REFLECTED SUNLIGHT IN URBAN CANYONS. TOWARDS A NEW APPROACH

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ABSTRACT

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. 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 to the internal illuminance of a room and should not be underestimated. Furthermore, 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.
Real data collected in Lisbon showed a linear relationship between the global horizontal solar illuminance, Egh, and the total vertical illuminance, Etv, at the building facade, when the facade is not receiving direct sunlight. This relationship can be described by an equation $Etv = k * Egh + C$ where the slope k depends on the reflectance of the obstruction, the canyon geometry and the height of the point under investigation on the façade. The constant C is mainly the contribution of the diffuse sky illuminance to building daylight and is more significant at higher floors. Simulations undertaken with RADIANCE as well as analytical calculations confirmed that an approximate linear relationship existed except under specific conditions occurring mainly in the summer when the street or ground was fully sunlit.
This paper presents a simplified method for estimating the illuminance that reaches an external point on the façade under clear skies distributions taking into consideration the reflected sunlight from the obstruction and the ground, as well as the diffuse illuminance from the sky.

KEYWORDS

Daylighting, reflected sunlight, urban canyon

INTRODUCTION

Reflected sunlight can play an important role in the illumination of buildings along an urban canyon. Direct sunlight incident on windows will usually result in blinds being used. More interesting is the situation where the façade is lit by reflected sunlight, which will be the case to varying extents on the north, east and west façades.
On the north hemisphere, a building facing north will only have direct sunlight in the early morning and late afternoon during the summer period. An east façade will have sunlight incident in the morning hours and similarly a west façade will have sunlight incident in the afternoon period. Although facing buildings can obstruct direct sunlight and reduce skylight

they can become a useful source of reflected sunlight in the time of the day when the sun is behind the building. In densely built up areas such as cities, the orientation and size of urban canyons can be planned to take advantage of reflected daylight and provide a better uniformity of daylight during the whole day.
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. Several calculation methods or computer simulation programs 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. A simple daylight calculation that takes into consideration the sun component is therefore of major importance in the initial phases of a project.
This paper presents some results based upon real data for the north facing façade for a building in Lisbon and computer simulations as well as from a theoretical analysis of the illuminance falling on a building façade facing an obstruction from skylight and reflected sunlight from the obstruction and ground. A simplified linear relationship between the total vertical illuminance and the global horizontal illuminance derived using the three different approaches can be used as a method for predicting the light level at a point on the façade under clear skies distributions.

COMPUTER SIMULATIONS

The geometry presented consists of an urban canyon with a building surface orientated north, facing an obstruction of equal height, h=18m, with a horizontal ground plane of width w. The canyon is relatively long with 55m. Results are presented for exterior points in the middle of the façade at different heights.
Computer based lighting simulations were undertaken with the RADIANCE software [2] for a narrow (width = 0.5 * height), equal width (width = height) and wide (width = 1.5 * height) urban canyon with four minutes intervals for local solar time. Initially, the simulations were made for the summer and winter solstice and an equinox day. This can be considered a fair representation for the yearly daylight distribution. Additionally, the 21st of each month were also analysed.
All the surfaces, vertical and ground, were modelled as diffuse reflectors. Results are presented for 0.2 reflectance.

The results show a linear relationship between the global horizontal illuminance, Egh, and the total vertical illuminance, Etv, at the façade when there is no sunlight incident. This can be expressed as given in Eqn. 1 below:

$$Etv = k * Egh + C \tag{1}$$

Where

- Etv is the illuminance on a vertical plane due to direct sunlight, skylight and the inter-reflections;
- Egh is the illuminance on a horizontal unobstructed plane due to direct light from sun and diffuse light from the sky;
- C and k are constants.

Fig. 1 shows a linear relationship between the global horizontal and total vertical illuminance on a building facing north at the first, third and fifth storey for the solstice and equinox days. There is a strong relationship between the estimated values of the linear trendline and the simulated values with a coefficient of determination, R^2, higher than 0.89 for all floors.

