# Solar Energy Potential of Low Density Urban Zones in Mendoza's Metropolitan Area

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ABSTRACT: The study of the solar potential of urban buildings in the temperate arid zones of central-western Argentina, contributes to the knowledge required to optimize the interrelationship between urban habitat and energy efficiency, aiming at attaining a more sustainable urban development in the near future.
The main purpose of the study is to assess the solar potential of low-density urban environments, deepening the knowledge on the relationship between urban morphological indicators and the availability of solar energy for space heating, domestic water heating and eventually, in situ PV generation.
The typical low density gridiron tissues of Mendoza's Metropolitan Area (MMA) have been evaluated through the analysis of 32 sample units (city blocks). Low-density urban environments represent more than 90% of the total built-up area of the city.
The results obtained include: useful insolation of potentially collecting surfaces and the masking due to neighboring buildings and urban trees, in public and private open spaces.
From these results, several quantitative indicators have been drawn relating morphological features and potential solar energy use, thus contributing valuable information for the advance of energy management in urban design and planning.

Keywords: Urban morphology, Useful insolation. Building morphology.

## 1. INTRODUCTION

The complex problematic of urban development includes the environmental damage caused by the city's uncontrolled growth, and by the conventional energy consumption that does not take into account the consequent environmental degradation, drifting progressively away from the sustainability paradigm.

The urban morphology poses important limitations, physical, economical and legally viable, to most design alternatives. They must be clearly defined to minimize energy waste and maximize the potential use of renewable energies, mainly solar radiation in urban buildings, considering active and passive space heating, domestic water heating and eventually "in situ" PV generation. [1] [2]

The transition towards a more sustainable urban energy system will be imperative in mid terms. It is therefore essential to broaden the knowledge on the subject, arriving at conclusions, useful to develop proposals, aimed at improving energy efficiency by maximizing solar access in the urban environment.[3]

Mendoza's Metropolitan Area (MMA), on the dry lands of western Argentina, has been chosen as case study. It is settled on the western edge of a man-made agricultural oasis; its population is close to a million and its geographical coordinates are: latitude –32.88, longitude 68.85 and altitude 827m.a.s.l. Its main climate data are: yearly hours, in comfort: 21.5%; heating needed: 70%; cooling needed: 8.5%; heating DD (B 18°C) 1384, cooling DD (B 23°C) 163; yearly mean global solar radiation: 18.06 MJ/m2 day.

## 2. METHODOLOGY

The low density built-up areas in MMA are those of greater extension: over 90% of the city's total area.

The potential use of solar energy, conditioned by the formal and spatial configuration of typical city-blocks was assessed, being the aim of the study the future implementation of planning and design strategies to maximize solar energy use in urban buildings, either new constructions or the recycling of existing ones. [4] [5]

In order to perform such assessment, a set of urban and building variables was defined. They are:

Urban variables: shape and orientation of city blocks, urban canyon's width, and incidence of urban trees.

Building variables: building's morphology, soil occupation and building density.

In order to analyze the influence of each variable on the city-blocks solar potential, similar urban scenarios featuring significant differences of the single variable under study were comparatively assessed. The sample selection criteria for the definition of each scenario was a function of the nature of the analyzed variable.

2.1 Definition of the solar potential indicators.

For the analysis, two morphological indicators were defined: 1. the Effective Insolation of Potentially Collecting Areas for space heating (north facing façades) $EIA_{n..w.}$, and water heating (horizontal projection of roofs) $EIA_{h.r.}$; defined as the ratio of the sum of hourly insolated areas to the sum of the total hourly potentially collecting areas in the city block ($m^2$), expressed as percentage:

$$EIA_{n.w.} = \frac{\sum_{21Set.-14:30hs}^{21Apr.-9:30hs} \text{Insolated areas of north facing walls } (m^2)}{\sum_{21Set.-14:30hs}^{21Apr.-9:30hs} \text{Total areas of potential insolation: north walls } (m^2)} \times 100$$

2. the Effective Volumetric insolation of Potentially Collecting Areas ($EVIA_{n.w}$) i.e. the ratio between the sum of effectively insolated areas of north facing walls and the horizontal projection of roofs ($EVIA_{h.r.}$) in $m^2$, to the sum of built volumes in the city-block ($m^3$).

$$EVIA_{n.w.} = \frac{\sum_{21Set.-14:30hs}^{21Apr.-9:30hs} \text{Insolated areas of north facing façades } (m^2)}{\sum \text{Building volumes } (m^2)}$$

The second indicator accomplishes the purpose of relating the effectively insolated areas to the total built-up volumes to be hourly heated or served, providing provisional information on the quantitative relationship between collector areas and building volumes.

