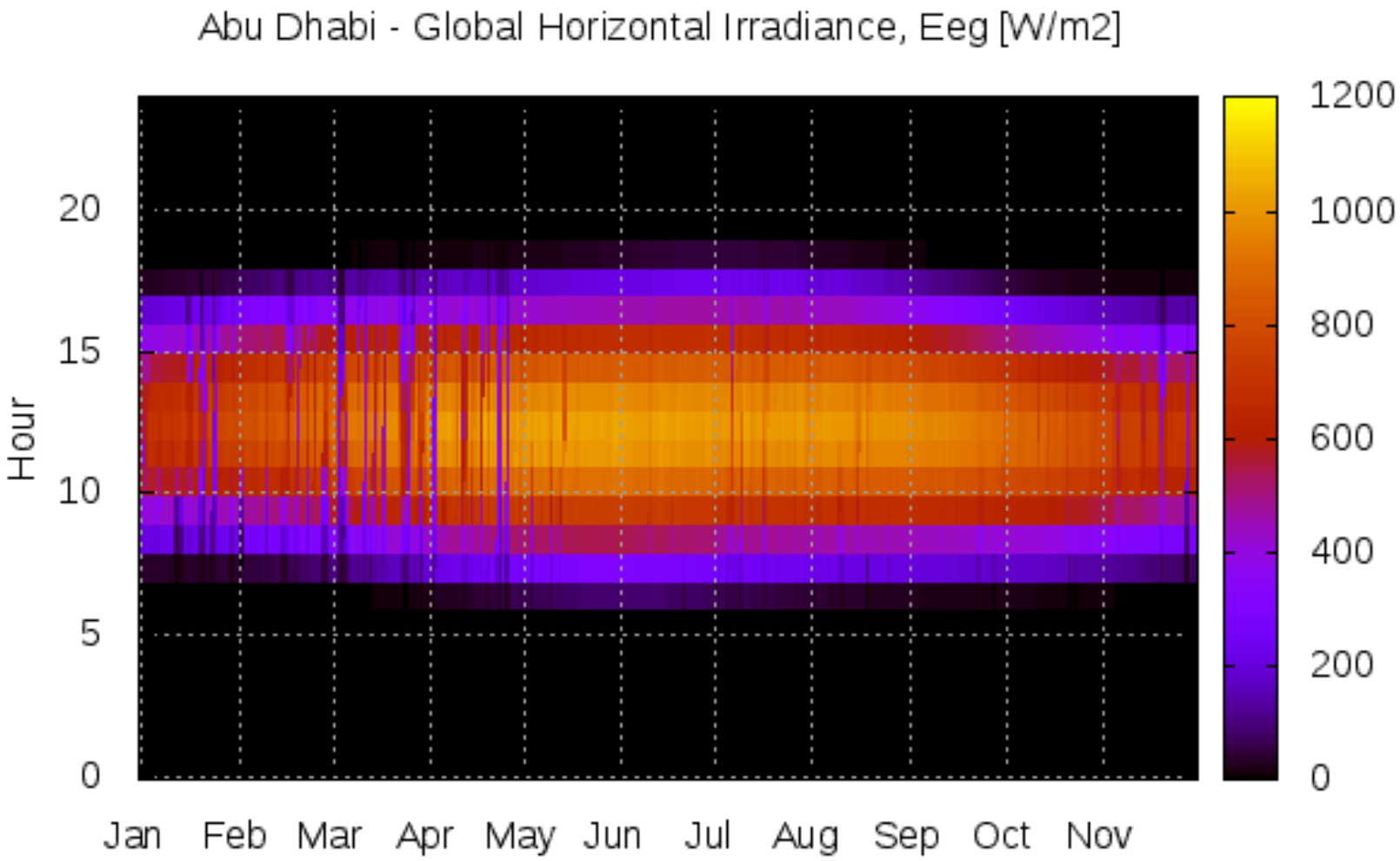
- Commission after completion of interior furnishing.
- Allow for 100 hrs burn-in of lamps
- Calibrate artificial lights at night, daylight systems during the day
- Calibrate each zone individually
- Educate the users and building manager
- Define maintenance plan.

V *Dynamic Daylighting*

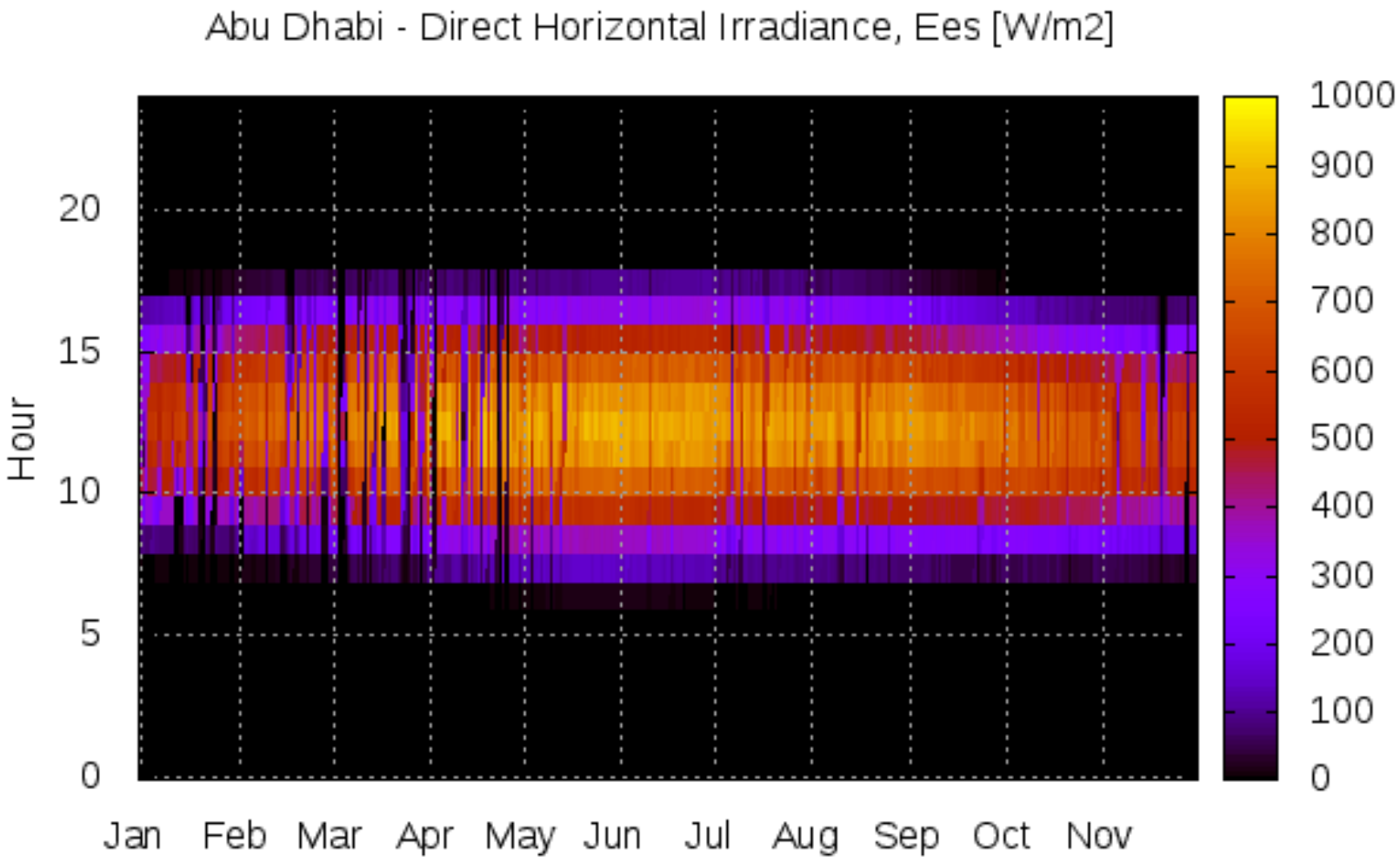
Static Daylighting

- Ideal overcast sky, irrespective of climate and latitude.
- Use of DF.
- No account taken of building orientation.
- Many crude assumptions, but still good for quick calculations during the early stages of building design, when important and far-reaching design decisions are made.
- Used in most daylight regulations

