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# ASSESSING DAYLIGHT AND SUNLIGHT ACCESS IN THE BUILT ENVIRONMENT: A NEW TOOL FOR PLANNERS AND DESIGNERS


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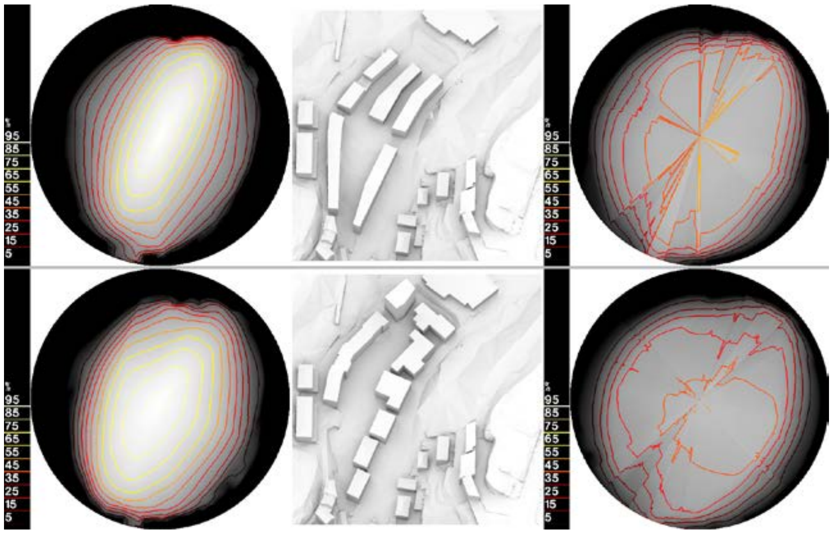


Fig 1: so called “multishading mask” stereographic pictures indicate the percentage of an area that is unobstructed toward each direction on the sky vault. This figure compares two different urban designs. Left column: multishading masks calculated for the open spaces surrounded by the buildings. Right column: multishading masks calculated for the buildings’ vertical façades.

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?

**Research summary**

The need for densification in cities creates a challenge for designers and policy makers in order to provide sufficient access to daylight and sunlight to buildings and to the open public spaces in-between. Guidance and policies should provide site specific recommendations and targets to designers and developers to allow for an optimal dimensioning of the massing for new development. This guidance should be based on the local climate and specific to the site. At the core of this guidance should be an objective method of assessment based on climatic data with flexible targets.

The proposed method is based on “multishading masks” (Fig. 1) or “effective envelope area pictures” which are two different ways of “mapping” the visibility between buildings’ envelope or the open spaces and the sky vault. These are later processed to compute a set of quality indicators that can be used to compare proposed massing configurations and select the most efficient ones. Some of these indicators such as the Sky Component are independent from the site while others such as the Potential or Actual Sunlight Exposure are latitude or site specific respectively.

**Keywords**: solar access, sunlight exposure, open spaces, urban form, shading masks, sky view factor

## 1. Introduction

It is commonly admitted that, in temperate and cold climates, providing ample access to sunlight and daylight to buildings and surrounding open spaces is a key strategy to improve buildings energy performances as well as their users' satisfaction. In hotter climates or seasons, ensuring enough shading becomes essential. Ideally, these issues should be carefully addressed at the early stage of design. Several manual or computerized methods are already available to help in this purpose. They often involve the use of obstruction masks superimposed on diagrams representing the sky vault and sunpaths. Some relevant indicators are then estimated (e.g. sky view factor, vertical sky component, probable sunlight hours, irradiance or illuminance level) usually for a limited number of points of interest. Thus, their applicability to the design of new developments or to the redevelopment of neglected areas located in an already densely built context is not straightforward.
As an example, the document BR 209 (Littlefair, 2011) is one of the most influential guidances on daylight and sunlight access provided for urban planning. Yet, it mainly relies on graphical tools which must mostly be applied manually and it remains specific to the northern European countries and in particular United Kingdom.
The method presented hereafter is also based on principles described in BR 209 and aims to provide a more flexible methodology enabling the automated calculation of several indicators for whole areas of interest (e.g. a building façade, a roof pane, the whole external envelope of a building, the ground area of an open space).
The method relies on two types of stereographic pictures of the sky vault so called "multishading masks" as defined in (Compagnon & Goyette-Pernot, 2013) and "effective envelope area pictures". In a second step, these particular pictures are processed, graphically or numerically, in order to visualize or compute relevant indicators that can be either dependent or not to the local climate.

