Assessment of Solar Access in different urban space configurations in two southern latitude cities with mild climates.

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ABSTRACT
One of the characteristics of passive low energy architecture is the dependence of its facades on solar access. However this aspect is little considered by law or in the practice of real estate development. On the one hand, urban space configurations such as streets are defined in planning guidance by law to safeguard the common good, but on the other, real estate activity puts pressures on land and creates large buildings occupying maximum plot ratio. This is particularly the case in developing societies and emerging economies. One of the direct effects of this process is solar obstructions on the urban space, i.e. facades, ground and sky. This means that indirect passive low energy opportunities which affect the possibility to capture energy for passive or active systems are lost with new high-rise developments creating unequitable environments. Therefore, the design of urban space which considers solar access to facades becomes an important issue as a means to avoid these problems.

This paper seeks to explore designs which permit solar access within the context of urban practice which permits large building volumes. Here different street configurations are examined to evaluate to what extend it is possible to balance solar access and plot ratio criteria in planning guidelines. This investigation examines four urban space configurations from lower to higher density to discover the range in which both criteria present compatibility. Two cities located at two different latitudes are compared to assess solar irradiation availability on the surfaces of facades, the ground, the roof and the urban space. A simulation was carried out on winter and summer solstice with 2 urban orientations: east-west and north-south axis. Results show an inflexion point in the curve of irradiance according to geometrical profile. These findings help to orientate planning guidelines in the consideration of passive low energy architecture to promote a more sustainable habitat in developing societies.

INTRODUCTION
Contemporary cities in the context of emerging economies tend to experience growth both outwards on the periphery and upwards in high density central areas with planning guidelines trying to control development. Whether in horizontal or vertical expansion the built environment is shaped by economic forces that try to maximize plot ratio and building floor-space. One of the effects of these developments are towering high rise blocks which shadowed streets and surroundings impacting on solar access for urban spaces, facades and buildings in cities as shown in Figure 1.

On the other hand the Chilean urban regulations try to order urban morphology and spatial arrangements through morphological constraints such as; distance to boundary (“rasante”), plot ratio,
built floor coefficient, shadows above plot, amongst others. These parameters are useful to shape urban form for individual buildings on a single plot but not necessarily achieve a coherent morphology at city-block level. The emphasis on individual buildings in the urban regulations results in the poor design of three dimensional spatial surroundings. Regulations determine parameters which are concerned with architectural built form which theoretically allow the access of sunlight but in practice shadows are really only taken into account as a spatial limit to the height of buildings rather than any concern for energy use in passive and low energy architecture.

Figure 1 (a) dark street from shadowing and high rise buildings and (b) panoramic view of Santiago city to the East side.

Nonetheless, from a solar perspective planning guidance should consider the shading effects of buildings on their surroundings because this has an impact on the opportunity of daylighting and passive or active heating. Equity is put at risk when solar obstructions from high buildings fall on a neighborhood regardless of a minimum solar access to sunlight or daylight. The question is how to protect solar resources for every neighbour within cities? This is particularly important in cities which belong to the world’s ‘sun belt’ which have extremely high irradiance and opportunities to benefit from this resource, such as in the case of Chilean cities. As an example the southern German city of Freiburg is known as the “solar city” with enormous solar PV cells and solar thermal investment integrated to the architecture. It is located at latitude 45°N which is considerably further north and therefore receives less radiation, than Chile’s southerly cities, for example Puerto Montt at latitude 41°S. Therefore there is enough radiation to justify exploring solar options in Chilean cities not only in the north but also in the southern territory. Therefore it is argued that urban planning instruments should recognise the potential of solar access throughout the whole of Chile whilst considering the different contexts which may create different opportunities.

International institutions have stated that traditional approaches to urban planning have failed to promote equitable, efficient and sustainable human settlements for addressing twenty first century cities in developing countries (UNHS, 2009). However, there are many authors studying specific issue such as solar access on buildings and cities to deal with energy and spatial conditions to save urban morphology. (Capeluto, 2001; Košir et al., 2014; Lau et al., 2011; Benoit, 2012)

The general objective of this paper is to explore urban design which allows solar access within the context of urban development which permits large building volumes regardless of energy capture on urban surroundings. Cross-section of streets with different configurations (width/height ratio) are examined to evaluate to what extend it is possible to balance solar access and plot ratio criteria in urban planning guidelines.

Amado et al (2013) state that solar urban planning is a complex process that requires interplay between many factors related to urban form and solar energy inputs. The authors use a parametric approach to quantify solar energy from photovoltaic systems in the urban context (Amado, 2013). They argue that solar power plays a strategic role in improving the energy efficiency of cities because it could be used to generate clean energy for consumption and perhaps match demand. Both these functions are key indicators to understand the balance of energy performance in city neighbourhoods.

