Solar Access Assessment for Mediterranean Urban Environments: The Extent of the "Crossing Effect"

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ABSTRACT: Street intersections are often disregarded in energy studies, despite being one of the defining features for any urban fabric. This paper addresses the issue of Winter solar access precisely on the crossing vicinity in the case of Barcelona, a Mediterranean urban dense environment. For three models, this intersection influence has been assessed through two parameters: Sky Factor and direct solar radiation. Results show that the "crossing effect" extends up to a variable distance within the canyon depending on the surface orientation and the intersection side under assessment, being particularly remarkable for South, SE and SW façades.

Keywords: Solar Access, Sky Factor, Urban Morphology, Mediterranean Environment

INTRODUCTION

Cities constitute the main human habitat and are responsible for an important fraction of the energy and resource consumption worldwide. Thus, understanding its energy behaviour plays an important role towards the sustainability challenge of urban structures. In this regard, urban texture has been highlighted as one of the key factors regarding city energy performance (Ratti et al. 2005).

The street canyon has been widely used as a simplified representation of a certain urban layout for energy analysis, especially for those related to radiative phenomena (Nunez & Oke 1977; Oke 1981; Arnfield 1990). Despite the undeniable usefulness of this straightforward concept, the inherent 3D-complexity of real urban morphology should not be overlooked for a better understanding of energy exchanges within the city (Montavon et al. 2004; Robinson 2006).

In contrast to the endless canyon theoretical approach (previously addressed in Garcia-Nevado et al. 2015), this paper focuses precisely on street intersections, distinctive features of any fabric which have so far received little attention in energy studies (Moscoso 2015). Specifically, this study aims to assess the influence of crossings on solar access for a Mediterranean urban environment. To this end, the correlation between the amount of visible sky and direct solar radiation over the facades of street intersections has been explored.

Regarding the effect of crossing, some interesting questions arise: How meaningful is the deviation when considering an endless street instead of a corner position? How far from the corner does the presence of a street junction affect in terms of Sky Factor? How important are the changes in solar radiation availability due to the crossing?

METHOD

The method described in this section is based on a previous work (Garcia-Nevado et al. 2015). Nevertheless, this process has been adapted to take into consideration not only the canyon aspect ratio (W/H, W: street width, H: building height) but also its longitudinal dimension, hereafter referred as the distance from the crossing edge.

To analyse the influence of urban intersections on solar access, the quantity of visible sky and Direct Solar Radiation (kWh/m^2) are chosen as the assessment parameters. The visible sky fraction can be quantified through two distinct geometrical descriptors: sky view factor (SVF) (Oke 1987; Unger 2004) or sky factor (SF) (Beckers 2009; Capeluto 2003). For this study, the Sky Factor has been selected (Hämmerle et al. 2011).

Both, Sky Factor and direct radiation have been accounted on vertical surfaces at different XY positions all over the façade. Specifically, calculation points are located along the midline of each floor level and at an increasing distance from the corner edge, so as to provide a grid with representative values for the façade as a whole.

The workflow comprises three phases which encompass morphological and energy approaches. Firstly, a geometrical analysis of the fabric is developed based on Sky Factor values at the previously specified points.

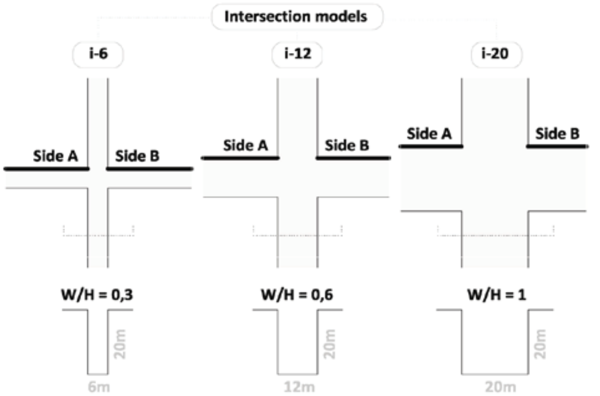

Figure 1: Plan of the three intersection models with the reference facade in bold (at the top). Street Sections of composing each crossing model (at the bottom).

