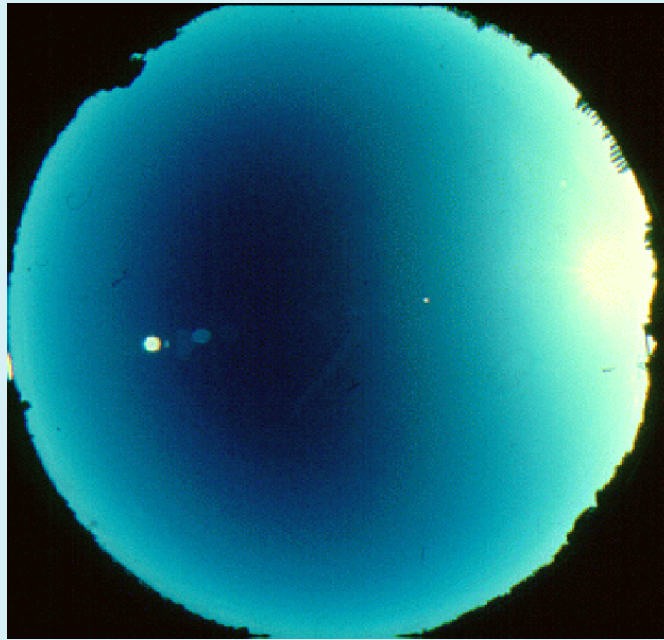


THE AVERAGE TOTAL DAYLIGHT FACTOR



Luisa Brotas

LEARN - Low Energy Architecture Research Unit
London Metropolitan University

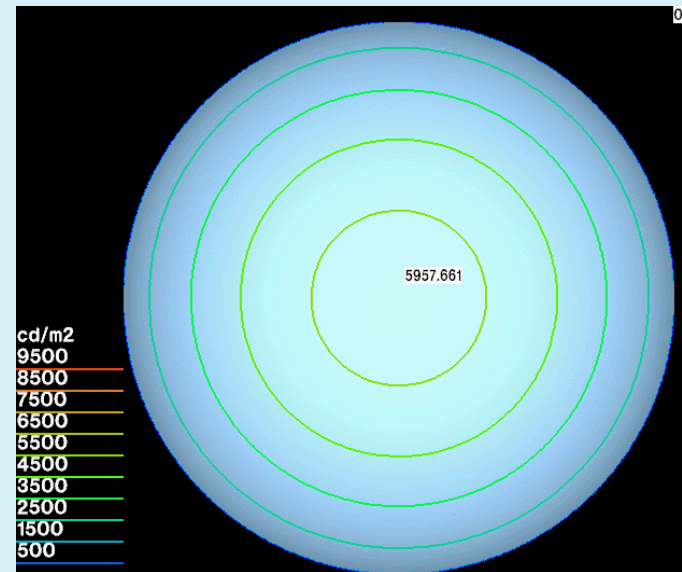
INETI Department of Renewable Energy

National Institute Engineering, Technology and Innovation I.P.

l.brotas@londonmet.ac.uk

CIE Overcast sky

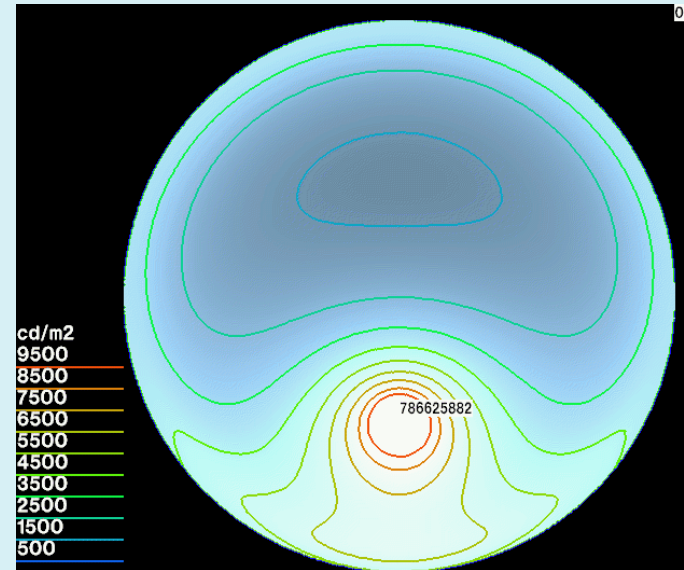
- the sun is invisible although its position above the clouds affects the brightness of the sky depending on the turbidity of atmosphere
- the luminance of the CIE overcast sky depends on the altitude of the point of the sky in relation to the zenith, independent of the sun position and for the same altitude is equal in all azimuth



- the luminance distribution varies with location time density and uniformity of the clouds
- the luminance at the zenith is 3 times brighter than the horizon

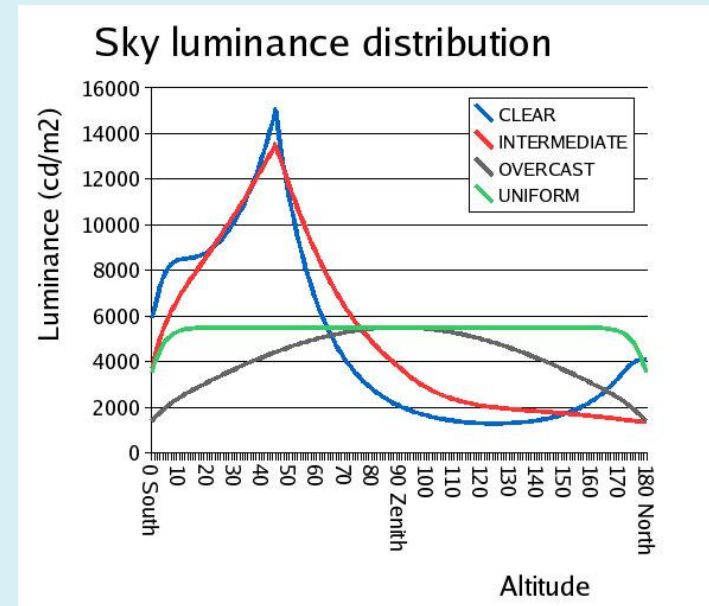
Clear sky

- the brightness of the sky varies in terms of altitude and azimuth of the point
- the sky luminance varies with the position of the sun and the amount of atmospheric dust or haze
- the brightest point is the sun. It tends to progressive darken to the opposite point around 90 degree in azimuth. The luminance at the horizon is a value between these two extremes



