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Comparative Study of Solar Radiation Availability in Dry Climate Urban Environment Forested Areas in Mendoza, Argentina

Arboit, M.[1], **Betman, E.**[2]

[1] *Instituto de Ciencias Humanas, Sociales y Ambientales. (INCIHUSA – CONICET)*

[2] *Instituto de Ambiente, Hábitat y Energía. (INAHE – CONICET) Av. Adrián Ruiz Leal s/n Parque General San Martín. (5500) Mendoza, Argentina*

Abstract

The study proposes determining the potential of solar collection in urban environments, considering urban building different morphological variables corresponding to representative urban settings in the Mendoza Metropolitan Area (AMM), Argentina.

The methodology involves monitoring the global solar irradiance on the vertical plane in north facades, completely and partly sunny, affected by solid masking and masking woodland.

Results obtained so far indicate that solar masking is critical for vertical surfaces, with a reduction of the available solar energy between 2% and 66% in the winter season, depending on the type of trees and the building morphology. In the summer season, the measured solar masking values range from a maximum of 83% and a minimum of 10% influence of surface shaded by the neighboring buildings and trees. The results demonstrate the impact of the main variables that determine access to the sun in an urban environment (Urban Tree Canopy, Building Morphology, Building Height, Urban Street Width).

The study will allow for future reform and progressive updating of urban and building codes to implement higher levels of energy efficiency and minimum environmental impact by urban buildings, considering the principal urban building variables.

Keywords

sustainable urban development; urban morphology; solar potential; forested urban environments

1. Introduction

The study of morphological variables of urban buildings and urban tree canopy cover is essential for sustainable urban development in arid areas. Access or masking of solar radiation in highly forested urban environments with dry climates and their interrelationships influence energy consumption and environmental conditions. The problems of the environment and energy have been debated intensely by scientific sectors, and much has been discussed about the relationship between energy consumption and urban morphology (Givoni, 1998; Breheny, 1996; Oke, 1987; Garcia, 1993).

On the level of urban configurations, urban green spaces provide great social and environmental benefits that benefit the quality of life in cities. The contribution of urban trees in improving the microclimate, air quality, and living in cities is well-documented (Bernatzky, 1982; Rowntree, 1986; McPherson, Simpson, & Livingston 1989; McPherson, 1992; Mcpherson, Simpson, Xiao, & Wu, 2011; Simpson & Mcpherson, 1998; Scudo & Ochoa de la Torre, 2003; Santamouris, Synnefa, & Karlessi, 2011; Santamouris, Papanikolaou, Livada, Koronakis, Georgakis, Argiriou, & Assimakopoulos, 2001; Mascaró, 1996). Urban trees improve air temperature and humidity, evapotranspiration, absorption of pollutants, and wind speed (Akbari & Konopacki, 2005; Block, Livesley, & Williams, 2012; Simpson, 2002; Tooke, Coops, Christen, Gurtuna, & Prévot, 2012; Tooke, Coops, Goodwin, & Voogt, 2009; Tooke, Coops, & Meitner, 2011; Armson, Stringer, & Ennos, 2012; Hamada & Ohta, 2010; Loughner, 2012; Morakinyo, Balogun, & Adegun, 2013; Shashua-Bar & Hoffman, 2000; Shashua-Bar, Pearlmutter, & Erell, 2009).

Some authors have evaluated the reduction of solar radiation on horizontal surfaces (Gómez-Muñoz, Porta-Gándara & Fernández, 2010; Heisler, 1986) and on the surrounding surfaces that radiate heat (Parker, 1983; Papadakis, Tsamis & Kyritsis, 2001). To date, some studies have focused on the ceiling masking woodland, (Tooke et al., 2009, 2011, 2012; Wang, Chang, Merrick, & Amati, 2016) but the shading trees' effect on the walls and windows has been unevaluated.

The present work-studies available regarding solar radiation on the north facades of highly forested urban environments typical of the Mendoza Metropolitan Area (AMM), Argentina. This is part of the environmental and energy-sustainable development issues regarding the construction industry in cities of the arid sub-Andean mesothermal region of the West-Central Argentina. Its population is about one million inhabitants, and its geographical coordinates are latitude -32.85, longitude 63.85 and altitude 746 m. The main climatic characteristics are the following: in comfort for 21.5% of yearly hours, heating needed for 70% of yearly hours, and cooling needed for 8.5% of yearly hours. Heating DD (base 18°C) is 1384 and cooling DD (base 23°C) is 163. Yearly mean horizontal global solar radiation is 18.06 MJ/m^2 day.

The AMM is no stranger to the intense population growth of cities in developing countries and the unsustainability of current development has inexorably deteriorated through time due to a lack of knowledge, management and planning actions.

Given this scenario, the following question arises: what are the impacts of both urban-building morphologies and the different tree species that predominate in the urban environment in the availability of the solar energy resource?

In the AMM, several specific studies have been developed, considering the representative groups of the urban-building morphology, which were determined by the solar potential in low and high density environments, highly-forested areas and its foreseeable evolution (de Rosa et al., 1988 ; Córica & de Rosa, 2004 ; Fernández, Basso, Córica, & de Rosa, 2003; Mesa, de Rosa, 2010 ; Basso, Fernández, Mesa, Córica & De Rosa, 2003 ; Arboit, 2013 ; Mesa, Arboit, & Rosa, 2010). Studies have been developed with the objectives of: i. preserving the physiognomy of the forested city, maintaining the scale and homogeneity of the constructions and the aesthetic contribution and environmental services of urban forest; ii. enabling the maximum use of solar resource for space and sanitary water heating, through the control of urban morphology and of the forest; iii. Improving habitability conditions of the building area; iv. contributing to the sustainability of local development, by enabling the recycling of existing constructions that were well maintained and of good quality. In this way, extractive processes and solid waste emission (rubble) in the ecosystem are reduced.

