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CHARACTERIZATION OF SOLAR ACCESS IN MEDITERRANEAN CITIES: ORIENTED SKY FACTOR

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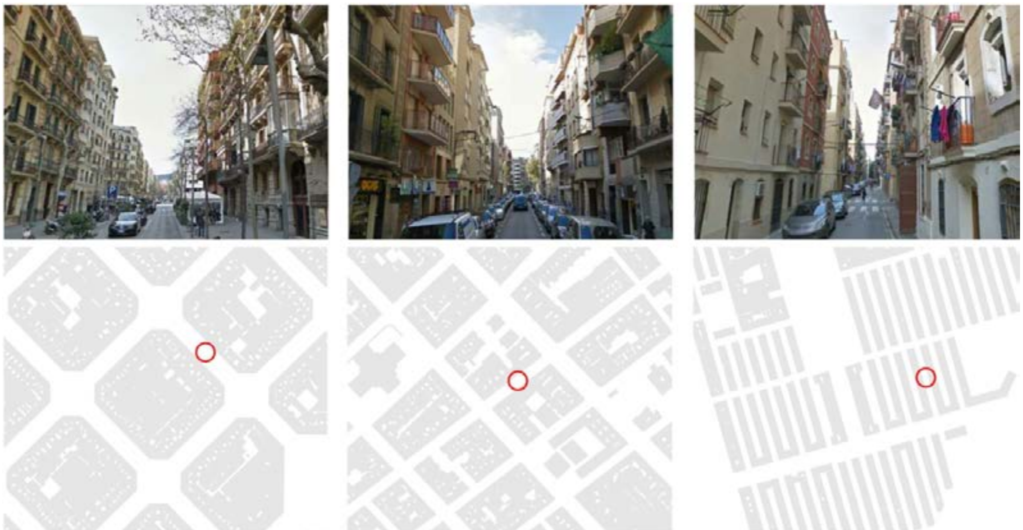

Fig 1: Barcelona urban fabrics. From left to right, basis for typological street models A, B and C

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

Research summary

The link between city morphology and urban energy consumption, although proved, requires further research. In that sense, the analysis of parameters describing the urban texture may be a useful approach for energy assessment at a city scale. Some geometrical parameters have been used to study urban energy aspects related to the radiative phenomena, such as *heat island* or even a rough indicator of solar energy availability in locations where direct radiation is not determining. This paper aims to explore the correlation between one of these parameters -the *Sky Factor* (SF)- and direct solar radiation over facades, as a characterization tool of solar access within an urban context. Barcelona, a Mediterranean city where direct sunlight and the built environment density are deciding factors, has been chosen as case study. At different points of the facade for several urban canyons, SF value and direct solar radiation for different orientations and times of the year have been computed using *Heliodon* software. Both results have been related one to another and it has been found that, for a specific latitude, it is possible to define a smooth dependence between these parameters, if the orientation is taken into account. This paper shows that, beyond the SF threshold of 0.42, direct solar radiation on the facade reaches an almost asymptotic value for all orientations and times of the year.

Keywords: Sky Factor, Solar Radiation, Urban morphology, Mediterranean environment