Sky distribution

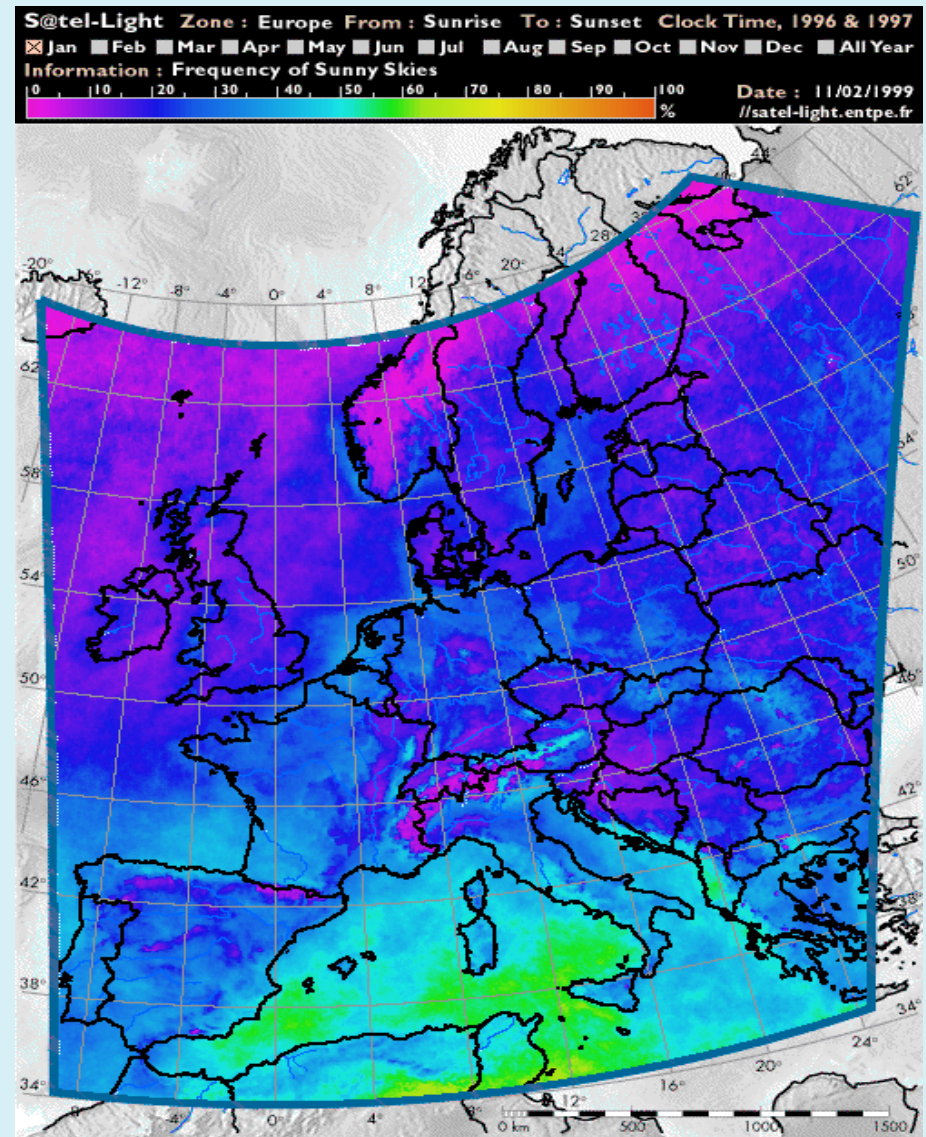
- when the sun is behind the building a vertical window can face a less bright part of the sky on a clear day than on an overcast day
- the illumination on a vertical surface receiving light from half of the sky of uniform luminance is greater than from an overcast with the same zenith luminance, the ratio being approximately 1.6



- except the circumsolar area around the sun position the clear sky is brighter at the horizon than overhead

Clear sky frequency

Daylight calculations are usually based on uniform or overcast skies, but in areas where clear skies are predominant it may underestimate the illuminance levels and might lead to inappropriate urban and window design



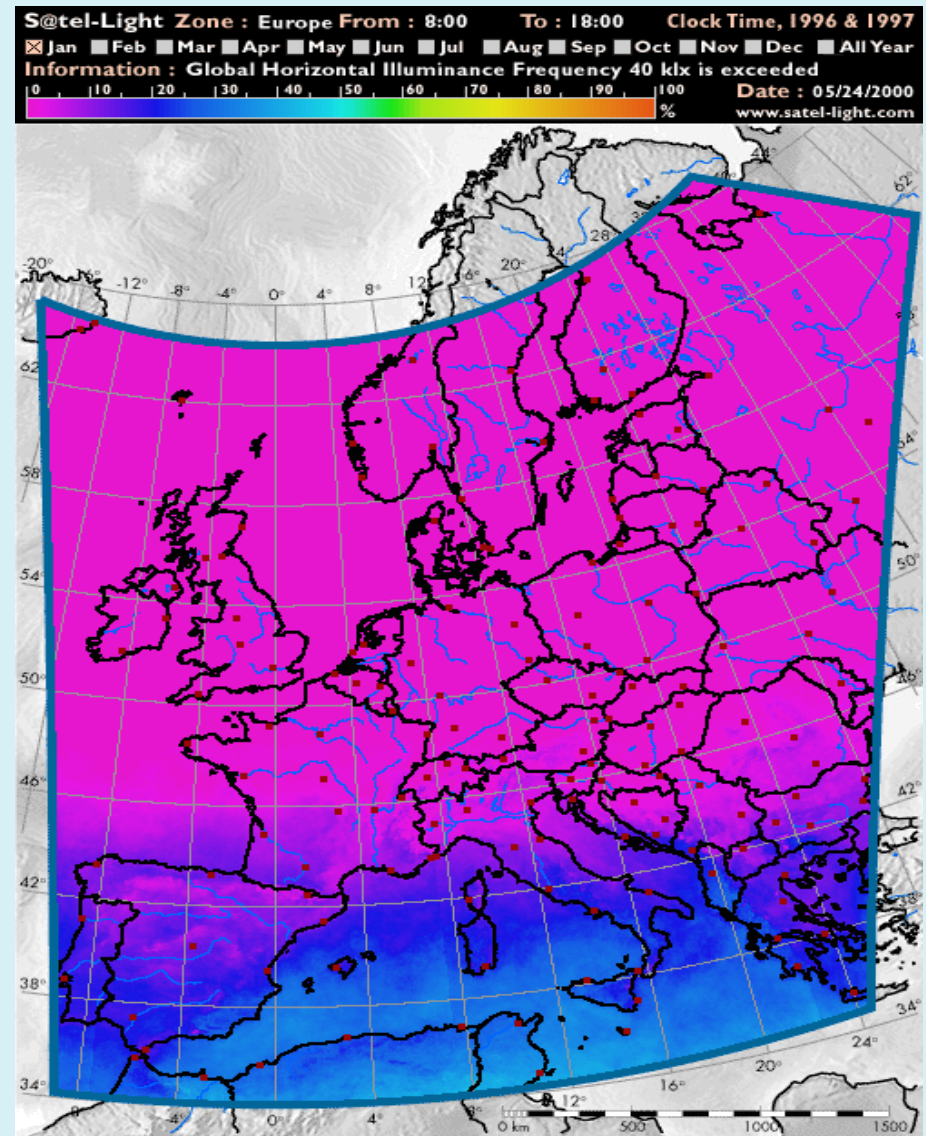
Global horizontal illuminance

Frequency exceed 40 000 lux

The amount of light reflected by a ground reflecting 25% of light is equivalent to the one provides by an overcast sky delivering 10 000 lx horizontally.