## 2. Outline of the method

This section explains the entire workflow for applying the proposed method. For a potential user, the most demanding step is the preparation of the input data. The generation of the aforementioned specific pictures as well as the computation of various indicators are both fully automatic steps.

### *2.1 Input data preparation*

At first, a numerical 3D model of the studied site has to be prepared in an appropriate CAD tool. Its content is limited to the information typically available at the master planning stage namely: the shapes and positioning of the buildings surrounding the site (i.e. the urban built context), the buildings' shapes and positioning of the development to be analysed, the vegetation elements that are supposed to cast shadows, the perimeters of the open spaces that have to be evaluated and the ground relief in case it cannot be simply modelled as a single horizontal plane. At this stage, neither the windows nor the materials have to be specified on the building envelopes.
The second step involves the creation of sample points' grids located in front of building envelope elements (i.e. façades or roofs) or above the ground of open spaces on which various indicators will be computed. A grid is defined by the x,y,z coordinates of each point as well as the xdir, ydir, zdir components of the direction vectors normal to the surfaces to which the points belong. Such grids can either

be automatically generated by the CAD tool or by an external program.

There is no predetermined rule regarding which points to include or exclude into sample points' grids; it depends from case to case. For instance if the purpose of the analysis is to analyse daylight and sunlight access of a single building façade, then the relevant grid should only include the points spread over this unique façade. In case the locations of the windows openings are already precisely defined, then the sample points could even be spread only in front of the windows while those which are located in front of opaque walls could be omitted. A single grid can also contain points spread over several different surfaces for instance to evaluate the daylight and sunlight access of a whole group of buildings.

*2.2 Multishading masks and effective envelope area pictures*

The 3D model and the grids are then used to compute "multishading masks" and "effective envelope area" stereographic pictures using proper developed programs based on the RADIANCE open source ray-tracing software (http://radiance-online.org/). Both kind of pictures are in fact methods of "mapping" the buildings' geometry onto the sky vault.

For a specific grid attached to a surface or a group of surfaces, the corresponding "multishading mask" picture contains pixels whose values $M_p$ range from 0 (black) to 1 (white) indicating the fraction of the grid that has an unobstructed view to the sky patches associated to each pixel (Figure 1).

The "effective envelope area" picture is a slightly different concept: it contains pixels whose values $U_p$ are calculated as the total projected envelope area (in m2) that can be seen from the sky patches associated to each pixel. The formulas used to compute $M_p$ and $U_p$ values are detailed in section 9.

*2.3 Performance indicators*

Several indicators characterizing the provision of daylight or sunlight to the chosen areas can be computed from their corresponding "multishading masks" and "effective envelope area" pictures. These indicators fall into three categories: those which are totally independent from the location, those which are latitude dependent and finally those which depend from the location's specific climate. Tables 1 and 2 show a list of the indicators we have used so far either for analyzing open spaces or building envelopes. Several of them are directly inspired by the document BR 209 (Littlefair, 2011).

The sky component indicator (SC) is used to evaluate the provision of sufficient daylight. It is computed as the ratio of the illuminance received directly from the sky (assuming a standard CIE overcast sky luminance distribution) at the sample points' locations to illuminance received on a horizontal unobstructed plane. For open spaces, SC is always computed horizontally. Conversely, for evaluating buildings' façades or roofs, SC is computed in the same planes as those of the sample points. For instance, for purely vertical facades, the indicator SC matches the "Vertical Sky Component" as defined in BR 209. For a totally unobstructed site SC=1 whereas for a vertical façade SC=0.396.

The Sky View Factor (SVF) is computed similarly but with a uniform sky luminance distribution. It indicates the fraction of the considered area that has an unobstructed view of the sky vault. For a totally unobstructed site SVF=1 whereas for a vertical façade SVF=0.5. In absence of climatic data, SVF can serve as a rough indicator of the mean solar irradiance received by the corresponding surfaces either for open spaces or buildings' envelopes. Since SVF affects the long wave infrared exchanges between the urban fabric and the sky, it can also serve as an indicator of the urban heat island effect.

The provision of direct sunlight can be characterized using several different indicators. Two options are available at this stage: either by only taking into account the latitude of the site (i.e. the direct sun rays' directions are computed from purely geometrical formulas, hence the qualifier "potential" of the associated indicators) or by taking into account the local climate (i.e. the direct sun rays' directions depend from hourly data specific for the site, hence the qualifier "probable" of the associated indicators).