1. Introduction

Cities are responsible for about two thirds of the total global energy consumption and greenhouse gas emissions worldwide. In the current context of ecological crisis, improving the understanding of their energy performance should be a main environmental concern.
Urban morphology has been highlighted as one of the significant factors regarding the energy behaviour of cities (Ewing, 2010; Ratti et al., 2005; Steemers, 2003). Unfortunately, no "standard recipe" exists for a sustainable urban layout and this subject requires further research based on local features. The discussion about urban compactness, which is a widely accepted strategy for sustainable developments, and the needed solar gains in passive design may be a recurrent example of this complex balance (Gordon & Richardson, 1997; Neuman, 2005).
Parameters characterizing the urban geometry can be useful tools to describe how energy exchanges happen within a built environment. Nevertheless, more research in this regard is needed in order to analyse accurately the energy demand of urban patterns.
Some features of city morphology can be explained through the analysis of the visible sky fraction seen by urban surfaces. This geometrical approach has been intensely used in urban research and planning due to its strong relationship with radiation balance of a particular location and, accordingly, to its energy budget (Johnson & Watson, 1984; Oke, 1987). Several of these applications have been the study of heat island intensity (Unger, 2004), daylighting possibilities (Cheung & Chung, 2005) or even, as a rough indicator of the solar energy received by the urban surfaces in some locations where direct radiation is not determining (Robinson, 2006). However, the assesment of solar potencial based just on the portion of visible sky is not accurate enough in locations where direct radiation is a deciding factor, as Mediterranean cities.
The amount of visible sky at a particular urban spot is calculated using several techniques (Gál et al., 2008; Matuschek & Matzarakis, 2010; Matzarakis et al., 2010; Watson et al, 1987). This geometrical concept has been assessed through two dimensionless parameters, *sky view factor* (SVF) and *sky factor* (SF) (Beckers, 2009; Capeluto et al, 2006). The difference between them lies on the way of weighting sky depending on their zenith angle, resulting in the presence or absence of a cosine weighting factor respectively (Hämmerle et al., 2011; Szegediensis, 2011).
The aim of the present contribution is to characterize Mediterranean urban canyons through exploring the relationship between the *Sky Factor* (SF) and direct radiation over facades, as an indicator of solar access in a dense built environment (Beckers, 2013).

3. Method

Two parameters have been taken into consideration in this research: *Sky Factor* (SF) and direct solar radiation. All the calculations are conducted using Heliodon software, a computer application suitable for calculating and visualizing both of them (Beckers & Masset, 2006).
Regarding solar radiation, this computer tool runs its calculations taking into account clear sky conditions and only considering the direct component.
Both parameters will be accounted on vertical surfaces of an urban canyon at different heights. In this study, the midpoints of each floor facade are assessed and only the obstructions of an endless street have been considered.

On the previously specified points, direct solar radiation impinging on the facade (kWh/m^2) will be calculated for particular days and different orientations.
Finally, both results will be related one to another appropriately for drawing exportable conclusions.

4. Case study description

To study the correlation between SF and direct solar radiation, Barcelona (41^o 23$'$ N), an example of Mediterranean compact city, has been chosen as location for the present work.
The study case comprises three street models defined as a typological simplification of real canyons, which are selected according to an increasing level of urban density (Fig 1).
Geometrical configuration of the three models is depicted in Fig 2. Based on the Eixample District, model A consists of a 20-meters wide street with 20 meters height, i.e., a width-to-height ratio of 1. In the two other models, B and C, the height remains unchanged while the width decreases to 12 and 6 meters respectively, thereby generating more critical scenarios regarding to solar access.
The 20 meters height of the building models a standard six-storey building with five regular floors and a commercial ground floor.
Along a vertical column of the facade, at midpoint of each level, six points of calculation (P0-P6) have been defined for accounting SF. Solar radiation has been tested on the same points of each model for the main eight orientations (N, S, E/W, NE/NW, SE/SW) and on solstice days.