In this paper, the accent will be placed on insolated façades, since the calculation procedure for insolated horizontal roofs is totally similar and there is a more significant compromise to the building design in the first case.

In a further stage, adjustments should be made to consider the fact that the energy contents of the solar radiation are different at any time (month and hour) of the season under study.

2.2 Selection of representative cases

The selection of a 32 unit low density city blocks sample group was performed from cartographic information, maps, and aerophotogrammetries, provided by the province's Cadastral Office. The information was complemented by "in situ" surveys when necessary. [6]

The study begun with the determination of environmentally homogeneous sectors, based on their morphological features, particularly those with influence on solar access.

The geometric shape (length- width relationship) of 4 city- block typologies (Fig.1) representing 82% of the urban tissue, was evaluated. Besides, a map of MMA, identifying zones with different block orientations was produced.

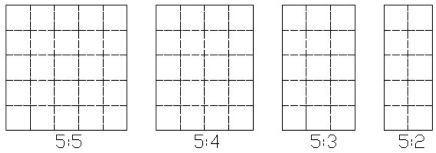



**Figure 1**: City blocks typologies.

In the city-blocks morphological analysis, two major types of residential low-density neighborhoods were identified: 1. individual houses built by their owners in a lot by lot fashion and 2. social housing ensembles, built as homogeneous complexes by local municipalities or non-government organizations.

In both cases it is possible to introduce modifications aimed at improving solar access: in the first case, due to a constant process of renovation and alterations that could effectively include solar retrofitting and in the case of social housing ensembles which, if properly designed, present the most propitious situation to integrally utilize solar energy with a significant social and economic impact, due to their high potential of conventional energy savings and the improvement of the life quality of the less affluent urban dwellers.

2.3 Indicators calculation

To determine the availability of solar radiation on north facing elevations (+-25°) and roofs during the heating season, a computational-graphic model [7] was developed and utilized. It yields the following results: fully insolated (direct + diffuse) areas of north facing façades and roof's horizontal projections, for the heating season. The sum of all building values in a city block is considered as a single value.

Calculations runs were performed for the 21st. day of each winter month, from April to September, from 9:30 to 14:30 (solar time), which approximately account for 85% of the total impinging radiation on the potential collectors. [2]

Insolation values on roofs are limited to the winter months for two reasons: during the summer months the amount of available solar energy will be greater and the demand for domestic hot water smaller.

## 3. ANALYSIS AND RESULTS

Urban variables

3.1. Form and orientation of city-blocks

The overall shape and orientation of city-blocks conditions the quantity of insolated areas, particularly during the season of maximum energy demand.

3.1.1. Form: two scenarios, corresponding to city-block typologies 5:5 and 5:2. were assessed. The results obtained from the model's runs indicate that at solar noon of June 21, 32% of the total potentially collecting areas of north facing elevations and 68% for the horizontal projection of roofs were effectively insolated.

There are significant differences in values of insolated surfaces when only solid masking elements (neighboring buildings) are considered. When the permeable masking due to trees is added to the former; this reduction is particularly important when single storeyed houses are considered 15.96% and 11.89%.

The 5:5 typology is the one of greater solar collection on north facing façades, with a value of 75.8% that is, a 3.18% over the 5:2 typology, which displays a value of 72.63%.

When the insolated areas are related to the respective built volumes, the differences are reversed and more significant: a value of 5:2 typology is: .058, that is, a .014 over the 5:5 typology, which displays a value of .044. (Fig.2). This reversal effect is due to the much larger built volumes in the 5:5 scenario. When the insolated areas are related to the respective built volumes, the differences are reversed and more significant: the value for 5:2 typology is .56, that is a 24% more than 5:5 typology with .44.

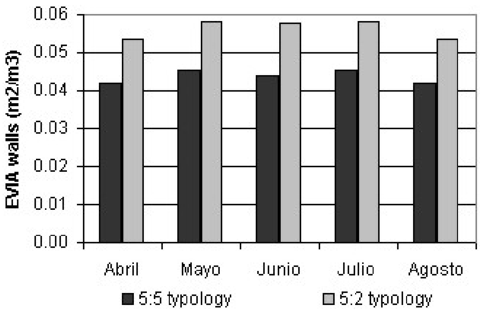



**Figure 2**: Effective volumetric insolation of north facing walls as a function of city- blocks typology.

On roofs, the insolation variation is less related to the form and orientation of the city block, with difference values of .04% and it is mainly dependent on the building's morphology.