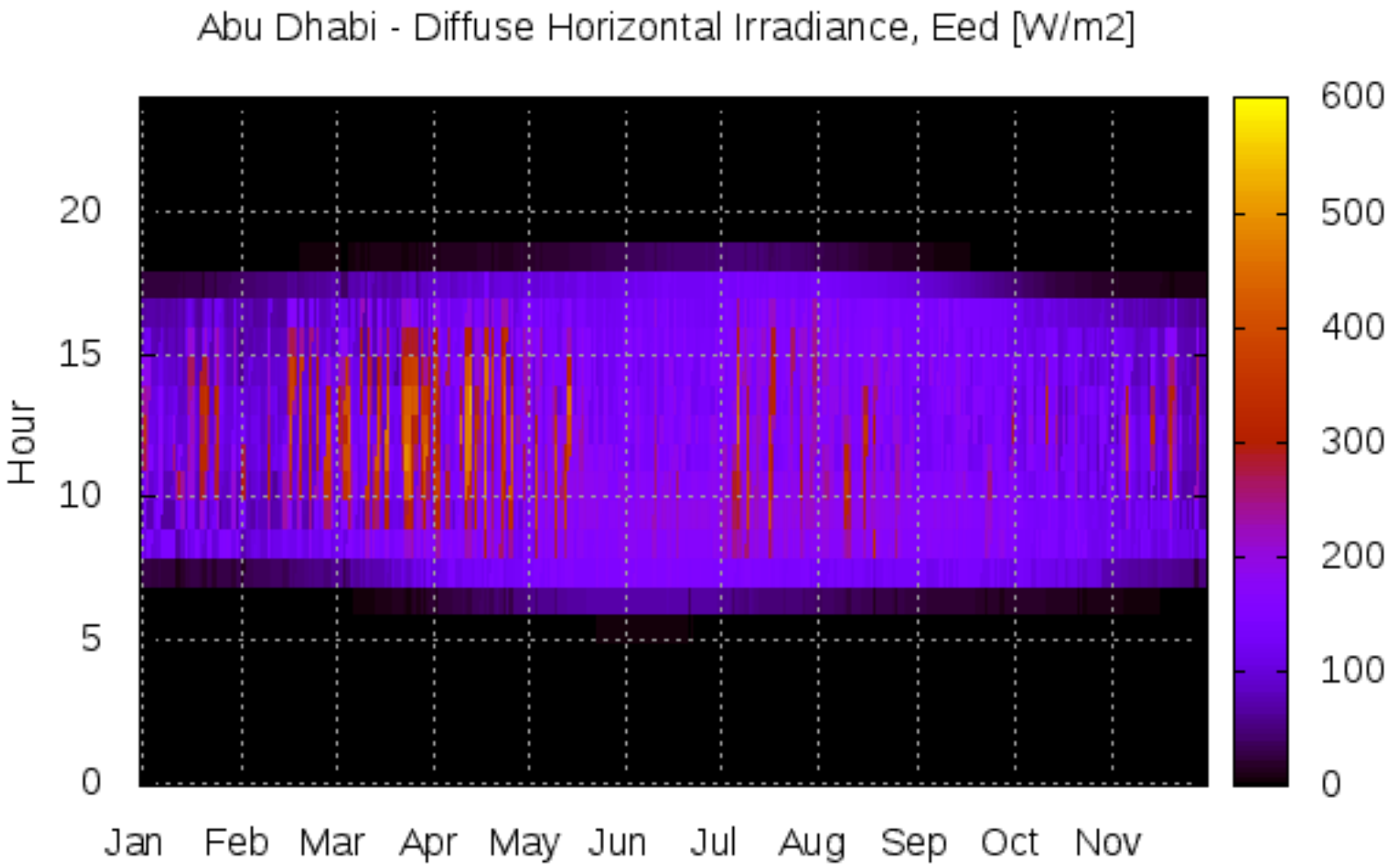
Example Weather Data



Example Weather Data



Example Weather Data



Dynamic Daylight Simulations

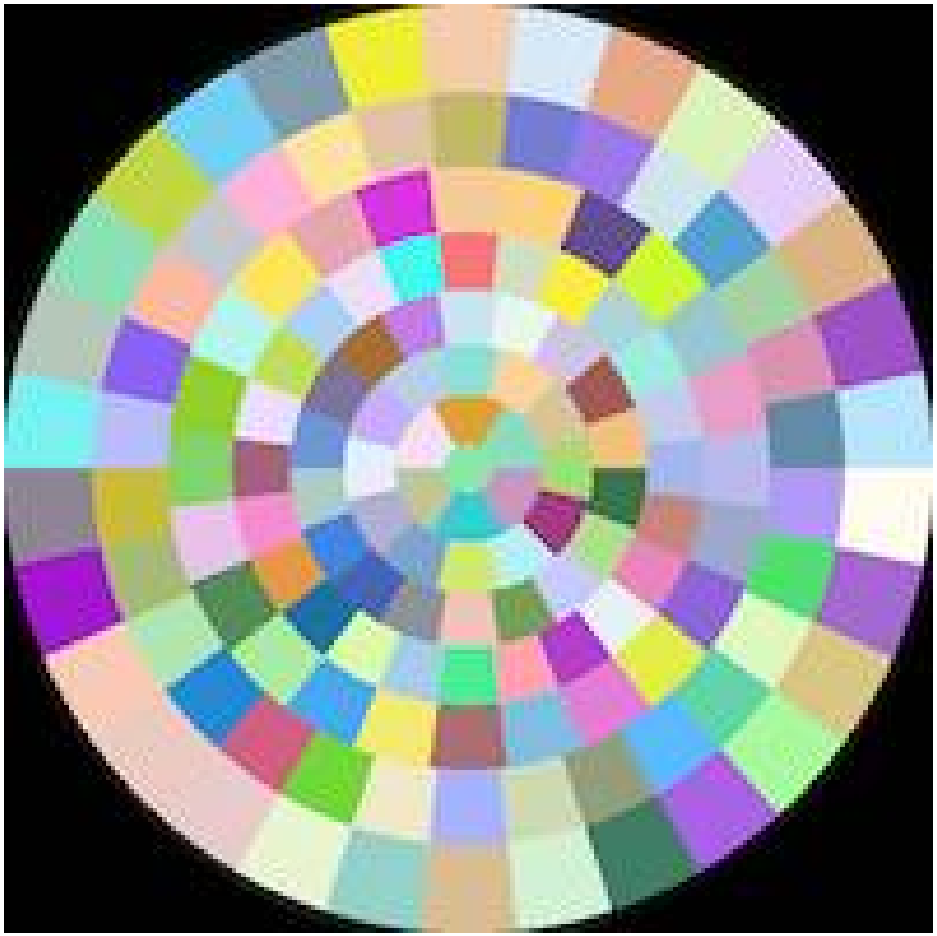
- Use real weather data for more accurate predictions
- 1 hrs time step, ~ 4,000 daylight hours per year
- Derive sky model from weather data
- Run simulation for each time step
- Interpretation of results: new daylight metrics
- For DDS with Radiance, see *Understanding rtcontrib*:

  http://www.jaloxa.eu/resources/radiance/documentation/docs/

4,000 simulation?

You're mad!