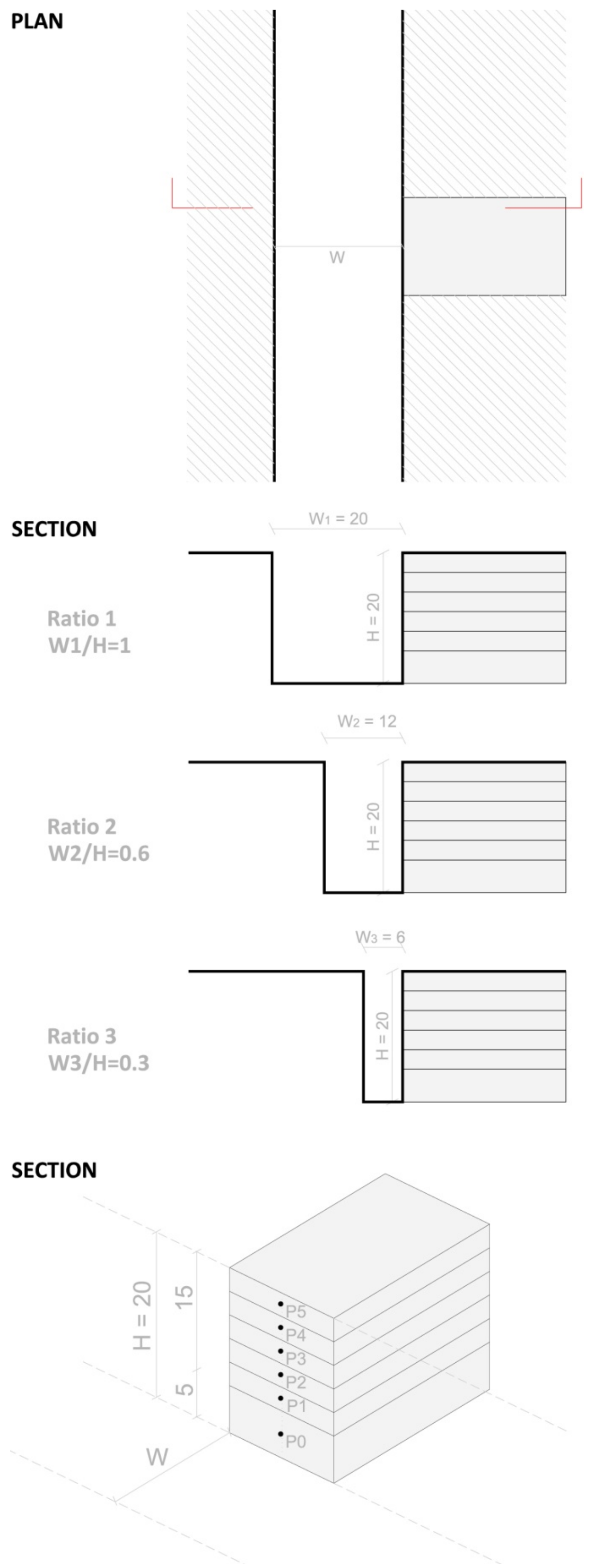

Fig 2: Urban canyon model; Points (P0-P5) for SF and direct solar radiation calculations

5. Results and discussion

5.1. Sky Factor over facades

As all the analyzed spots belong to facades, the highest possible SF value is 0.50 (a point on vertical plane just can see a half of sky vault). Inside the urban canyon model, the lower height of the calculation point, the lower SF is accounted, reaching values of 0.10 (Table 1).

SF value is a geometrical issue, just dependent on the relative position between the calculation point and the obstacles which prevent it from seeing the sky. Therefore, the same "sky view situation" appears in streets with different aspect ratios, just modifying the height. For instance, the midpoint of the 4^{td} floor in a canyon with 0,3 aspect ratio (i.e., model C-P4), sees almost the same sky fraction (0,30) that a spot located at the ground level of a street with a ratio of 1 (i.e., model A-P0).

5.2. Solar radiation

Regarding to solar radiation, not only the street geometry but also orientation combined with time of the year are determining parameters, as shown Table 2 and 3.

Winter maximum value of solar radiation is reached in the south facade and rises up to 2,73 kWh/m^2, whereas in summer case, this maximum is located in east and west facade with 2,70 kWh/m^2.

Energy consequences of considering deeper points within the canyon are more significant the narrower the street and the lower the sun elevation are. In summer solstice, maximum differences between the highest and lowest floor can be founded in NE/NW and E/O orientations. In winter, this effect is further accentuated by lower sun positions and the most extrem changes shift towards S and SE/SW orientations, passing from a partially sunlit floor facade to a completely shaded one.

5.3. Correlation between SF and Radiation

Figures 3 and 4 show the relationship between the sky fraction seen by the selected facade points and the direct solar radiation which is received on the solstice days.