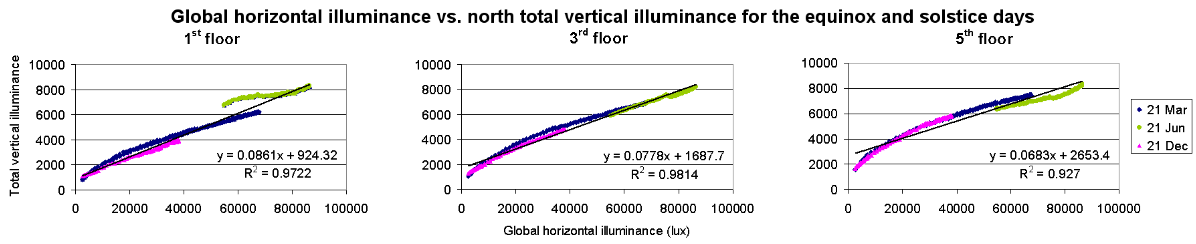

Figure 1 Relation between the total vertical illuminance at the first, third and fifth floors of a building facing north in an urban canyon in Lisbon and the global horizontal illuminance when sunlight is not incident at the façade for the solstice and equinox days.

At the summer solstice the sun's altitude is high when it is incident on the south-orientated obstruction. In the winter period the sun's altitude is much lower and during the daylight hours it is mainly incident on the obstruction. See Figure 3.

For a canyon with a ratio of 1:1 in latitude 38.73º (Lisbon) the obstruction is always fully sunlit during spring, summer and autumn. There is no sunlight incident on the ground plane during the winter. In particular the relative amount of sunlight reaching the ground as opposed to the obstruction is high when the sun is in the east and west. This particularly affects the lower floors and hence the linearity of the relationship at the time of year and sun orientation.