In order to complete these studies, a solar irradiance measurement was performed on the north facades of seven selected cases, according to previous results. The intention of the study was to offer a contribution, both conceptual and operative, so that, through the transfer channel in the future, the official sector will become aware of the seriousness of the situation and soon begin to implement new urban and building norms. These could also reduce the consumption of natural gas and other non-renewable energy in urban buildings.

2. Methodology

In previous work (Arboit, Diblasi, Fernández, & De Rosa, 2008), the Mean Insolation Factor (MIF) indicator has been defined. The Mean Insolation Factor (MIF) provides a measure of the potentially collecting north facing walls, not masked by neighboring buildings and trees, calculated as: the ratio of the sum of insolated collecting areas of north facing walls, times the sum of the energy received at each considered hour, during a heating season, to the sum of the total areas of the same surfaces, free of all masking, times the sum of the hourly impinging radiation during the considered heating season, as a percentage. It is defined in Fig. 1.

TPCA: Total potential collecting area of the North facade (m^2)

SMA: Solid Masking Area (constructions):

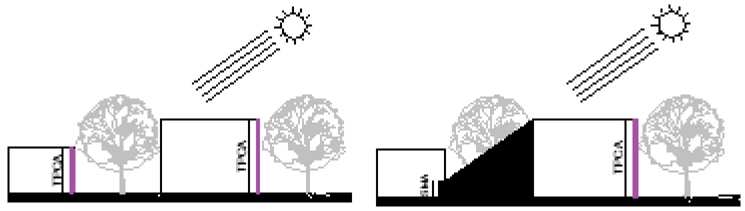
Potential collecting facade affected by shade projected by constructions of close buildings (m^2). (Fig. 1)

TMA: Transmissible Masking Area (trees): Potential collecting facade affected by shade projected by urban trees (W/m^2).

P: Monthly Transmissibility Factor. Solar Transmissibility percentages of each vegetable species and for each month of the heating season (%).[42]

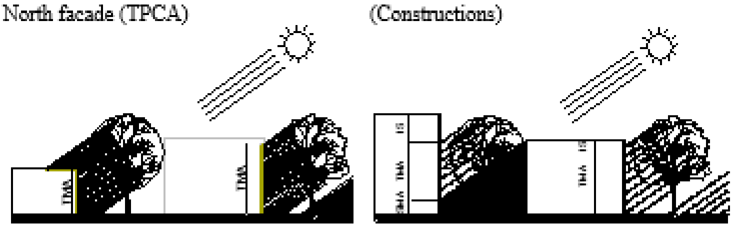
R(m-d-h): Energy by surface unit available in the North facades for each hour, day and month of the heating season (Wh/m^2). Hourly impinging radiation on North facing walls for each month (Wh/m^2).

Sub-indicators:
m: Month of heating. It varies between April and September. Number of months to which the heating season is extended (n).
d. Day of the month. It varies between 1and 30. h: Hour. It varies between 9:00am and 6:00pm.



Total potential collecting area of the North facade (TPCA)

Solid Masking Area (SMA) (Constructions)



Transmissible Masking Area (TMA) (trees)

Net Insolated Area (NIA): Addition of the values of insolated surfaces IS+ (TMA*T) (transmissibility)

Figure 1. Descriptive diagrams of TPCA, SMA, TMA and NIA

$$MIF = \frac{\sum_{m:4}^{08}\sum_{d:1}^{30}\sum_{h:9:30}^{14:30}\left[TPCA-(SMA_{m-d-h}+(TMA_{m-d-h}\cdot(1-T)))\cdot R_{m-d-h}\right]}{NFA\cdot\sum_{m:4}^{08}\sum_{d:1}^{30}\sum_{h:9:30}^{14:30}R_{m-d-h}}\cdot 100 = \tag{1}$$

$$MIF = \frac{[exp\,(4.1969 - 0.148\; St.\,Wi - 0.0127 F.Tress + 0.8547\; B.\,Morp - 0.4721\; TOF)]}{[1 + exp\,(4.1969 - 0.1486\; St.\,Wi - 0.0127 F.Tress + 0.8547\; B.\,Morp - 0.4721\; TOF)]} \tag{2}$$

Considering the Mean Insolation Factor (MIF) on north facades and using a Multiple Linear Regression Model, the main variables that influence the access of the sun were determined (Arboit et al., 2008). These variables are: Building Morphology (B. Morp.), Street width between construction lines (St. Wi), Fullness of trees (F. Trees) - relationship of the existing (healthy) trees around a city block to the total number of trees that could fit around the city block, considering the dominant species and their corresponding distance between individuals, as percentages- and Total Occupation Factor (TOF)-Total built-up area to total buildable area of corresponding parcels, as percentages-. (eq.2).

The easiest way to note the influence of the urban-building variables with access to the sun is by measuring global solar irradiance over the vertical plane of the completely sunny north facade and measuring the same variable of the facade that is partially sunny. The latter is affected by the urban-building morphology (building morphology, street width, fullness of trees, and building height).

The measurements were carried out with portable irradiance data-measuring systems, equipped with Eppley 8-48 pyranometers.

The measurement period was established according to the latitude and longitude of the place of study, for a given day. Considering the local time, the solar noon was defined (» 1:30pm), and four and a half hours before and after the solar noon were taken into consideration. This approach left nine definite solar hours to measure from 9am-6pm. Data was registered every minute during the autumn-winter and spring-summer seasons.

Based on what has been presented, the corresponding measurements were selected during a clear day for each urban environment. Clear sky conditions allow the evaluation, in its complete magnitude, of the influence of the trees and the urban morphology.

Selection of case studies

For the monitoring of global solar irradiance on north facades affected by solid and tree masking, seven cases were selected, in which different measuring conditions were present. For the selection of case studies, the urban-building and forest morphology of the MMA urban environments were considered based on the Mean Insolation Factor (MIF). In Table 1, the case studies and the characteristics of urban and building variables can be observed.