Daylight Coefficients

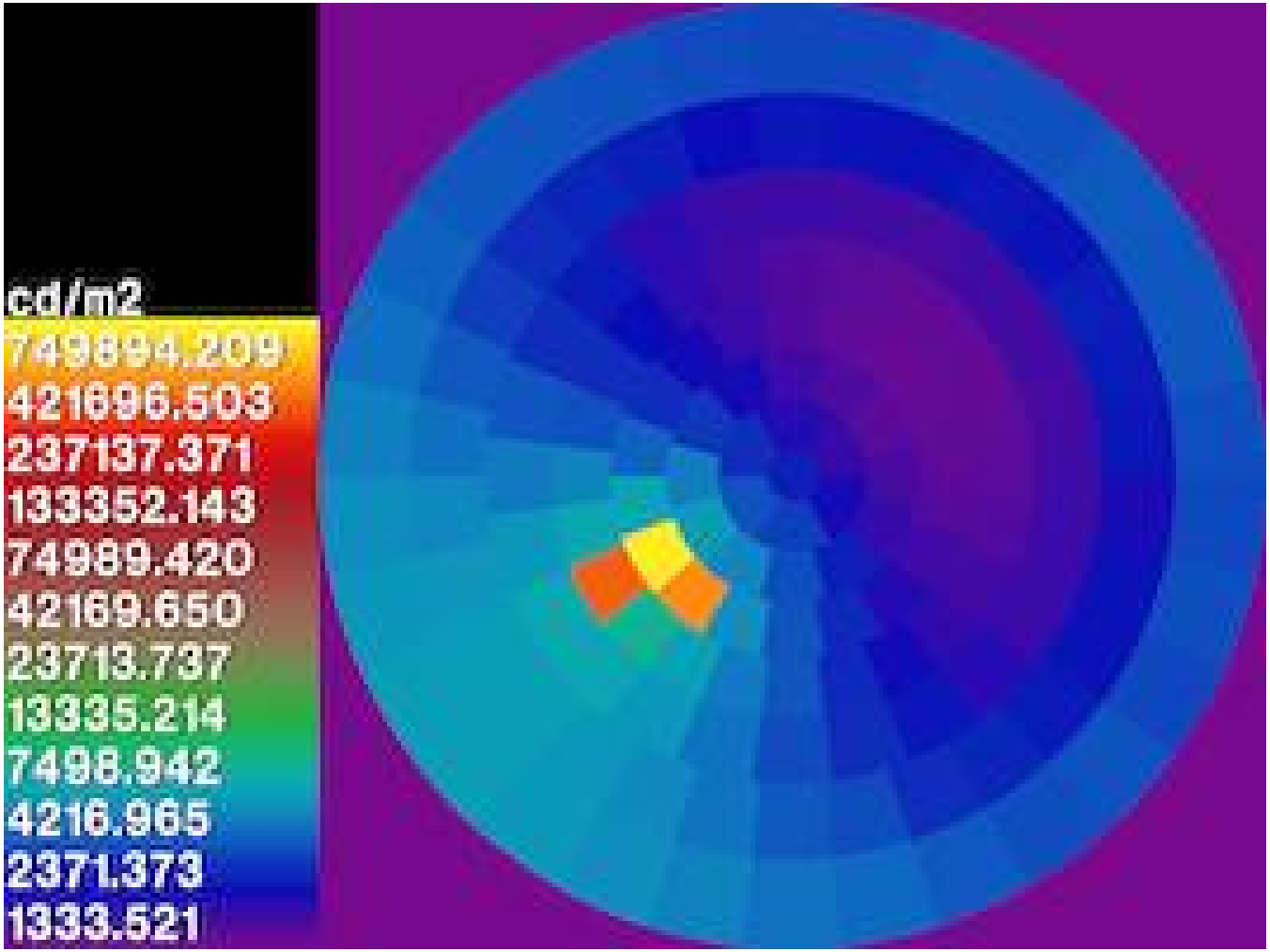


Work out contribution of each sky patch towards internal illuminance

Dynamic Daylight Simulations

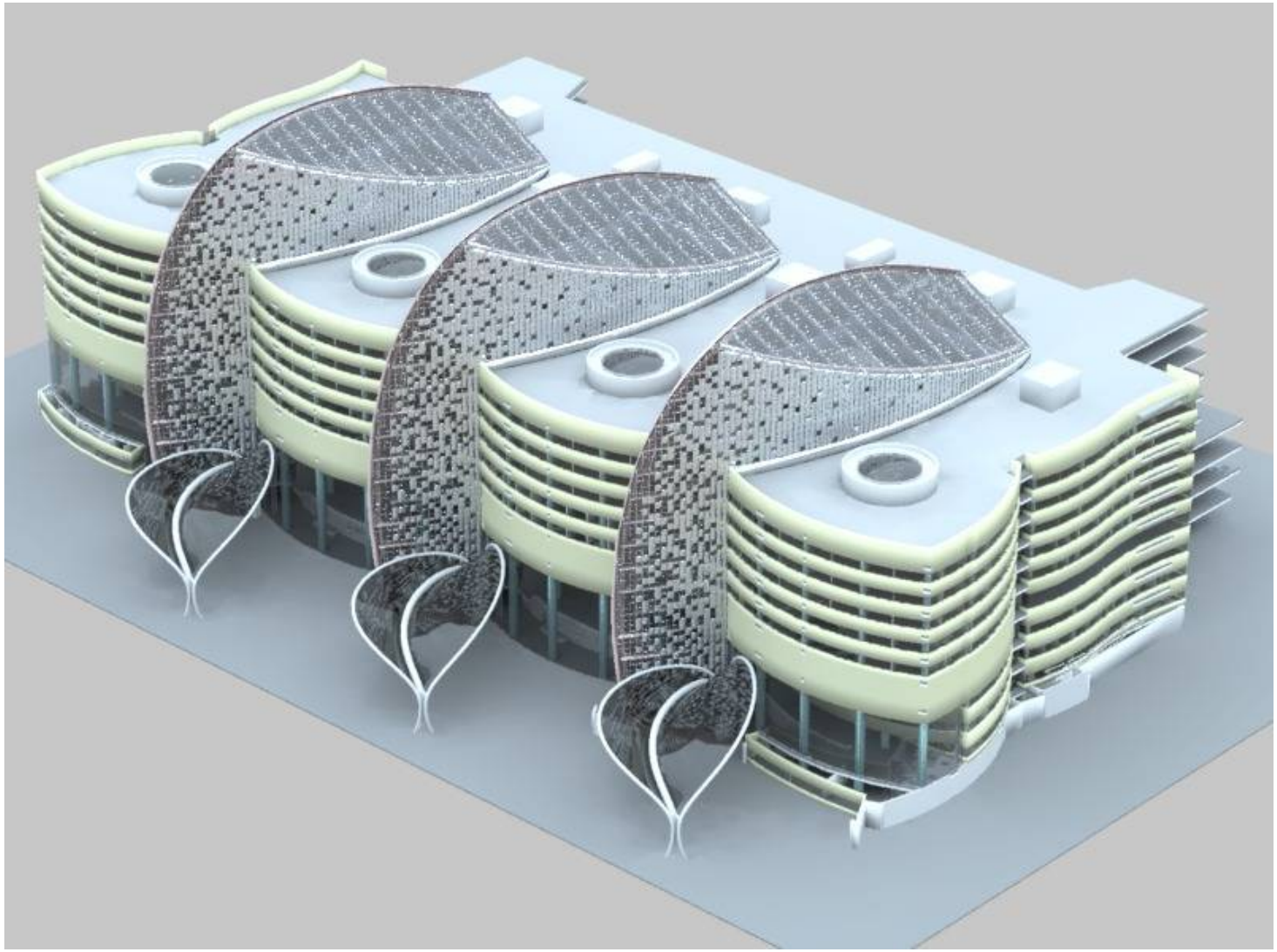
- DDS results in 145 or more images and/or illuminance readings
- Multiply result from each sky patch by patch luminance for sky distribution for each time step
- Add it all up
- Annex B (informative) to BS8206:2-2008: Climate-based Daylight Modelling