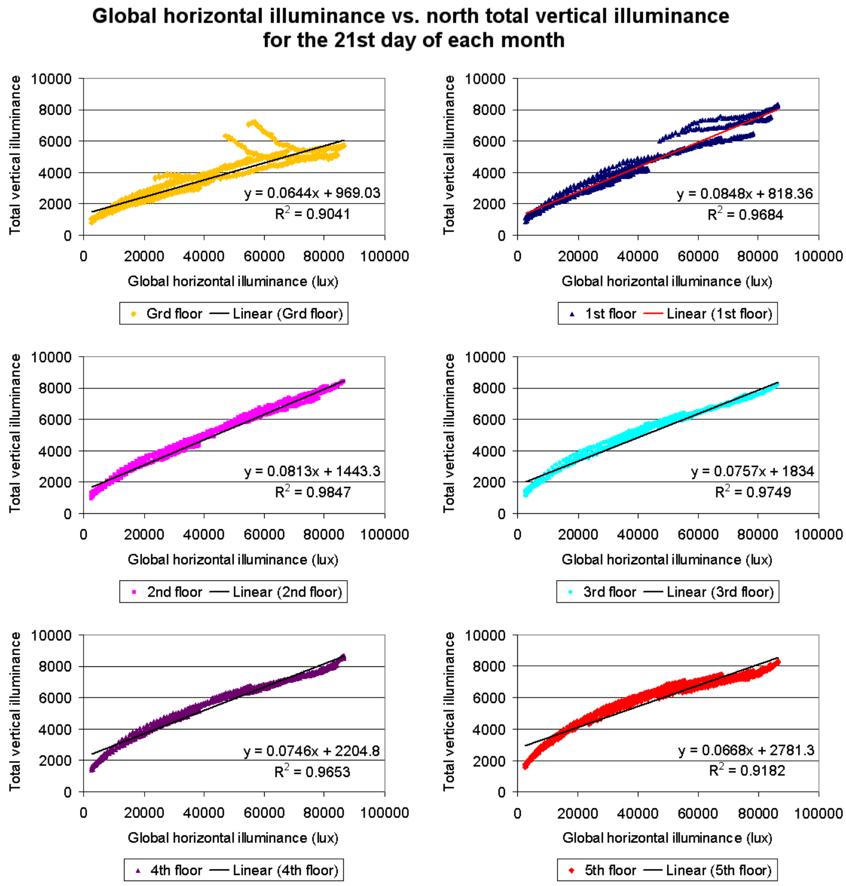

Figure 2: Global horizontal illuminance versus total vertical illuminance at different heights on a north façade in an urban canyon of 1:1 ratio for the 21^{st} day of each month in Lisbon.

Fig. 2 shows that the relationship between the global horizontal and total vertical illuminance derived for the 21^{st} days of each month are within a similar trendline that can be representative of the whole year. Although some values are off the trendline in the lower floors due to higher sun altitude incident on the ground plane during the summer period, they do not weigh significantly on the year average.

Table 1: Slope k and constant C for Eqn. 1 and coefficient of determination R^2 for different canyon ratio (narrow, equal and wide) at different window heights on a north façade.

	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

Tbl. 1 presents the variation on the slope k and constant C in eqn. 1 for the year period for three different canyon ratios at different window heights on a north façade in Lisbon.
Except for the lower floor where the light reflected from the ground is significant therefore increasing C, and the higher floor where the diffuse sky contribution is dominant, k in Eqn. 1 is fairly constant for all floors. The constant tends to increase with higher storeys and wider canyons due to a higher contribution from diffuse skylight and a reduced contribution from the light reflected from the obstruction and ground.

ANALYTICAL APPROACH

This approach at present is restricted to the solar contribution rather than total daylight. It is being further developed to include the diffuse sky contribution.
The following results of the sunlight contribution to the illuminance reaching a point on the façade were derived analytically based on solar geometry [4] and the flux transfer between a point and a surface when the sun is not incident on the surface. [5, 6] The formula used calculates for diffuse surfaces with reasonable accuracy the first reflection of sunlight from the obstruction and ground and the inter-reflection contribution for the following reflections within the canyon. Comparisons of results with simulations made with Radiance show an average error of less than 11% except for altitude angles lower than 10º where RADIANCE considers the solar normal illuminance constant and the formula approaches the reality. [1]

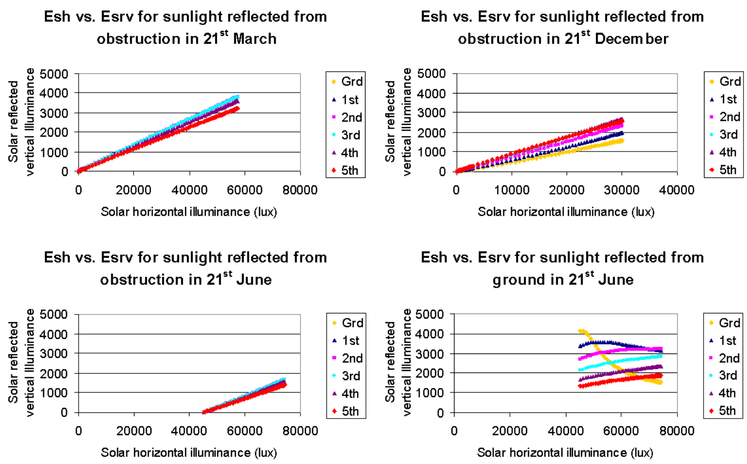

Figure 3: Contribution of the sunlight reflected from obstruction and/or ground to the solar reflected vertical illuminance, Esvr, and the solar horizontal illuminance, Esh, for several floor heights on a north façade for the equinox and solstice days.

