Solar reflected glare

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LONDON metropolitan university

Radiance
25 years
trillions of rays served

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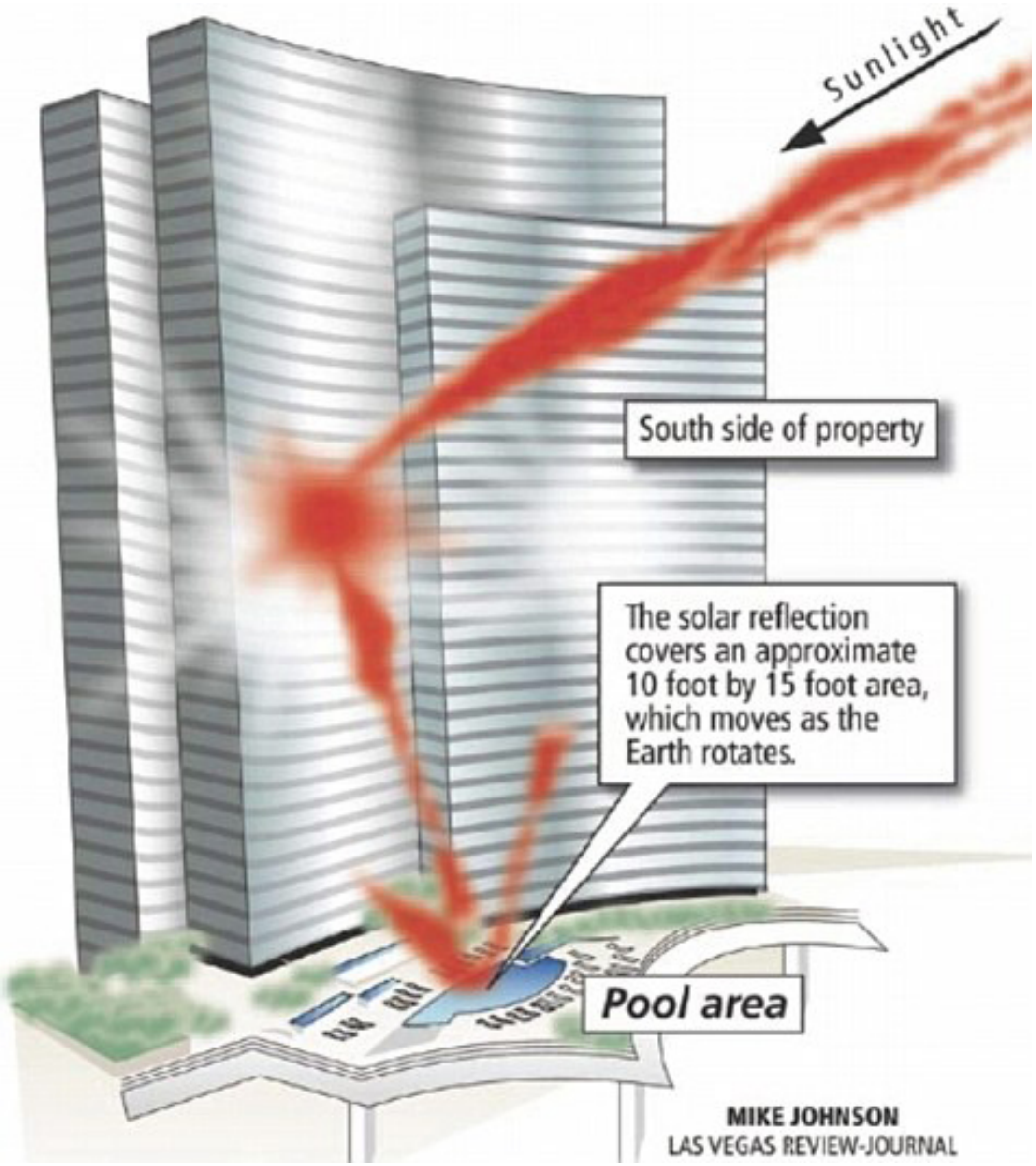

Sunlight
South side of property
The solar reflection covers an approximate 10 foot by 15 foot area, which moves as the Earth rotates.
Pool area
MIKE JOHNSON
LAS VEGAS REVIEW-JOURNAL

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„Natural“ glare situation

Every glazed or metal surface could cause severe glare!

What is glare?

CIE- Definition

"*Condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or by extreme contrasts*"

What is glare?

Glare can be subdivided in

- Veiling glare
- Disability glare
- Discomfort glare

Disability glare is an effect caused by the scattering of light in the eye which reduces the luminance contrast of the retina image. The disability glare formula was originally developed by Stiles and Holladay, and later with Crawford. Their work was further developed by Vos who highlighted the importance of the eye pigmentation and the age of the observer. In 2002, CIE published 3 disability formulae in the form of report 146.

Solar reflected glare

- Glare effects are driven not by the type of application (e.g. solar panels) but by the surface properties!

- Also in nature and “normal” life glare situation can occur

- There are three dimension of glare: Temporal, Spatial and Intensity

Solar reflected glare

different dimensions:

- Traffic:

  It can cause severe problems for the driver/pilot of vehicles when reducing contrast and/or causing disability glare

  -> problems/slowing down in object recognition

  -> safety risk

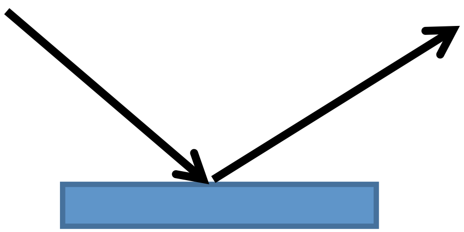
- Discomfort:

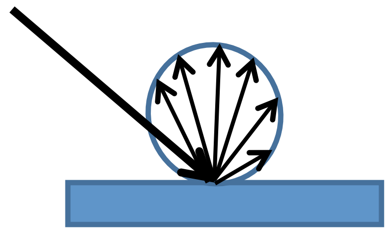
  People perceive discomfort glare in their homes or in outdoor spaces

These two dimensions have to be treated separately. Why?

- For the traffic, critical situations should be avoided whereas in discomfort is a question of the frequency of occurrence and duration
- The critical "glare intensity" for the traffic situation is MUCH higher than for the discomfort situation

Reflection Types

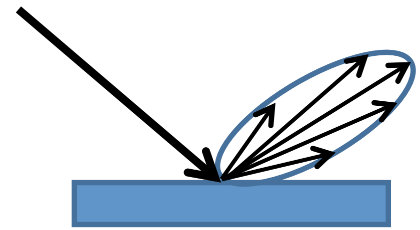




Diffuse reflection
Scattering
Modeling: diffuse reflection

Examples:

- Plaster
- Bricks

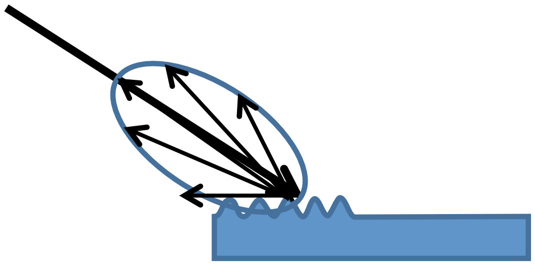


Specular reflection
With forward scattering
Modeling: BSDF-Model

Examples:

- Metals
- Glazing with surface treatment

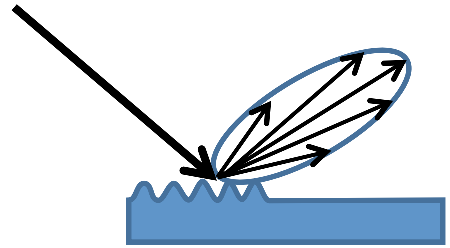
Reflection Types



Off-Specular reflection
With arbitrary scattering
but not diffuse!
Modeling: BSDF-Model

Examples:

- Metals
- Glazing with special surface treatments (e.g. structuring)

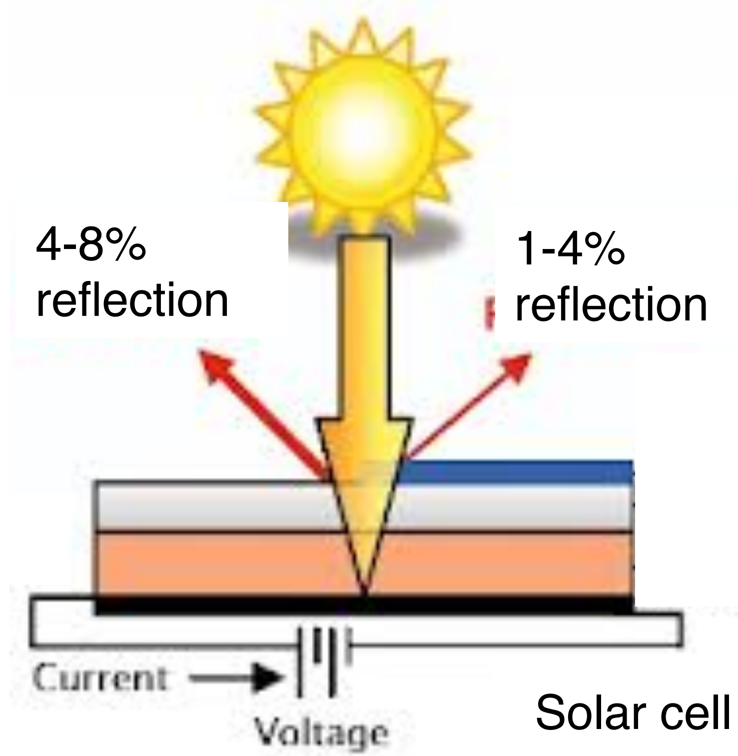


Specular reflection
With forward scattering
but not diffuse!
Modeling: BSDF-Model

Examples:

