

578: Spanish-American Urbanism Based on the Laws of the Indies: A Comparative Solar Access Study of Eight Cities

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Abstract

The Spanish establishments in America were located in a vast territory between southernmost American continent and California. It can be considered as one of the greatest construction processes of planned cities in the history of the humanity. Although for more than three hundred years a great number of cities were constructed on very different territories and cultural atmosphere, all of them present common elements due to the existence of an urban pattern regulated by the Laws of the Indies.

The basic urban layout consisted of a grid formed by parallel streets in whose center the main public space was located. The most representative buildings, the City Council, the church and the main market were constructed around this square in which the most important activities of the city took place. Different variations and proportions with respect to this model existed.

In this paper the incidence of solar radiation in the original urban layout of eight cities has been studied using the software Ecotect. The obtained data have been classified as a function of the latitude of the cities. With this criterion, graphs have been made that allow us to compare the incidence of solar radiation in all the cities based on the orientation of the urban layout (45° intervals) and width-to-height ratio of the streets.

The results allow us to establish criteria about the most advisable orientation and proportion of the streets according to the case.

Keywords: urban street layout, environmental design, Laws of the Indies

1. Introduction

Most of the literature shows that the primary climate-control mechanism is the city layout. The street can be seen as the interface of architectural and urban scales as it consists of the shared surfaces between the building and the open urban canopy [1].

The influence of urban geometry on building heat losses, or the demand for cooling, is of direct relevance to energy conservation [2, 3]. We have to take into account that the width-to-height ratio and street orientation with respect to the sun were found to have a great influence on the amount of both incoming and outgoing radiation [4].

In general terms, a densely packed urban fabric tends to reduce solar penetration into narrow streets [5] but may result in "trapping" of both short-wave [6] and long-wave radiation [7]. As a result, the main difficulty faced by the planner in the design of a street is the conflict between seasonal needs. Indeed, the necessary protection from the sun in the summer and the need for solar access in the winter implies, theoretically, compactness and openness to the sky, respectively.

When starting to consider such a question, it is easy to become overwhelmed by the vast range of possibilities and special cases. These are associated with the almost infinite combination of different climatic contexts, urban geometries,

climate variables and design objectives. Obviously, there is no single solution or a universally optimum geometry.

In the case of Spanish-American urbanism, a global legislation existed with the aim of regulating the planning of cities during the colonization process. Known as the Laws of the Indies, they were promulgated by Felipe II in 1573. The text, based on some previous regulations applied during the first 70 years of the America colonization, was influenced by the renaissance treaties of Vitruvio and Alberti. It constitutes one of the first city planning texts of the Modern Age.

The document is constituted by 148 ordinances grouped in three sections. In the second one, the dimension and disposition of the urban elements is regulated. The proposed model consists of a regular and ordered layout with a central square, known as *Plaza*, from which the streets leave as an orthogonal grid that can have a limitless growth. This urban disposition had as Spanish precedents, the Ordinances of Jaime II, king of Mallorca (1300), the Theoretical City of Exiemenis (1385) and medieval cities with a military origin, like Santa Fe (1492).

There are some references in the Laws to the adaptation of the urban layout to the local environment. They say in particular that "the four corners of the main square must look at the four dominant winds in order to avoid that the streets from the square were exposed to the wind"

(Ordinance 114) and " the streets in cold places must be wide and in the hot ones narrow" (Ordinance 116). Following the proposed model, 911 cities were constructed until 1810 [8]. Although they do not comply with each ordinance in detail, all of them present similar reticular pattern, articulated from the *Plaza*. Cities which follow the Spanish-American urban pattern, as they are located in different climatological contexts, offer different responses to environmental demands. However, the study of the relationship between different climatological and geometrical possibilities is potentially helpful to assist in the formulation of urban design guidelines.

2. Methodology

This paper aims to describe the mutual interaction between urban geometry and incident solar radiation in eight cities in which urban planning follows the Laws of the Indies.