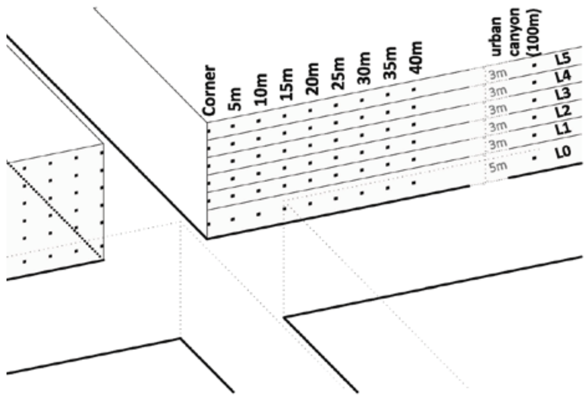

Figure 2: Calculation points on each façade level, increasing its distance from the intersection edge till the middle of a theoretic endless urban canyon.

Secondly, under clear sky conditions, direct solar radiation impinging on the same façade spots is calculated, once the time of the year and the orientation are defined. Finally, both results are correlated one to another for coming to general conclusions related to the intersection impact on solar availability.

Heliodon software, a computer tool able to calculate and visualise both parameters (Beckers & Masset, 2006), has been selected for running all the calculations.

CASE STUDY DESCRIPTION

The extent of "street-crossing effect" has been assessed for a mid-latitude location corresponding to the city of Barcelona (41º 23' N), example of a Mediterranean dense urban environment.

The present case study comprises three intersection models representing urban scenarios with an increasing level of compactness. All the models are created by the crossing of two endless urban canyons with identical dimensions, thereby generating 8 semi-infinite facades (Fig. 1).

In this work, the same façade pattern has been applied to all vertical surfaces within the canyon. It responds to a widely used typology within the city: a 20-meter-high and six-storey building. Hence, the difference on aspect ratio among the models only lies in the gap between the two building arrays. For the three cases here considered, this distance has been fixed in 20m, 12m and 6m, which means, respectively, a distinctive aspect ratio of 1, 0.6 and 0.3 for each model.

For Sky Factor analysis carried out in this study, a 2D grid is defined covering the reference façade from the crossing edge (Fig. 2). Specifically, calculation points are located at the nodes of the matrix obtained by the intersection of horizontal rows at the midline of each floor level (L0-L5) and columns every 5m starting from the corner (0m-40m).

Solar radiation is tested at the same points for the main orientations (N, S, E, W, NE, NW, SE and SW). This paper focuses on Winter Solstice since this time of the year represents the most critical situation regarding solar access, especially within compact fabrics as the studied ones.

RESULTS AND DISCUSSION

The influence of the crossing on the Sky Factor

In an urban intersection context, two phenomena overlap with regard to the amount of visible sky. On one hand, as in any canyon, Sky Factor decreases when lower heights of calculation point are considered. On the other hand, the closer corner is, the higher Sky Factor is observed in comparison with the same floor within the canyon. In any case, Sky Factor will never exceed 0.50 since a point on a façade is not able to "see" more than half the sky vault.

The crossing presence has uneven effects on Sky Factor depending on its morphology, as depicted in Fig. 3 and 4. In absolute values, the proximity to the corner can increase the Sky Factor up to 0.05. Regarding percentage terms, the narrower the canyon crossings are, the more pronounced the Sky Factor rise is at the edge , up to 35%, though this contribution has a smaller horizontal extent (beyond 8m the change is below than 3%). In any model, the effect is not noticeable (<3%) beyond a 20m distance from the corner.

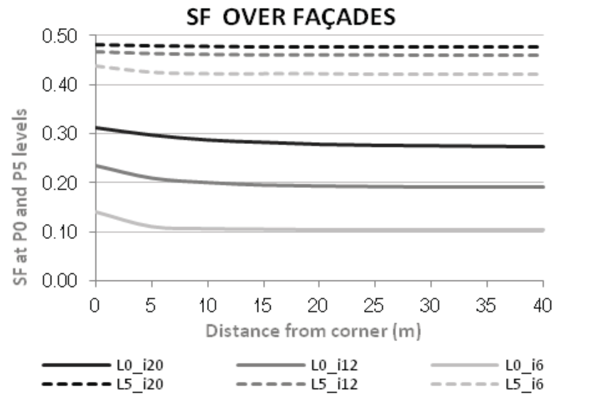

Figure 3: Variation of Sky Factor (SF) values because of the nearness to the corner on Levels 0 and 5 of the three intersection models.