Maps show a strong potential to use outdoor reflected sunlight to light interiors:

- above 60% of the time for most Europe from April to August
- for the rest of the year, the section of Europe located above 45° in latitude cannot benefit from reflected sunlight.



Daylight

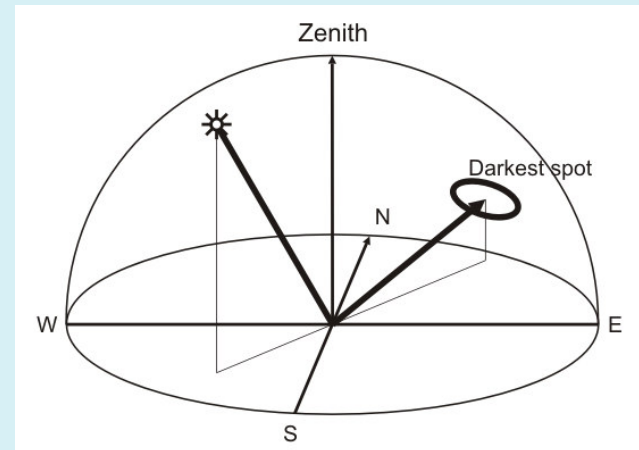
The sun is the main source of light

The light that reaches a surface has:

- a direct component – from the sun
- a diffuse component – light from the sky

Both may be reflected by external surfaces, namely buildings and obstructions and internal surface of a room

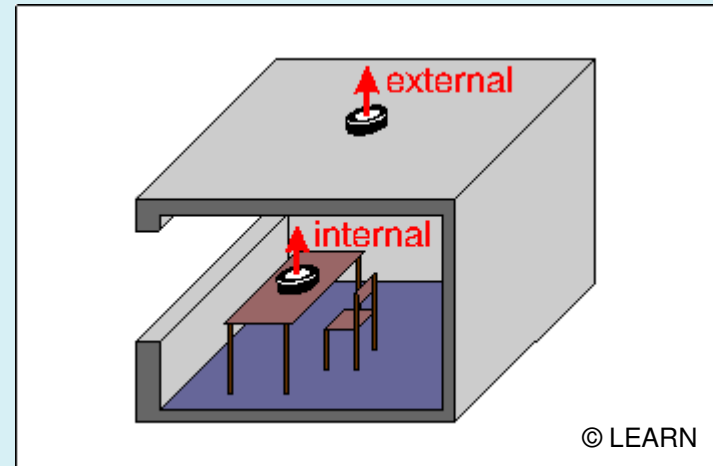
On an overcast sky the sun component is excluded



Daylight factor

- D most used method for daylight calculations
- D at a point is the ratio of the indoor illuminance to the outdoor unobstructed horizontal illuminance, expressed as a percentage

$$D = \frac{E_{in}}{E_{out}} \cdot 100\%$$



By definition the sun component is excluded

Daylight factor

Daylight factor may be calculated as

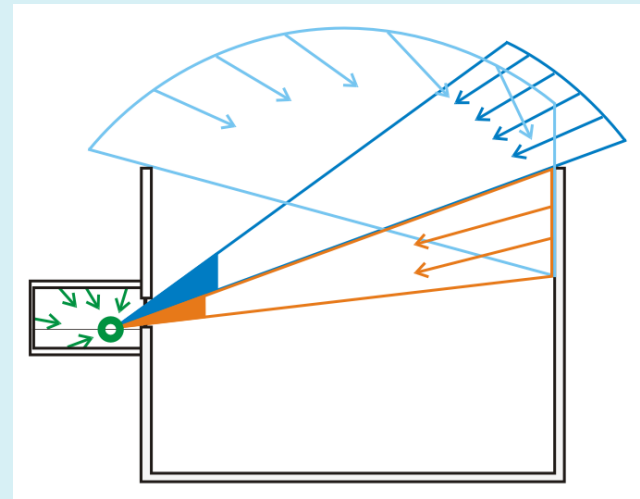
$$D = D_c + D_e + D_i$$

where

D_c is the sky component

D_e externally reflected component

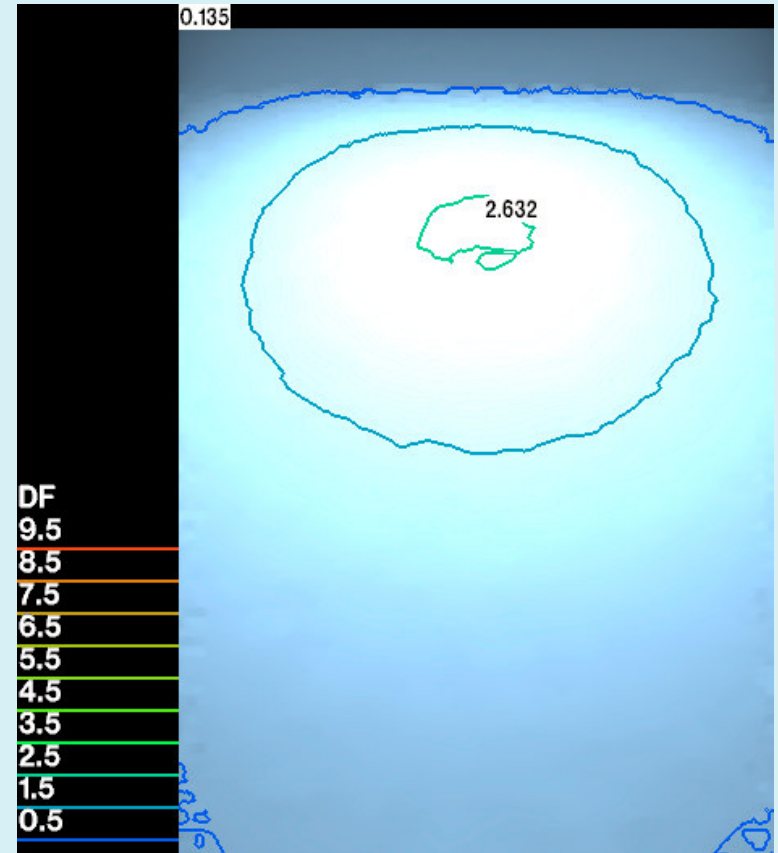
D_i internally reflected component



Daylight analysis

Daylight analysis in the UK has been traditionally associated with the CIE overcast sky for the following reasons:

- If the natural lighting is sufficient on an overcast day it is likely to be more than adequate during a clear day;
- The overcast sky luminance is independent of the azimuth therefore the effect of orientation is not considered in the calculation;
- The indoor illuminance is directly proportional to the simultaneous outdoor horizontal unobstructed illuminance independent of the overcast sky brightness.