Point	Height	Model A W/H = 1	Model B W/H = 0.6	Model C W/H = 0.3
P5	18,50	0,48	0,46	0,42
P4	15,50	0,44	0,39	0,30
P3	12,50	0,40	0,32	0,22
P2	9,50	0,37	0,27	0,17
P1	6,50	0,34	0,23	0,13
P0	2,50	0,30	0,19	0,11

Table 1: SF at calculation points of facades

Model		Direct Solar Radiation on June 21 (kWh/m^2)				
		N	NE/NW	E / W	SE/SW	S
A W/H=1	P5	0,43	1,67	2,70	2,40	1,47
	P4	0,43	1,63	2,67	2,40	1,47
	P3	0,40	1,50	2,47	2,40	1,47
	P2	0,40	1.33	2,23	2,37	1,47
	P1	0,37	1,17	1,97	2,37	1,47
	P0	0,37	1,00	1,53	2,23	1,47
B W/H=0.6	P5	0,43	1,63	2,70	2,40	1,47
	P4	0,40	1,43	2,33	2,40	1,47
	P3	0,37	1,10	1,80	2,33	1,47
	P2	0,30	0,83	1,37	2,00	1,47
	P1	0,23	0,67	0.93	1,60	1,47
	P0	0,20	0,47	0,67	1,13	1,47
C W/H=0.3	P5	0,43	1,57	2,60	2,40	1,47
	P4	0,33	0,97	1,50	2,20	1,47
	P3	0,23	0,57	0,80	1,40	1,47
	P2	0,20	0.37	0,50	0,80	1,47
	P1	0,13	0,23	0,33	0,50	1,47
	P0	0,10	0,17	0,17	0,33	1,47

Table 2: Direct solar radiation on summer solstice day (kWh/m^2)

Model		Direct Solar Radiation on Dec. 21 (kWh/m^2)				
		N	NE/NW	E / W	SE/SW	S
A W/H=1	P5	0,00	0,00	0,57	1,93	2,73
	P4	0,00	0,00	0,53	1,87	2,70
	P3	0,00	0,00	0,47	1,63	2,50
	P2	0,00	0,00	0,40	1,20	1,43
	P1	0,00	0,00	0,30	0,80	0,00
	P0	0,00	0,00	0,23	0,47	0,00
B W/H=0.6	P5	0,00	0,00	0,57	1,93	2,73
	P4	0,00	0,00	0,47	1,43	2,17
	P3	0,00	0,00	0,30	0,67	0,00
	P2	0,00	0,00	0,20	0,27	0,00
	P1	0,00	0,00	0,13	0,10	0,00
	P0	0,00	0,00	0,10	0,03	0,00
C W/H=0.3	P5	0,00	0,00	0,50	1,73	2,67
	P4	0,00	0,00	0,23	0,40	0,00
	P3	0,00	0,00	0,10	0,07	0,00
	P2	0,00	0,00	0,07	0.03	0,00
	P1	0,00	0,00	0,03	0,00	0,00
	P0	0,00	0,00	0,03	0,00	0,00

Table 3: Direct solar radiation on winter solstice day (kWh/m^2)