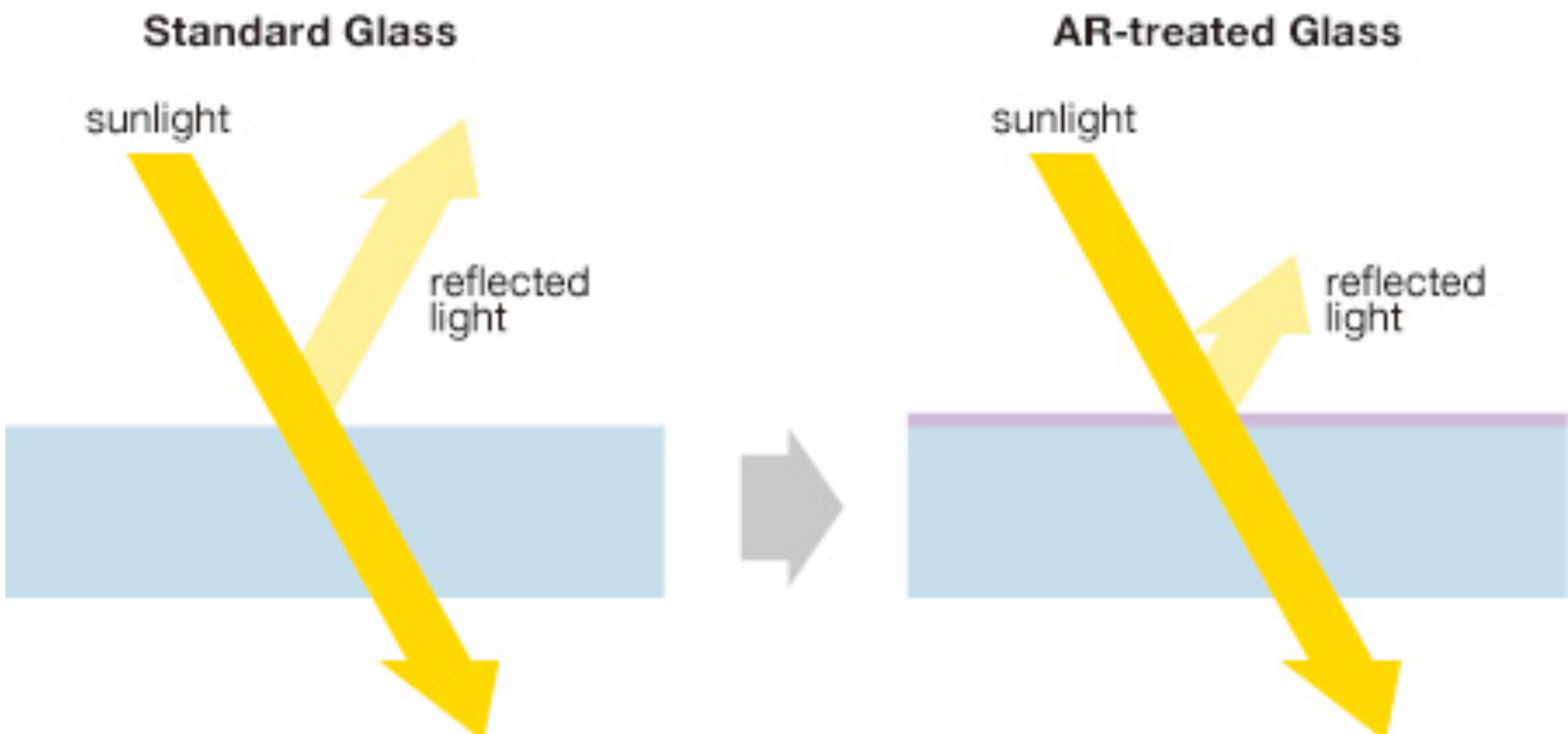
- Metals
- Glazing with special surface treatments (e.g. structuring)

Surfaces of PV panels



Antireflective Coatings

AR-Coatings usually don't cause additional scattering

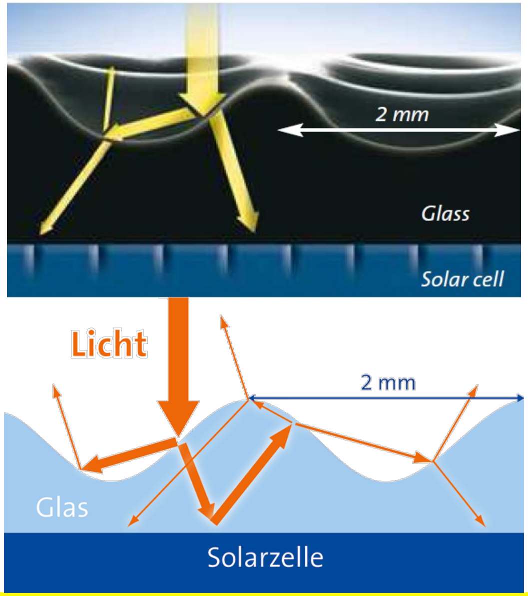


Structured surfaces

Goal: Increase of the transmission in order to increase the efficiency of solar panels

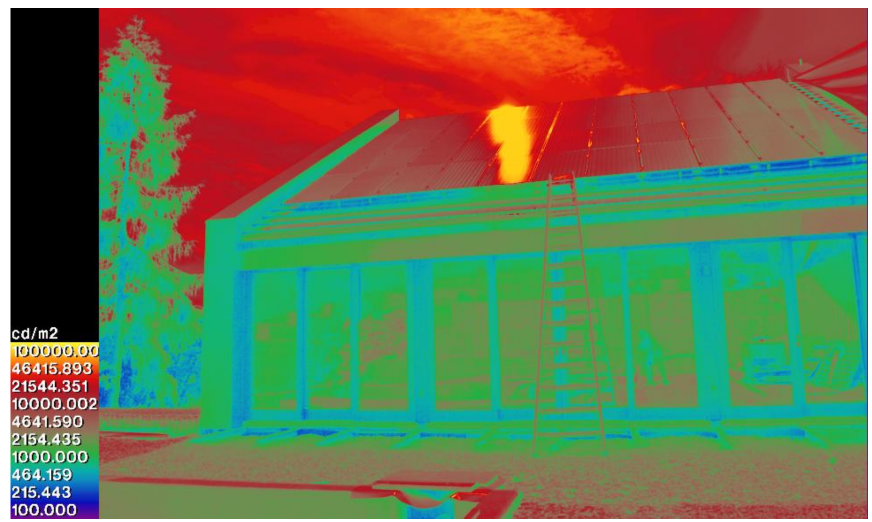
In total the reflection is reduced

But: Possible reflection in arbitrary direction, scattered specular and off-specular possible!



Structured surfaces

- Depending on the technology of the surface, the reflected light can be scattered
- Even the overall reflection is reduced, large sized reflections of high luminance can occur and the perceived glare can increase



And what about other outdoor spaces?
Questions

Are there suitable glare metrics to identify a glare situation, separated for traffic and discomfort topics?
CIE disability equations?

What are suitable criterion? What are acceptable thresholds?

How can this be calculated?
How often does this occur?
What is necessary to avoid glare situations?

When does a sun patch changes from a delight to an annoyance or impairment?

Glare metrics

For exteriors : CIE equations? Are they validated for bright sunlight?

For interiors: Daylight Glare Probability (DGP) or DGI:
But not applicable for exteriors, because of
boundary conditions are significantly different (workplaces)

Also for disability glare it is unclear whether methods are valid under daylight conditions (higher adaptation level)

Relevant?

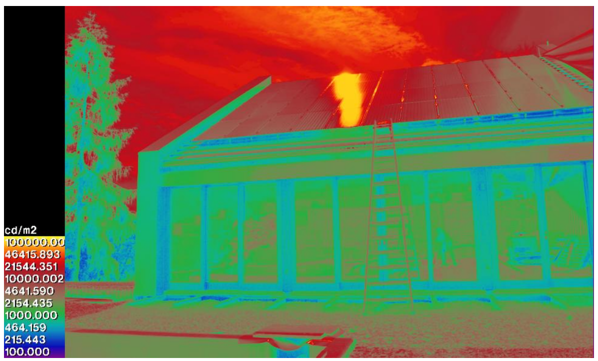
Yes, but can’t be avoided

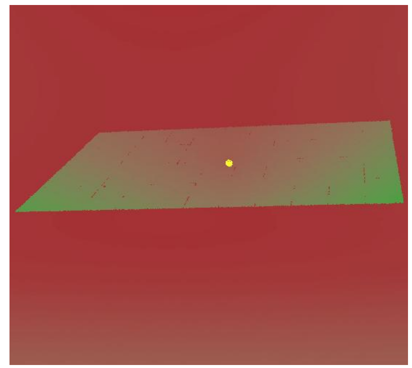
Relevant?

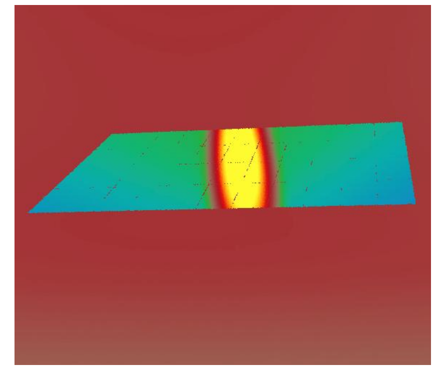
No, but is discussed because missing metrics !!!

Modeling of the surface properties

Reflection properties have to be modeled, otherwise the size of the reflection (and intensity) is underestimated







Measurement in field:

scattering leads to widening of the reflection -> larger glare source

Modeling as specular reflection only
-> glare source too small, but higher luminance

Modeling the “real” reflection using BSDF reflection model

“Official” calculation method in Germany

to calculate and evaluate glare by solar panels (so far)

- The departments of environmental affairs of the states in Germany agreed on a document to calculate and evaluate glare on PV panels
- Only for discomfort evaluation
- Based on a study of the stroboscopic effect of wind power stations
- Limits the amount of occurrence to 0.5h/day and 30h/year max.
- Every possible reflection is counted -> no real weather data is taken into consideration!
- The reflection properties are not taken into account, the PV is assumed as mirror!