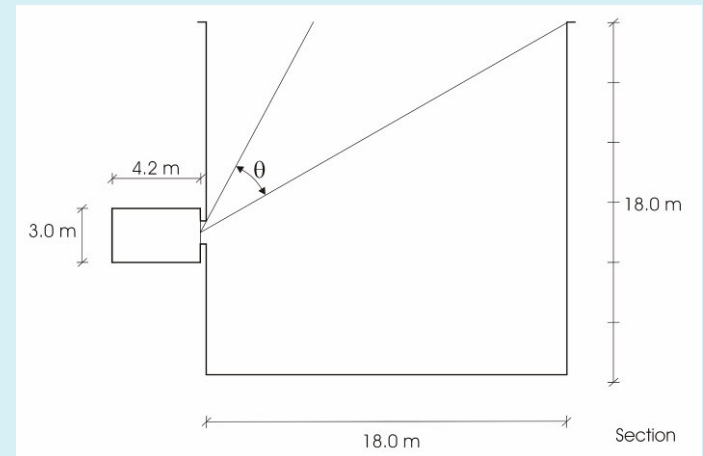
Average Daylight Factor

BRE formula
$$ADF = \frac{M \tau A_w \theta}{A(1 - \rho_{av}^2)}$$

Lynes's formula
$$ADF = \frac{\tau A_w \theta}{2A(1 - \rho_{av})}$$

where

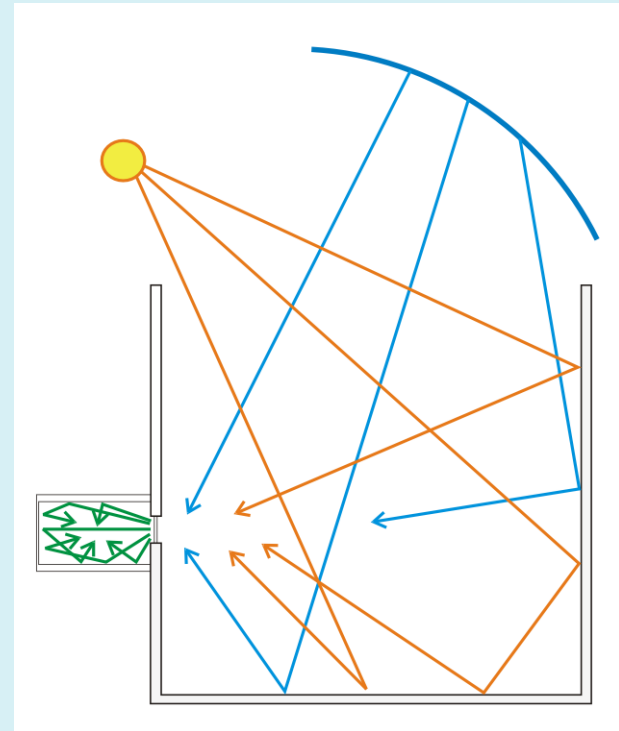
- τ diffuse transmittance
- A_w net glazed area
- θ vertical angle
- A total area of interior surfaces
- ρ_{av} area weighted average reflectance of interior surfaces
- M Maintenance factor



Daylight calculations under clear skies

Daylight calculations under a clear sky distribution should consider:

- sun component – direct light from the sun and reflected from obstructions and ground
- sky component – diffuse light from the sky and reflected from obstructions and ground
- Interreflections inside the space



Reflected sunlight in urban canyons

Reflected sunlight can play an important role in the illumination of buildings, particularly in orientations and during times of the day where sunlight is not incident on the windows

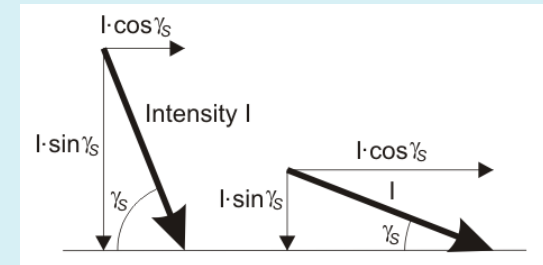
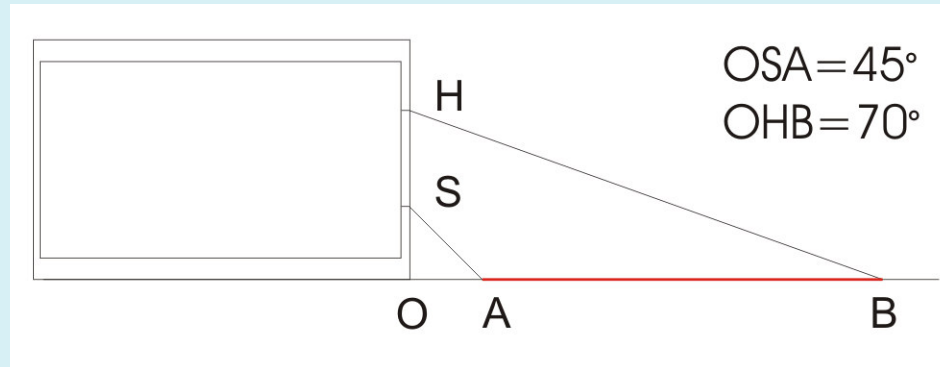
Obstructions and ground can redirect the light to other interior surfaces rather than the horizontal plane and promote a better uniformity of light inside the space

Depends on:

- reflectance of surfaces
- geometry of the canyon
- position on the facade

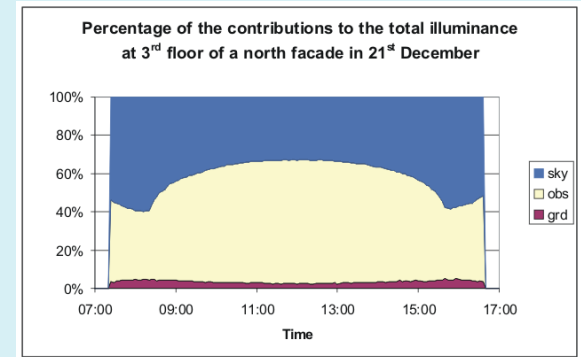
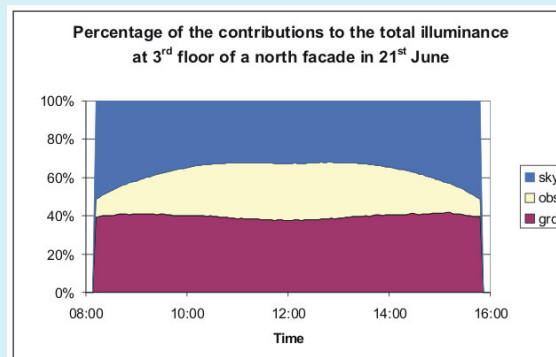
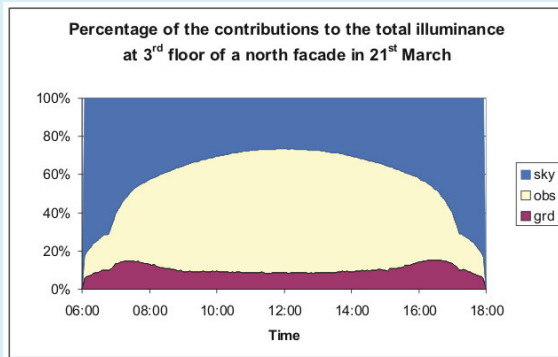