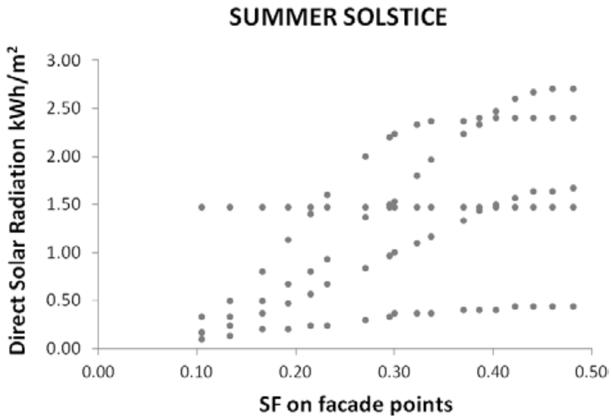

Fig 3: Direct solar radiation (kWh/m^2) by *Sky Factor* in summer solstice

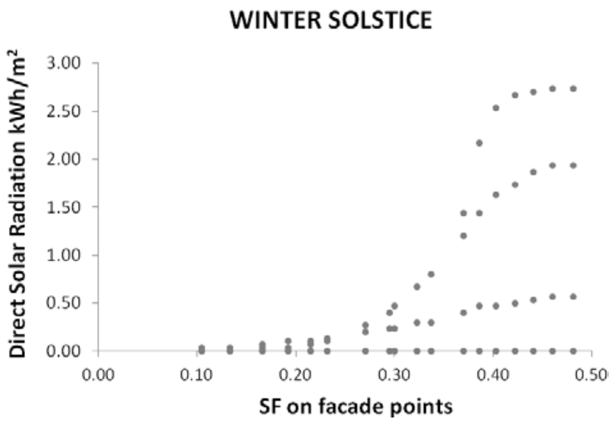

Fig 4: Direct solar radiation (kWh/m^2) by *Sky Factor* in winter solstice

As expected, meaningful solar radiation differences are accounted for equals SF, due to the strong dependence between the solar energy and the facade orientation. Therefore, predicting direct solar radiation from SF without further consideration, can lead to significant under and overestimations between the average values and the calculated ones.

However, a deeper analysis by classifying the outcomes according to orientation may be more revealing, as shown below. Figures 5 and 6 reflect a dependence between SF and direct radiation, which can be approximated as a branch of hyperbolic tangent function.

Variations in SF due to the urban canyon obstructions have uneven impacts over solar access depending on the time and orientation. This fact is evident from the sharp change in winter radiation over the south facade - detected around a SF value of 0,37- contrasting to the more gradual trends for other orientations.

In addition, it can be observed that, the amount of incident solar radiation remains stable beyond a specific SF threshold, for each orientation and time of the year. This value marks the height limit above which the partially shaded facade fraction turns into a completely sunlit surface, not being affected by the cast shadows of its built environment. At any time of the year and orientation, direct solar radiation approaches an almost asymptotic value (deviation <5%) beyond a 0,42 SF value.

Concerning the winter case, two aspects should be highlighted regarding the link between solar radiation and SF for the case study. On one hand, almost negligible direct solar energy is received below a SF value of 0,23 for all the orientations. Therefore, this 23% of SF should be considered as the minimum amount of visible sky needed to have quantifiable solar loads in winter case. On the other hand, it is remarkable that, within the SF span between 0,23 and 0,37, no solar radiation impinges on a south facade yet, whereas those orientated to east, west, south-east and south-west already receive a small fraction, even considering an endless street canyon.

These results show that, although the maximum winter solar potential is traditionally associated to an unobstructed south facade, other urban layouts are more suitable regarding solar gains in narrower environments, characterized by facades with SF values lower than 0,37.