This latter option makes use of hourly global irradiance data obtained either from measured records or from meteorological databases like the METEONORM software or the satel-light web service (see: http://meteonorm.com and http://www.satel-light.com).

| | **Indicator name's, symbol, value range, [unit]** | **Indicator's signification** |
|---|---|---|
| **Independent from location** | Sky component, SC, 0 to 1, [-] | Daylight sky component |
| | Sky view factor, SVF, 0 to 1, [-] | Unobstructed fraction of the sky vault |
| **Latitude dependent** | Potential sunlight exposure, WSE<br>0 to X (depending from the time period studied), [hours] | Number of sunlit hours weighted by the multishading mask values |
| | Potential overlit hours, HOL<br>0 to X (depending from the time period considered), [hours] | Number of "overlit" hours (i.e. during which ≥80% of the open space is sunlit) |
| | Potential adequate sunlit hours, HOK<br>0 to X (depending from the time period considered), [hours] | Number of "adequate sunlit" hours (i.e. during which between 20% and 80% of the open space is sunlit) |
| | Potential overshaded hours, HOS<br>0 to X (depending from the time period considered), [hours] | Number of "overshaded" hours (i.e. during which <20% of the open space is sunlit) |
| | Potential adequate sunlit hours at equinox, HEQ<br>0 to 12, [hours] | Number hours for which, on an equinox day, at least 50% of the open space receives sunlight |
| **Dependent on the local climate** | Actual sunlight exposure, AWSE | Same as above but computed from measured or simulated direct irradiance hourly values |
| | Actual overlit hours, AHOL | |
| | Actual adequate sunlit hours, AHOK | |
| | Actual overshaded hours, AHOS | |
| | Mean irradiance, I<br>0 to ~1000, [W/m$^2$] | Mean global irradiance over the time interval considered |

Table 1: indicators for analysing daylight, sunlight and global irradiance incoming on open spaces. They are all computed from multishading masks. Apart from SC and SVF, all other indicators can be computed for various time intervals (typically over an entire year or separately for each month).

| | **Indicator name's, symbol, value range, [unit]** | **Indicator's signification** |
|---|---|---|
| **Independent from location** | Sky component, SC, 0 to 1, [-] | Daylight sky component |
| | Sky view factor, SVF, 0 to 1, [-] | Unobstructed fraction of the sky vault |
| **Latitude dependent** | Potential sunlight exposure, WSE<br>0 to X (depending from the time period studied), [hours] | Number of sunlit hours weighted by the multishading mask values |
| **Dependent on the local climate** | Actual sunlight exposure, AWSE | Same as above but computed from measured or simulated direct irradiance hourly values |
| | Mean irradiance, I<br>0 to ~1000, [W/m$^2$] | Mean global irradiance over the time interval considered |

Table 2: indicators for analysing daylight, sunlight and global irradiance incoming on buildings' envelopes. WSE and AWSE indicators are computed from multishading masks while the others require effective envelope area pictures. Apart from SC and SVF, all other indicators can be computed for various time intervals (typically over an entire year or separately for each month).

Only those hours for which the direct normal irradiance exceeds a threshold of 120 [W/m$^2$] are considered for computing these indicators. This is in line with the "sunshine duration" parameter as defined by (WMO, 2008).

The sunlight exposure indicators (WSE and AWSE) are used to quantify the provision of sunlight. It is important to note that these indicators are obtained by summing hours weighted by the values stored in the multishading mask. For instance if, for a specific hour, the multishading mask contains a value equal to 0.5 for this sunray's direction, then this hour is weighted by 0.5 in the sum. This means that this particular sunlit hour is accounted just half in the sum because the multishading mask indicates that just half the area considered has an unobstructed view of the sun.

As presented in (Compagnon & Goyette-Pernot, 2013), another way of evaluating the multishading mask of an open spaces is to split the potential sunlit hours into three categories: overlit hours (HOL, AHOL), overshaded hours (HOS, AHOS) and adequate sunlit hours (HOK, AHOK). This is done by counting the number of hours when the sunpath is crossing the respective zones of the multishading mask. The number of hours for which at least 50% of an open space can potentially benefit from sunlight during an equinox day (HEQ) is computed similarly (Littlefair, 2011).

Finally, the mean solar irradiance I can also be estimated as long as statistical sky models computed for various time intervals (e.g. the whole year or the heating season) are available for the considered location (Compagnon, 2004). The calculation of I involves a pixel by pixel product between the "effective envelope area" picture and a stereographic view of the radiance distribution of the sky vault. This operation can be visualized by superimposing these pictures. Some interactive examples demonstrate this procedure on a dedicated online web tool: http://phybat.eia-fr.ch/ibic/.