Reflected **light** from ground and obstruction



Reflected sunlight is an important contribution to the illuminance of buildings when the sun is behind the building

Reflected **light** from ground and obstruction



In a 1:1 canyon reflected sunlight from vertical surfaces contributes significantly to the illuminance of the building in comparison to reflected sunlight from the ground. The contribution from the obstructions is around ten times higher than the contribution from the ground at the equinox in a canyon in Lisbon. For higher latitudes this difference may increase as the sun reaches lower altitude angles, therefore predominantly being incident on vertical surfaces. During the summer however, the ground contribution can be high, but for the remaining period of the year it is reduced or is even non-existent as the lower winter sun angles may never reach the ground in a canyon.

Reflected **light** in urban canyons

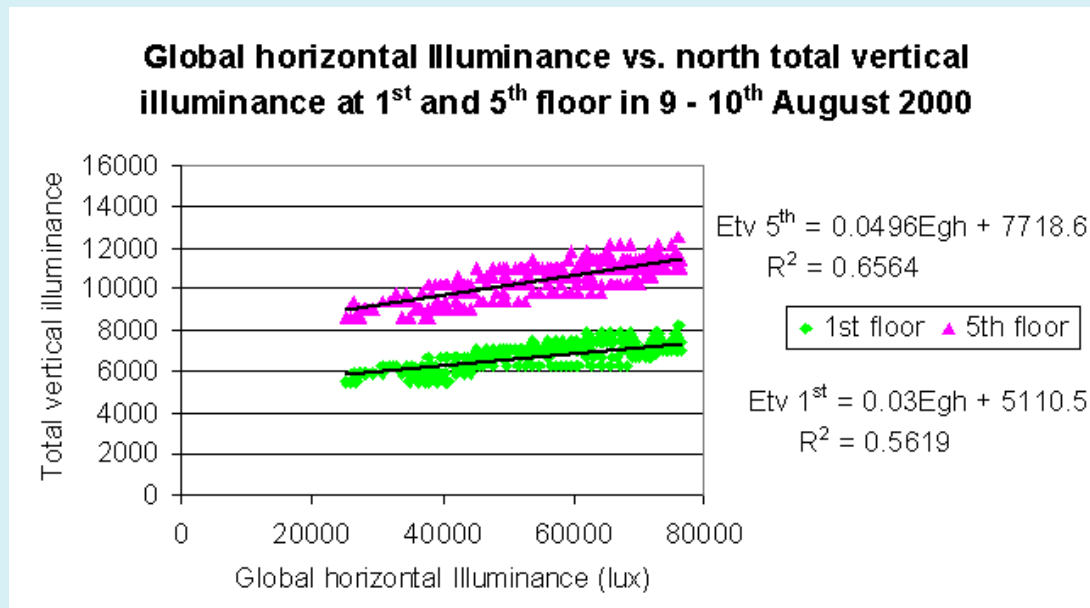
Higher reflectance will significantly increase the illuminance of the building. However, the effects of reduced facade maintenance, dark colours, window reveals, setbacks and balconies casting shadows may significantly reduce the effective reflectance of the facades. A conservative figure of 0.2 reflectance may not be far distant from the reality.



Real measurements

urban canyon

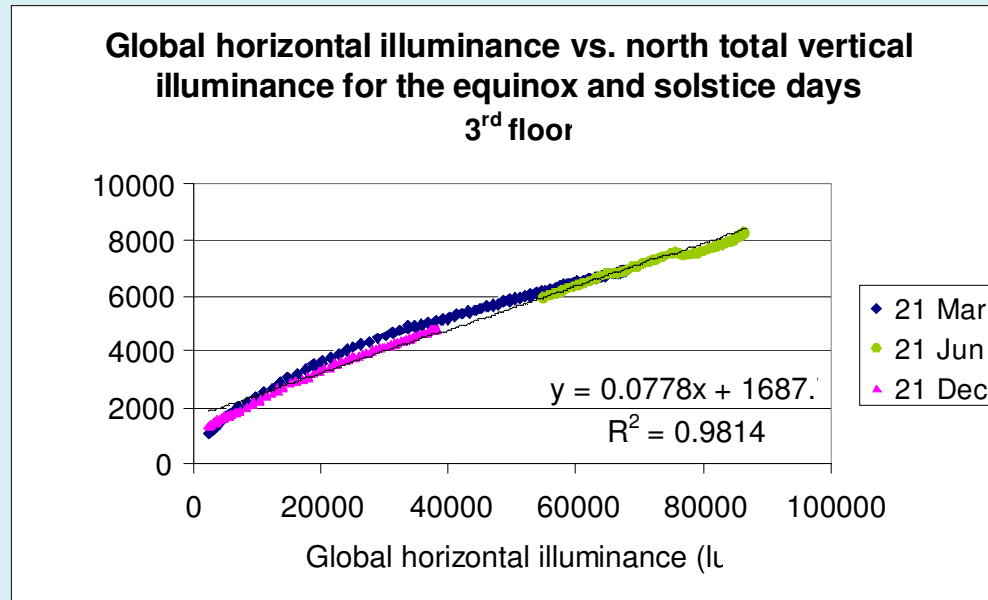
- facing buildings provide considerable obstruction to daylight by reducing the skylight contribution and sometimes blocking the access to sunlight
- however, reflected sunlight is an important contribution in the time of the day when the sun is behind the building



- there is a linear relationship between the global horizontal illuminance and the total vertical illuminance