3.1.2 Orientation.

A comparative analysis of two scenarios of similar city blocks with different orientation was performed.

The 5:2 typology was selected as being the most representative with a 27.98% participation of the city's total low-density units.

Scenario 1 presents an eastward deviation of 23°, while scenario 2 a westward deviation of 66°.(Fig.3)

Their calculated EIA values are:

Scenario 1 $EIA_{n.w}$ = 74.77% $EIA_{h.r.}$ = 94.99%
Scenario 2 $EIA_{n.w}$ = 66.57% $EIA_{h.r.}$ = 97.27%

There is a difference in the EIA values of the analyzed cases (5.29%), for the city blocks of scenario 1 (74.77%) over those of scenario 2 (66.57%).

In the case of roofs the values do not present significant differences.

The city blocks with different proportion of their sides are those of greater variance in their insolated areas as a function of their orientation. The highest values of EIAn.w. (74.77%) are achieved by the typologies with N-S orientation, while significant reductions of this values (66.57%) are present for cases of E-W deviations. Volumetric insolation presents more significant differences in favor of the better oriented city blocks (Fig. 4).

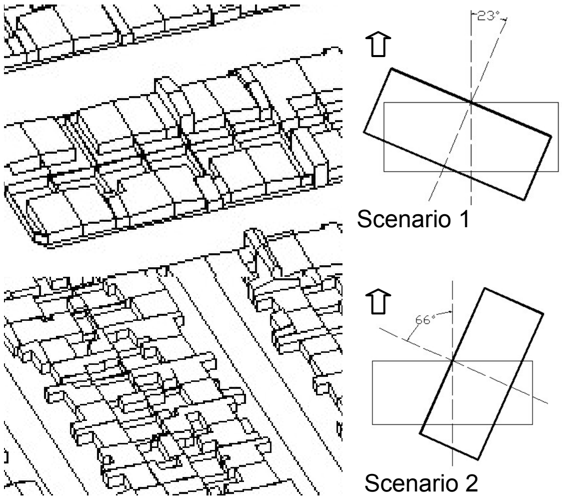



**Figure 3**: Orientation scenarios 1 and 2

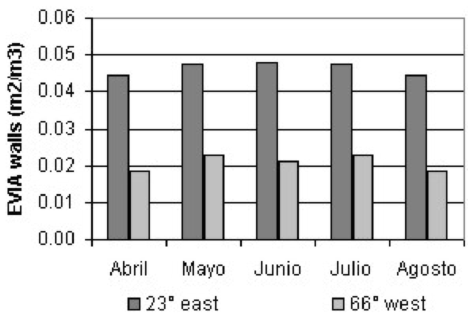



**Figure 4**: Effective volumetric insolation of north facing walls as a function of city-blocks orientation.

Their calculated EVIA values are: Scenario 1: EVIAn.w .046, EVIAh.r. .21. Scenario 2: EVIAn.w .020, EVIAh.r. .19.

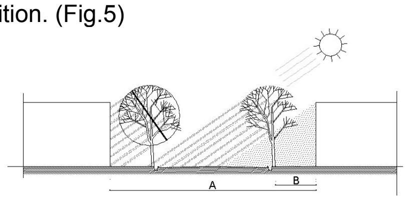
3.2 Urban canyon width- urban trees incidence

The relationship between the urban canyon width and the built volumes defining it, is essential to allow good levels of insolation and ventilation. The reduction of the insolation levels on potentially collecting north facing walls is the result of different combinations of the canyon's width, its orientation and the urban trees morphology, including their size, location, separation, seasonal solar permeability and foliation cycles.

The street width in the low-density neighborhoods varies between 13,00 and 30,00m, according to successive past prescriptions of the Provincial Law of Subdivisions. Today the most typical value is 20,00m, for high and low-density neighborhoods as well.

The predominant tree species in MMA low-density areas are: white mulberry (*morus alba*), European ash (*fraccinius excelsior*) and china berry tree (*melia azedarach*); featuring important differences in their morphology and size, even for individuals of the same species. [8] Plane trees are not used in recent low density developments.