Table 1. List of urban and building variable values of the sample.

Cases				URBAN VARIABLES			BUILDING VARIABLES		
N°	Blocks		Street width		Urban forest		Morphology	Front Setbacks (m)	Building Height
	Density	Orientation (°)	(m)	Tree Magnitude	Tree species	Fullness of trees			
1	High	13	30.00	2^a	Morus alba	Several pairings	Regular	0	3rd
2	Low	4	13.40	2^a & 1^a	Morus alba y Fxaxinius excelsior	2 individuals	Irregular	5	1st
3	High	13	30.00	2^a	Morus alba	Several pairings	Regular	0	2nd

Continued on next page

Cases				URBAN VARIABLES			BUILDING VARIABLES		
4	Low	5	16.40	2^a & 2^a	Melia azedarach y Morus alba	2 pairings/ Young	Regular	0	1st
5	Mid	5	16.40	2^a	Morus alba	Individual	Irregular	3	2nd
6	High	8	30.00	2^a	Cupressus sempervirens	Individual	Irregular	2	1st
7	Mid	7	14.20	2^a & 1^a	Morus alba y Platanus acerifolia	Several pairings	Irregular	0	2nd

3. Results

Figures 2 and 3 show the diversity of energy situations according to the analyzed urban environment, and they show a preponderance of each of the variables in equation 1. Measurements of shaded surfaces registered a reduction in the autumn-winter season from 2% to 66% of the total energy received on the plain sunlight sections, and in the spring-summer season from 10% to 83%.

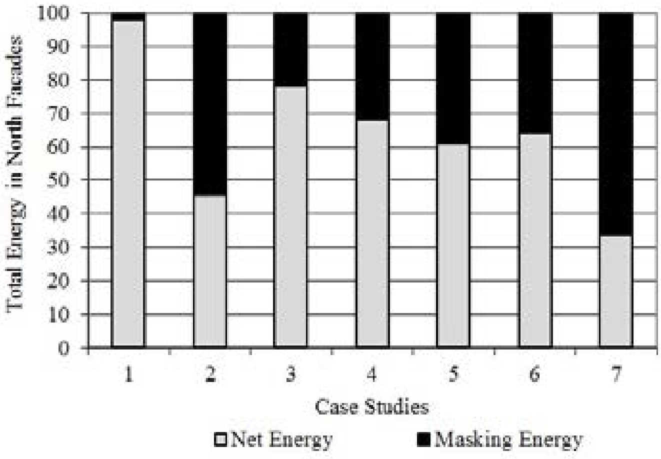


Figure 2. Total Energy %.

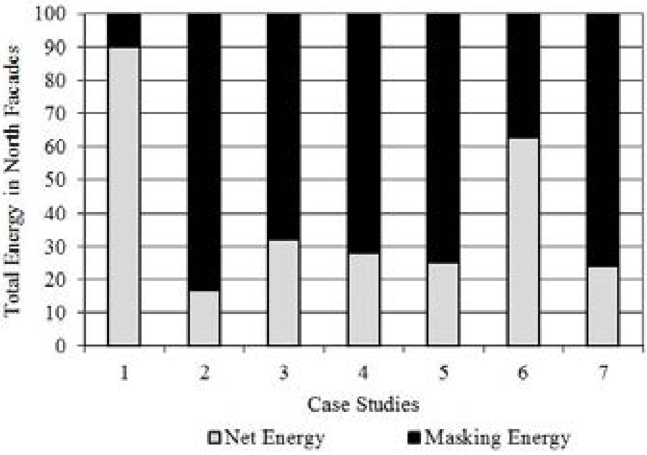


Figure 3. Total Energy %.

This said percentage is dependent on the urban building environment. Cases 3, 4 and 5 are those with the most favorable ratio between maximum insolation in winter and maximum masking in summer. The irradiance measured on the vertical plane and oriented towards the north of Case 3, in partial sunlight condition, presents a relationship for the summer months of a masking effect of 68%, and for the winter months of an available net energy of 78%.

While in Case 1 the percentage of net energy available on north facades in winter is 98% (favorable from the point of view of the solar energy use), in summer, the energy masked is 10% (the lowest value of solar masking of the cases analyzed). The environment involved has a street width of 30 meters and homogeneous building morphologies at a height of 10mts (with scarce influence of forest at the crown canopy level and little influence on surfaces shaded by neighboring buildings).

In the autumn-winter season, the maximum reduction percentage, 66%, corresponds to Case 7, which is characterized by a wide street channel of 14.20 m, and the measurement surface is partially shaded by trees at a second magnitude *Morus alba* and first magnitude *Platanus acerifolia*, with the consequential reduction of the available energy.

In the spring-summer season, the maximum reduction percentage, 83%, corresponds to Case 2, which is characterized by the influence of two different species, *Morus alba* and *Fxaxinius excelsior.* In winter, masking for the same case study is 55% resulting from the urban forest, a variable first order masking solar resource in highly forested urban environments.

Cases 1 and 3 for detailed study are compared in the first instance, as they represent the extreme conditions, through the ratio between maximum sunlight in winter and maximum masking in summer. In this way, the variables of street width, tree canopy cover, and building height and morphology will be analyzed. How both will influence the quantity of the received solar energy on north facades will be observed.

3.1. Influence of Building Height

In order to analyze the impact of urban building morphology in relation to building height, measurements have been made by vertically displacing the sensor that measures the partially shaded zone of the façade. See Figs.4–6.

In Case 1, the results indicate that the maximum incident radiation was on the north side captured in autumn-winter season (98%), in contrast to the minimum masking incident solar radiation in spring-summer (10%). This case is representative of the situation in an urban environment without the presence of urban trees, and without considering design strategies above the treetops or wood species that do not accompany the building height.