Computer simulations

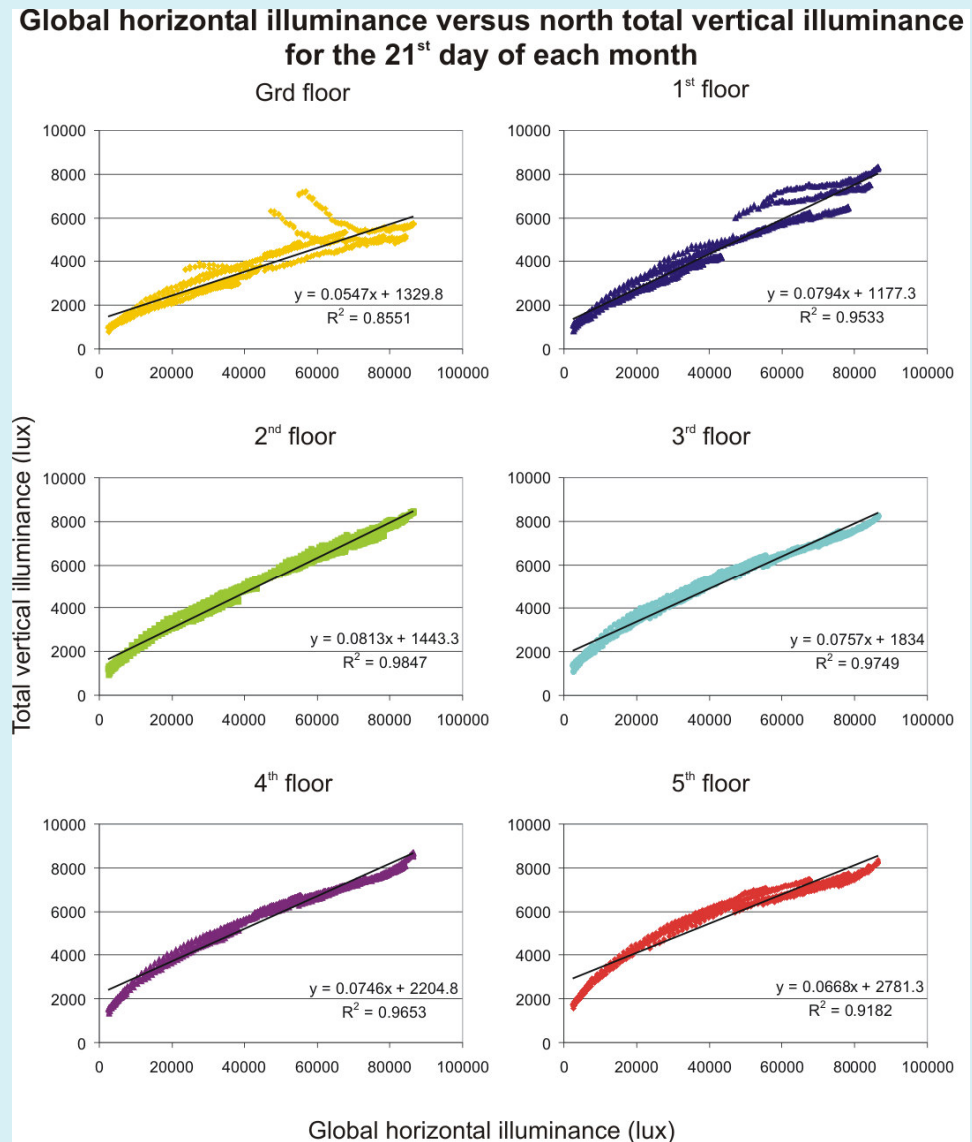
- Several methods are available to predict daylight conditions under sunny conditions, but either require a well advanced state of the project or tend to be difficult to use by architects



Although absolute values of illuminance are strongly dependent on sun altitude and therefore are variable for different times of day and latitudes, the linear relationship between the global and the total vertical illuminance on a north facade remains relatively constant at the equinox and solstice days.

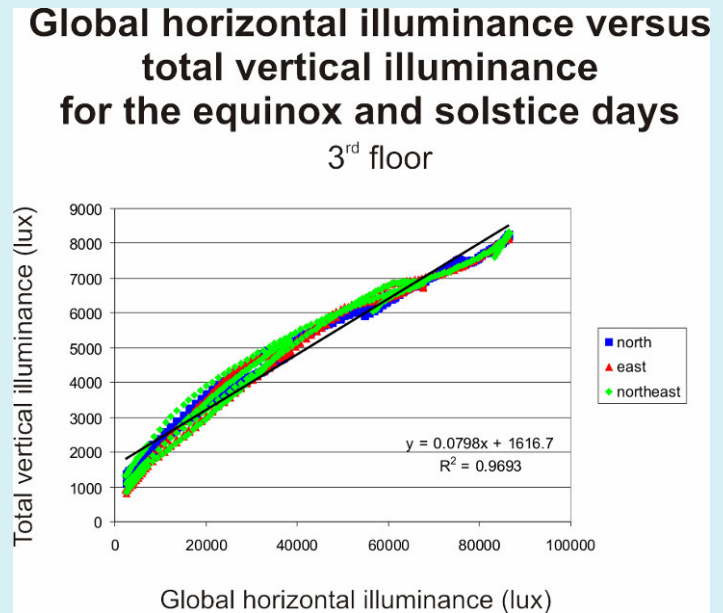
Computer simulations

- The linear relationship is fairly stable at different times of the year
- A few exceptions occur in the summer months when the sun's azimuth is around 90 or 270 particularly affecting the lower floors



