ASSESSMENT OF THE POTENTIAL FOR SOLAR ENERGY APPLICATIONS IN URBAN SITES

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ABSTRACT

This paper defines various indexes that serve to assess the potential of facades and roofs located in urban areas for active and passive solar heating, photovoltaic electricity production and daylighting. These indexes are computed from solar irradiation and illuminance values obtained through numerical simulations.

INTRODUCTION

Extensive exploitation of the solar irradiation in urban zones appears more and more clearly as an essential and practicable strategy to foster sustainable development [1]. What we need now are advanced methods for the study of solar penetration in different urban textures.

Older or more recent tools that have served for this purpose up to now are mainly aimed to preserve the direct solar irradiation of buildings (e.g. [2 to 4]). The method presented hereafter deals with a further step where the global solar irradiation reaching the buildings envelopes (facades and roofs) is accurately quantified in order to asses the potential of the zone for active and passive solar heating, photovoltaic electricity production and daylighting.

METHOD

The assessment of the final energy that can be produced by active or passive solar techniques or saved by daylighting strategies in an urban area can be summarised as a symbolic equation that involves two parts:

[Final Energy] = [Urban Solar and Daylight Availability] ⊗ [Utilisation Factors]

[Urban Solar and Daylight Availability] describes the resource available over the building envelope area whereas the technical characteristics of the solar collectors or daylighting devices effectively installed on the buildings are grouped into [Utilisation Factors]. These two separate terms serve to clearly divide the resource evaluation from the technical means used to capture this natural energy flux.

Since the main focus of this method is to study the effects of building geometry, layouts and orientations on the potential for solar energy in urban areas (i.e. passive and active solar thermal applications, photovoltaic modules, daylighting strategies), this work concentrates on the first term, which can be further detailed as:

[Urban Solar and Daylight Availability] = [Sky Model] ⊗ [3D Buildings Model]

The ⊗ sign describes the major interactions that occur between the incident irradiation (coming from the sun and the whole sky vault) and the built environment (ground and buildings envelopes). These interactions (mutual shadowing between buildings, interreflections) need to be precisely estimated in order to quantify the [Urban Solar and Daylight Availability]. References [5] and [6] describe how the required sky and building models are prepared from climatic data and land use register maps respectively.

These models are then processed using the RADIANCE lighting simulation software that works with a ray-tracing method whose physical accuracy has already been proved by several studies [7]. RADIANCE computes a series of irradiance G_i (in [W/m^2]) and illuminance values E_i (in [lx]) by positioning virtual pyranometers and photometers at points located in front of all building external surfaces. These measurement points are typically positioned on a regular grid, whose width is comprised between 0.5 and 1 [m]. Even for a single façade, this procedure would be impossible to perform on a real building.

After being computed by RADIANCE, the large number of G_i and E_i samples is aggregated in order to provide an overall view of the solar and daylight availability. For this purpose, histograms are produced with their horizontal axis subdivided into equal intervals of either irradiation (Figure 2) or illuminance values (Figure 3). For each interval, the building external surfaces (either facades or roofs), which are lit by the corresponding level, are plotted on the vertical axis.

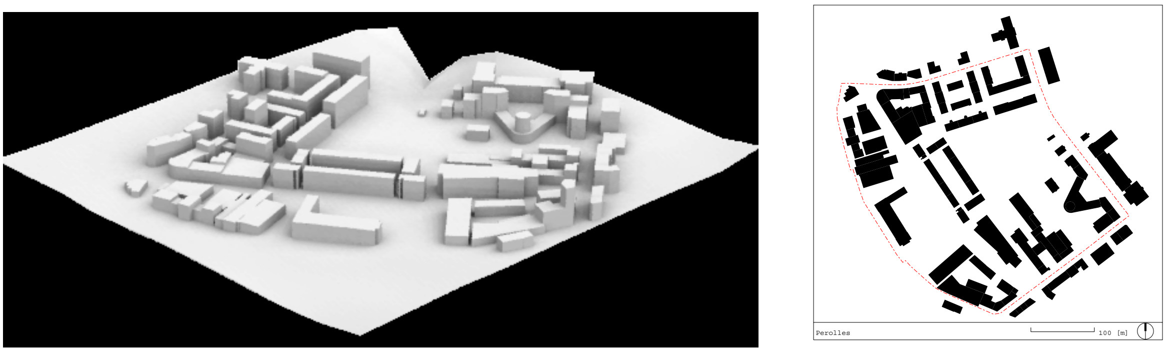


Figure 1: A part of the Perolles area located in Fribourg (Switzerland) that serves as an application example throughout this paper. The analysis is performed on the 61 buildings within the dotted outline (Ground surface = 11.7 [ha], Plot ratio = 1.2). Left: district model rendered by RADIANCE. Right: site plan.

