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Assessing the solar potential of low-density urban environments in Andean cities with desert climates: The case of the city of Mendoza, in Argentina. 2nd. Part

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ABSTRACT

Energy use in the built environment is globally recognized as a key issue for sustainable urban development. In temperate-cold arid regions with a generous solar resource, such as those of western Argentina, adequate design and technology can substantially reduce the energy demand for space and water heating in urban buildings. The solar potential of low-density residential urban areas in the city of Mendoza's Metropolitan Area (MMA), has been studied earlier in this research [1]. Several indicators of the solar potential were elaborated. They provide necessary information when planning and designing new urban structures or refurbishing existing ones. However, a more direct indicator, relating the available solar radiation during a heating season to the space volume to be heated, the Volumetric Insolation Factor (VIF), seems to be of most practical use as far as contributing a helpful evaluation indicator, to the above mentioned design processes. The present study follows the methodological steps used in the former research, evaluating comparatively the results of a Graphic-Computational Model and a Multiple Linear Regression Statistical Model. As in the earlier study, the good fit of both models' results clearly point at the reliability of the statistical procedure and its valuable contribution of a simplified calculation tool as its by-product.

1. Introduction

Many studies have evaluated the interrelationship between urban form and energy use [2–8]. Energy consumption in urban environments can roughly be divided in two main sectors: transportation and buildings. The energy consumed by the building sector is mainly dependent on the conditions of urban climate and the micro-scale of the city's inner structure, mainly the configuration of neighbourhoods, urban spaces and morphology (design) and materials (technology).

While constant advances in energy-efficient building technology have provided significant and well known contributions to energy conservation, progress in urban morphology has been more complex, limited and conflictive [9–11]. Physically, economically and legally feasible alternatives are required to minimize energy waste and maximize the potential use of renewable energies, namely, solar radiation in urban buildings [12–14].

The features of the reference urban environment in MMA provided the justification for the research, given the present unsustainable situation of energy use in Mendoza's urban building sector. They have extensively been dealt-with in the previous paper [1] and will be only summarily addressed in this presentation. It is however necessary to emphasize the importance of the Volumetric Insolation Factor on north facing walls (VIF_{nw}) (space heating) and on horizontal roofs or horizontal projection of tilted roofs (VIF_{hr}) (domestic water heating), as the most expressive and useful indicator relating the energy demand for space and water heating and the actual insolation of the building components performing as potential solar collectors.

2. Reference situation and methodology: synthetic overview

2.1. Site and climate

MMA, an urban conglomerate of nearly one million is settled on the mid-latitude (−32.86) arid region of central-western Argentina. Presently low-density urban environments account for almost 90% of the urbanized land area.

It features a mesothermal arid climate (1384 heating DD, base 18 °C; cooling DD: 163, base 23 °C) with intense solar radiation throughout the year (18.06 MJ/m^2 day) (Figs. 1 and 2).

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Fig. 1. Mendoza's metropolitan area aerial view.

2.2. Methodology

Since the methodological development of this research has been informed in the previous publication [1], it was considered necessary to present here only a short synthesis of it, in order to ease the comprehension of recent studies results, presented for the first time in this paper with greater degree of detail, particularly on the statistical procedures used. The already published stages have been:

Definition of a set of urban and building morphological variables, for the analysis of their incidence on the access to the solar resource in urban buildings. The urban city-block is taken as analysis unit.

The variables considered in the analysis can be grouped into two main types: urban and building. The urban variables included: city-block shape, city-block orientation, vial channels width and urban forest features; these including: magnitude, solar permeability of trees and completeness of tree stocks per unit. The building variables included: morphology (homogeneily/heterogeneily), form factor (FF), soil occupation factor (SOF), and total occupation factor (TOF) [15].

The last 3 (three) variables were calculated as the sum of the total built-up areas on a city-block as if dealing with a single building (Table 1).

The data collection procedure included: official cadastral files, satellite images, on-site photographic survey of units, photo digitalization and integration of 3D models, with and without the inclusion of the urban forest. The determination of the representativity degree of the analysis units was performed through the use of a statistical procedure and their spatial distribution through a random routine. A set of 32 analysis units (city-blocks) was finally determined.

Fig. 2. Typical downtown forested street.

The actual insolation of building volumes (north facing façades and roofs) were calculated through the use a graphic-computational model for the two situations relating the inclusion of trees. Detailed data of seasonal crown's permeability for tree species was considered (Figs. 3 and 4).

Determination of the collecting area (CA) for direct gain: The potentially available CA (m^2) for space heating is the effectively insolated net glass area of north facing façades ($+/-$ 15°). The glazed surfaces that receive shadows cast by solid elements (neighbouring buildings) and by permeable masses (trees) are deducted and the reduction percentages due to sash mullions, security bars and side frames (-25%) are taken into account as well. (Fig. 5)

Energy calculations for solar space heating were performed for the present situation, without changes and a target theoretical situation after solar refurbishing of all sample units. The Load Collector Ratio (LCR) method of Los Alamos National Laboratory (LANL) was used.

3. Solar indicators

A numerical indicator relating urban morphology and heated space volume of analysis units was developed:

3.1. Volumetric insolation factor (VIF)

Expresses the relationship between the total net energy impinging on unmasked north facing vertical surfaces ($+/-$ 15°), during a heating season, and the total space volume to be heated. The indicator is probably the one that best describes the space heating solar potential through passive solar systems, particularly Direct Gain, in Mj/m^2 year. Its mathematical expression is:

$$\mathbf{VIF} = \frac{\sum_{m:4}^{08} \sum_{d:1}^{30} \sum_{h:9.30}^{14.30} [[\mathrm{TCA} - (\mathrm{SMA} + (\mathrm{PMA} \cdot (1 - P)))] \cdot R]}{\text{Volume to be heated}} \tag{1}$$

Where:

TCA: Total potentially collecting areas of north facing façades (m^2)

SMA: Solid masked area (buildings): potentially collecting façade shaded by neighbouring buildings (m^2).

PMA: Permeable masked area (trees): potentially collecting façade shaded by urban trees, the typical permeability values of each species are applied to determine the actual collecting area (m^2).

P: Permeability factor: solar permeability percentage of each species (%).

R (m-d-h): Daily mean solar radiation on north façades for each month the heating season (Wh/m^2). number of heating months (n), d: number of days per month (5), h: number of hours per day (Fig. 6).

These values include the diffuse radiation (considered isotropic) as a function of the sky view factor and the reflected radiation from the immediate environment as a function of urban morphology and its corresponding albedo. Recent literature on related studies for the development of this stage is currently being consulted [16–19].

4. Results

VIF values are presented on Table 2 for the 32 selected analysis units. Existing urban morphology configurations that allowed