In the city of Oeiras, Portugal, an algorithm has been developed to estimate the annual energy production for PV systems. This has been applied to specific urban configurations such as the cellular unit called the “warped parallel”. Three factors were used to classify the city into different cellular units;
year/period of construction, population density and representative morphological patterns. The element of ‘roof surface’ was the mean element used to study the PV solar electricity potential. Here they compared energy demand and solar supply in the urban system with existing typologies of building block and street pattern. This appears to be a useful tool for consolidated urban areas but the question arises as how to plan the future urban configuration with a huge diverse morphological pattern.

With this in mind, we propose that a simple cross section analysis might support planning guidance in the future to control height of buildings considering both interests of maximizing urban densities and providing solar access to neighbouring buildings.

Current controls and guidance on urban morphology include “Site Layout Planning” of the Building Research Establishment (BRE) of Great Britain which has been in use since 1991 (Littlefair, 2011). This document advocates access to skylight and sunlight because these contribute to building energy efficiency. Daylight will reduce the need for electric light, while solar gain can help meet heating requirements in winter.

Additionally ‘Development Advice Notes’ exist at local municipal level in the UK to help applicants in submitting their planning applications. For example, Stirling Council in Scotland has produced a document to give general advice on daylight, sunlight and privacy on new development or extensions. Here they look for a balance between expectations of the homeowners and the effect of that development on the locality. The discretion of the Council is relevant to give permission for any changes in the built environment and daylight in this case is a guiding principle rather than sunlight.

These guidelines are set out to minimize the overshadowing of neighbouring properties for the majority of the day where the design should confine shadow projection to the applicant’s own land. The factors considered in the design are height, distance to boundary, size of plot, orientation and topography on plan. A “degree approach” refers to the angle allows daylight at the “centre of the closest ground floor habitable room window of neighbouring properties” (Stirling Council, 2002).

Finally, urban canyon has been analyzed as an element used to characterize the street in relation to the climate, meteorology and urban design by many authors (Oke, 1986; Mills, 1993; Pearlmutter et al., 1999; Venegas y Maceo, 2012; Andreou, 2014; Botillo et al., 2014). In this paper urban canyon was chosen to create a conceptual model for studying available solar direct radiation.

**RESEARCH METHODOLOGY**

In order to analyse effects of different urban configurations on solar access a parametric approach was applied. To achieve this objective a digital model was constructed considering a typical cross section of a street found in central areas of the city as shown in **Figure 2**. Two parameters were tested: irradiation (Wh/m²) and ratio height/width (1:1, 1:3, 1:5, and 1:7) where the heights of buildings were changed while maintaining a constant street width as shown in **Figure 3** for each city and **Table 1**. This model was chosen because it represents urban spatial configuration that involves a topological relationship between facades and urban space. This means that analysis is not only of single buildings, as is traditional, but of two buildings which interact with the urban spaces and hence the human habitat.

**Figure 2** A cross section model of urban street canyon
Table 1. Parameters of the model based on Cross section of streets

<table>
<thead>
<tr>
<th>ID</th>
<th>Width of street between official line</th>
<th>Height of building (N° of floor)</th>
<th>Proportion of urban space (W/H)</th>
<th>Factor of constructibility (ratio: floor surface / site surface)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>11</td>
<td>4</td>
<td>1:1</td>
<td>0.99</td>
</tr>
<tr>
<td>B</td>
<td>11</td>
<td>12</td>
<td>3:1</td>
<td>1.98</td>
</tr>
<tr>
<td>C</td>
<td>11</td>
<td>20</td>
<td>5:1</td>
<td>3.96</td>
</tr>
<tr>
<td>D</td>
<td>11</td>
<td>28</td>
<td>7:1</td>
<td>7.92</td>
</tr>
</tbody>
</table>

Two cities which have witnessed rapid growth and urbanization located in different latitudes and climates were selected to examine incident radiation on facades and urban space. To achieve this, the same cross section model was analyzed to compare how spatial configuration works in different climates. Four configurations were chosen according to proportion of urban space and two street axis orientations: North-South and East-West. The criterion for urban spatial configuration was a growing density from a lower to a higher extent to discover the range in which both objectives present compatibility: solar access and density. The questions were; To what extend it is possible to raise the height of buildings and have available solar radiation? and, How to balance both objectives to get a maximum solar energy on facades and a maximum high rise buildings?

Figure 3  Urban spatial configuration proposed for analyses pointing out solstice angle.
Table 2. Simulated value of solar incidence on facades and urban space in two cities: Puerto Montt and Santiago as a daily average on solstices: 21Jun and 21 Dic.