The original urban layout of the Spanish precedents of Palma de Mallorca and Santa Fe have been studied, along with the American cities of Buenos Aires, Lima, Caracas, Santiago de Cuba, Mexico and Los Angeles (Figure 1). These settlements were founded at different times during the colonisation process and they are located in a wide range of latitudes, from 34.82 S to 39.55 N.

The width-to-height ratio and street orientation with respect to the sun have been found to have a great influence on the thermal street environment [9]. Ecotect software was used to calculate the incident solar energy on the surfaces which delimit the urban space in all of its possible orientations at intervals of 45° at both the winter and the summer solstice. The influence on street shading of the width-to-height ratio of the streets has also been analysed, since it has a great influence on the urban climate and outdoor thermal comfort [10].

In order to compare and draw conclusions from the results obtained, the examples analysed have been classified by latitude. To do so, all of the cities were treated as if they were located in the northern hemisphere. In this way, the cities located south of the equator (Lima and Buenos Aires) were treated as if they were in the northern hemisphere at the same latitude and, therefore, reference to the northern façade, really refers to the south, and vice-versa.

Comparative tables were drawn up to analyse the incidence of solar radiation on different orientations during the winter and summer solstice and the relationship between the values obtained in both cases. The influence of the width-to-height ratio of the streets was also analysed.

3. Incident solar radiation in winter

Figure 2 shows the incidence of daily solar energy (kWh/m²day) during the winter solstice as a function of the orientation (intervals of 45°) in the cities analysed, ordered by latitude. The following can be deduced from the results obtained:

- In all cases, a south-facing orientation is that which receives most solar energy. The highest value is seen in the tropics, when the latitude is equal to the maximum declination (23.5). This is due to two opposing factors: the increased height of the sun and its reduced angle of incidence on vertical surfaces nearer the equator.
- The SE/SW façades are those which receive most sunlight after the south-oriented façades. It was observed that the loss of energy due to the 45° rotation with respect to the south was not very significant. This relationship decreased with the latitude. The lowest percentage of energy lost in the SE/SW orientation with respect to the south was seen, therefore, in Caracas (8.7%), while in

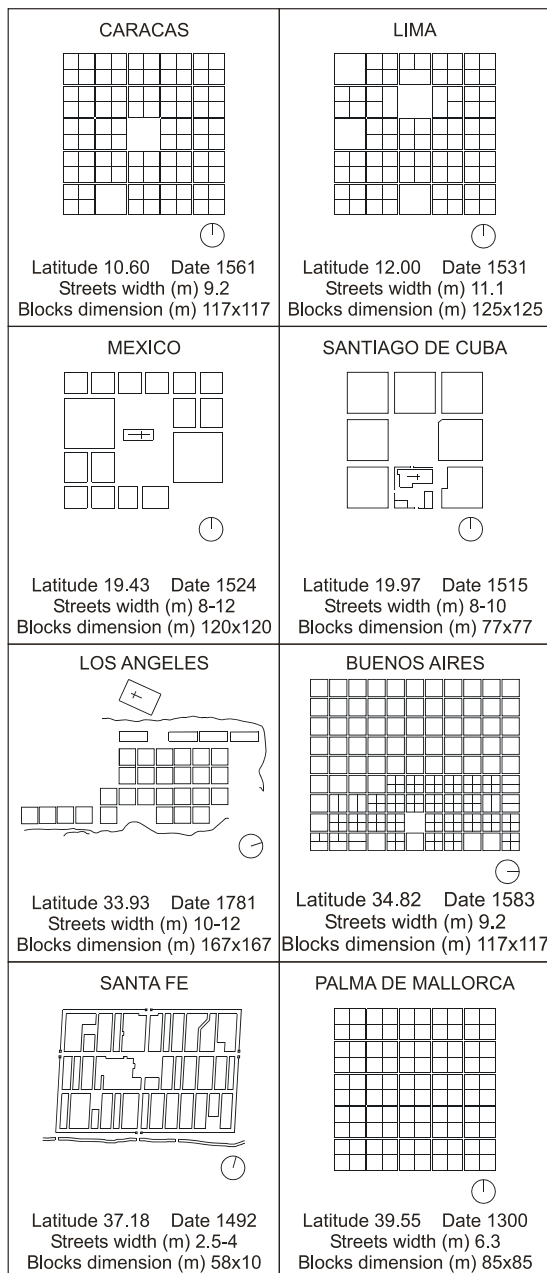


Fig 1. Original urban layout of the selected cities, latitude, date, streets width and blocks dimension