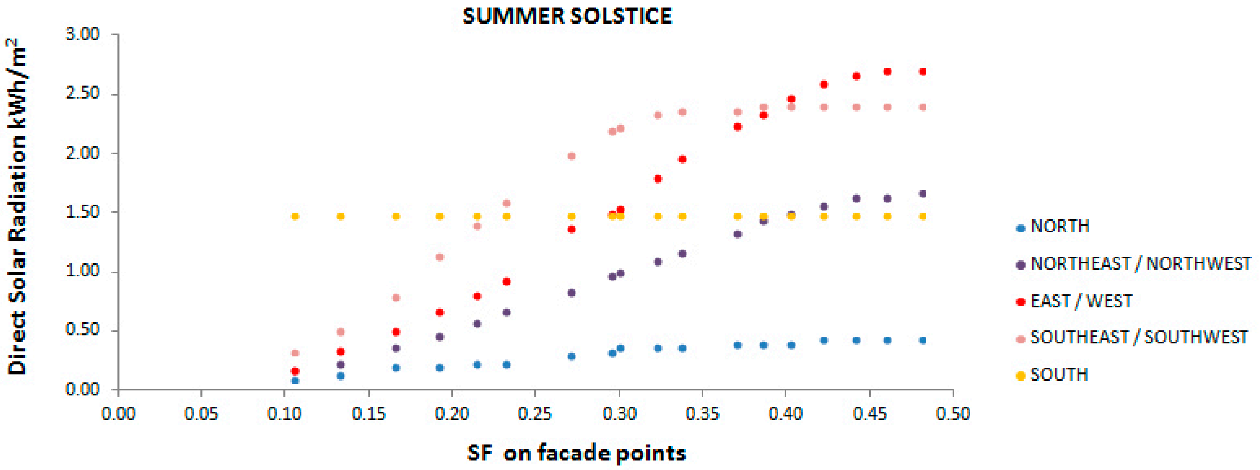

Fig 5: Direct solar radiation (kWh/m^2) by *Sky Factor* and orientation in summer solstice

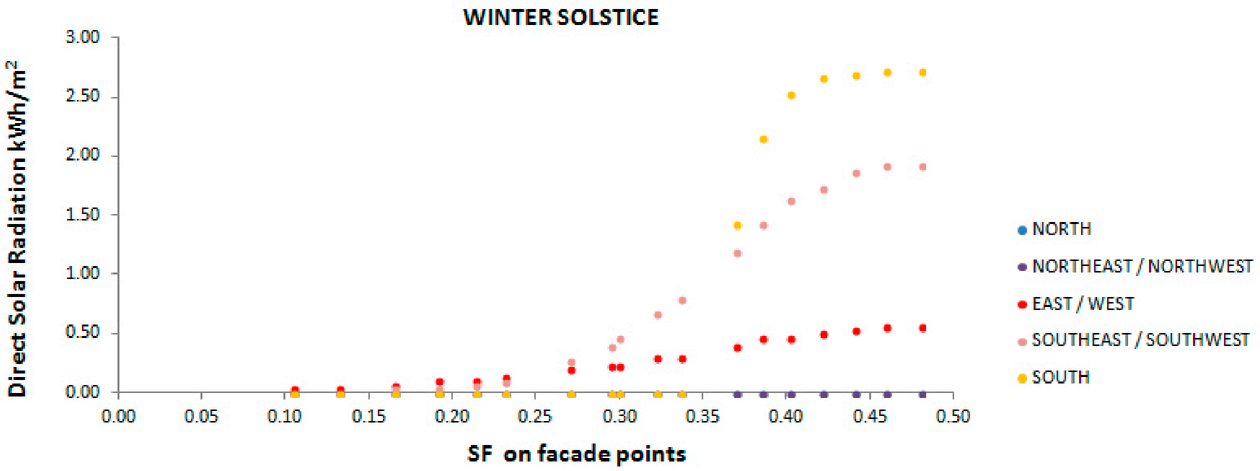

Fig 6: Fig 4: Direct solar radiation (kWh/m^2) by *Sky Factor* and orientation in winter solstice

6. Conclusions

This paper shows that it is possible to characterize solar access in Mediterranean urban canyons considering an *Oriented Sky Factor*.

This research demonstrates that both relative height over the street and width-to-height ratio (W/H) are not significant parameters to estimate solar radiation if they are analysed separately. On the contrary, the SF value, whose calculation implies these two former concepts jointly, can be used as an accurate indicator of direct radiation over facades once the orientation is settled.

The results of this work show that, for a given latitude, it is possible to find a smooth dependence between SF and direct incident radiation taking into account the orientation of the urban canyon facade.

This relationship can be approximated as a branch of hyperbolic tangent function. A meaningful SF threshold (about 0,42) is detected beyond the impinging direct radiation shows an asymptotic trend for all orientations and time of the year.

This approach can provide a better understanding of the urban energy behaviour, a necessary step towards a sustainable and resilient city.

7. Acknowledgments

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