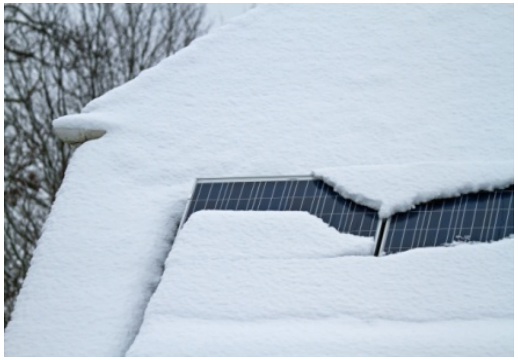
-> Is this reliable? Neither the real reflection properties (BSDF) nor the local weather (e.g. snow, fog, typical cloud patterns) are taken into account

“Official” calculation method in Germany

to calculate and evaluate glare by solar panels (so far)

Is this reliable? Neither the real reflection properties (BSDF) nor the local weather (e.g. snow, fog, typical cloud patterns) are taken into account

Not good enough …



“Official” calculation method in Germany

to calculate and evaluate glare by solar panels (so far)

It cannot capture structured glazing behavior

Normal glazing

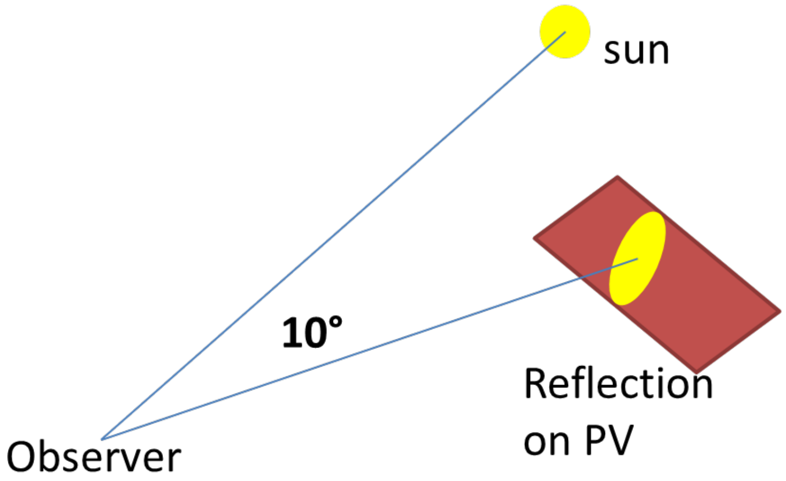
Reflection in sun direction

Structured glazing

Reflection in arbitrary directions

Proposed calculation method

- Takes into account real weather (incl. snow cover, if relevant)
- Takes into account real reflection properties
- Only glare situations are taken into account, when angle between glare source and sun is larger than 10 °

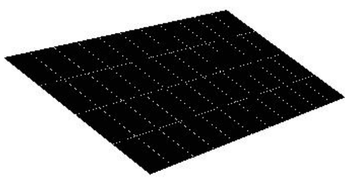


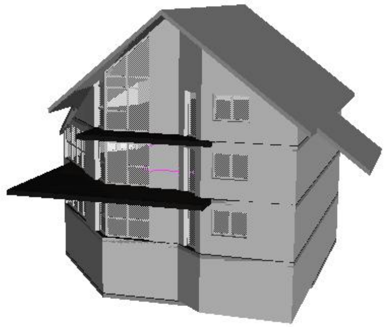
Proposed calculation method - example

- Is based on minute-timestep weather data
- Is using the RADIANCE simulation environment
- Until there exist no better metrics, the luminance of the glare source is used as metric ($L > 1.6 * 10^6$ cd/m² -> glare situation).

BUT: Solid angle has to be considered, too. User assessments are necessary!

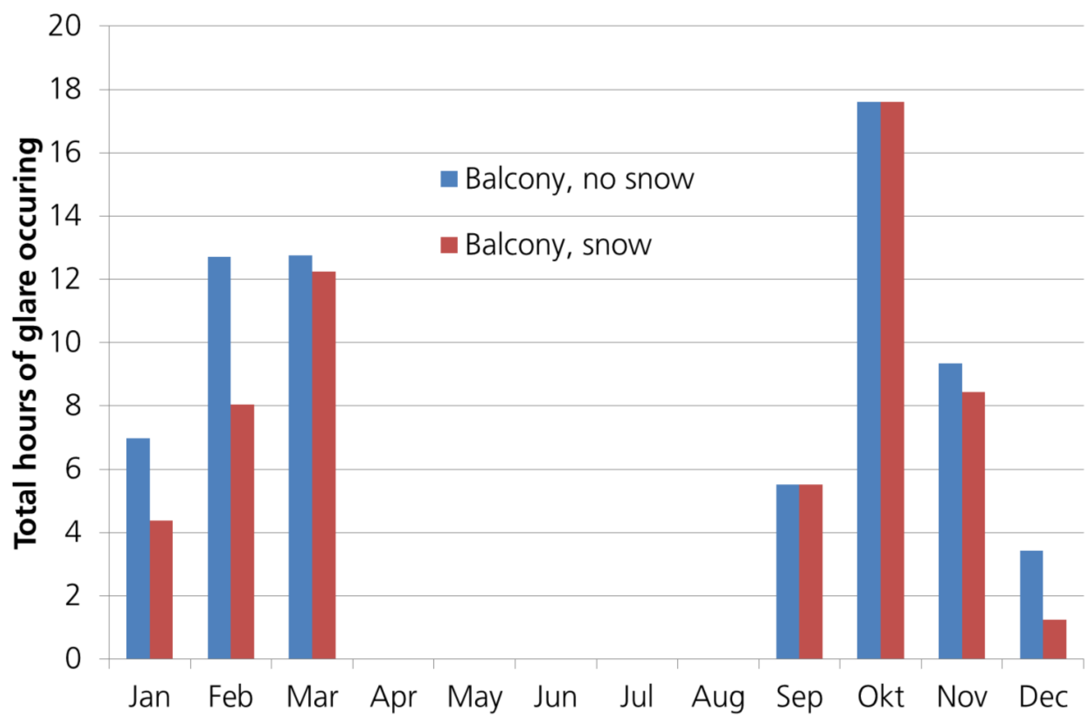
Example: Court trial, two residential buildings, southern part of Germany





Example results

- Influence of snow
- In winter months (Nov-Feb) a “reduction” of the hours occurring glare is reduce by 33%

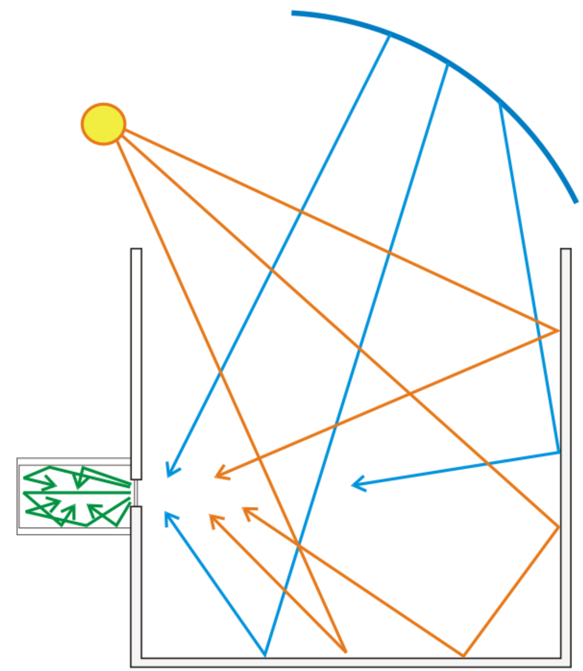


Daylight calculations under clear skies

Brotas 2004 PhD

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
- Inter-refections inside the space

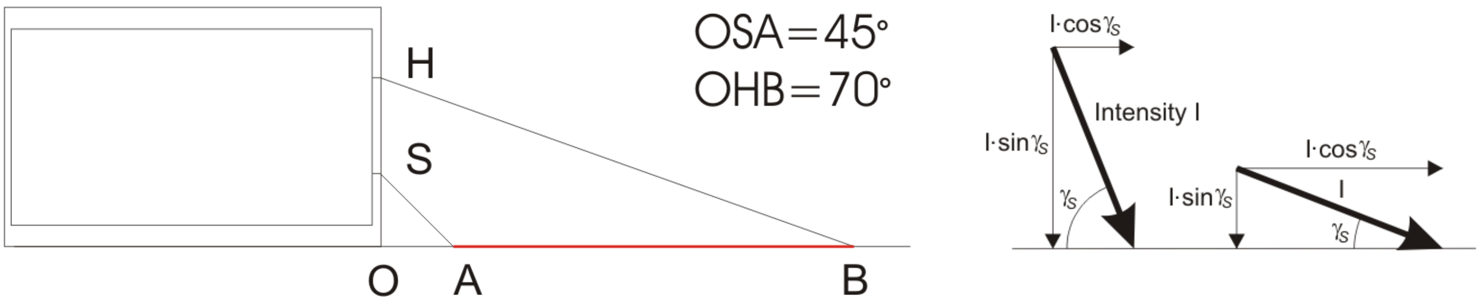


Reflected sunlight in urban canyons

Depends on:

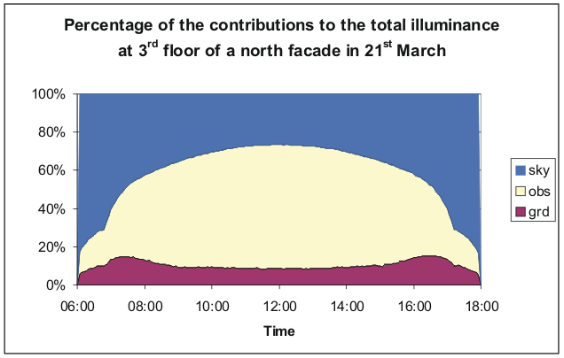
- reflectance of surfaces
- geometry of the canyon
- position on the facade