Fig. 3 presents the contribution to the vertical illuminance on a north façade due to sunlight reflected off the obstruction and the ground. Although not presented in the graphs, there is a ground reflected component at the equinox day which amounts to about 10% of the sunlight reflected by the obstruction.
During the summer more sunlight may be reflected from the ground than from the obstruction. Hence the ground floor and to a lesser extent the other floors receive more light than predicted by the general linear trend.

REAL MEASUREMENTS

External measurements of the total vertical illuminance, for the first and top floor windows of buildings and the global horizontal illuminance were made in urban canyons in Lisbon for 5 day periods in August and December 2000 for a north orientation.
For the real data some discrepancy of the values to the linear relation between the vertical and the horizontal illuminance can be explained by the obstruction façade not being a perfect diffuser nor a flat surface in regard to windows reveals or setbacks and to the different locations of the instruments for collection of the horizontal and vertical measurements.

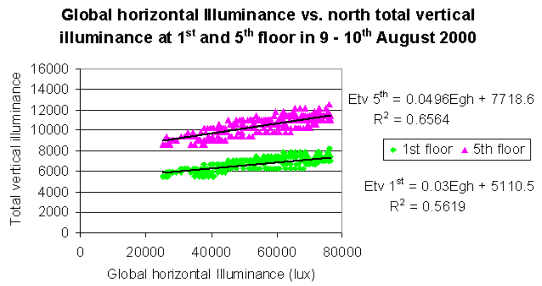

Figure 4: Relation between the total vertical illuminance on the first and fifth floor windows of a building facing north in an urban canyon, to the global horizontal illuminance when sunlight is not incident at the façade on 9th and 10th August 2000.

Fig 4 presents real data collected on the exterior of a first and fifth floor of a building (normal 5° east of north) facing a parallel obstruction of the same height, distant 1.5 times its height. The graph only presents measurements in the time of the day when the sun is behind the building, therefore sunlight is being reflected from the obstruction or ground.
As the obstruction is relatively distant the sky contribution is high and weighs significantly on the total illuminance reaching the reference points in the façade. Also the ground reflected component on this time of the year is high. The constants k and C in Eqn. 1. are low and high respectively.

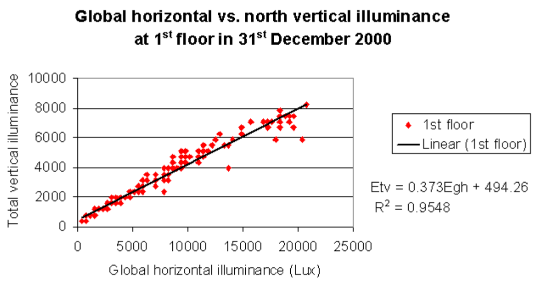

Figure 5 Global horizontal and north total vertical illuminance in 31st December 2000 in Lisbon.

Fig. 5 shows real measurements for the previous 1st floor location in December. The linear relationship Eqn. 1 has a higher coefficient k and the constant C is almost zero. This may be due to measurements being taken on a partially cloudy day. Also during that time of the year there is no direct sunlight in the ground. See Fig. 3, representing the sunlight reaching a north façade reflected from the obstruction for winter solstice day.

CONCLUSIONS

There is a linear relationship between the global horizontal illuminance and the north total vertical illuminance when the façade is not receiving direct sunlight.

Results from simulations show that this relationship does not change significantly during the year and a general equation can be representative for the whole year with a reduced error.

Although the real measurements present significant variations to the simulated data, the linear relationship dominates.

Except at the higher stories in the building C may be ignored so there is a simple relationship between Etv and Egh analogous to the daylight factor, which relates the internal Illuminance on the working plane to the outside unobstructed horizontal level. The level on the working plane may be calculated from Sumpners formula or a derivation from the BRE average daylight factor formula both which are based on a direct proportionality between the vertical sky component and the average horizontal internal level.

Just as the average daylight factor may be used to characterise the perception of how well a space is lit the simple relationship allows the development of such a characterisation for sunlit buildings.

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