Case 3 presents an optimal relation between the scenarios analyzed, considering both seasons. With the sensor that measures the partially sunny area located on the second floor, values indicate that 78% of the total irradiance were available in winter. While, for the spring-summer season, the measured values indicate masking of 68% from the resource.

The difference between the values of masking solar radiation, 2% and 22% in the autumn-winter season and 10% and 68% in spring-summer season, in Cases 1 and 3 (Figs.7–10), can be explained by the maximum development of the crown canopy of the existing trees of the north facade that reached a mean altitude of 10 m (Figs.5 and 6). The data, measured by moving the sensor in a vertical direction on the same facade, gives us information to elaborate strategies that consider the conditions above and below the crown canopy of trees, in order to maximize the use of the available solar resource in urban environments.

The building height and the different levels of construction allow defining desirable situations in the conservation and full access to solar resource.

Figure 4. Hemispherical photographs of the environment, taken from the sensor location. Facade zone with full insolation. Terrace.

Figure 5. Hemispherical photographs of the environment, taken from the sensor location.Case 1. Facade zone with partial insolation. Third floor.

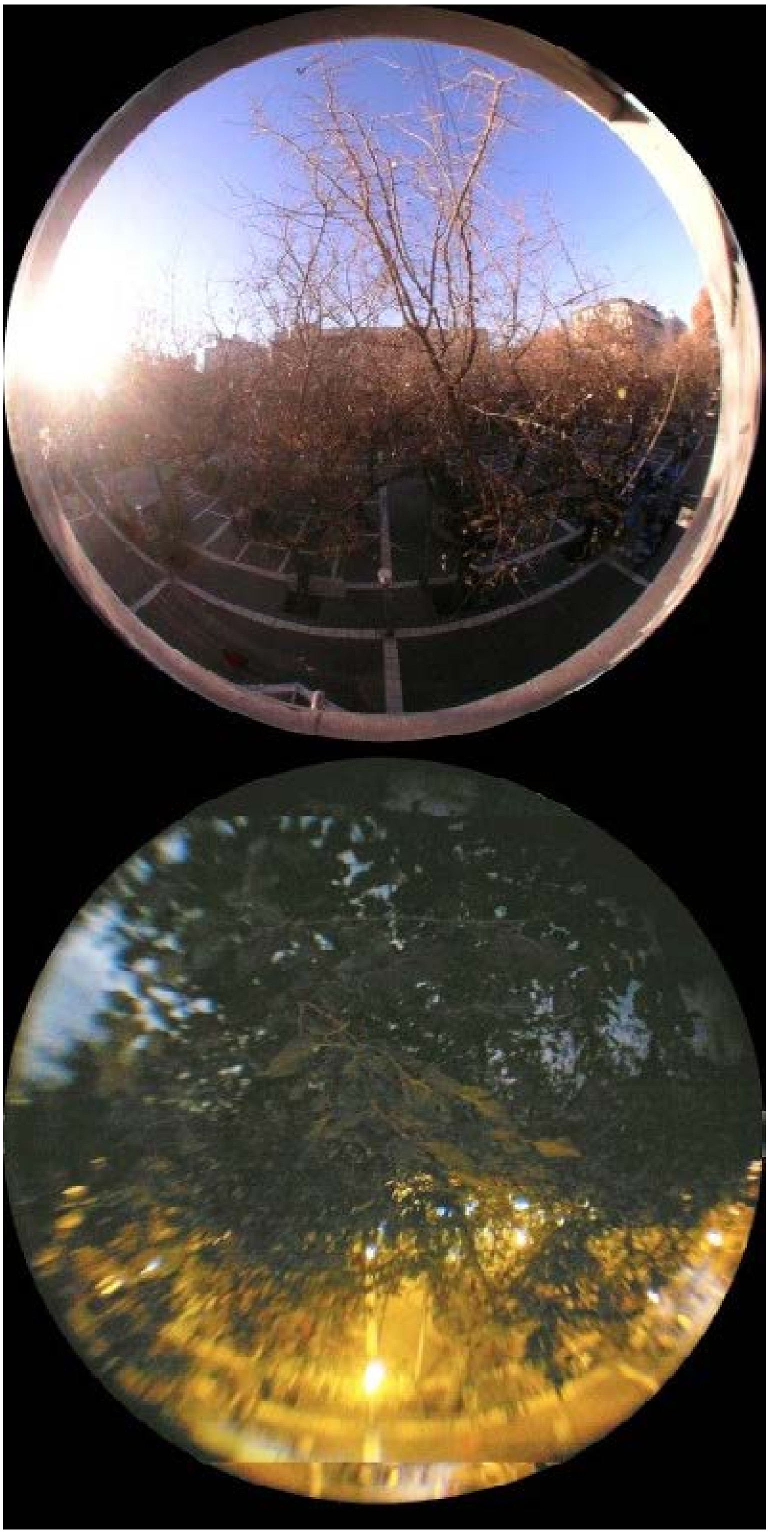


Figure 6. Hemispherical photographs of the environment, taken from the sensor location Case 3. Facade zone with partial insolation. Second Floor.

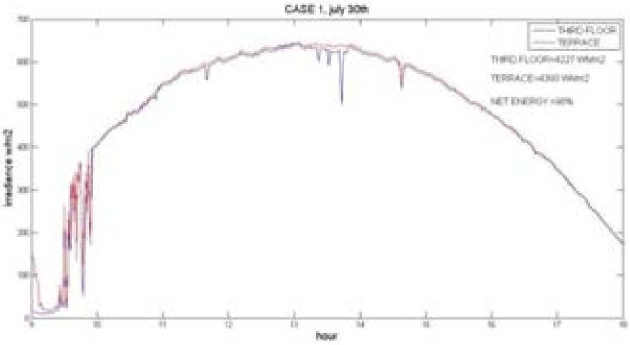


Figure 7. Irradiance measurement in the autumn-winter season of the N facade, case N°1 (Third Floor, approximately 7m of height).