Palma de Mallorca, the percentage was not much higher (25.6%). However, in the case of an E/W orientation, the reduction of radiation with respect to south was considerable. The maximum was seen in Palma de Mallorca (67%), and the lowest value in Caracas (34.95%). The façades receiving least solar radiation were NE/NW followed by N.

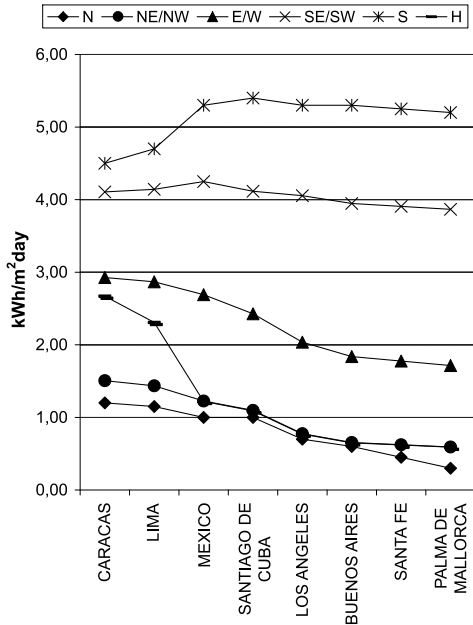


Fig 2. Comparison of incident solar radiation on urban surfaces of the different cities as a function of the orientation (45° steps), winter solstice

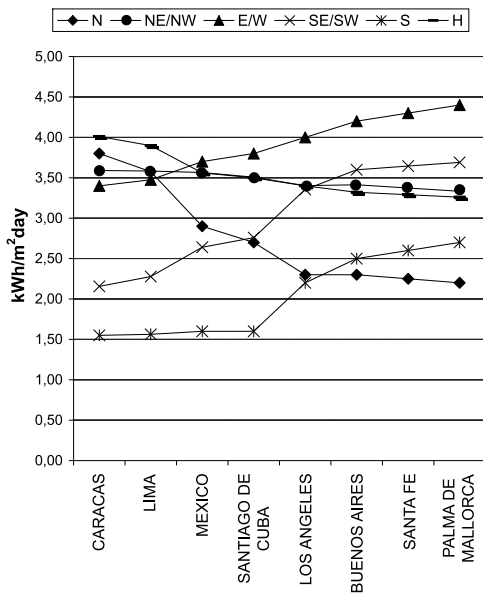


Fig 3. Comparison of incident solar radiation on urban surfaces of the different cities as a function of the orientation (45° steps), summer solstice

4. Incident solar radiation in summer

The analysis of solar energy captured during the summer solstice (Figure 3) shows that:

- The N and S façades received least sunlight in higher latitudes. However, closer to the equator, especially in latitudes lower than the Tropic, the more energy was captured on the N façade, increasing significantly to the point that it even became the vertical surface which received most sunlight.

- In higher latitudes, the E/W orientations were those which received most solar radiation. Therefore, in these cases they were the least favourable façades in summer. Nevertheless, the incident energy on said orientations decreased slightly to the point, in latitudes close to the equator, that it was exceeded by the incident radiation on the N/NE/NW façades.

5. Incident solar radiation in winter with respect to the summer

The results shown in Figure 4 demonstrate that:

- The orientation which receives most solar energy during the winter solstice, compared with the summer solstice, is always the southern façade, followed by SE/SW. However, as the latitude decreases, the temperatures are higher and more stable during the year, in some cases it is unnecessary to capture energy during the winter solstice. Therefore, discussion of this aspect should be taken as a function of the latitude and local climate in each case.