![Table 2](image)

RESULTS AND CONCLUSIONS

First of all energy simulation has carried out by using Heliodon™ software to measure irradiation on facades and urban space assembled on two axis: North-South (N-S) and East-West (E-W). Total direct radiation incidence on both facades in front of the urban canyon was calculated which was divided by available surface on building in square meters to give the average energy. Masking has been

![Figure 4](image)
considered in calculations during one whole day: summer and winter solstice, as shown in Figure 4. The same method was used for ground as horizontal data and all those values were registered in Table 2. In Figure 5 the chart shows curves energy performance according to proportion of street expressed through ratio H/W (height/width) such as 1:1, 3:1, 5:1, and 7:1.

Figure 5. Solar irradiation available on facades and urban space considering mask from buildings in front during solstice and growing density.

Results from Figure 5 show an inflexion point of facades curve at 3:1 proportion of the canyon in both cities of Santiago and Puerto Montt. After that radiation curves continue to slowly descend as density increases (higher buildings). Energy available on facades also changes according to the orientation of street axis and climate. If direct radiation is compared between the two cities the maximum values are observed in East-West facades during summer solstice (21 Dec). Similar values are observed in East-West facades during winter solstice as well (21 Jun). However values (kWh/m²) in North-South facades present differences in both cities whether summer or winter solstice. For instance, Puerto Montt registers almost twice the amount of solar energy values in summer and same situation as in Santiago but in winter. A conclusion might be that North-South facades within an urban canyon are relevant to assembled grid on urban design project and hence planning guidance.

In Figure 5 (a) it is also observed that the proportion of urban canyon becomes another relevant parameter for similar values. Given 3:1 in winter solstice in Santiago city is of a similar energy value to 1:1 in winter solstice in Puerto Montt city. So a conclusion for planning guidance is high rise buildings should be allowed in latitude closer to the equator (Santiago) rather than far from them (Puerto Montt). If the width of street is enlarged it would capture solar energy. A balance between solar gains in front urban facades is possible when a proportional magnitude of streets is managed by town planners at local government level.

Following this conclusion it is relevant to find out that some different orientations and different solstices in the same city of Santiago deliver equivalent solar direct radiation on facades. Values obtained from East West facades in winter are equivalent to North-South facades in summer solstice. By contrast, in the city of Puerto Montt different orientation in the same climate delivers equivalent values. Therefore a conclusion is that each city has equivalent values combining orientation of the street and weather (solstice). These findings might be useful for urban planning guidance which wants to consider solar energy as input for the architectural envelope in the urban context rather limited to the isolated
conditions of laboratory simulation.

In Figure 5 (b) solar irradiation on urban spaces presents a higher value in Santiago than in Puerto Montt as expected, at the summer solstice there is a 1 kWh/m² difference in value. However values tend to be similar when approaching winter with a similar curve at the solstice of June 21th. An inflexion point occurred at the 3:1 proportion of urban space in both cities. The north-south axis presents more dispersion in respect to the east-west. The proportion of 7:1 in Santiago is equivalent to 3:1 in Puerto Montt therefore high-rise building might be managed to have a similar potential of solar access.

Finally a comparison of irradiation performance on facades and ground surface regarding the proportion of urban space has been analysed with simulation modeling. Solar energy performance changes significantly if facades or ground surfaces are analyzed considering masking. A balance between both initial objectives, highlighted at the beginning as solar access and urban density, is possible to achieve when analysing values from simulation as this paper demonstrated. Decision making might be taken by local planners through physical parameters such as proportion of street canyon. It is interesting to discover that similar solar energy values can be obtained depending on the height of buildings in two cities with different latitudes. More specifically, it is possible to manage the proportion of urban space through finding out the relationship between ground width and building height. These parameters would help urban design and planning guidance at local government.

To evaluate more complex changes in building geometry the model is rebuilt with different heights for both cities during the day of least favorable solar radiation, the Winter solstice (June 21). In this new arrangement buildings of different heights are placed on land plots as an alternative to the continuous urban canyon and this time varying the width of the street. Figure 6 shows a simulation of solar flux intensity (kWh/m²) falling on the façade of a building on a street of 20m (top) and 30m (bottom). An inverse relationship was discovered; as the width of the street becomes greater the direct solar radiation available on the north façade facing a solar obstruction is slightly lower for Santiago. However the model for Puerto Montt shows a direct relationship; as the width of the street increases the direct solar radiation available on the north façade increases. Since Puerto Montt is at a lower latitude than Santiago it could be inferred that in high latitude cities, increasing the width of the street optimizes solar energy in northern facades, but in cities of a lower latitude this spatial parameter works the opposite way.
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REFERENCES