The two scenarios analyze the effect of two cases of canyon's width: 13.00m. and 20.00m. with a distance of 2.00m. and 4.00m. from building line to trees position. (Fig.5)




| | A | B |
|---|---|---|
| **Scenario 1** | 13,00m | 2,00m |
| **Scenario 2** | 20,00m | 4,00m |

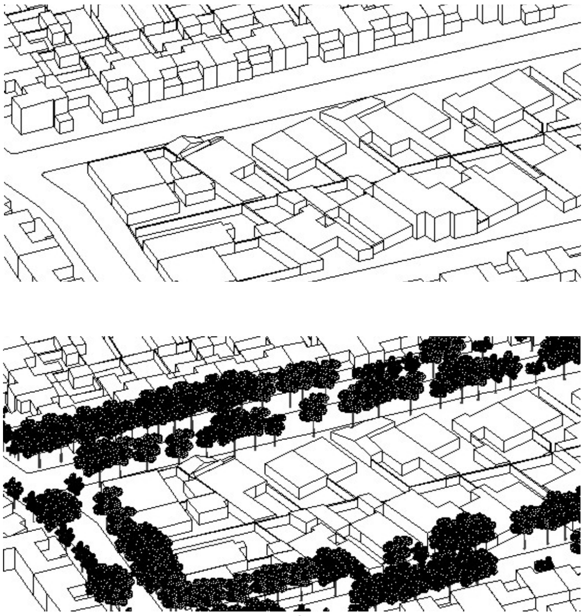


**Figure 5**: Typical section of urban canyon and aereal view of scenario 1 without and with trees.

The results from the calculation of the effective insolation of north facing elevations, for the most representative street widths: 13,00m and 20,00m, without considering the effect of trees, varies between (88.45% and 86.11%). When the masking due to trees is added the insolation values decrease to 13.21% and 15.97% respectively. Effective volumetric insolations values are 75.23% and 70.15%. (Fig.6)

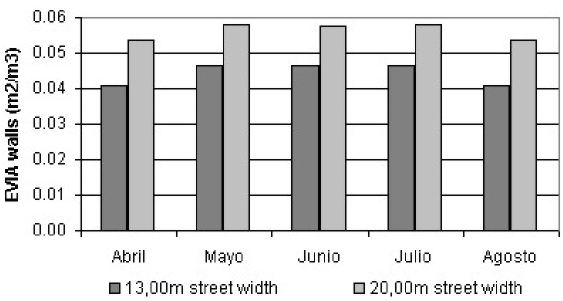



**Figure 6**: Effective volumetric insolation values for different street widths.

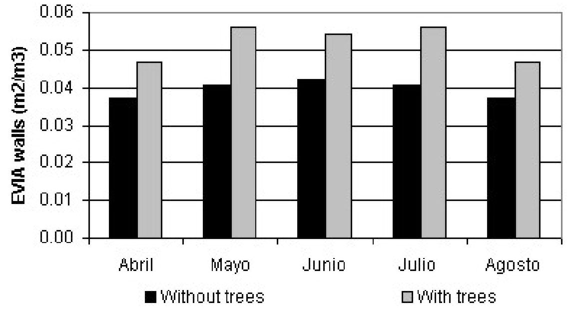



**Figure 7**: Effective volumetric insolation of north facing walls solid masking only and solid plus trees masking.

When the insolated areas are related to the respective built volumes, the differences are more significant: the value for street widths of 13.00m is: .046, that is, a 20.68% under that for street widths of 20.00m, which display a value of . 058. (Fig.7)

3.3 Building variables- Houses morphology

The main goal of this analysis is to assess the incidence of homogeneous and heterogeneous building morphologies in city-blocks and their potential insolation.

The two scenarios analyzed consider heterogeneous (individual) and homogeneous (social) housing typologies. (Fig.8)

In the former case tilted roofs are predominant as are flat horizontal roof in the social housing.

Parcel areas average 200.00 $m^2$ for either case, while street widths vary between 18.50m and 20.00m.