- NE-SW and NW-SE orientations seem to be a good compromise, as they are nearly as efficient as N-S streets in the summer in terms of outdoor comfort. At the same time, they allow a greater degree of exposure of the façades to sunlight in the winter than the N-S orientation. This issue, however, falls outside the scope of this paper and deserves to be thoroughly investigated in further studies.

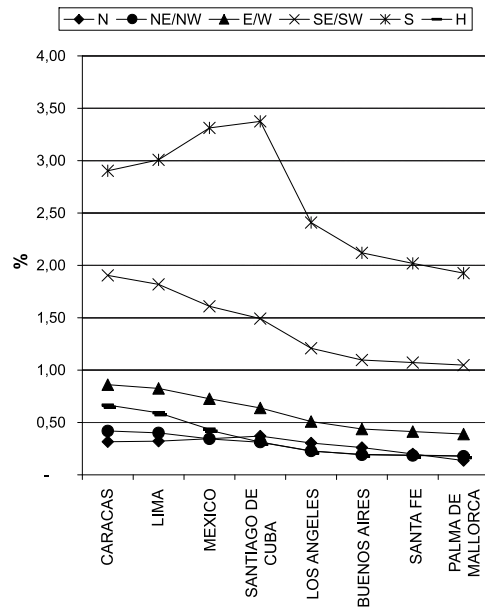


Fig 4. Comparison of incident solar radiation on urban surfaces of the different cities as a function of the orientation (45° steps), winter solstice / summer solstice ratio

6. Incident solar radiation as a function of the width-to-height ratio of the streets

A compact urban form with very deep streets gives good protection during the summer as such a design results in lower temperatures (cool islands) and provides shade for pedestrians during the warmest hours of the day. A dispersed urban form, on the other hand, was shown to create an extremely uncomfortable environment in the summer. However, there are also disadvantages to a compact urban form, especially lower exposure to sunlight in winter in cold climates.

- In cases where it is desirable to capture sunlight in winter, it is necessary to study the width-to-height ratio of N-S oriented streets in order to guarantee that there are no excessive obstructions to sunlight on the southern façade, since this is the orientation which receives most solar radiation in winter (Figure 5).

- In E/W orientations, the inclination of the sun's rays is lower due to the fact that exposure occurs at sunrise and sunset. In this case, the reduction of the width-to-height ratio of the streets has a greater effect on the reduction of incident radiation. It was observed that, at higher latitudes, where exposure to sunlight in the E-W orientation was greater in summer and therefore less advisable, it is when shading of the sun could most effectively be achieved (Figure 6). The reduction of energy in the winter solstice would not be a great disadvantage since, as observed previously, the level of radiation is not very high.

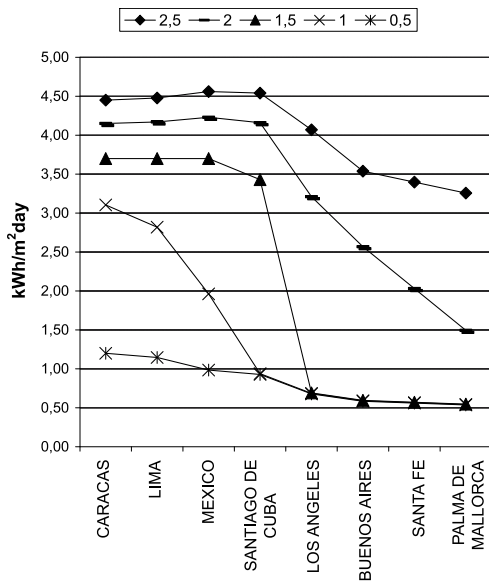


Fig 5. Comparison of incident solar radiation on south oriented surfaces of the different cities as a function of the width-to-height ratio of the streets, winter solstice