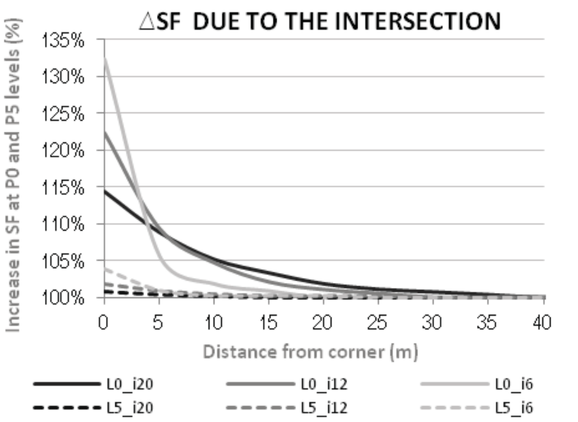

Figure 4: Percentage change in Sky Factor (SF) due to the nearness to the corner compared to the same level within an endless canyon.

The crossing influence on solar access

An overview of the radiation differences due to the proximity to a street crossing is provided by graphs on Fig. 5 on the Winter Solstice. Regarding to solar energy analysis over intersection façades, the side of the crossing (A or B) under assessment needs to be specified since its solar behaviour can vary substantially, as shown below.

For a façade facing South, the crossing introduces an identical change in radiation on both sides of the intersection, as might be expected from the sun path symmetry for this orientation. The most significant radiation rise is accounted in the lower façade levels, with a shift in direct solar energy from 0 (at the endless canyon middle) up to a third of the radiation on the higher floor (at the corner). However, this contribution is strongly related to the distance between the corner and the analysis point, being imperceptible beyond the 20m for all the models.

Unlike a strictly South (or North) façade, different radiation patterns appear on each side of the crossing for other azimuth angles. An antisymmetric radiation behaviour is observed when comparing symmetric facades about the North-South axis; i.e. the same radiation distribution can be found on the A side of a SE façade and on the B side of a SW one. For this reason, W and SW graphs have been omitted from this section, as its behaviour can be inferred from E and SE results respectively.

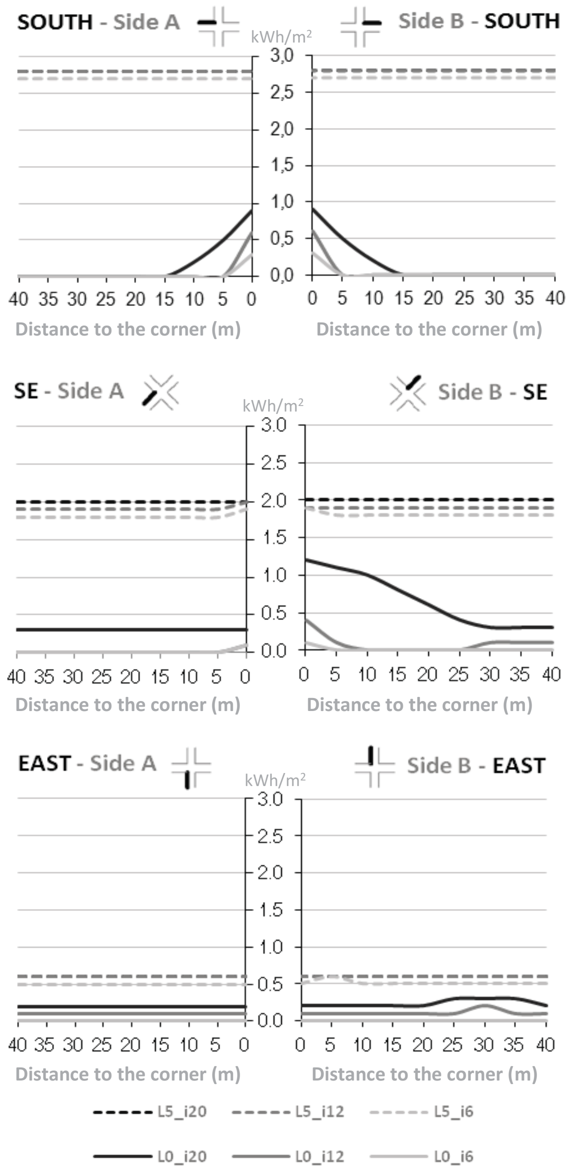

Figure 5: Direct solar radiation over façades (kWh/m²) by distance from the corner on the Winter solstice.