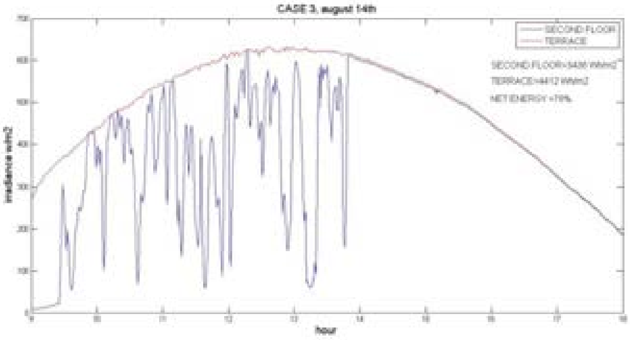


Figure 8. Irradiance measurement in the autumn-winter season of the N facade, case N°3 (Second Floor, approximately 4.5m of height).

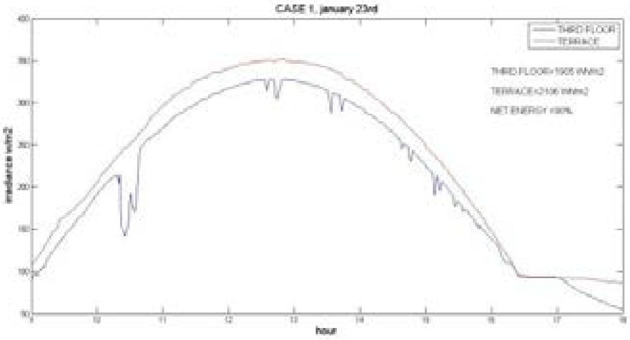


Figure 9. Irradiance measurement in the spring-summer season of the N facade, case N°1 (Third Floor, approximately 7m of height).

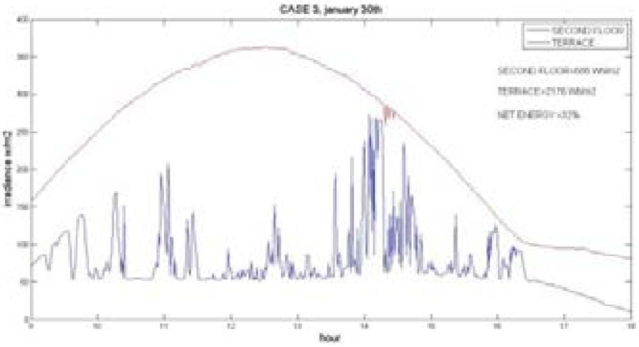


Figure 10. Irradiance measurement in the spring-summer season of the N facade, case N°3 (Second Floor, approximately 4.5m of height).

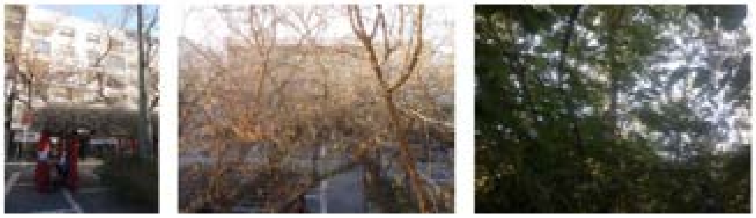


Figure 11. Photographs of Case Study 3

3.2. Influence of Heterogeneous Building Morphology

The solar potential in selected urban environments is determined by the aspects of the urban and building morphology, with different possibilities of interaction between volume and access to solar radiation, and this can be analyzed in Case 6. In this scenario, 64% of incident radiation on the north facade is captured in the autumn-winter season, with masking of the incident radiation in summer 37%. This is principally to the surrounding building morphology that gives shade to potential collecting areas, and to the transmissible masking that the trees provide. With the goal of evaluating solid masking separately, Fig. 13 depicts a graph. In the early hours of the morning and the afternoon, there is fairly small access to the available solar energy, 22%, and the contribution is exclusively due to the diffused and reflected solar radiation components.

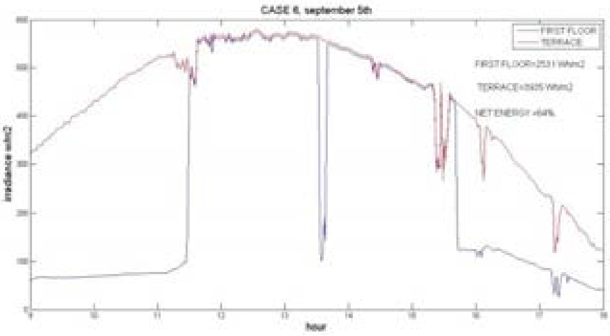


Figure 12. Irradiance measurement of the N facade, case N°6.

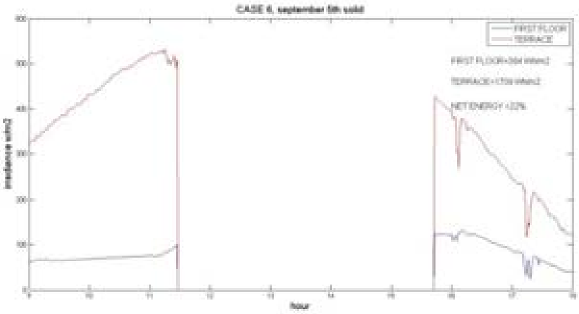


Figure 13. Irradiance measurement of the N facade, case N°6 (Solid masking evaluation)

When separately comparing the morning (16%) and afternoon (34%) availability, one observes that, in the afternoon hours, the reflected radiation has a greater impact due to the deviation of the urban outline's orientation with respect to the North (8° towards the East). It should be kept in mind that the important reduction of solar resource that this case presents would be much greater if the building morphology affects the access of solar radiation in the middle hours of the day.