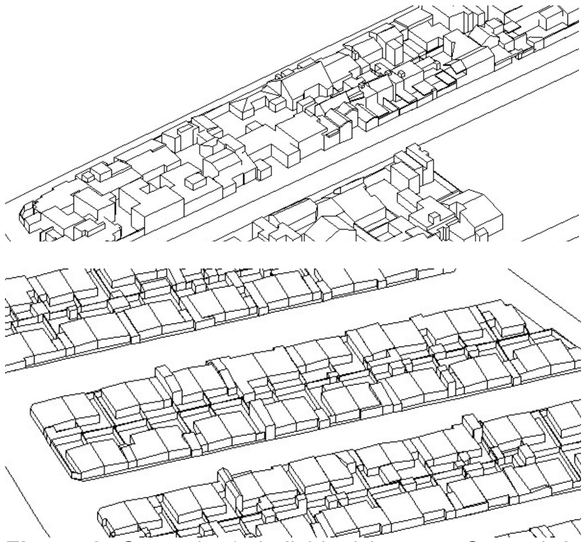


**Figure 8**: Scenario 1: individual houses. Scenario2: social housing ensembles.

The results yield greater values of useful insolation for space heating for the homogeneous ensembles (74.77%) Individual houses city blocks present greater obstructions, particularly due to roofs morphology, dropping their insolation values to 70.14%. This differences are large for solar water heating, (96.70% and 90.56%) precisely due to the roofs morphology.

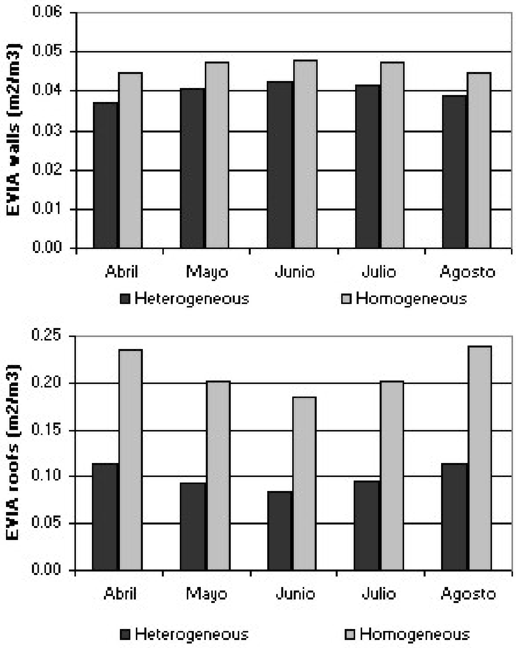



**Figure 9**: Effective volumetric insolation for heterogeneous and homogeneous housing city-blocks.

When the insolated areas are related to the respective built volumes the effective insolation of roofs of Scenario 1 is .09. and for scenario 2 is .21 (57.14%). (Fig.9)

The value of north facing façades for Scenario 1 is .040, that is a 13.04% less than Scenario 2 with .046.

3.4 Soil occupation

The soil occupation variable is a direct consequence of the urban parcels layout and the prescriptions of buildings codes for frontal and rear setbacks, patio dimensions, Soil Occupation Factors (SOF: built-up area on ground level/total buildable area) and the presence of green open spaces at the city-block cores.

Scenario 1 displays a greater and more heterogeneous soil occupation, with a mean 45% of the parcel area used as patios, while in social housing ensembles the values is a close 47%.

The insolated areas in scenario 1, in relationship to the built volume amount to a (.039) while the value increases to (.044) in scenario 2. This significant difference is due to the fact that in the former case it does not exist a homogeneous pattern of built volumes and open spaces at the city block cores. In the case of scenario 2, in spite of minor modifications introduced by the owners, the front and rear setbacks have been mostly preserved. (Fig.10)

Effective insolation of north facing façades is greater for the homogenous scenario 2 (77.33%) than for the heterogeneous scenario 1 with a 69.18%.

In the case of effectively insolated roofs, the differences are more noticeable 85.27% for scenario 1 and 94.26% for scenario 2.

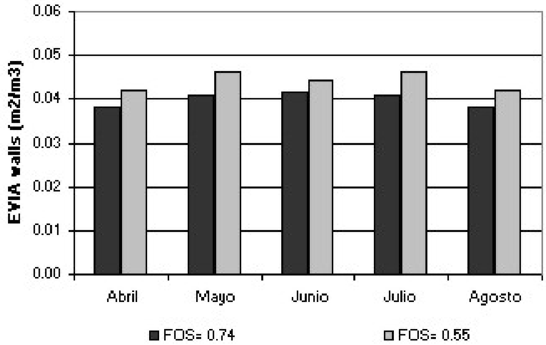



**Figure 10**: Effectively insolated north facing façades, solid masking, for different values of the soil occupation factor.

3.5 Building density

The building **density commonly expressed as Total Occupation Factor** (TOF): (total built-up area/total buildable area in the city block).