*2.4 Evaluating indicators' values*

Ideally, in order to evaluate an urban design at the master planning stage, it would be convenient to refer to some specified target values for each of these indicators. Such targets have already been set for a few indicators. Here are some examples as found in BR 209:

- SC to be ≥0.27 for vertical façades to ensure window openings can bring sufficient daylight inside buildings;
- SC should never be <0.05 because under this limit *"it is impossible to achieve reasonable daylight, even if the whole window wall is glazed*";
- For open spaces, HEQ should be ≥2 [h] to ensure they appear adequately sunlit throughout the year.

For some indicators, no defined targets have been set yet. However, some recommendations can be made. For instance for open spaces, indicators HOK and AHOK should be maximized while the others (HOL, AHOL, HOS, AHOS) should better be minimized. The difficulty in setting targets comes from various causes:

- depending on the local climate, some indicators are either simply irrelevant (e.g. SC in regions where overcast skies are very rare) or should have target values specifically tuned;
- even for a single location, the target values may vary according to the season;
- some of these rather new indicators still need more research to demonstrate their relevance and usefulness.

One other aspect to consider is the fact that, at the master planning stage, these indicators could be of great help for comparing different designs. Thus, a method able to "measure" indicators differences is probably more important than to set up target values. For this purpose we introduce a function m defined as:

$$m(X_1; X_2) = \frac{\log(X_2 / X_1)}{\log(\alpha)}$$

where:

$X_1$, $X_2$ are two values of the same indicator X

$\alpha > 1$ is a parameter whose value depends from the indicator X

If $X_2 > X_1$ then $m > 0$ and reverse when $X_2 < X_1$

The parameter α is in fact the smallest multiplying factor for which $X_2 = \alpha X_1$ is considered to provide a noticeable difference.

With such a definition, m can be interpreted as a kind of "magnitude" of change: if $-1 < m < 1$ the difference between the two values can be considered as acceptable or barely noticeable. Conversely, when $|m| > 1$ this value can serve to weight the severity of the change.

In order to compare SC or SVF values we therefore propose to use $\alpha = 1.47$. This is consistent with the fact that, for humans, a variation of illuminance can be perceived as long as the illuminance level changes by a factor of at least 1.5. When comparing the target values SC=.27 with that for a vertical unobstructed façade, m is just equal to -1 which indicates a tolerable decrease. Doing the same with the minimal limit SC=0.05, the "magnitude" of this change becomes m=-5.37.

Based on recommendations found in BR 209, to compare sunlight hours indicators, a value of $\alpha = 1.25$ seems appropriate. For now we also adopt the same value for comparing mean irradiances. It is of course clear that these adjustments should be further investigated in order to ascertain their validity.

## 3. Application example

### *3.1 Case studies*

Two different design proposals for a site located in a in a little valley of Lausanne city Switzerland (latitude 46.52°N) were chosen to illustrate the method. The site is currently a brownfield situated on the northern part of an existing neighbourhood (quartier du Vallon). Both proposals are rather dense (plot ratios above 1) and comprise buildings enclosing an open space (Fig. 2). The purpose of the analysis conducted using our method is to assess which of these two designs performs better in term of daylight and sunlight access for buildings' façades and open spaces.

### *3.2 Results*

Results are compared in Fig. 2. Significant differences appear among the open spaces but not among building's façades. Indicators AWSE and HEQ show that Case B open space is significantly better sunlit than case A. However, the much higher value of AHOL indicates that case B would require additional shading elements to enhance users' satisfaction. Regarding buildings' façades, case B benefits from slightly less daylight and sunlight. This is due to the fact that case B comprises several buildings blocks separated by several rather narrow streets while case A comprises elongated buildings with fewer and larger streets.

## 4. Conclusions

The method presented in this paper is still at an early stage of development. Specific software tools were developed and successfully tested but, however, further