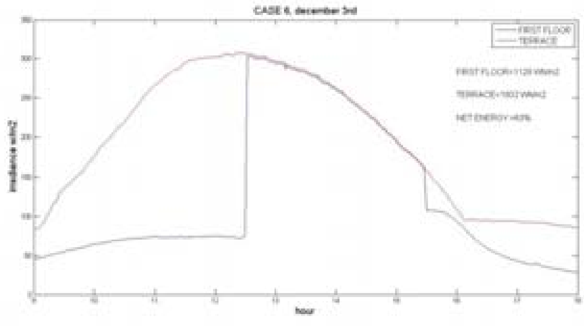


Figure 14. Irradiance measurement, in the summer season, on the vertical plane and facing North tofull sunlight and condition of partial sunlight.

Figure 15. Hemispherical photograph of the environment, taken from the sensor location.

For the summer season, the incident radiation is 63% with a zero masking woodland (due to the morphology of the species, its planting distance relative to the façade, and the solar angle on the day of the analyzed season). Masking occurs through the surrounding building morphology, principally in the morning until 12:30pm, and from 3: 30pm, due to the orientation of the facade in the North. Full access to solar resource in the middle of the day impacts on maximum availability of net energy values received in the summer season and is an example of city design that considers only the heterogeneous building morphology, with planting strategies of species of urban trees not suitable for a model city oasis.

3.3. Influence of the Street Width

Case 7 shows that, in winter, the percentage of maximum reduction of 66% solar resource reached in this work, and 76% of masking solar radiation in the spring-summer. Both the street width and its orientation determine the solar potential of urban buildings. In this case, although the direction E-W is the best orientation of the facade, and consequently, its best sunlight and maximum energy efficiency. The width of the 14.20 m street channel seriously affected the mentioned advantages. A narrow urban canyon, when combined with the urban forest of first magnitude, has a first order incidence in solar potential.

Case 7 results indicate a maximum reduction of the available solar energy in autumn-winter season, even with the leafless branches of the urban forest. Masking produced by the leafless branches can be considerable in autumn-winter, especially with species of considerable size (1^{st} and 2^{nd} magnitude and narrow street channels from13m to 16m).

In the spring-summer season, the net energy available is 24%, which is a significant masking of the solar energy for the presence of urban trees and urban building morphology. In this case, it is observed (Figs.19 and 20) that the transmissibility of the solar radiation offered by the trees in the narrow urban channels present great variations according to the position of the sun.

Figure 16. Views of the facade in autumn-winter season.

Figure 17. Views of the facade in autumn-winter season.

3.4. Influence of Trees

Case 2 results express the percentage of maximum reduction of solar radiation in spring-summer to be 83%. In the autumn-winter season, in masking walls facing north and for days studied, it is 55% (Figs. 28 and 29).

Figure 18. Treesseen from the sensor.

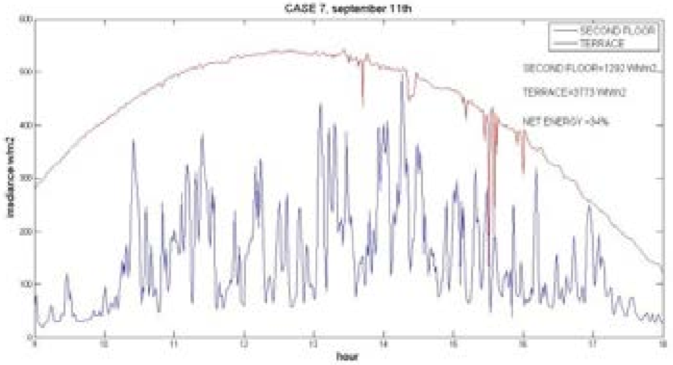


Figure 19. Measured irradiance of N facade, autumn-winter season, case N°7.

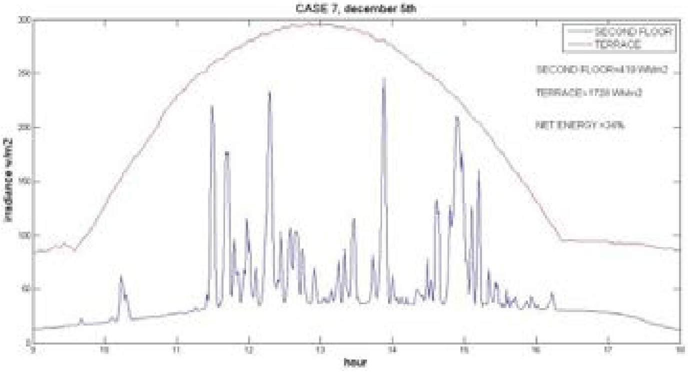


Figure 20. Measured irradiance, in the summer season, of the vertical plane and oriented North tofull sunlight and insolation condition.

Figure 21. Views of the studied facade. Summer. Case 7.

Figure 22. Views of the studied facade. Summer. Case 7.

Figure 23. Frontal photograph of the facade.

In the autumn-winter season, in order to study how trees condition the access of the sun, we have selected a case that presents the influence of the leaves of two different deciduous species. When analyzing Fig. 28, it is seen that, in this case, the reduction of available energy is 55%, and that the influence of each species is very noticeable. In morning and mid-day hours, the reduction of the availability of the solar resource is 39% (Fig. 30). This value corresponds to the *Morus alba* (species 1) bare foliage obstruction. Comparatively, in the afternoon hours, the resource reduction is 85% due to the high density of leafless branches that *Fxaxinius excelsior* (species 2) presents (Fig. 31).

If only species No. 1 (*Morus alba*) is used, combined with an urban morphology characterized by: frontal building shelters, good orientation of the urban layout, height and building morphology, it would be possible to obtain maximum solar obstruction in summer of 89% and considerable access to the sun in winter of 61%, and it would be possible to achieve an optimal ratio considering both seasons of the year, between the maximum incident radiation on the north facade captured in winter and the maximum masking of the incident solar radiation in summer.