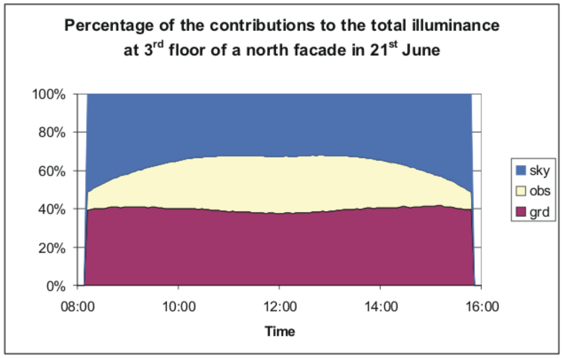
Reflected light from ground and obstruction

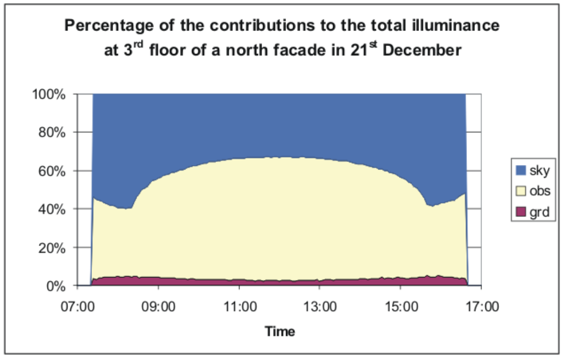


Reflected sunlight is an important contribution to the illuminance of buildings when the sun is behind the building

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.

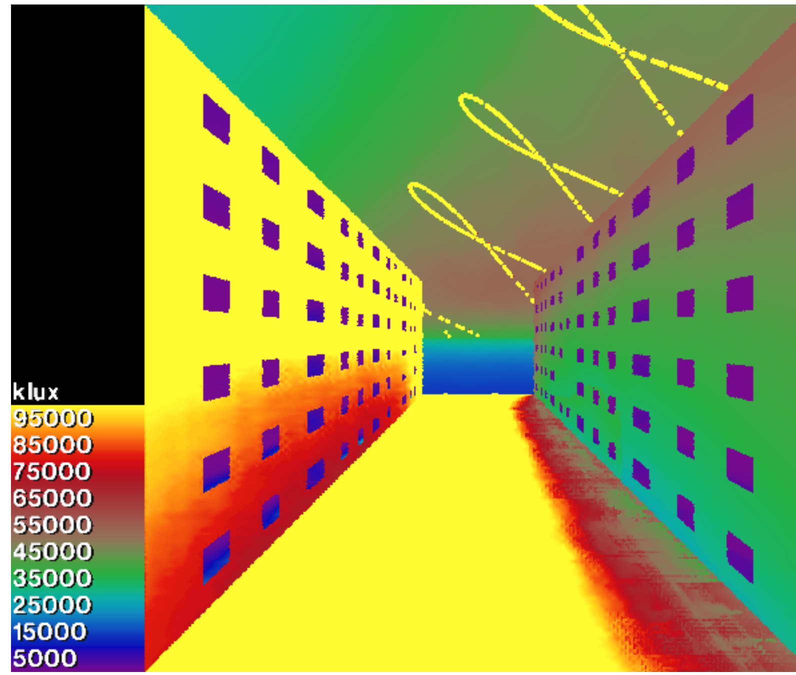
For higher latitudes this difference may increase as the sun reaches lower altitude angles, therefore predominantly being incident on vertical surfaces. During the summer however, the ground contribution can be high, but for the remaining period of the year it is reduced or is even nonexistent as the lower winter sun angles may never reach the ground in a canyon.

Obstruction angles for sunny climates approaches

- obstruction angles to provide sunlight incidence on the facade for a minimum period of four hours on the south facade on the equinox day according to latitude.

- When the building is facing east a minimum of 2 hours of sunlight should be desirable. This assumes that at least another two hours of reflected sunlight may be expected.

- In this approach no climate analysis has been taken into consideration.



Year cumulative illuminance based on Lisbon's weather data

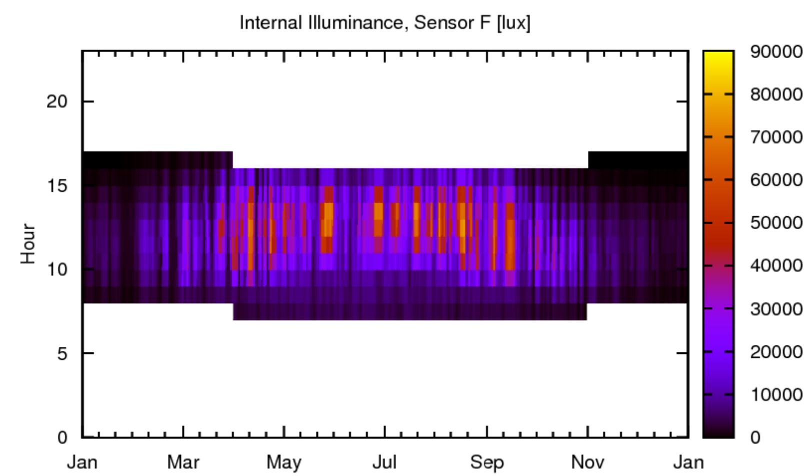
Climate based daylight modelling

Two main analysis methods derived from this approach are:

cumulative measurements: prediction of some cumulative measurement of daylight over a period of time, usually a year, based on climate datasets. Typical uses are estimation of long-term exposure of artworks to daylight, dynamics of daylight in a space, in analysis of shading devices or solar access to urban environments

time series analysis: prediction instantaneous measurements based on all hourly values in the period of time considered, based on climate datasets. Typical uses are evaluation of overall daylight potential of a space and the occurrences of excessive levels of irradiance or illuminance.

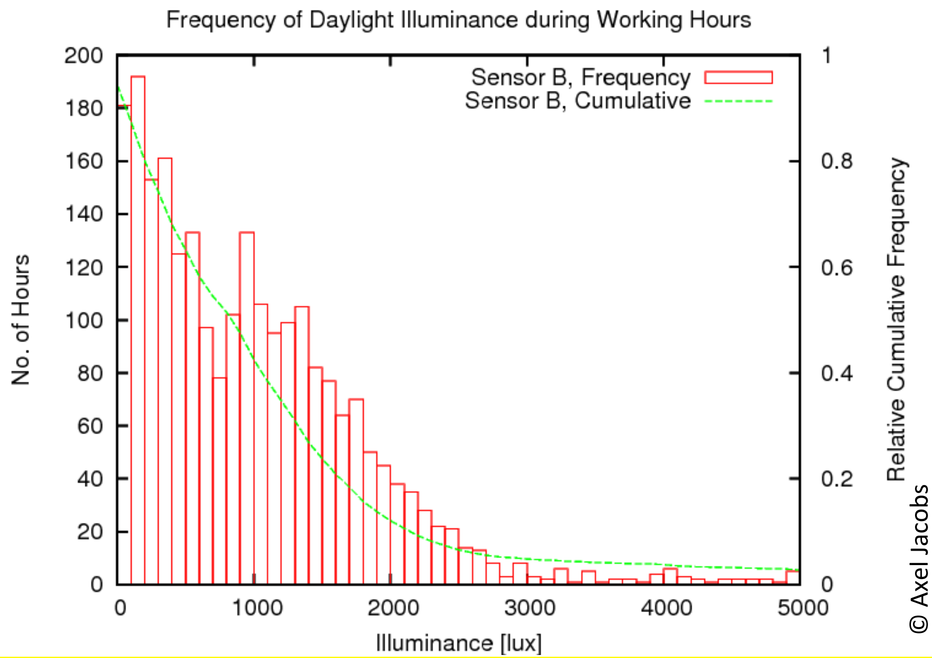
An informative reference this approach of climate based daylight modelling has been included in annex B of the BS 8206-2:2008.



UDI

Based on the previously defined method, the *useful daylight illuminance* has recently been proposed.

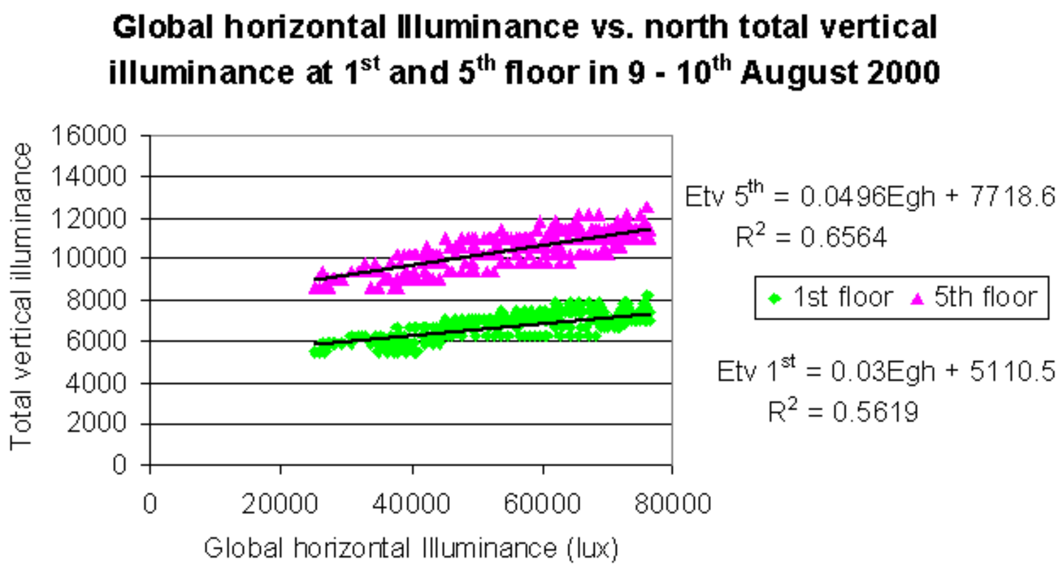
UDI is defined as the annual occurrence of illuminances across the work plane that are within a range considered “useful” by the occupants. This is assumed to be within the range 100 – 3000 lux. This range of illuminances was based on occupancy preferences and behaviour in daylit offices found in previous works.