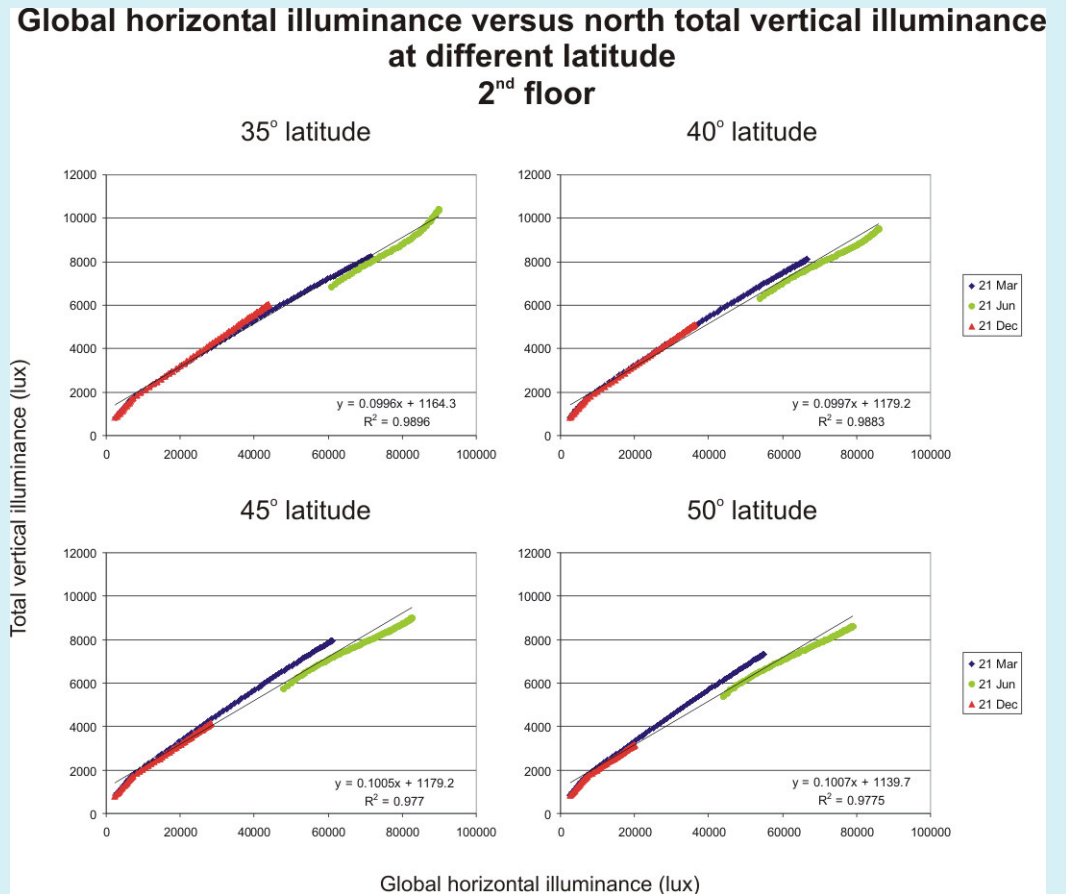
Computer simulations

- The linear relationship is fairly stable for different orientations when the sun is not incident in the façade



Analytical approach

- The linear relationship doesn't change a lot for latitudes between 35 and 50°



Equation

$$E_{tv} = k \cdot E_{gh} + C$$

where

E_{tv} is the illuminance on a vertical plane due to direct sunlight, skylight and the inter-reflections

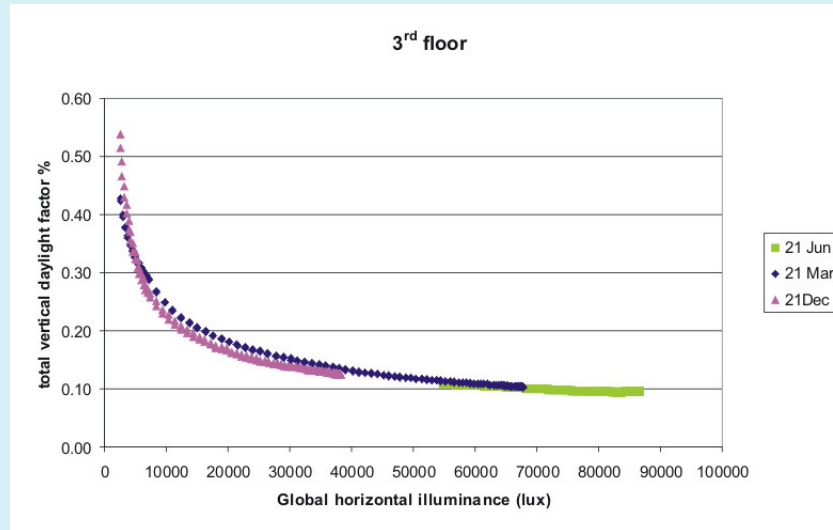
E_{gh} is the illuminance on a horizontal unobstructed plane due to direct light from sun and diffuse light from the sky

k and C are constants

	1:0.5			1:1			1:1.5		
	k	C	R ²	K	C	R ²	k	C	R ²
Ground	0.052	-	0.845	0.069	845	0.915	0.068	1404	0.878
1 st	0.067	-	0.938	0.089	674	0.979	0.091	1085	0.939
2 nd	0.072	145	0.970	0.090	958	0.993	0.095	1294	0.967
3 rd	0.070	721	0.896	0.085	1412	0.985	0.093	1654	0.980
4 th	0.066	1473	0.816	0.080	1975	0.961	0.089	1921	0.981
5 th	0.062	2395	0.794	0.076	2438	0.939	0.086	2300	0.974

The slope of the equation is fairly constant for different floors

Constant

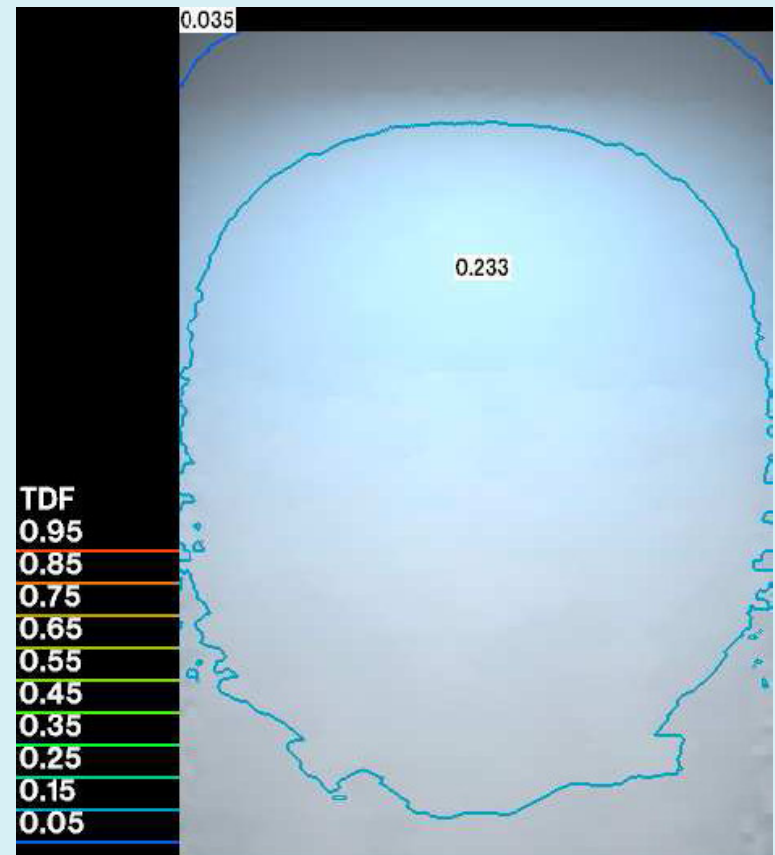


The constant C weighs significantly in the illuminance on the facade when global illuminance is low. However, on a clear day the illuminance obtained on the horizontal plane can be high, therefore C may be ignored.

The Figure shows that the constant C contributes significantly to the overall illuminance on the facade when the global horizontal illuminance is below 10 000lx. On a clear day these values will correspond to a solar altitude below 10° , therefore can be ignored without significant influence on the overall illuminance.

Total daylight factor

The 'Total Daylight Factor', TD, at a point is the ratio of the total internal illuminance, i.e. direct and indirect for both sky and sun, to the external unobstructed global illuminance.



Total daylight factor on a working plane on a 2nd floor room facing north in a 1:1 canyon in Lisbon in spring equinox

Total average illuminance

The average illuminance within the room can be based on the principle of the interreflection.