DC Example: Sunny Sky

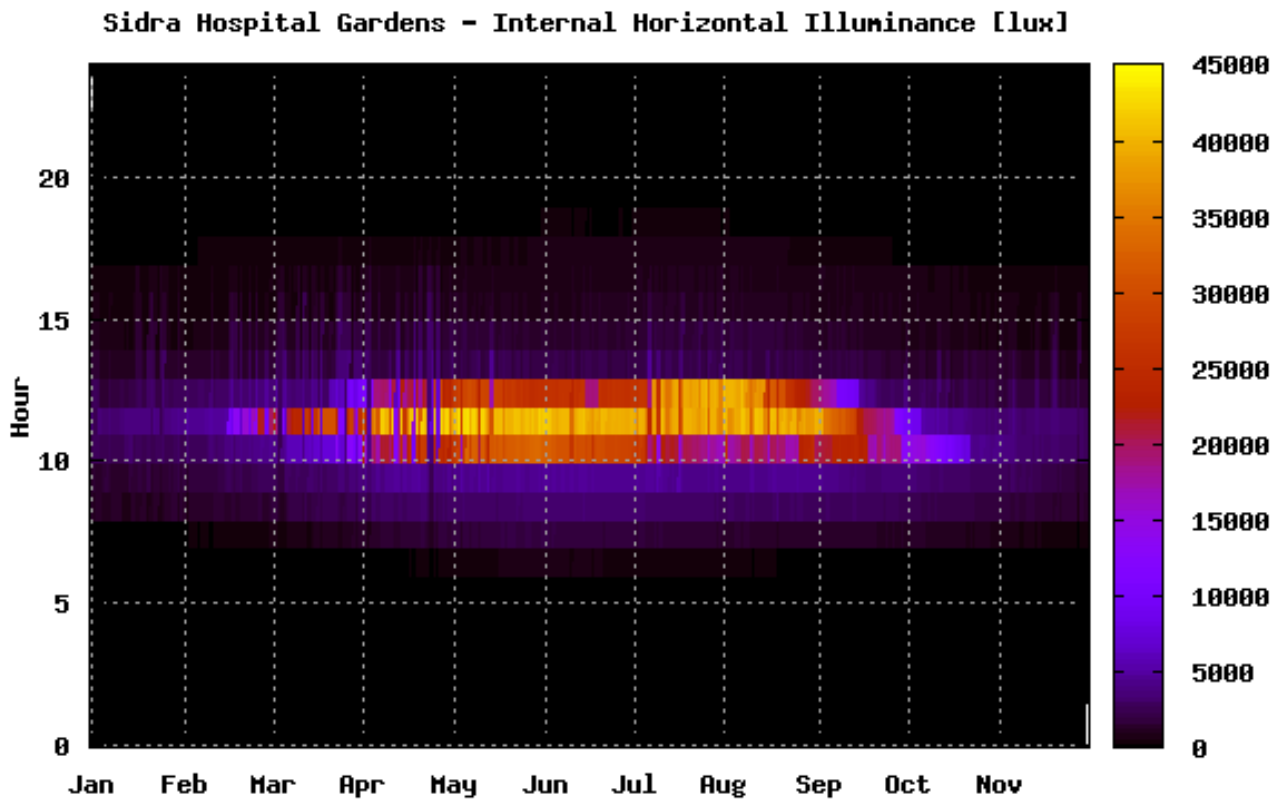


Sun's contribution is simply assigned to three nearest patches

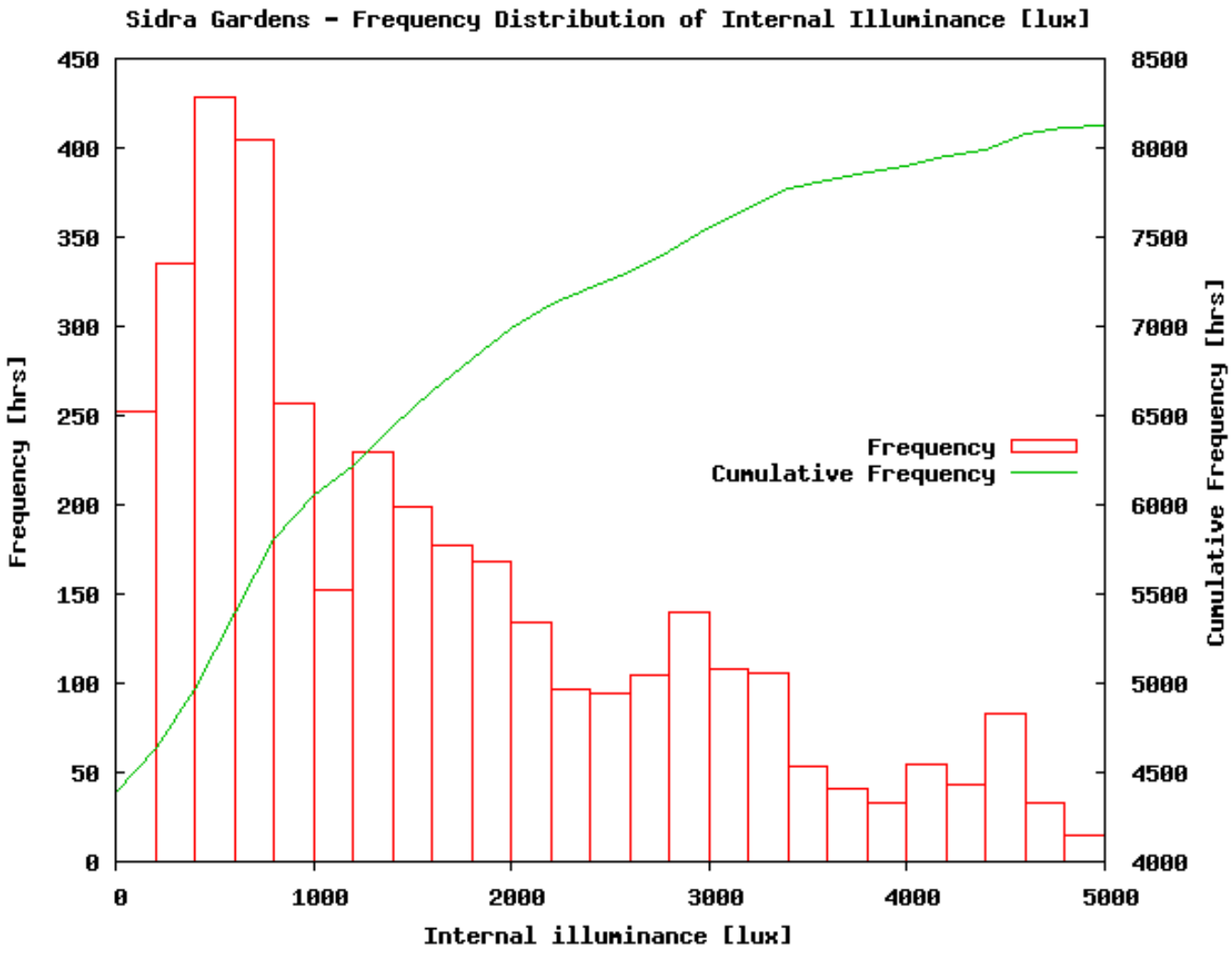
Example: Hospital Atrium Gardens



Results: Time Series



Results: Frequency Distribution



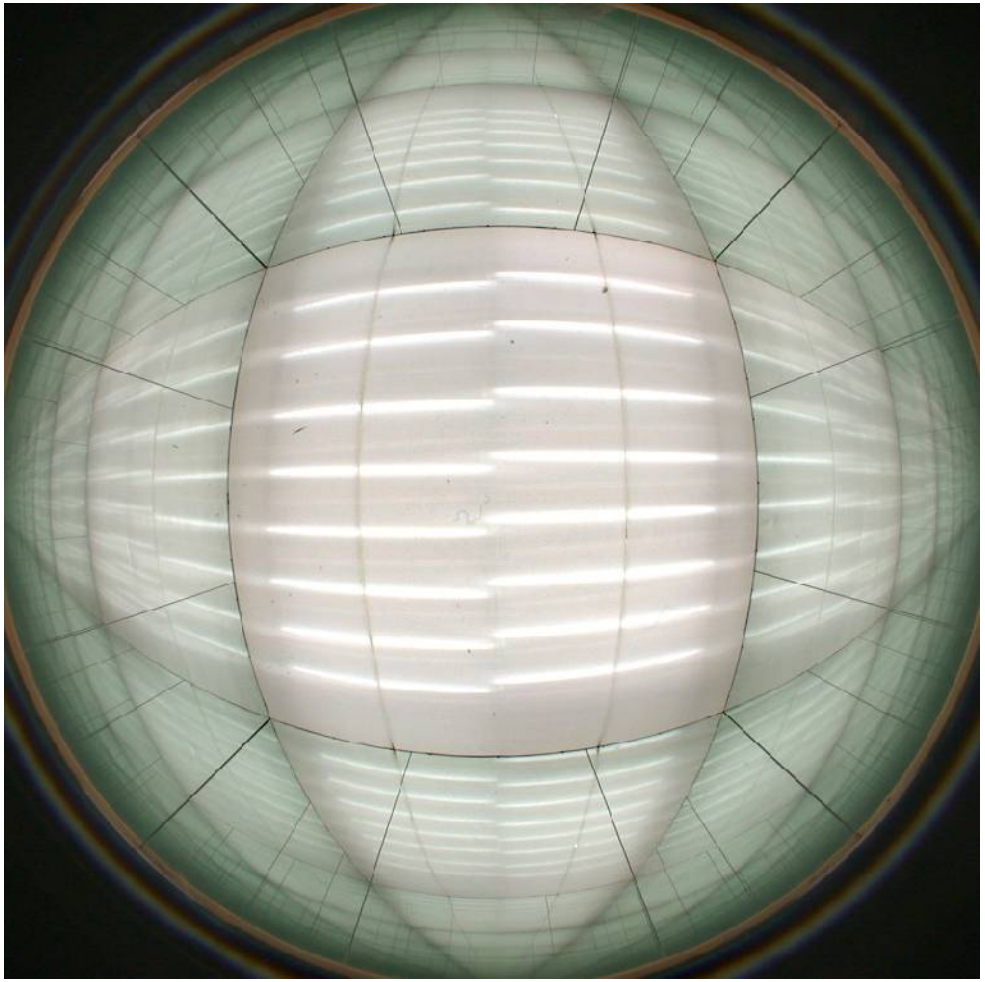
New Daylight Metrics

- TFS: Temporal Fraction of Satisfaction
- DA: Daylight Autonomy
- UDI: Useful Daylight Illuminance

All are based on frequency distribution,
but with different thresholds (still debated)
Example for UDI:
Too low < 200 lx < good < 2500 lx < too high