Figure 24. Hemispherical photograph of the environment taken from the sensor location.

Figure 25. Wide angle photograph, taken from the sensor location.

Figure 26. Frontal Photographs of the facade.

Figure 27. Wide angle photograph, taken from the sensor location.

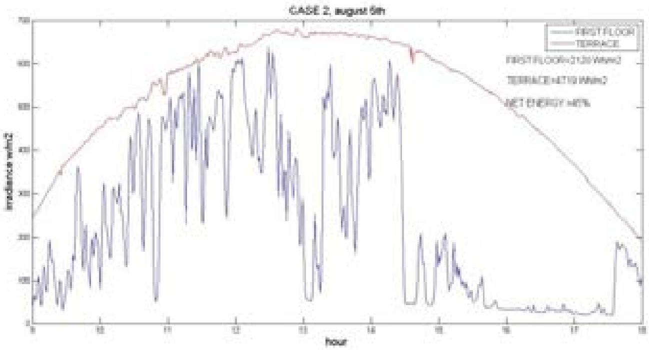


Figure 28. Irradiance measurement on the North facade, autumn-winter season, case N°2.

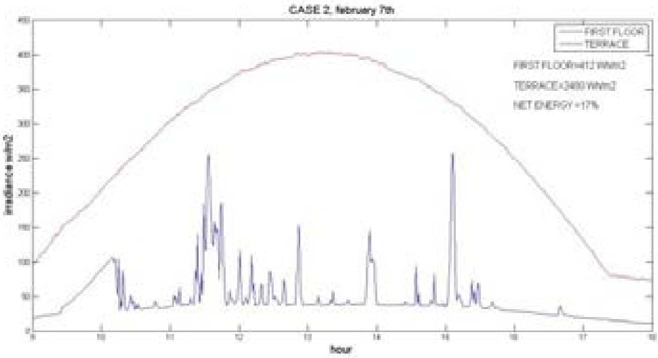


Figure 29. Irradiance measured on the vertical plane and oriented north to full sunlight andcondition of partial insolation.

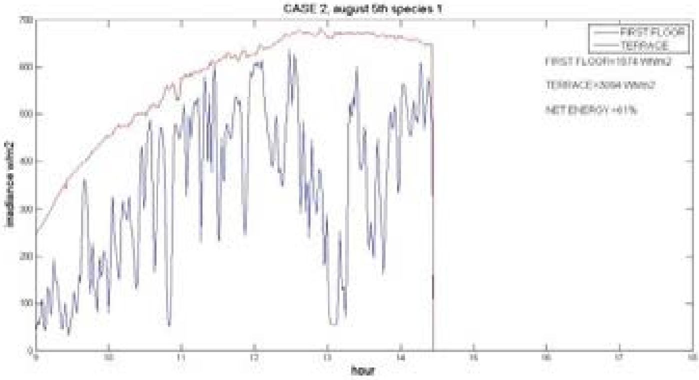


Figure 30. Irradiance measurement on the N facade, case N°2 (Influence of Morus alba, species)

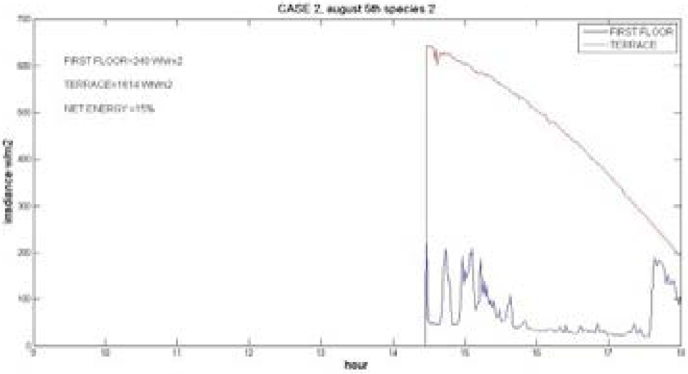


Figure 31. Irradiance measurement on the N facade, case N°2 (Influence of Fxaxinius excelsior, species 2).

3.5. Influence of Urban Canyon Width and Trees

Cases 4 and 5 show the second and third best ratio between the maximum insolation in winter and the maximum obstruction in summer. The energy available in winter is 68% for Case 4 and 61% for Case 5. The masking of the radiation incident on the north facade captured in summer is 72% and 75%, respectively.

In both cases, the variables that result in the most influence are the narrowness of the urban canyon width (16.40mts) and the tree species of 2nd magnitude with its planting characteristics: white cedar (*Melia azedarach, also known as chinaberry*); mulberry (*Morus alba*) in Case 4; and mulberry (*Morus alba*) in Case 5.

Figure 32. Case 4, Winter, (in the photograph, the shadow cast by bare branches on the North facade can be observed) and an appropriate value of SVF (tree top shadow partially occupies the surface of the street).

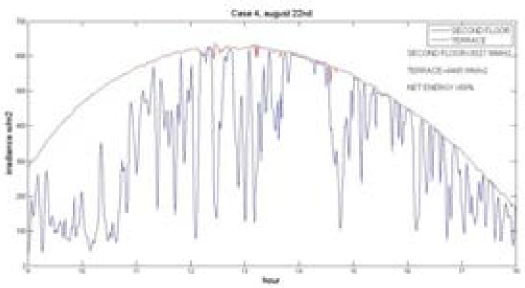


Figure 33. Irradiance measured on the vertical plane and oriented north to full sunlight and condition of partial insolation, WINTER.