The building height is the most significant morphological feature as a consequence of greater building density. In the case MMA's, housing buildings are exceptionally higher than two storeys.

Two scenarios were analyzed; they share the following features: 5:2 typology, 13,00m wide urban canyon, 23° of eastward orientation and similar features of urban trees. The TOF values of houses were .79 for scenario 1, with two storey houses and .57 for scenario 2, with single storey built-up units. (Fig.11)

**Figure 11**: Aerial view of housing ensembles with different building densities: Scenario 1, two storey and Scenario 2 single storey.

The insolation values calculated for both scenarios show larger values for north facing façades of two storey dwellings (77.33%) and smaller values (76.49%) for the single storey houses of scenario 2.

The significant difference in the two studied cases clearly indicates the better morphology for solar collection in the case of the two storey constructions.

In the case of effectively insolated roofs the values are larger for single storey units (7.20%)

The considerable reduction in the case of two storey buildings (.07) is not the consequence of roofs slope but of the built volume, even so the solar availability on roofs is significant. Referred to the built volumes, the insolated areas vary from 77.33% to 76.49%. Their calculated EVIA values are: Scenario 1: EVIAn.w .044, EVIAr .13 and scenario 2: EVIAn.w .044 and EVIAr .19. (Fig.12)

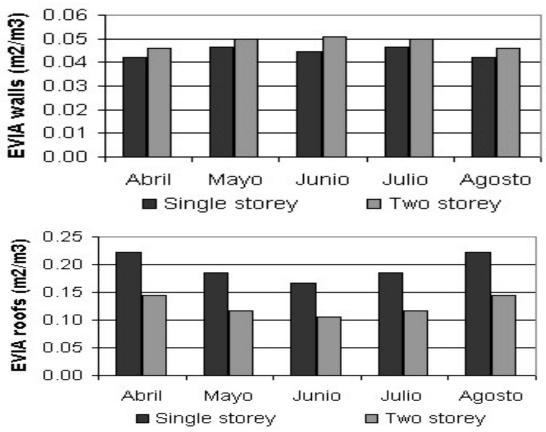



**Figure 12**: Effective volumetric insolation of north walls and roofs as a function of building density. (single and two storeys)

## 4. CONCLUSIONS

The precise knowledge of the influence of each of the intervening variables in useful insolation of urban building is of absolute necessity when aiming at tackling the problem for real implementation, since greater conservation plus solar are, so far, the only foreseeable options to move toward a measure of greater energy sustainability in urban buildings in the near future.

The present urban morphology is the result of the accumulation of buildings that, over the years, have consistently ignored the advantages of good orientation with a total disregard of the energy consequences of urban and architectural design, and as a result, drifting progressively away from a sustainable future.

The shape and orientation of city blocks have a strong incidence on the solar potential use. The oblong blocks with an east-west longitudinal axis present the greater percentages of insolated areas of north facing elevations in winter EVIAn.w= .046.

Oppositely, when the axis presents a north-south orientation, the lowest values of effective and volumetric insolation are reached EVIAn.w =.020.

The width of urban canyons has an important incidence on the effective insolation of north facing façades. The values drop to a .012 when the street width is reduced from 20.00m to 13.50m, while for roofs the reduction is significantly less: from .001 to .015 when the presence of trees is added, a further reduction of the available insolation is met: .06.

Building homogeneity favours a .006 (6.17%)of greater solar availability on north facing walls, in the case of social housing ensembles, where compact typologies and horizontal roofs are consistently used. Complementarily, flat horizontal roofs receive .11 (6.18%) more insolation that those with diverse slopes.

A fundamental roll is accomplished by the Soil Occupation Factor variable, which conditions the presence of open spaces at the city-block cores combined with front and side setbacks, allowing for a (11.51%)of less restricted solar access on wall.

Even when the increase in building density improves some of the solar potential indicators, it is important to assess such increments for the future, studying diverse soil occupations and set backs.

Summing-up conclusions, comparing the results obtained for Effective Volumetric Insolations of north facing walls, the most influential urban variable is the orientation of the city block (56.25%).

For the building variables the major benefits go to the homogeneous morphologies (54.34%) and in a second place to building density factor (37.12%).

Another important aspect is that, from the total solar energy impinging on an urban low density city block, only 32% is available for space and water heating and during the winter months.

In future stages of the study, the aspects of the energy contents of solar radiation for the season (daily and hourly values) and the real useful collecting surfaces of north facing façades and roofs will be addressed.

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