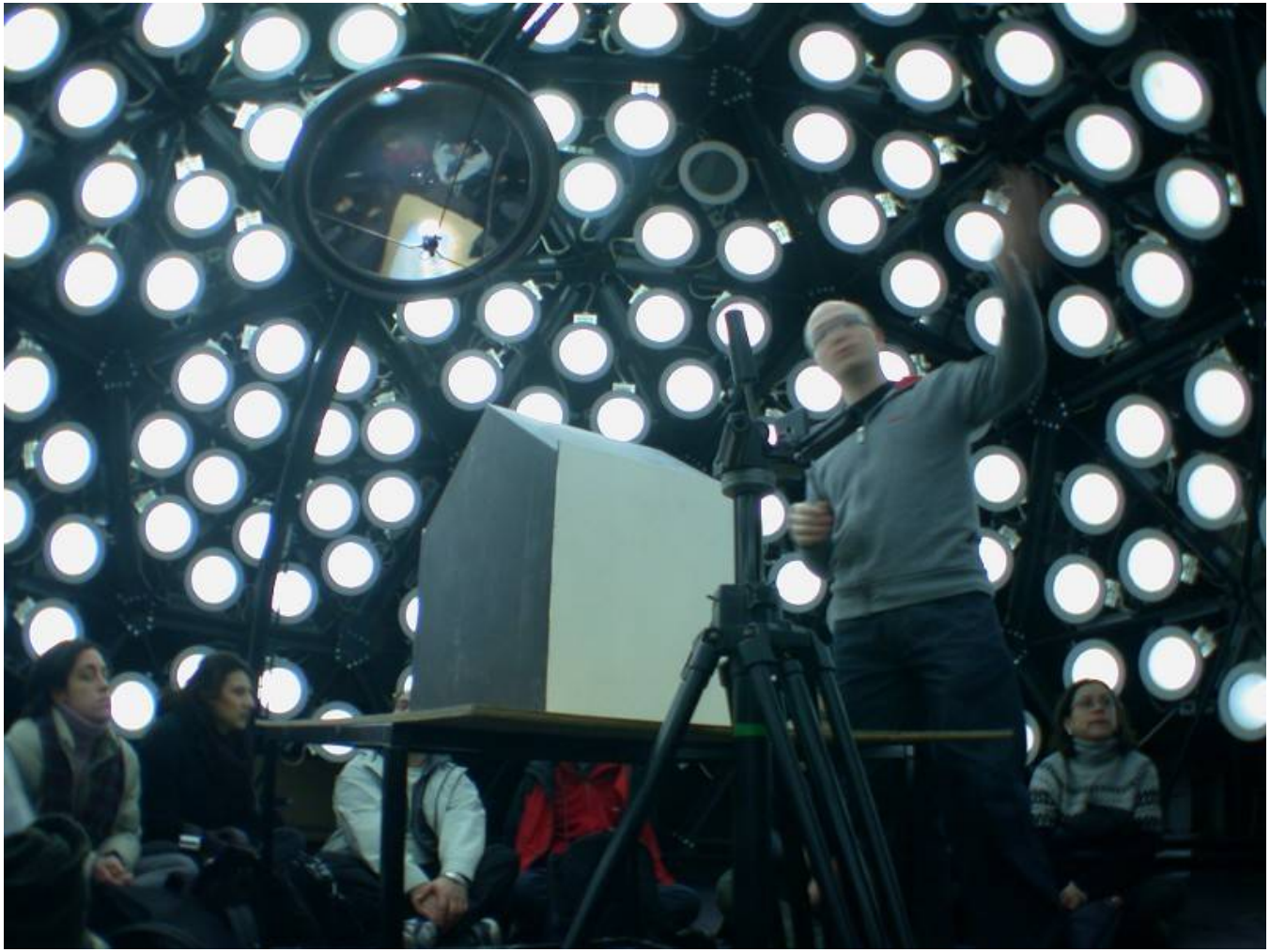
VI *Axel's Thesis*

Mirror Box Artificial Sky



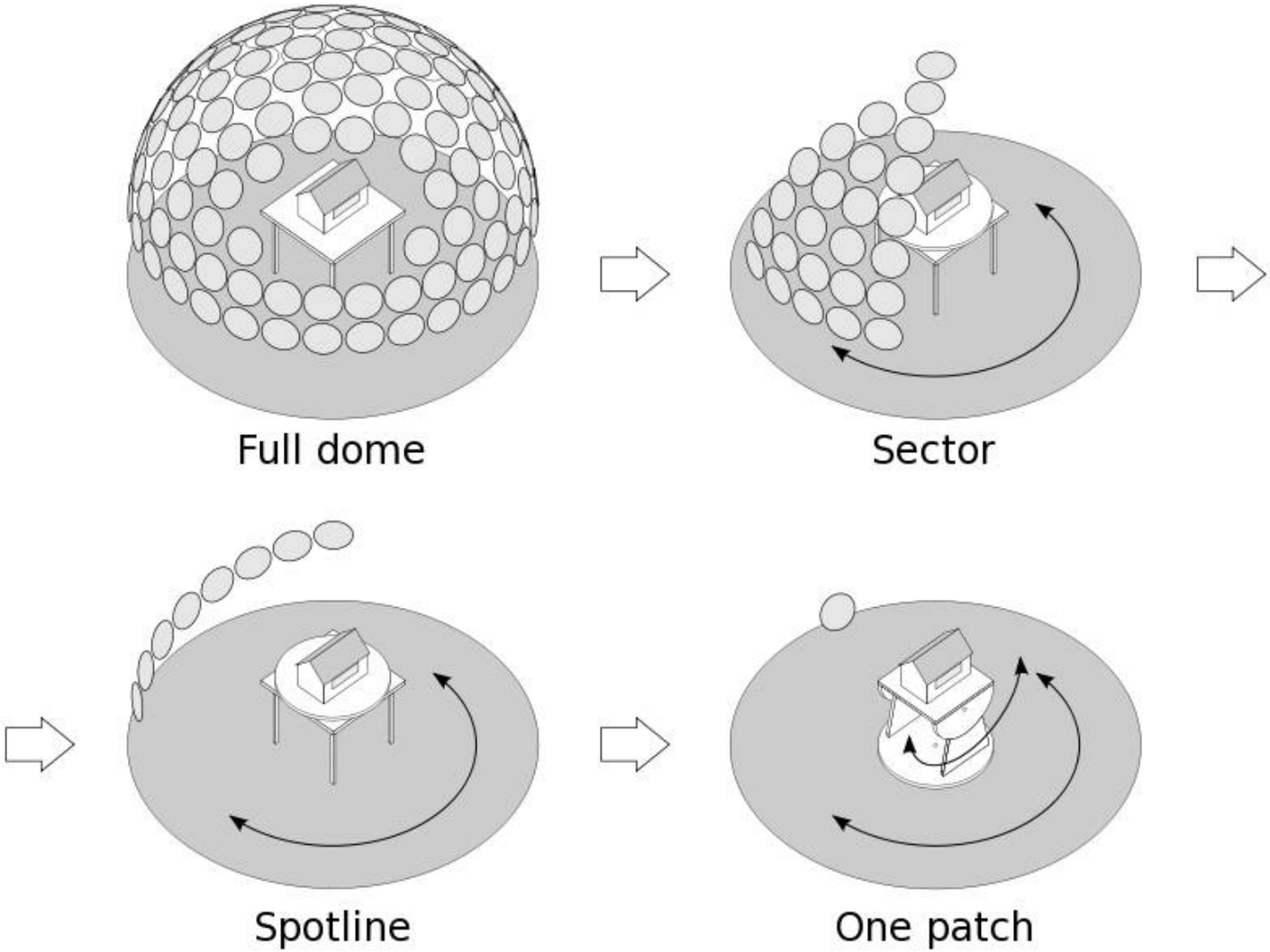
Cheap and cheerful, but only CIE Overcast distribution

Sky Simulator Dome



Very expensive but can reproduce any sky distribution.
Two of those in the UK: Bartlett, London and Cardiff

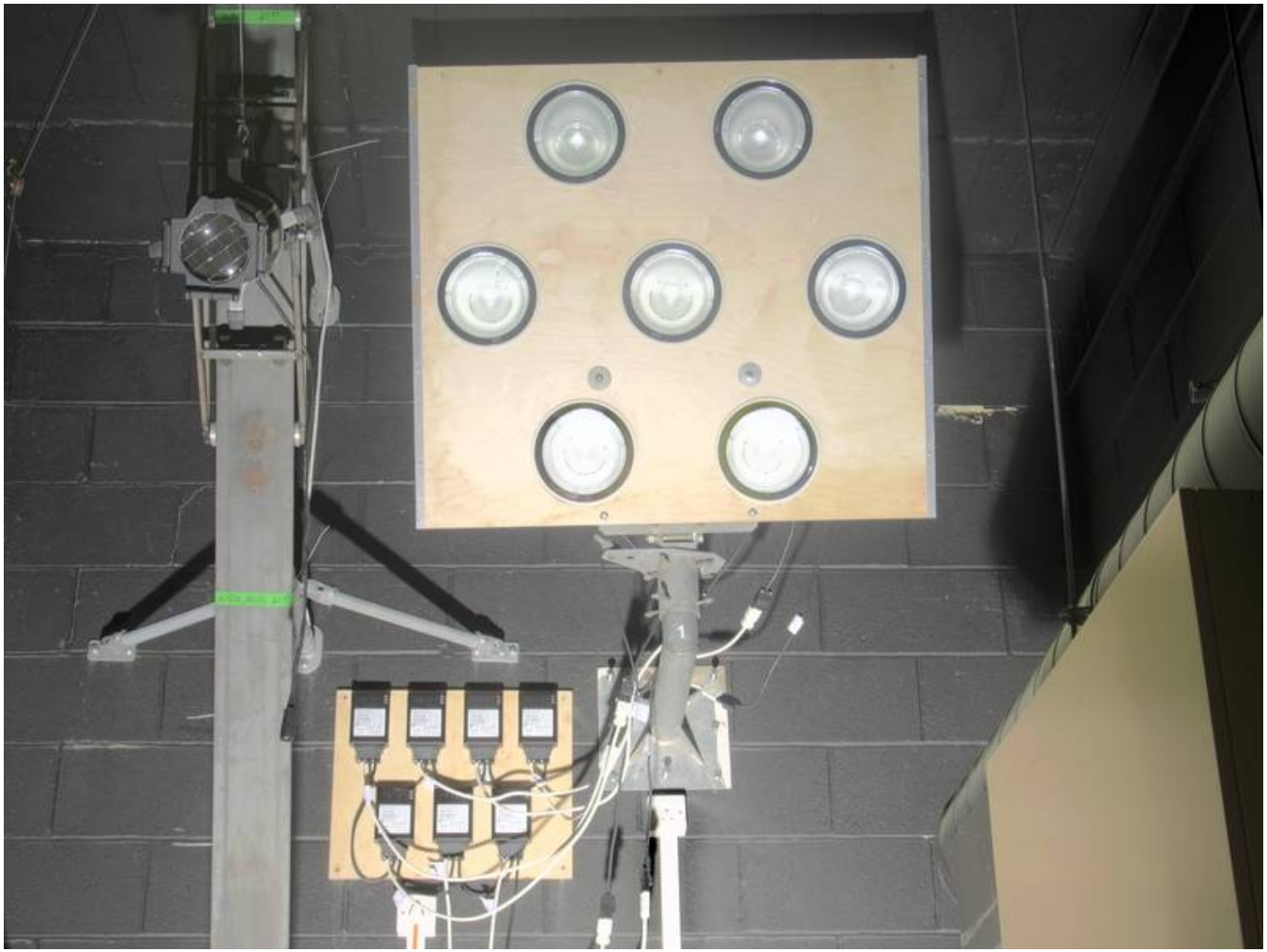
One-lamp Artificial Sky



One-patch Artificial Sky

- Fixed light source as sky patch, 11° angle
- Model is rotated on a two-axis table
- Daylight Coefficients:
  145 individual measurements are made
- Post-processing: Any sky distribution
  Use EPW weather, Radiance tools
- Dynamic Daylight Simulation
- Integrated HDR capturing