Real measurements

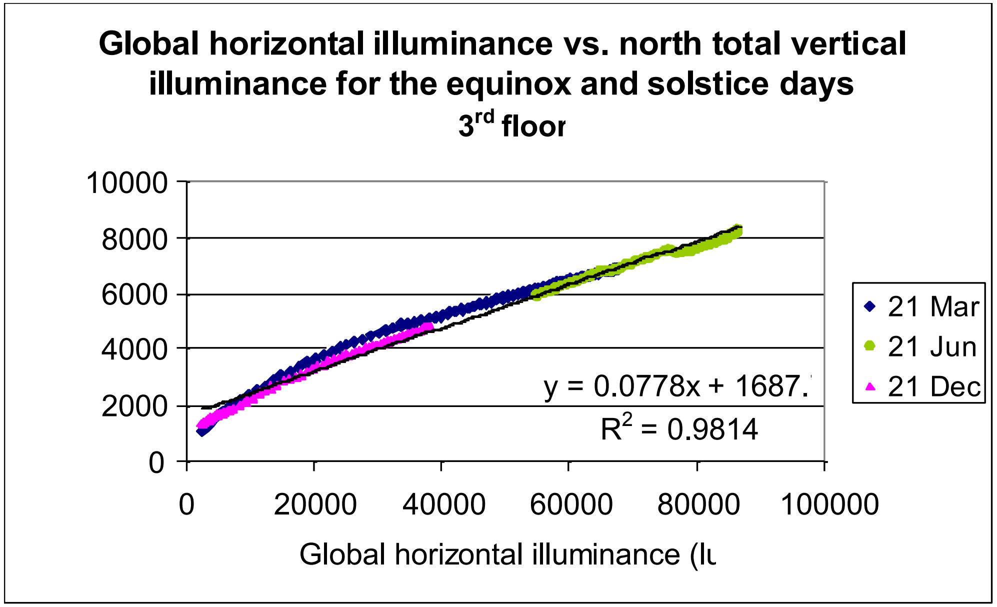
urban canyon

- 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



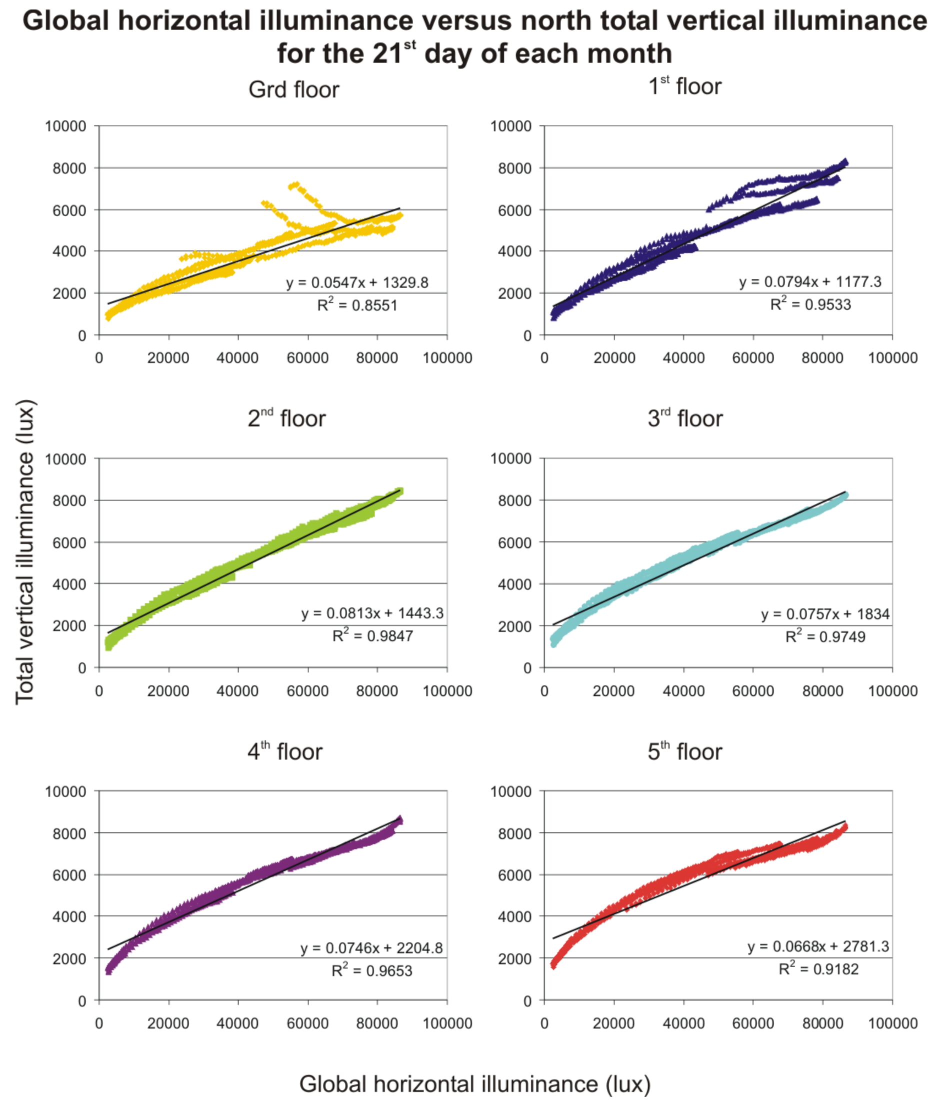
there is a linear relationship between the global horizontal illuminance and the total vertical illuminance

Computer simulations



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.

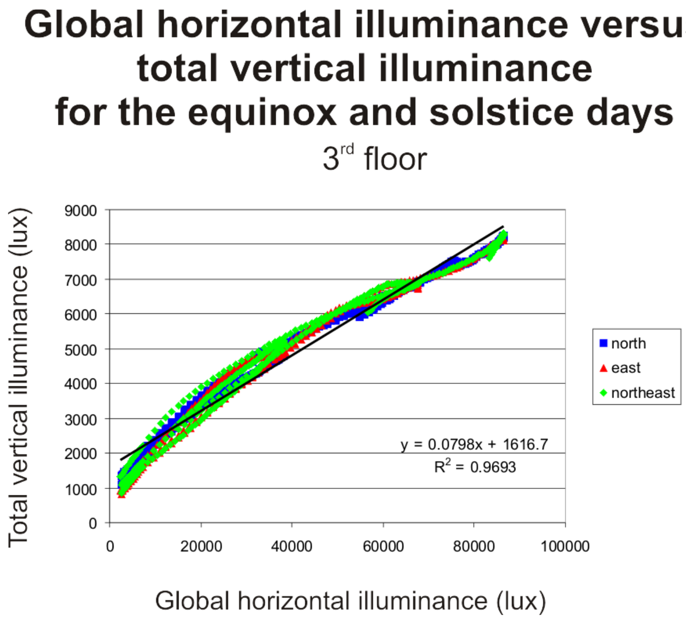
Computer simulations



- 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

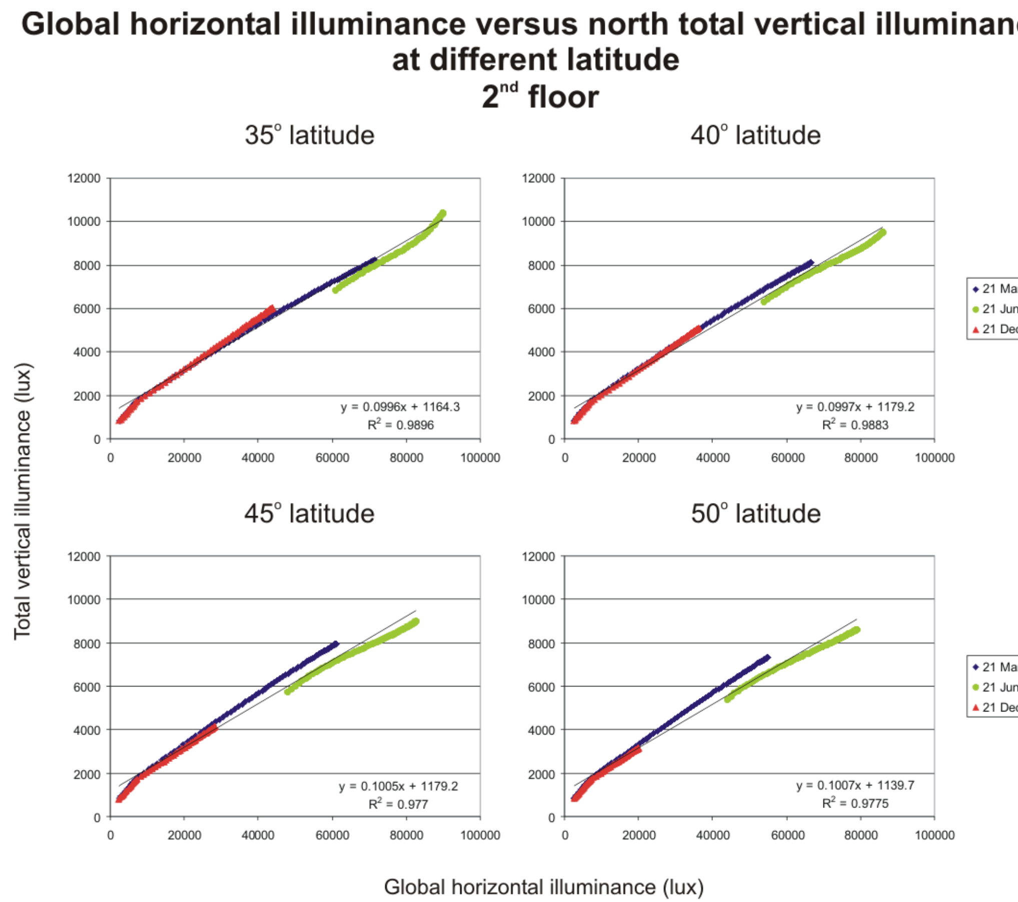
Computer simulations

- 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 50º



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Radiance 25 years trillions of rays served