In the case of a SE façade, radiation changes exist on both sides of the intersection, but in different quantity and distribution. Variations on the B side are much more significant (up to 1.3 kWh/m^2 at the corner) and its effects span a higher horizontal range, especially, the wider the model is.

For an East façade, the crossing effect on received radiation is just noticeable on the B side (between 20 and 40 meters away from the corner), whereas the other one maintain the urban canyon profile. Although in absolute terms the maximum corner contribution is about 0.20 kWh/m^2 on the Winter Solstice, in relative terms this change might mean up to a 40% increase on the solar energy available for this period and location.

Correlation between Sky Factor and Solar radiation
The relationship between Sky Factor and direct solar radiation received on the Winter Solstice is depicted in Fig. 6.

Due to the strong link between façade orientation and solar energy availability, inferring the quantity of radiation just from the Sky Factor value might lead to significant deviations. As an example, for several points with the same Sky Factor of 0.48, radiation might vary from 0 to 2.8 kWh/m^2 in the Winter case, depending on the façade azimuth. In general, the higher visible sky fraction is, the greater discrepancies in radiation are found, remarkably beyond a 0.30 Sky Factor.

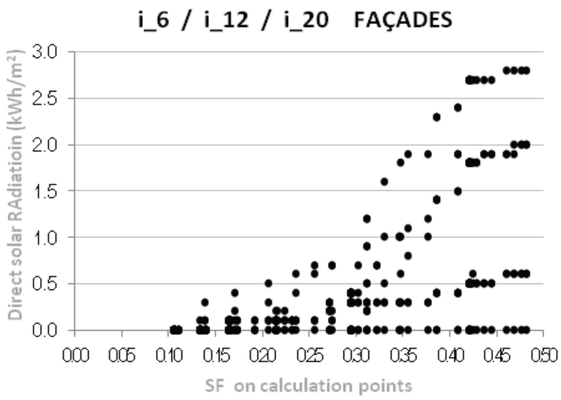

Figure 6: Direct solar radiation (kWh/m^2) by Sky Factor (SF) for the three intersection models and the 8 orientations on Winter solstice.

Nevertheless, if these results are assessed considering the façade orientation, this deviation range can be reduced, as shown in graphs included on Fig. 7.

For S, SE and E orientations, the correlation between Sky Factor and radiation in the Winter period has been plotted in Fig. 6. A distinction between points placed in