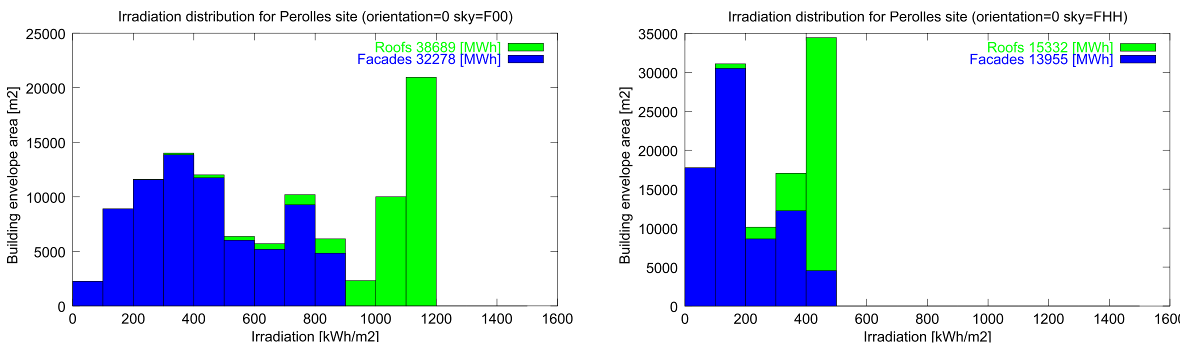


Figure 2: Histograms characterizing the solar irradiation of the Perolles area (dark colour: facade areas; light colour: roof areas). Left: annual solar irradiation (serves to compute the potential for building integrated photovoltaic systems and solar thermal collectors). Right: heating season irradiation (serves to compute the potential for passive solar heating techniques).

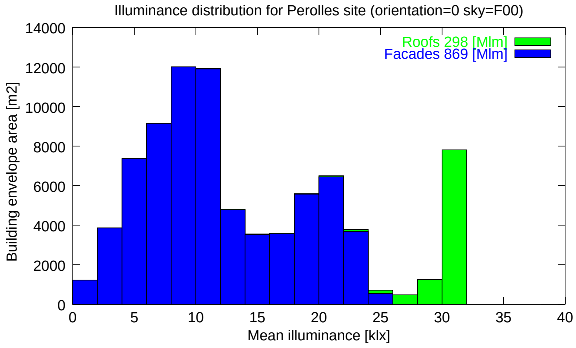


Figure 3: Histogram characterizing the mean annual illuminance of the Perolles area (dark colour: facade areas; light colour: roof areas). This distribution serves to compute the potential for daylighting systems.

Once these distributions are available, they can be analysed to assess the potential for different solar techniques. The procedure is rather straightforward: first an irradiation or illuminance threshold value is determined. For a specific technique the threshold value indicates the minimum amount of radiation that is required for such a solar installation to be worth considering. Current technical limitations as well as economic factors are taken into account in setting up the threshold. In a second step, the irradiation or illuminance distribution is scanned to compute the total amount of building envelope areas, which receive amounts of radiation greater than or equal to the threshold. Finally, the potential for the specific solar technique is quantified by computing the ratio (given as %) between the amount of adequately lit envelope area and the total building envelope area.

Table 1 shows the threshold values proposed for generic types of solar techniques. These values were defined with the help of experts in the corresponding fields but could easily be changed either to be adapted to very specific techniques or to reflect future technological improvements.

Solar technique	Threshold for systems mounted on facades	Threshold for systems mounted on roofs
Photovoltaic systems	800 [kWh m^{-2}] annual solar irradiation	1000 [kWh m^{-2}] annual solar irradiation
Solar thermal collectors	400 [kWh m^{-2}] annual solar irradiation	600 [kWh m^{-2}] annual solar irradiation
Daylighting systems	10 [klx] mean daylight illuminance during office hours (8h-18h)	
Passive thermal heating	Varies according to climate: is defined as the amount of solar irradiation required to fully compensate the heat-loss through a standard double glazed window during the heating season For Fribourg (Switzerland) this threshold = 151 [kWh m^{-2}]	

Table 1: threshold values proposed to compute the potential for the corresponding solar techniques. References [5] and [6] explain how these values were chosen.

Roofs are generally located at a height that does not largely vary between neighbouring buildings. This means they have a good view to the sky vault and shadowing effects are limited. The potential for solar energy collection on roof areas thus remains less affected by the urban texture. On the contrary, neighbouring buildings largely affect facades. Hence their use as solar and daylight collectors requires some careful examination also for architectural integration issues. Consequently, the remainder of this paper will deal with facade potential only.