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Equation

$$E_{tv} = k \, . \, E_{gh} + C$$

where

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

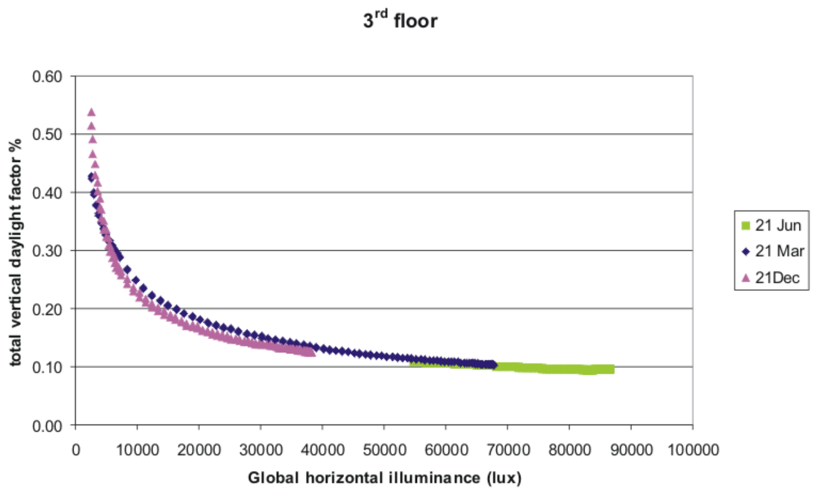
E_{gh} is the illuminance on a horizontal unobstructed plane due to direct light from sun and diffuse light from the sky

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
1st	0.067	-	0.938	0.089	674	0.979	0.091	1085	0.939
2nd	0.072	145	0.970	0.090	958	0.993	0.095	1294	0.967
3rd	0.070	721	0.896	0.085	1412	0.985	0.093	1654	0.980
4th	0.066	1473	0.816	0.080	1975	0.961	0.089	1921	0.981
5th	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

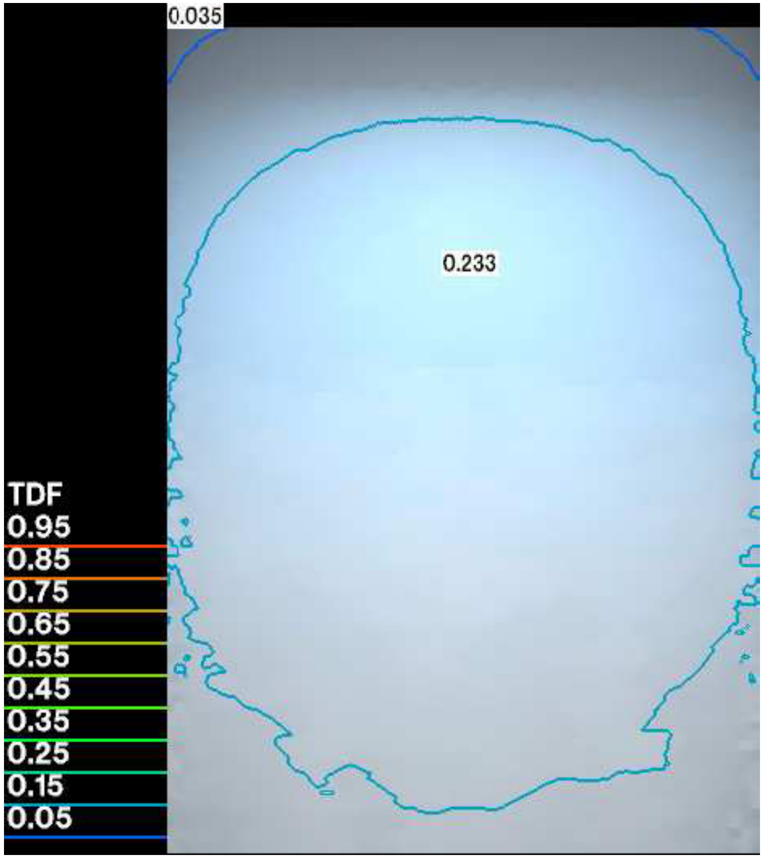
Constant



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 10º, 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

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

Where

E_{tv} is the total vertical illuminance

A_w is the net glazed area of window

τ is the diffuse light transmittance of glazing

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

$$\overline{E}_0 = \frac{\phi_0}{A} = \frac{E_{tv}.A_w.\tau}{A}$$

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

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

Total average illuminance

The average illuminance due to the second reflection

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

and the following ones

$$\overline{E}_{in} = \frac{\phi_0}{A} + \frac{\phi_0.\rho_{av}}{A} + \frac{\phi_0.\rho_{av}.\rho_{av}}{A} + \ldots$$

$$= \frac{\phi_0\left(1 + \rho_{av} + \rho^2{}_{av} + \ldots\right)}{A}$$

$$= \frac{\phi_0}{A\left(1 - \rho_{av}\right)}$$

$$= \frac{E_{tv}.A_w.\tau}{A.\left(1 - \rho_{av}\right)}$$

As

$$\overline{TD} = \frac{\overline{E}_{in}}{E_{gh}}$$

Average Total Daylight Factor

Brotas 2004 PhD
Daylight and Planning in Europe

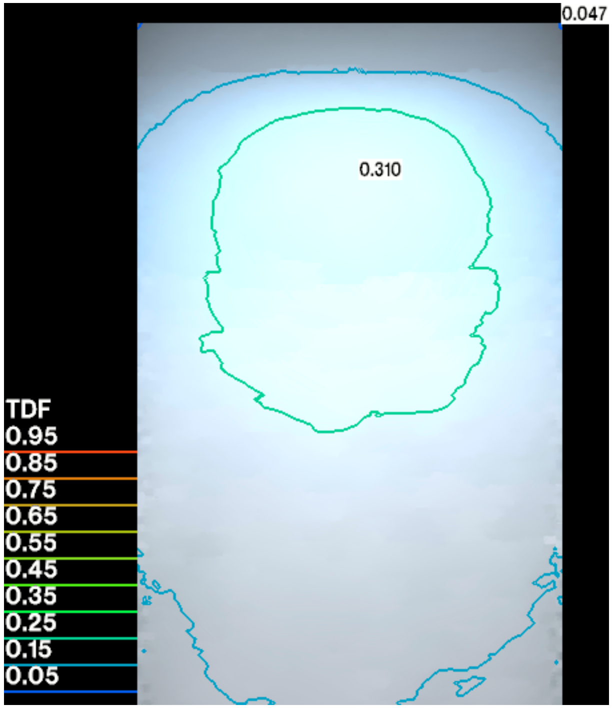
$$\overline{TD} = \frac{k.A_w.\tau}{A.(1-\rho_{av})}$$

Where

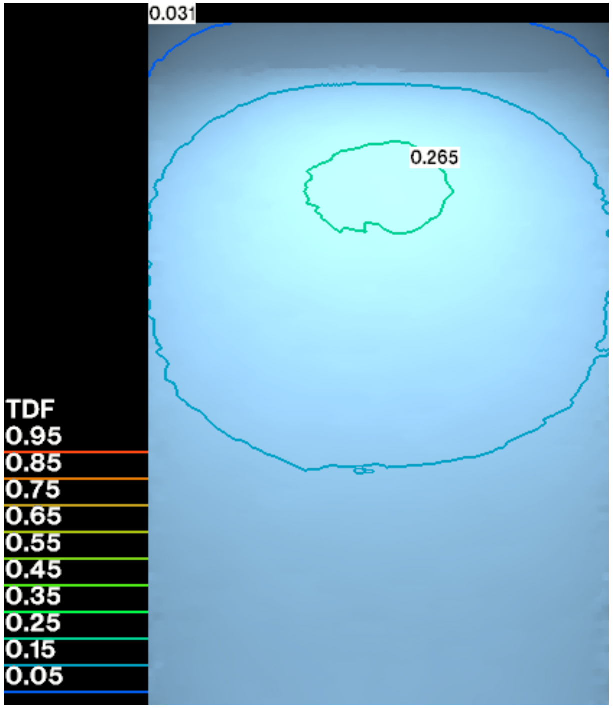
k	is the slope of equation previously defined
τ	is the diffuse light transmittance of glazing
A_w	is the net glazed area of window
A	is the total area of interior surfaces
ρ_{av}	is the area weighed average reflectance of interior surfaces

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

Average Total Daylight Factor



with obstruction



without obstruction

Brotas 2004 PhD 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;

- 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. In 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.

And returning to reflected solar dazzle

- Solar geometry is known !