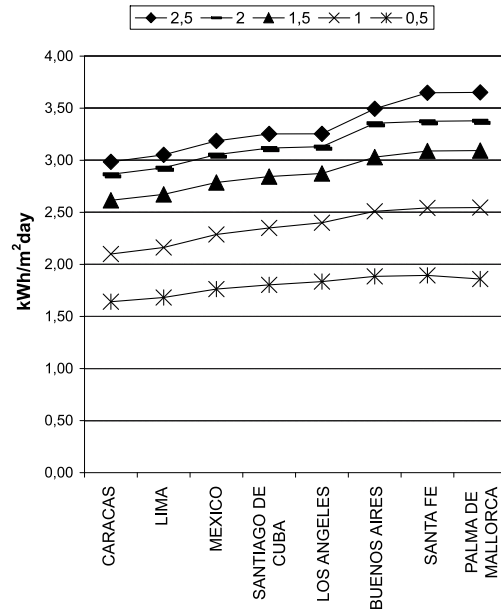


Fig 6. Comparison of incident solar radiation on E/W oriented surfaces of the different cities as a function of the width-to-height ratio of the streets, summer solstice

7. Conclusions

The effect of solar radiation on the urban layout is very different, depending on how close or far the location lies to the equator and, in some cases, the effect can even be the opposite. Consequently, in order to discuss the results obtained, the cities were classified by their latitude into two groups, taking the latitude of the tropics (23.5) as the dividing line. This line should not be taken as a rigid limit, but rather as a reference point as regards the evolution of the distribution of solar energy between mid-latitudes and subtropical latitudes. We shall now comment on each situation separately.

7.1 Mid-latitudes

Compact urban forms are known to be well adapted to the summer climate [11, 12]. However, if there is a cold season, the urban design should include some wider streets to provide solar access. This is the case of Los Angeles, Buenos Aires, Santa Fe and Palma de Mallorca. South-facing walls are preferred for optimal solar gains, however, the most appropriate width-to-height ratio should be studied as a function of the specific climate of each case.

Wider streets which function as sun-spots in the winter require solar protection at pedestrian level in the summer. This can be achieved through shade provided by trees, projection of the upper floors, arcades or any other type of horizontal shading device designed in such a way that they allow solar radiation to penetrate in the winter while providing shade in the summer. Vegetation may also be used as an additional shading device that can further improve the thermal environment of the street [13].

NE-SW and NW-SE orientations are alternatives as they offer some exposure to the sun in winter and allow easier solar control on the walls in summer. Although not as optimal as the south orientation, these intermediate orientations offer advantages as regards outdoor comfort which must also be considered.

East and west orientations capture some solar radiation. However, they require carefully detailed designs to prevent overheating in the summer. It would be useful to establish a maximum width-to-height ratio for E-W oriented streets in order to guarantee a significant reduction of solar gain. In winter, the loss of solar energy would not be significant, since solar warming on these façades is low, even for very high width-to-height ratios.

7.2 Subtropical latitudes

In Caracas, Lima, Mexico and Santiago de Cuba, the solar energy received in the summer solstice on N/NE/NW/E/W orientations is very similar, with values significantly higher than the incident energy on S/SE/SW façades. On the other hand, in the winter solstice, S/SE/SW surfaces are the sunniest and they show very uniform values. It can, therefore, be deduced that, in the annual energy count, the orientation of the urban layout is less critical than in mid-latitudes.

As the trajectory of the sunlight is very high, if wide streets are planned, shading strategies should be implemented directly at street level, such as galleries, arcades or rows of trees. Due to the verticality and uniformity of the movement of the sun, any type of horizontal shading device produces very effective, stable shading. The same occurs with glazed openings or façades, where it is advisable to design horizontal elements that project out from the façade (overhangs, cornices).

It is especially difficult to mitigate heat stress in N-S oriented streets since, as the sunlight falls during the central hours of the day, the walls provide only limited shading, even in very narrow streets. For the same width-to-height ratio, the rotation of the street to a NE-SW or NW-SE orientation leads to better comfort conditions, as the shading afforded by the walls is more effective in these cases.

The aim of this paper is to stimulate discussion of the mutual interaction between incident solar radiation and the urban layout of the selected cities. We think that the study of the obtained results in relation to the climatic characteristics of each city, can serve to formulate specific urban design guidelines governing street dimensions and orientations and is, therefore, a further subject for investigation.

8. Acknowledgements

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