The potential as presented above forms the core part of the proposed method. However, for planning purposes, additional information based on the same calculations can also be extracted. For instance, though the orientation of an urban area is a useful concept for solar and daylight access analysis, its definition does not seem to be clear and unique. The simplest method would be to calculate the facade surface area oriented towards each direction. Then these areas can be summed and aggregated into several azimuth sectors (typically 15° wide). The sectors that contain the largest facade area indicate the main orientations affecting the solar and daylight access of the buildings. However this method ignores the fact that some facades may be highly obstructed and therefore would fail to perform as potential collectors. A simple alternative method, which deals more accurately with this issue, consists of applying weighting factors based on Sky View Factors (also computed by the RADIANCE software) when counting facade areas for every azimuth sector. Finally the resulting figures are presented in a polar diagram named “Orientation rose” (Figure 4).

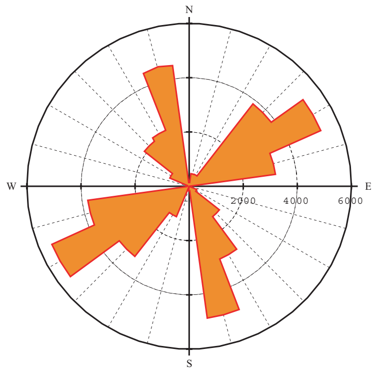


Figure 4: Orientation rose for the Perolles area showing SVF-weighted facade areas (in [m^2]) oriented towards each azimuth sector (15° wide).

The purpose of an orientation rose is also to serve at the early stage of urban planning before solar and daylight availability distributions are computed. It is expected that after having applied the procedure on several case study sites, some empirical relations can be found between the orientation rose and the solar and daylight availability.

APPLICATION

The central part of the Perolles area in Fribourg (Switzerland) has been analysed using this procedure. The case study site is an approximately square part of the Perolles area (Figure 1) occupied by a mix of light industrial buildings, warehouses, residential and commercial buildings. Recent residential/commercial buildings surround the central part of the site around a public open space. The western part of the site is presently occupied by old warehouses and can be considered as a fallow piece of land. In the future this area will be completely rebuilt. Since there are no definite plans yet available, this western part has been used to check several hypothetical urban forms. For these studies, the plot ratio was deliberately set to a relatively high value (2.0).

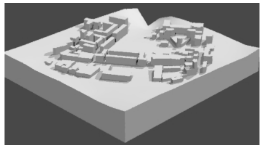
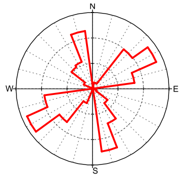
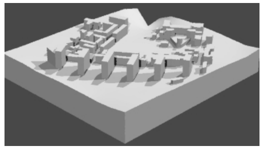
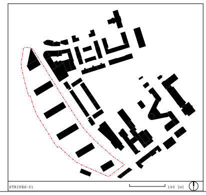
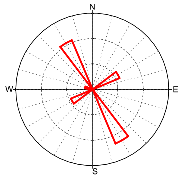
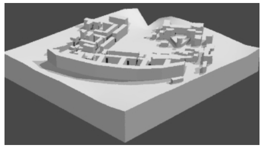
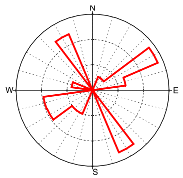
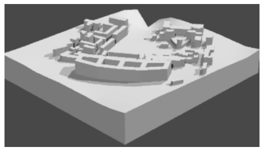
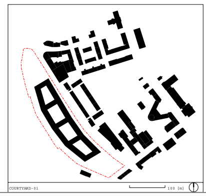
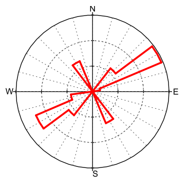
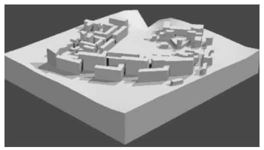
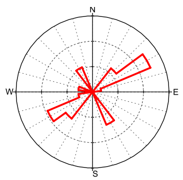
Urban area	View	Plan	Orientation rose	Facades annual irradiation per square meter floor area	Potential for passive solar heating techniques	Potential for photovoltaic systems	Potential for daylighting systems	Potential for solar thermal collectors
Whole area (present situation): plot ratio = 1.2				224 [kWh m^{-2}]	52 %	6.5 %	54 %	50 %
Stripes (10 storeys) plot ratio = 2.0				**309 [kWh m^{-2}]**	74 %	**21 %**	82 %	70 %
Comb (6 storeys) plot ratio = 2.0				251 [kWh m^{-2}]	67 %	**21 %**	68 %	69 %
Courtyard (6 storeys) plot ratio = 2.0				215 [kWh m^{-2}]	69 %	16 %	69 %	67 %
Stepped slab blocks (5 and 8 storeys) plot ratio = 2.0				290 [kWh m^{-2}]	**81 %**	17 %	**83 %**	**82 %**

Table 2: comparison of 4 hypothetical urban forms for the western part of the Perolles area (several other proposals are analysed in [6]). The analysis is performed on the buildings within the dotted outlines. The potential values are calculated for facades only. For each column, the maximal value is indicated in bold characters.