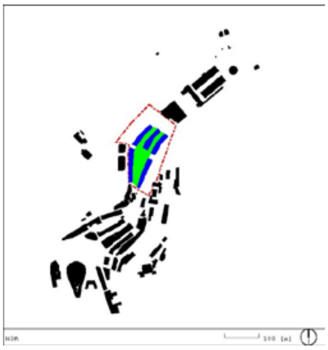
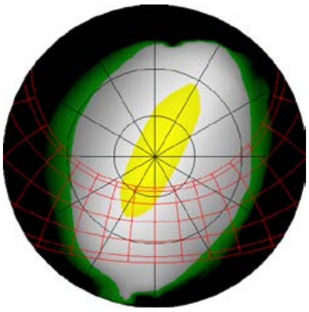
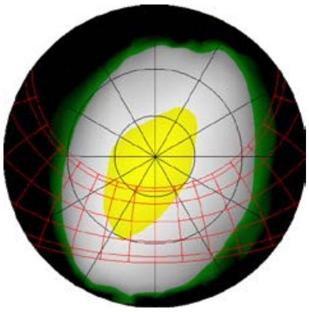
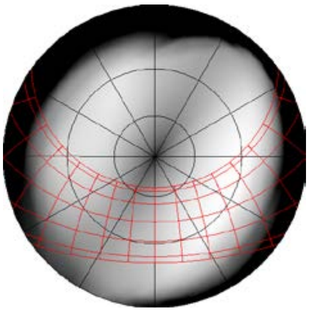
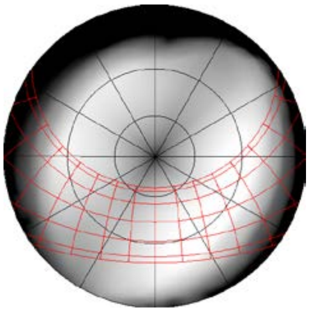
| **Case A** (Fig 1. 1st row), plot ratio: 1.13 | | **Case B** (Fig 1. 2nd row), plot ratio: 1.42 |
|---|---|---|
|  | Plan view<br><br>The open spaces taken into consideration are coloured in green<br><br>The buildings' taken into consideration are coloured in blue |  |
|  | **Analysis for open spaces**<br><br>Multishading mask |  |
| SVF=0.56 | 0.31 | SVF=0.63 |
| SC=0.61 | 0.28 | SC=0.68 |
| AWSE= 812 h | **1.1** | AWSE= 1029 h |
| AHOL= 179 h | **3.9** | AHOL= 429 h |
| AHOK= 1252 h | -0.5 | AHOK= 1126 h |
| AHOS= 731 h | -0.8 | AHOS= 606 h |
| HEQ=4.0 h | **1.6** | HEQ=5.7 h |
| I=66 W/m$^2$ | 0.75 | I=78 W/m$^2$ |
|  | **Analysis for buildings' façades**<br><br>Effective envelope area picture |  |
| SVF=0.70 | -0.27 | SVF=0.63 |
| SC=0.67 | -0.24 | SC=0.61 |
| AWSE=807 h | -0.17 | AWSE=777 h |
| I=91 W/m$^2$ | -0.1 | I=89 W/m$^2$ |

Fig 2: results obtained for the two case studies. The central column shows the "magnitude of change" m(A,B) between the indicators (significant changes for which |m|>1 are highlighted in bold characters). Sunpath for latitude 46.52°N is superimposed in red colour on the multishading mask and effective envelope area picture.

research is still required in order to ascertain the various indicators qualifying daylight and sunlight access are really able to provide valuable guidance in the master planning phase. In addition, some target values should in all likelihood be defined according to the climatic conditions.

To demonstrate the method in more details, we plan to set up, in a near future, an online web tool on which a series of "generic urban designs" can be processed in various climates (http://phybat.eia-fr.ch).

## 5. Acknowledgments

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## 7. Annex: multishading mask and effective envelope area pictures

A multishading mask stereographic picture (as shown in Fig. 1 and 2) is formed by pixels whose values are computed as:

$$M_p = N^{-1} \cdot \sum_{k=1}^{N} vis(p,k) \quad in\ [-]$$

where:

p is indexing all pixels which are tiny patches by which the entire sky vault hemisphere is subdivided

k is indexing the grid points

N is the total number of points in the grid

vis(p,k) is a function characterizing the visibility between sky patch p and point k. It is equal to 1 if a light ray coming from sky patch p can reach point k without any obstruction and 0 otherwise

An effective envelope area stereographic picture (as shown in Fig. 2) is formed by pixels whose values $U_p$ are computed as:

$$U_p = \sum_{k=1}^{N} A_k \cdot vis(p,k) \cdot \cos(\theta_{pk}) \quad in\ [m^2]$$

where:

$A_k$ is the area (in $m^2$) of the building envelope sample referred by point k

$\theta_{pk}$ is the angle between the ray linking point k to sky patch p and the sample's surface normal vector

The total envelope area "included" in an effective envelope area picture is defined as:

$$A_{tot} = \sum_{k=1}^{N} A_k \quad in\ [m^2]$$