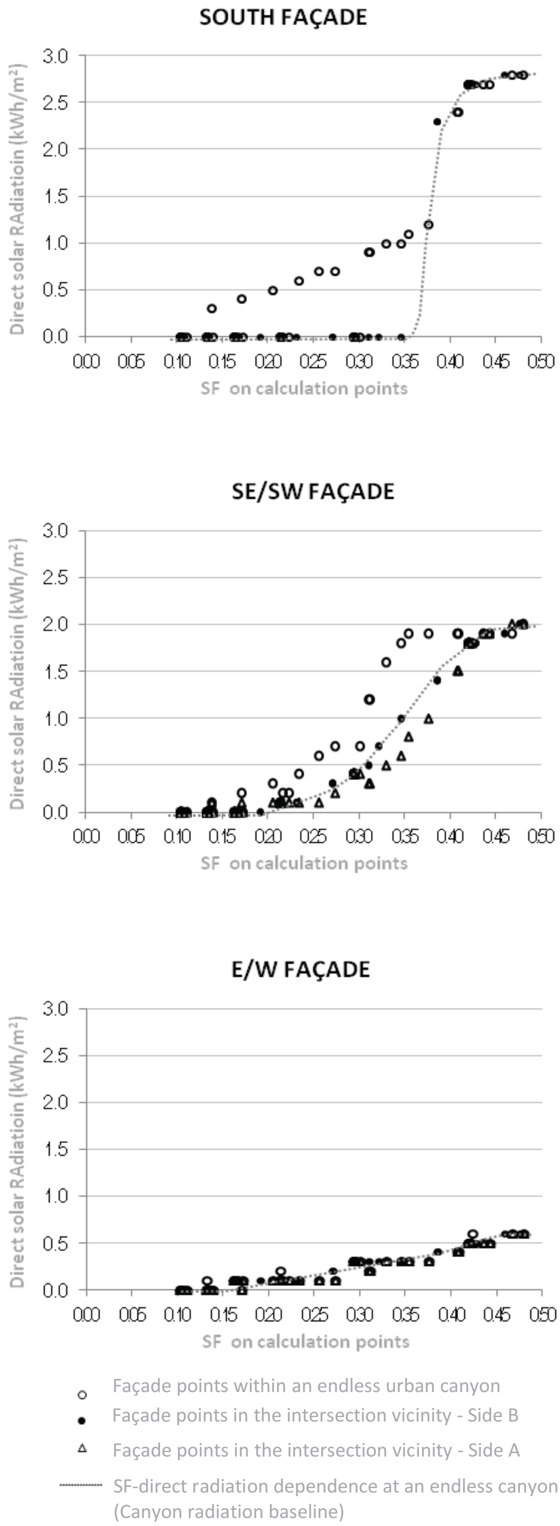

Figure 7: Direct solar radiation (kWh/m^2) by Sky Factor for South, E/W and SE/SW façades of the three intersection models on Winter solstice.

the middle of the canyon or near the intersections is shown. For an endless street, the dependence between Sky Factor and radiation can be approximated with a specific function once the orientation and time of the year are defined: a hyperbolic tangent branch. And this function will be precisely the baseline used to evaluate the deviation in radiation caused by the intersection.

Despite the fact that the corner proximity leads to an unequivocal rise in Sky Factor, this does not always result in an enhancement of direct solar energy availability. Graphically, it means that when the analysed spot approaches the corner, the point in the chart moves either horizontally (>SF) or vertically and horizontally at once (>SF, >radiation). These X or XY displacements explain the dispersion from the canyon baseline.

For a South façade, below the Sky Factor threshold of 0.37, the nearness to an intersection introduces significant radiation differences compared to a centred canyon position. The obstruction reduction allows these points to switch from a totally shaded state to receiving up to a 50% of the maximum radiation available for this orientation. Beyond a Sky Factor of 0.37, the amount of solar radiation remains stable since its maximum has been reached.

Contrasting to a façade facing South, lower disparity in radiation is observed for the remaining orientations on the Winter solstice. For the same Sky Factor:

- In the SE (or SW) case, the canyon baseline represents approximately the average between the radiation received by points on Side A (lower values) and B (higher values).
- Differences between the endless canyon and the intersection on an East (or West) façade are almost negligible.

CONCLUSIONS

In this paper the “crossing effect” on solar access over façades has been addressed from a twofold perspective through a purely morphological parameter (Sky Factor) and an energy-based one (direct solar energy).

On one hand, the intersection presence allows a growing trend in Sky Factor from the canyon towards the corner. This effect is noticeable up to a distance from the edge similar to the street width for uniform street crossings with W/H<1. In absolute terms, Sky Factor increases up to a maximum of 0.05, meaning a rise of 35% in the visible sky fraction.

On the other hand, radiation results for the Winter case show that the crossing effect arrives up to an uneven distance from the corner depending on its orientation and geometry. Noticeable increases have been detected on both intersection sides for a South façade, (up to a distance ≈W, reaching up to the 50% of the radiation on L5) and one side for SE/SW façade (up to a distance ≈1.5W, reaching up to the 100% of the radiation on L5).

Additionally, the deviation due to the nearness to an intersection has been assessed using the correlation SF-radiation for an endless canyon as a baseline. It has been found that for the same Sky Factor, the “crossing effect” ranges from negligible on the E/W facade to considerably significant on the South one (when the Sky Factor is lower than 0.37). For intermediate orientations such as SE/SW ones, there are under and overestimations which self-balance on both sides of the intersection.

Results of this work underline the importance of taking the discontinuities of the urban fabric into account as features capable of enhancing solar access on façades, especially in dense environments. Besides, insights about the extent of the crossing effect provided by this study might contribute to a more efficient discretisation of urban surfaces in solar access analysis, by differentiating areas requiring uneven degrees of calculation detail.

The present work is built upon a purely geometrical approach without any further consideration regarding material properties of urban surfaces (i.e. albedo). Future developments of this study might include these aspects for a more accurate assessment of crossing contribution to solar radiation availability by considering inter-reflections.

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