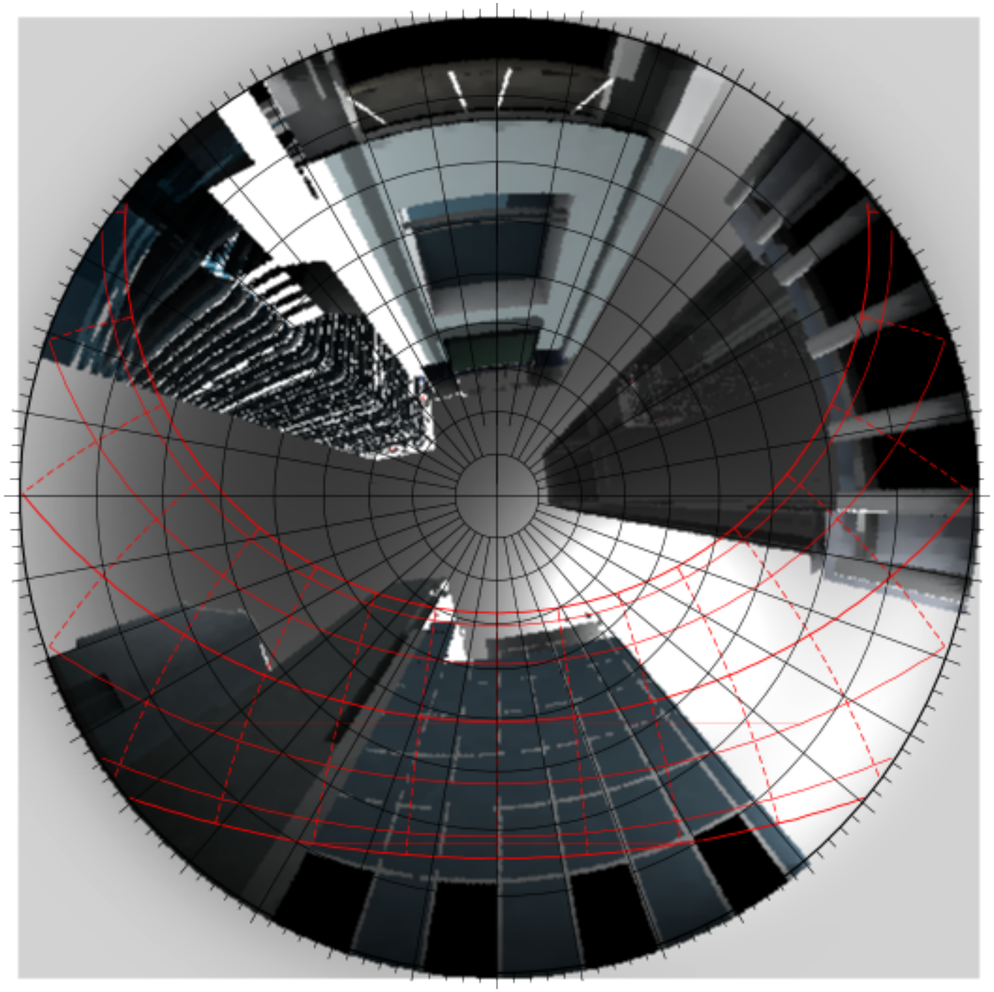
so the areas of specular high reflectance can be identified!

The problem lies in the thresholds for these definitions… which can be blurred by the adaptation of the eye to high luminance intensities.

Annual glare analysis

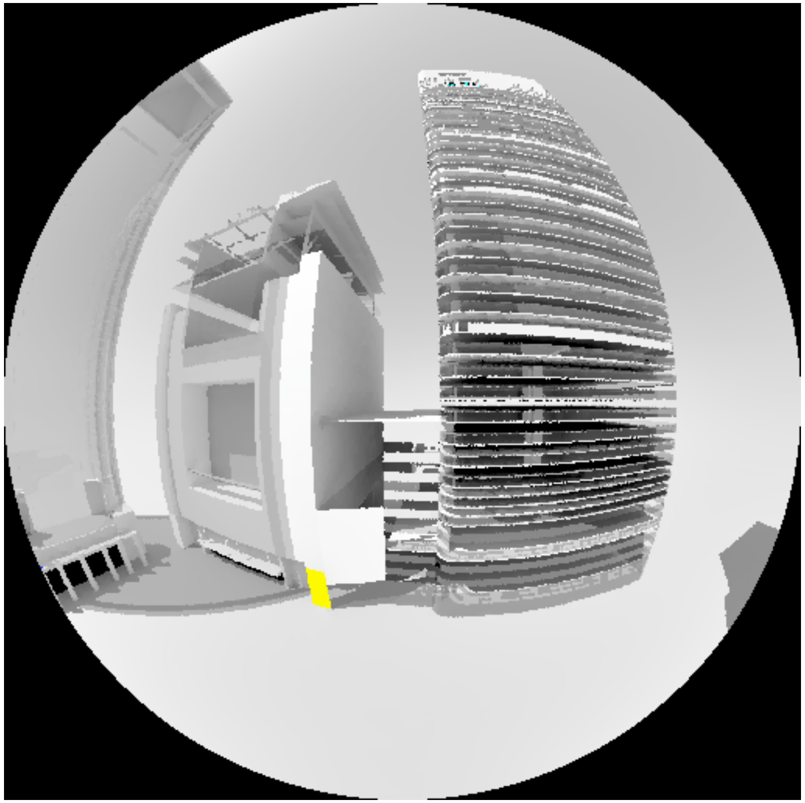
Remember the three dimensions to glare: temporal, spatial and intensity.

For these it is important to predict the times of day and year when solar dazzle can occur. Because of its high intensity, one may assume that if solar refection is within the field of view it will cause glare. Therefore it may be sufficient to estimate the period and position when it may occur.



Spatial

Previous research highlights that it is not important to quantify the intensity of the reflected source on the assumption that any reflected glare will cause nuisance. However the degree to which it is an annoyance or impairment is strongly related to the view field. It also becomes relevant how to mitigate its effect.



Criteria ??

The situation of dazzle glare from a PV panel or a sunlight reflection of a glazing faced it is also important to also address the temporal basis: its duration and time of occurrence. An analogy can be made to studies on thermal comfort in particular the recent publications EN 15251 (2007) and CIBSE (2013) on how to prevent overheating in buildings in Europe. Three criteria are presented and a space is classed as overheating if fails any two out of three criteria:

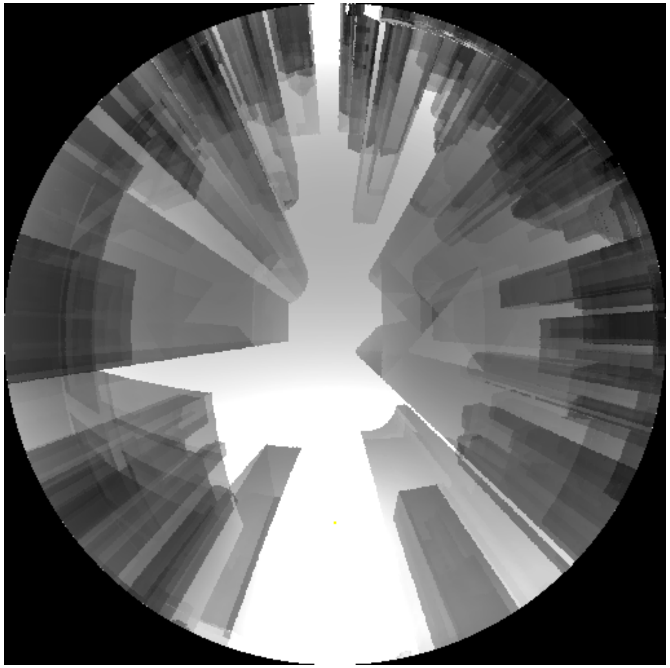
“ (1) The first criterion sets a limit for the number of hours that the operative temperature can exceed the threshold comfort temperature (upper limit of the range of comfort temperature) by 1 K or more during the occupied hours of a typical non-heating season (1 May to 30 September).

(2) The second criterion deals with the severity of overheating within any one day, which can be as important as its frequency, the level of which is a function of both temperature rise and its duration. This criterion sets a daily limit for acceptability.

(3) The third criterion sets an absolute maximum daily temperature for a room, beyond which the level of overheating is unacceptable.” (CIBSE, 2013)

Annual metrics

- Annual metrics based of rcontrib - daylight coefficients and BRTD of surfaces, evalglare/ daysim to be used



Areas of influence for solar glaze

Position of interest in regards to the view point (centre of image)

3 degree

10 degree

30 degree

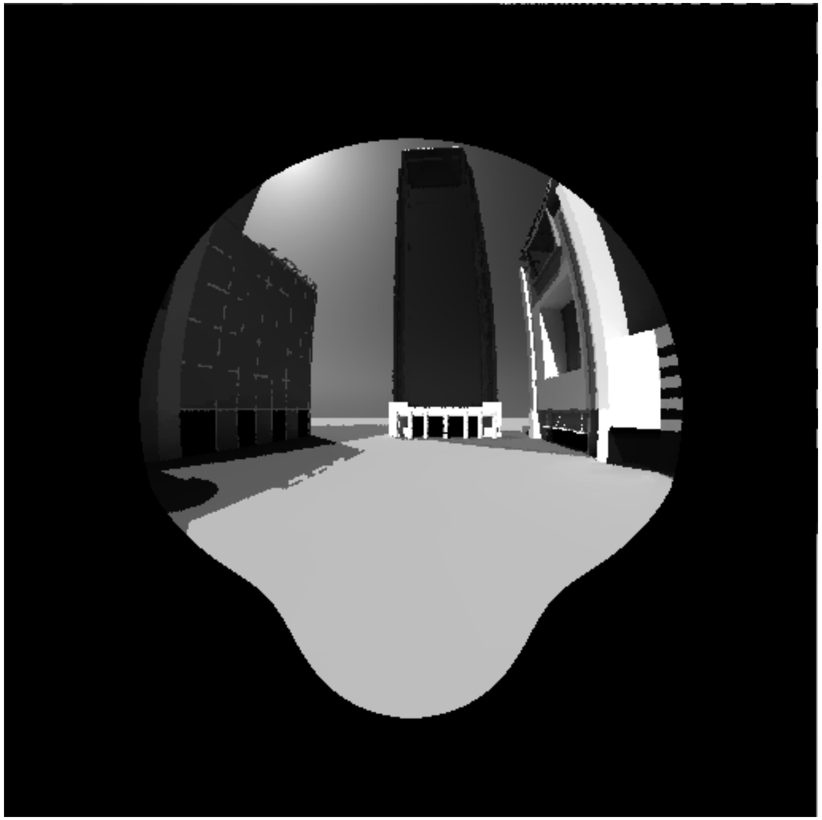
60 degree…

Guth eye view…

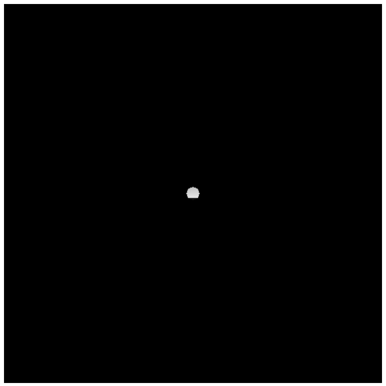
Above these solid angles

the image is interpreted

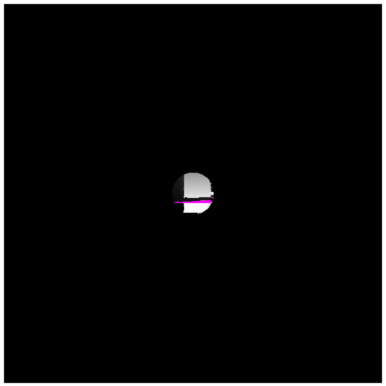
by the brain as “floggy”