A comparison of the facades' potential calculated for the existing area and for some hypothetical urban forms is given in Table 2. The results show that more than the half façade area is adequate for passive, active and daylighting techniques in the existing Perolles area although it was built without special planning measures regarding solar and daylight availability. When care is taken to maximise solar and daylight penetration, a large increase of the potential can be achieved even for denser planning proposals.

It is also interesting to compute the facades' total irradiation per square meter of floor area. For the Perolles area this amounts to 224 [kWh m^{-2}] (compared to 75 [kWh m^{-2}] for the roofs). This highlights the importance of vertical surfaces as solar energy collectors in the urban context. It also appears that the primary solar energy that reaches the facades well exceeds the final energy consumed by modern buildings or prescribed by actual standards. For instance in Switzerland, the MINERGIE® label prescribes annual heating final energy indices of 45 [kWh m^{-2}] for new residential buildings and 90 [kWh m^{-2}] for renovated buildings. This label is becoming mandatory in some regions (e.g. Fribourg) for public or publicly funded projects. Compared to such standards, the potential for solar energy collection becomes significant.

Apart from site pictures as shown in Figure 1 and Table 2, RADIANCE can be used to produce several types of visualisation. Figure 5 shows an example where the use of a shading scale helps the interpretation of the picture's physical content. Similar image processing methods are also used by other tools in the field [8] [9].

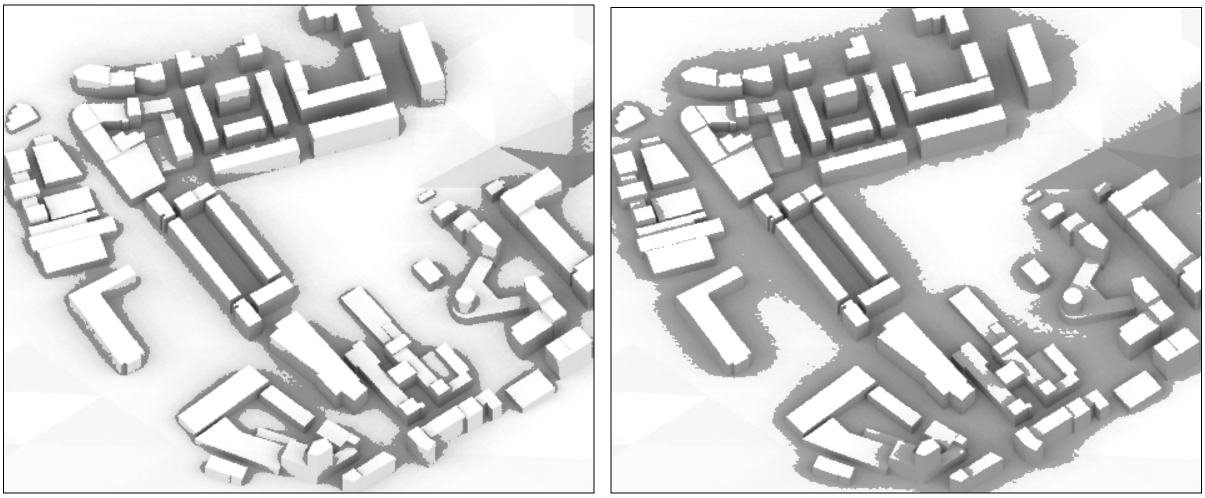


Figure 5: Left: visualisation of facade areas suitable for photovoltaic systems: all areas with annual irradiation below the relevant threshold value (800 [kWh m^{-2}]) are shaded in grey. Right: visualisation of roof areas suitable for photovoltaic systems: all areas with annual irradiation below the relevant threshold value (1000 [kWh m^{-2}]) are shaded in grey

CONCLUSIONS

The potential evaluations proposed in this paper indicate the fractions of the total facade or roof area that is appropriate for various kinds of solar energy techniques. The method still need to be refined, especially regarding the irradiation and illuminance threshold values, which need to be further validated and regularly updated to take into account technological and economic progress.

The main purpose of calculating these figures is to make quantitative comparisons between urban planning proposals comprising several buildings (there is no limit to the number of buildings for which the potential of different solar systems can be assessed except the CPU time allowed for the whole calculation process). By eventually selecting the proposals that offer the largest potential, an urban planning authority does not immediately maximise the production or final energy (which is generally not considered as a priority at all) but it will enhance the solar and daylight resource available on the site. Hence in the final building design phase, this strategy will ensure that the architects still have a wide choice in locating active or passive solar systems on the outer building envelopes.

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This method is currently being applied in the framework of the SOLURBAN Swiss project also presented at EUROSUN 2002 (see paper by J.-L. Scartezzini & al.).

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