Let the flux entering the room be

$$\phi_0 = E_{tv} \cdot A_w \cdot \tau$$

Where

E_{tv} is the total vertical illuminance

τ is the net glazed area of window

A_w is the diffuse light transmittance of glazing

The average illuminance on the surfaces due to the flux entering the room is

$$\bar{E}_0 = \frac{\phi_0}{A} = \frac{E_{tv} \cdot A_w \cdot \tau}{A}$$

The average illuminance due to the first reflected flux. The first interreflection

$$\bar{E}_1 = \frac{\phi_1}{A} = \frac{\phi_0 \cdot \rho_{av}}{A} = \frac{E_{tv} \cdot A_w \cdot \tau \cdot \rho_{av}}{A}$$

Total average illuminance

The average illuminance due to the second reflection

$$\overline{E}_2 = \frac{\phi_1 \cdot \rho_{av}}{A} = \frac{E_{tv} \cdot A_w \cdot \tau \cdot \rho_{av} \cdot \rho_{av}}{A}$$

and the following ones

$$\begin{aligned}\overline{E}_{in} &= \frac{\phi_0}{A} + \frac{\phi_0 \cdot \rho_{av}}{A} + \frac{\phi_0 \cdot \rho_{av} \cdot \rho_{av}}{A} + \dots \\ &= \frac{\phi_0 (1 + \rho_{av} + \rho_{av}^2 + \dots)}{A} \\ &= \frac{\phi_0}{A(1 - \rho_{av})} \\ &= \frac{E_{tv} \cdot A_w \cdot \tau}{A(1 - \rho_{av})}\end{aligned}$$

Then

$$\frac{\overline{E}_{in}}{E_{tv}} = \frac{A_w \cdot \tau}{A(1 - \rho_{av})}$$

Average Total Daylight Factor

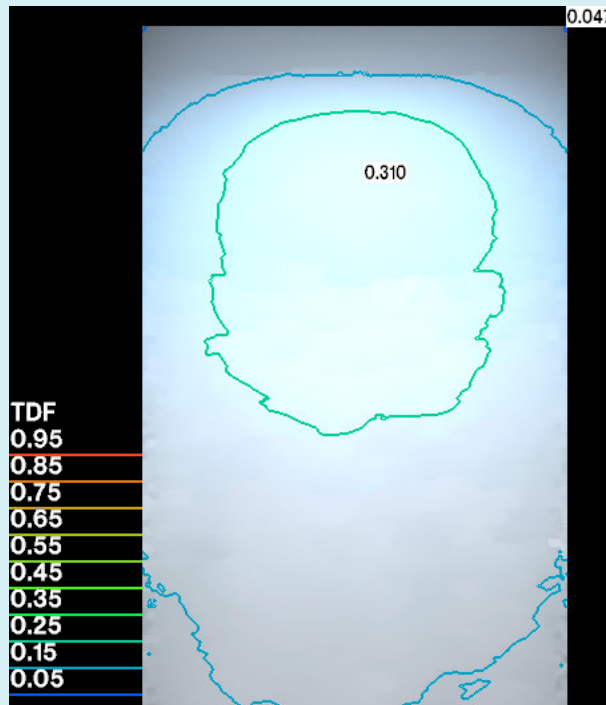
$$\overline{TD} = \frac{k \cdot A_w \cdot \tau}{A \cdot (1 - \rho_{av})}$$

Where

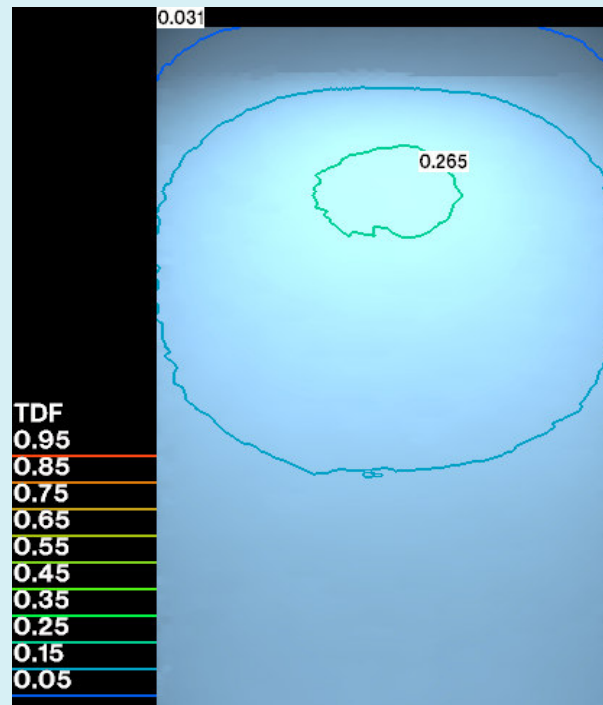
k is the slope of equation previously defined
 τ is the diffuse light transmittance of glazing
 A_w is the net glazed area of window
 A is the total area of interior surfaces
 ρ_{av} is the area weighed average reflectance of interior surfaces

$$k = \frac{E_{tv}}{E_{gh}}$$

Average Total Daylight Factor



with obstruction



without obstruction

Conclusions

- The definition of a simplified calculation for daylight analysis under clear sky distributions is important in order to avoid the use of calculations designed for overcast conditions and their consequent inadequacy;
- There is a relationship between the global horizontal illuminance and the vertical illuminance when sunlight is not incident on the facade;
- This relationship is relatively stable throughout the year;
- The slope of the linear relationship is similar for different canyon aspect ratios, but the constant of the equation tends to increase with floor height and for wider canyons due to larger angles of visible sky;
- The slope of the relationship is relatively constant at all floors for lower obstruction's reflectance, but varies with higher reflectance;
- the reflectance of the surfaces of the canyon, in particular that of the obstruction have the most effect on the illuminance of the buildings, for European latitudes;
- The orientation of the buildings does not affect the linear relationship when the sun is behind the building in an urban canyon;
- A variation of the latitude does not affect the linear relationship for the urban canyon;

Conclusions

- The average total daylight factor calculation is a simple calculation similar to the average daylight factor but taking into consideration reflected sunlight in an urban canyon;
- The average total daylight factor may provide a similar characterisation of how well a space is lit;
- The average total daylight factor is proportional to the window size, therefore may be an useful method for estimating window sizes in early stages of design. Particularly as it does not require the definition of the window shape or position to be known in advance.
- An initial estimation of average total daylight factor as a quarter of the recommended values of the average daylight factor has been put forward. It should be stressed that estimations proposed to characterise a daylit space are based on quantitative data obtained in this study with RADIANCE simulations. The definition of visual comfort indices similar to those assumed for the average daylight factor should mainly be based on experimental surveys in real situations.

Acknowledgements

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Thank you!
Luisa