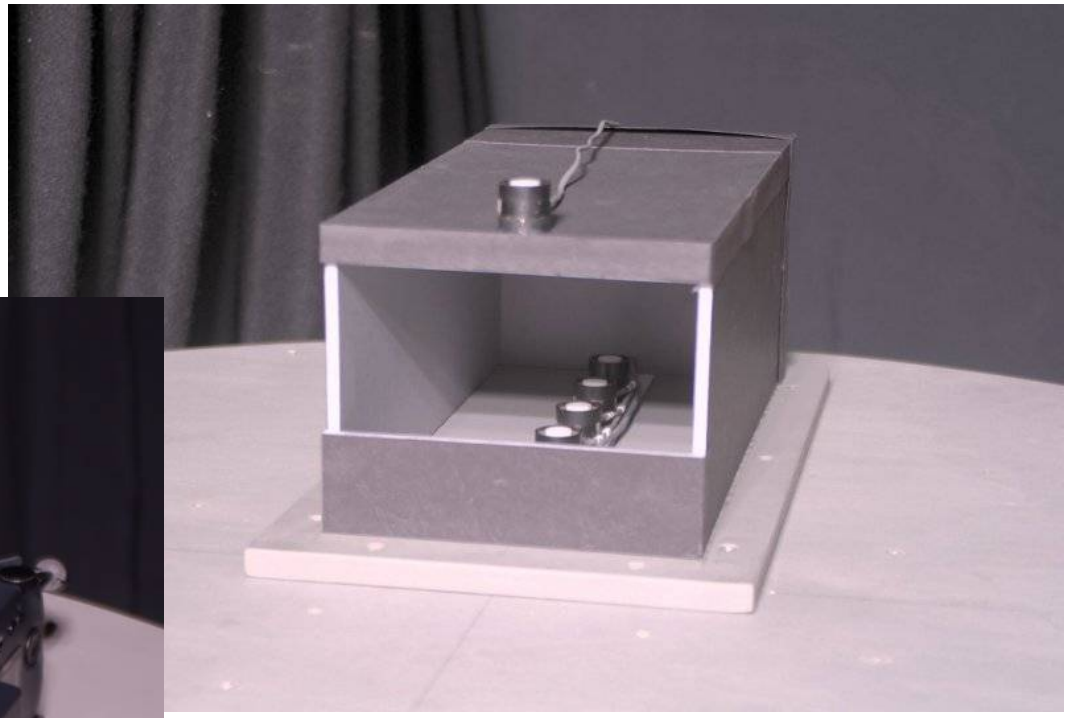
Light Source

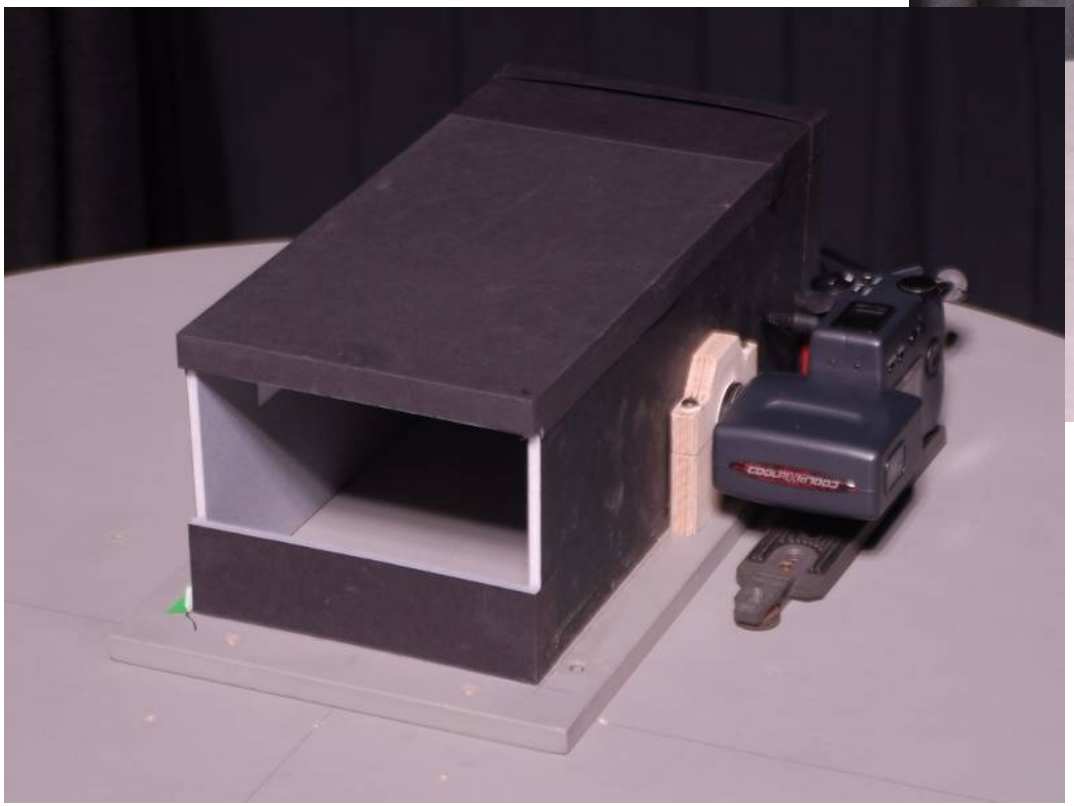


7 downlighters, 150 W metal halide, delivering 4500 lx at the model

Pan-and-tilt head

Model with Camera, Sensors

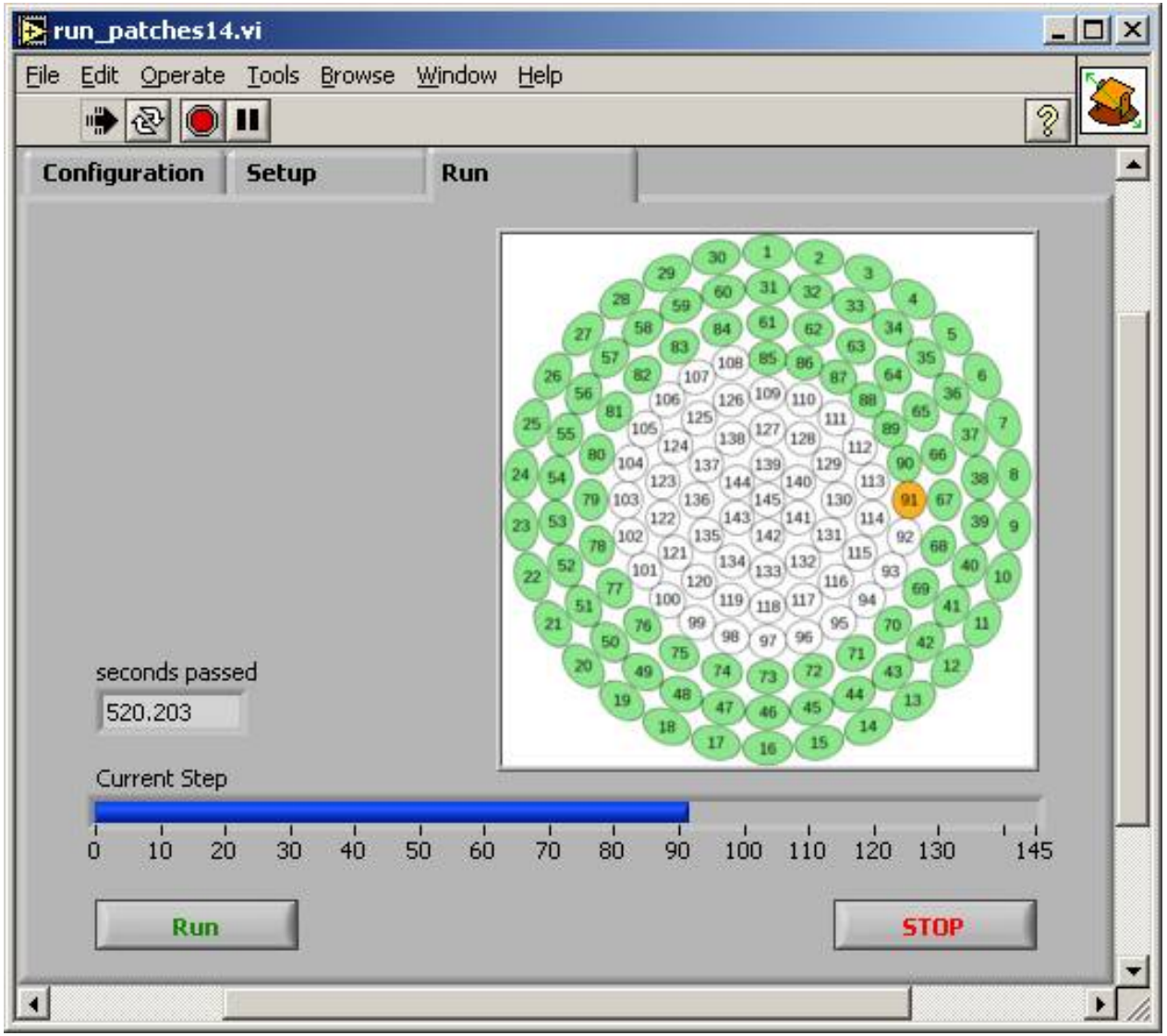




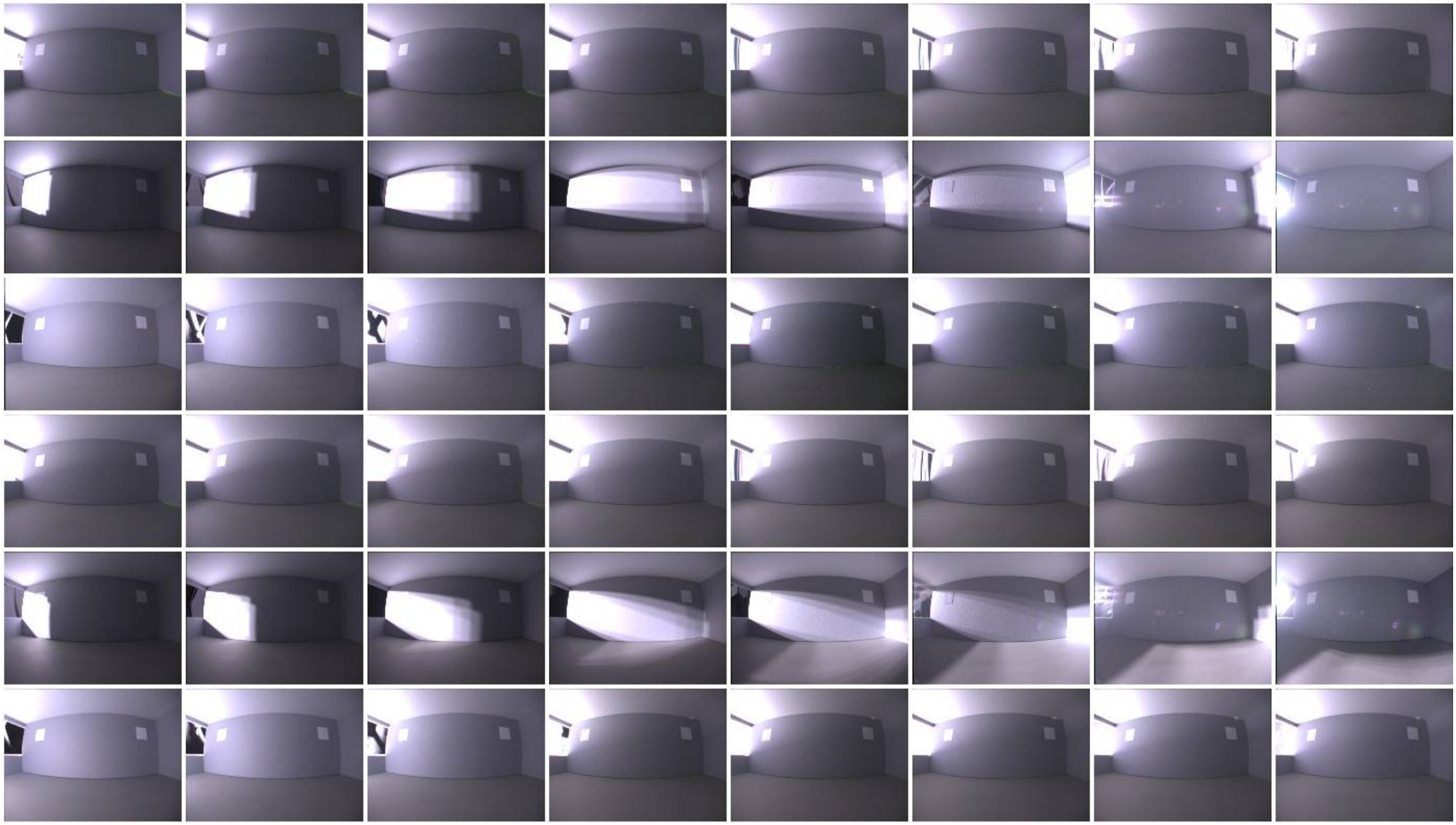
Lighting Lab

Radiance simulation

Fully Automated Control Software



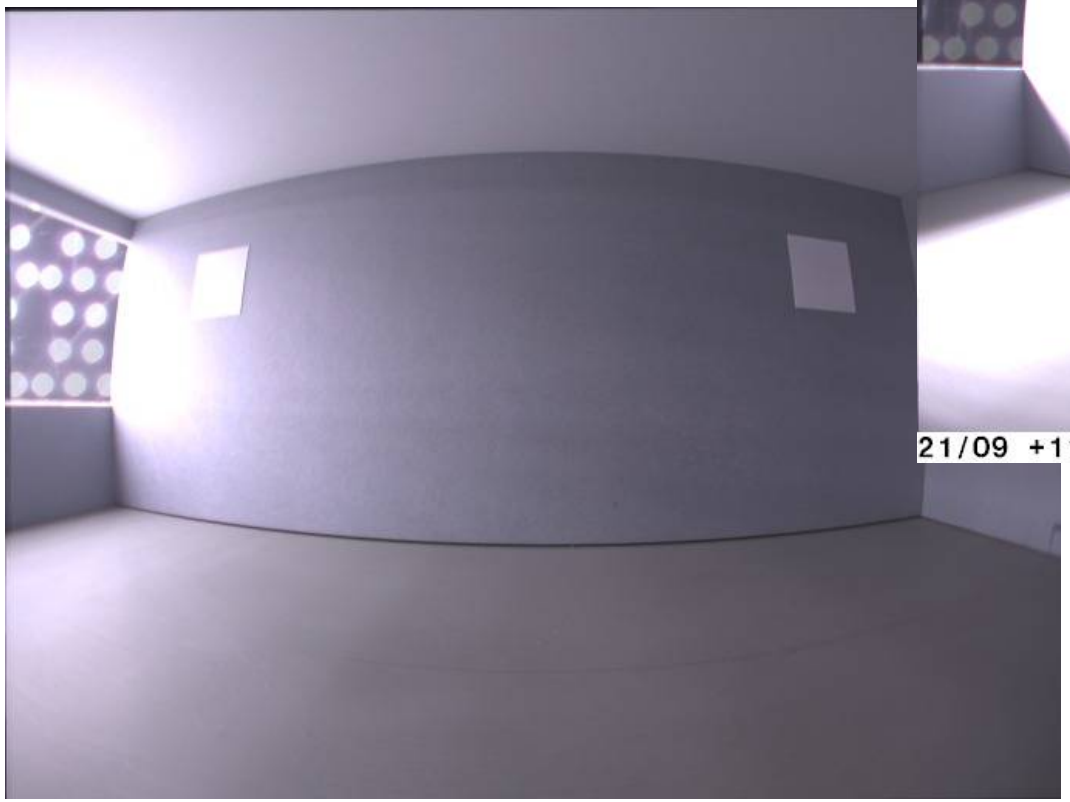
Example DC Images



Superposition

Any sky distribution can be composed.

Overcast



Clear

Further Reading

[1] International Energy Agency: *Daylight in Buildings*, 2000

[2] Public Works and Government Services Canada: *Daylighting Guide for Canadian Commercial Buildings*, 2002

[3] LBNL: *Tips for Daylighting with Windows*

[4] Otis and Reinhart: *A Design Sequence for Diffuse Daylighting - Daylighting Rules of Thumb*

[5] CIBSE LG10: *Daylighting and Window Design*

Many other good guides to daylighting are available on the Internet...

Architect, have you achieved 5%?