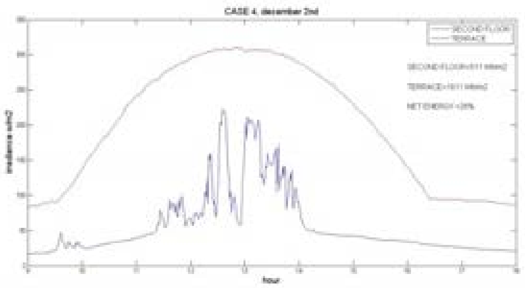


Figure 34. Irradiance measured on the vertical plane and oriented north to full sunlight and condition of partial insolation, SUMMER.

Furthermore, in both cases, homogeneous urban-building morphology (without entry or exit) allows full access to solar radiation in winter. Tree location, its planting distance in relation to the facade, and the magnitude in relation to building height all enable a good ratio between the maximum sunlight in winter and the maximum obstruction in summer. A suitable value of SVF (sky view factor), from the axis of the street (Case 4), allows good convective cooling at night in summer.

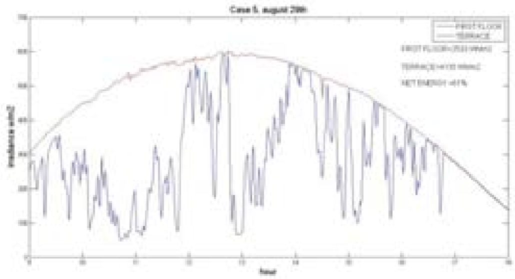


Figure 35. Irradiance measured on the vertical plane and oriented north to full sunlight and condition of partial insolation, WINTER.

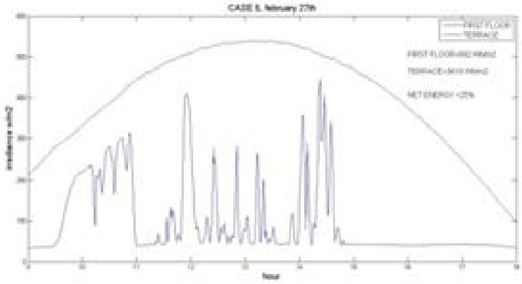


Figure 36. Irradiance measured on the vertical plane and oriented north to full sunlight and condition of partial insolation, SUMMER

Figure 37. Case 5

Figure 38. Hemispherical photograph of the environment taken from the sensor location, Winter.

Figure 39. Hemispherical photograph of the environment taken from the sensor location, Summer.

4. Conclusion

The obtained results provide evidence of the impact of the principal variables that condition the access of the sun in a highly forested urban environment. The seven urban configurations that were studied in the Mendoza Metropolitan Area (AMM) present differential characteristics with respect to the urban and building variables.

In forested urban public spaces, it is necessary to consider the benefits provided by trees in summer. When planning urban environments, proper choice of species seems essential to balance the positive and negative contributions of trees. The following should be considered: 1. tree species of magnitudes consistent with the building height (1^{st} high-magnitude density, 2^{nd} medium-density magnitude, and 3^{rd} low-magnitude density); 2. deciduous species (with maximum transmissivity values in winter, and minimum in summer); and 3. planting distance between chosen species (study of the position of and distance between the trees of each species).

The important influence that bare foliage presents in the autumn-winter season has been demonstrated. These characteristics can be accentuated in certain forested conditions and under determined solar positions, as is demonstrated by the measured values in case study 2, where afternoon hours recorded a resource availability of only 15%. However, case 2 presents the most favorable solar masking (83%) in the summer season. These results show that urban trees result in a first-order variable when capturing a solar resource in highly forested urban environments, and the choice of the optimal tree species at the moment of urban planning should be structurally considered when contemplating future design strategies.

In addition, the choice of tree species is also important in the consideration of combining high transmissivity values in winter and low values in summer. Moreover, it is necessary to reinforce the conclusion that the environmental and energy benefits of urban trees in a city with a desert climate and warm-dry summers, such as the AMM, should be considered as a first priority at the time of planning, designing and building any type of construction project, of any building density in a city.

The analysis of building height variable demonstrates the importance of establishing design strategies and legislation in accordance with a highly forested city that generates unique conditions above and below the trees. Furthermore, the influence of the surrounding buildings decreases when we consider greater building heights, as this combination of effects allows a measurement in winter uptake of solar energy of 98% of full sunlight condition in Case 1, and 90% in the summer.

Heterogeneous building morphology strongly conditions the possibilities of access to the sun, which has been demonstrated in case study 6, where during the heating season, a building with entrances and exits produces a solid masking up to 84% in the morning hours on its applicable North-facing facade. In the summer season, solar masking values of 44% were recorded. As for the vegetative presence of Cyprus (*Cupressus sempervirens*), its morphology and planting distance nullify the influence of the urban tree variable, when the results of case 6 in both seasons are considered.

Building morphology has been considered in this analysis in terms of heterogeneity that is generated by front and rear overhangs, which produces solid masking and compromises access to the sun. These types of heterogeneous morphologies are difficult to recover when implementing building recycling. In the same way, when planning and designing new complexes, homogeneity is a basic condition for assuring full sunlight in the winter season. In the summer season, measures for building-technology recycling, protection design, and green design could improve the present situation.

The analyzed urban determinants for solar energy collection on north facades (trees, building morphology and building height), have greater intensity when they are combined with a narrow street channel. This situation corresponds to case 7, where the minimum received solar radiation values are produced when considering all the hours of measurement. This demonstrates that the strategies recommended for narrow urban canyons should be demanding, concerning the type of permitted tree species, to the maximum height and the shape of buildings, and to the setback from the street.

In the spring-summer season, masking produced by green mass of trees generates multiple benefits: controlling the intensity of the urban heat island, the urban micro climate, the absorption of pollutants, the cooling and humidifying of the air through evapotranspiration and the reducing of thermal loads of buildings. Benefits also include improving the occupancy of public open spaces and making an invaluable contribution to the urban aesthetic.

The achieved results go towards contributing to the progressive reforming and updating of urban and building codes, in order to implement the highest levels of energy efficiency and to minimize any negative environmental impact from urban buildings.

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