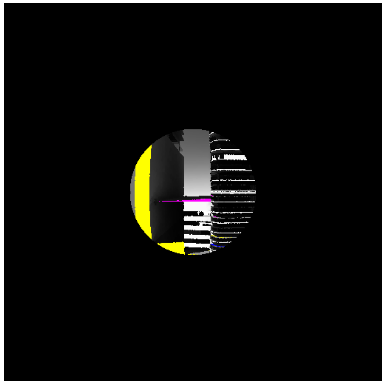
Masks for view angles



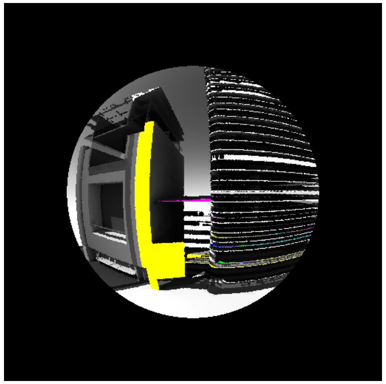
3°



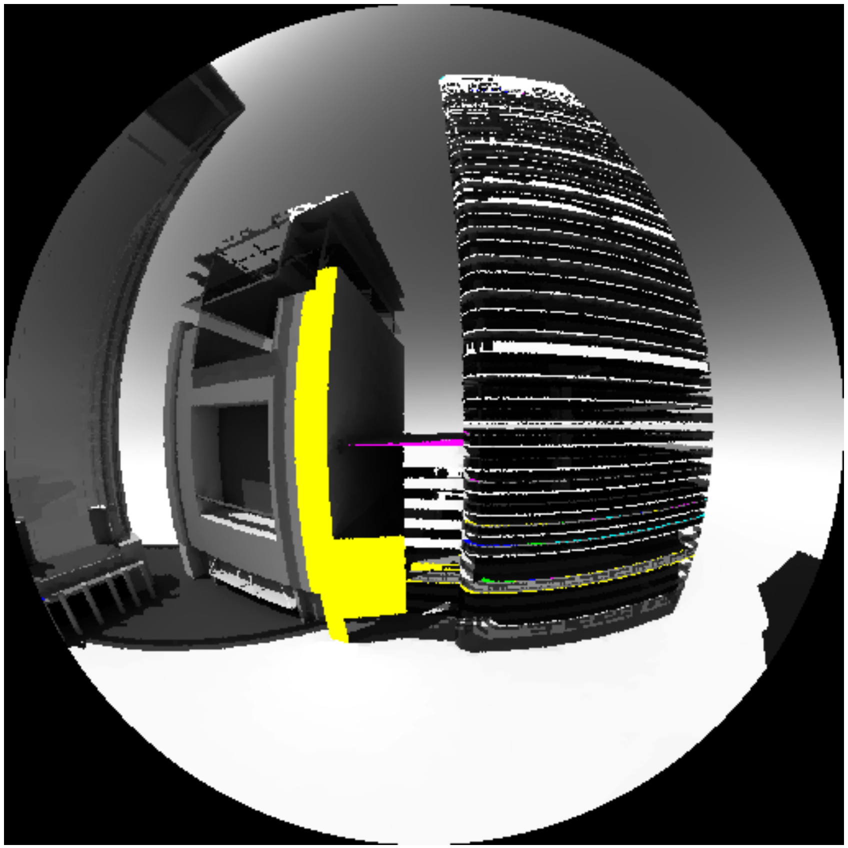
10°



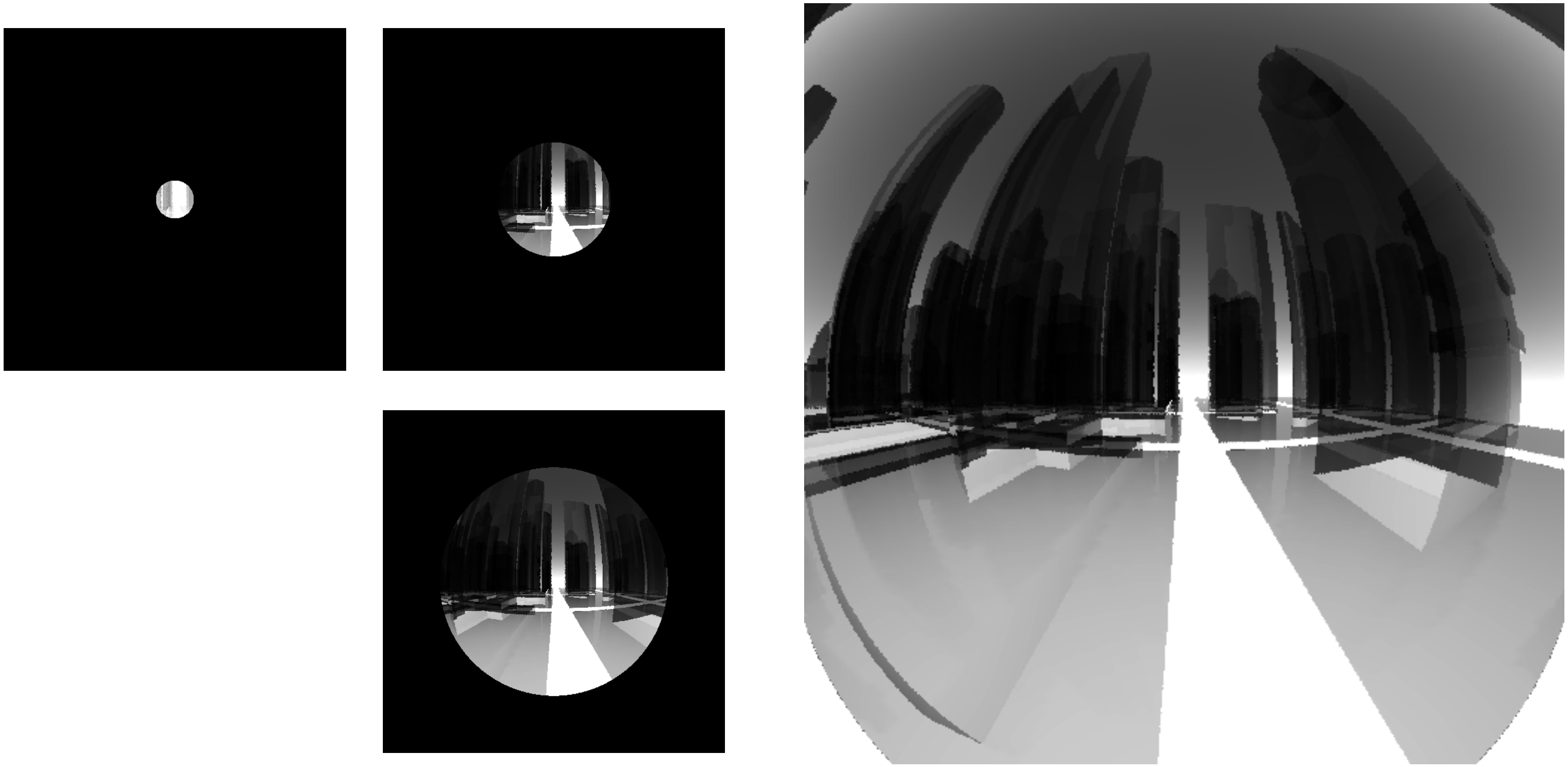
30°



60°

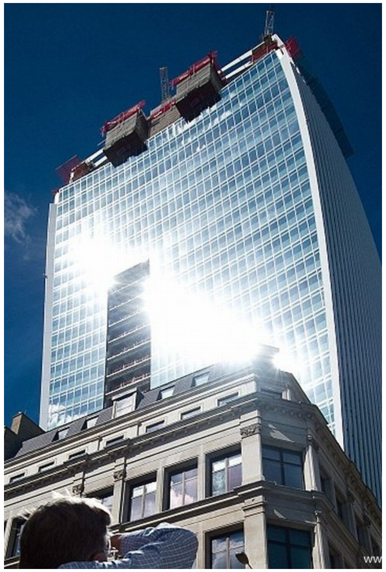


Luminance average in a area of interest



Conclusions

In outdoor tasks or overlooking windows with reflected solar dazzle ahead it is of major importance to assess the magnitude of disability glare as the impairment of vision can cause accidents.



New glare metrics for both, disability glare and discomfort glare in exterior spaces are needed

But We've already have great tools!!!!

Models need to be tested in real scenes and HDR photographs and user occupants questionnaires can complement and validate radiance simulation results


ENJOY GLARE!!!!
THANKS !!!!
Luisa