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HUMAN BIOCLIMATIC ATLAS FOR SPAIN PRESENT AND FUTURE IN THE FACE OF CLIMATE CHANGE

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Abstract: This study presents bioclimate maps of Spain, focusing on the thermophysiological well-being of humans and comfort for each month of the year. The hygrothermal comfort in each location was obtained using climatic data from the period 1981-2010, provided by the State Meteorological Agency (AEMET, 2022). Since these are the most recent data, they are designated as current or present. For the prospective scenario for 2050, the climatic data were generated using the Meteonorm program to assess the impact of climate change on the bioclimate. The selected study locations correspond to those recorded at 40 meteorological stations, distributed throughout Spanish territory, representing all climates in the country. The climatic data from AEMET consist of monthly averages of maximum, mean, and minimum temperatures, as well as relative humidity. To conduct the bioclimate study, hourly mean temperature and relative humidity data were estimated from the monthly data (Biosol, 2013). Using the monthly data and the equation proposed by Auliciems (1981), the thermal comfort zone for humans was defined, adapting the bioclimatic diagram of Olgyay (1963) for each month of the year in the various study locations, determining the hourly mean thermal sensation for each month. Based on the data, bioclimate diagrams were created to represent the perception of cold, heat, and comfort. These diagrams were the used to create maps representing the predominant thermal sensation in the regions of Spain for each month of the year. These maps can inform the design and bioclimatic adaptation of existing buildings to achieve energy efficiency in building climate control, with appropriate passive systems for necessary bioclimatic strategies, as informed the bioclimate studies.
Keywords: bioclimate, atlas, Spain, bioclimatic design, thermal comfort, and buildings.

INTRODUCTION

The primary objective of this study is to contribute to the analysis of Spain's bioclimate, aiming to provide a foundation for designin energy-efficient constructions. The research will facilitate the development of an atlas, aiding architects and engineers in defining bioclimatic strategies to leverage or shield buildings from the climate, utilizing it as a source of renewable energy for climate control. Consequently, the implementation of passive systems could potentially reduce energy consumption in buildings associated with climate control, by utilizing external environmental conditions for natural conditioning.

Given the climate crisis we are facing, it is essential to emphasize the significance of this preliminary analysis before the construction of new buildings. There is an increasing need for buildings to be more sustainable and move towards zero emissions. Therefore, this work analyzes the conditions of thermal comfort and discomfort throughout the Spanish territory over the course of the year.

Bioclimate is defined as the combination of meteorological elements that influence the physiological well-being of people (Hernández, 1984). This study presents maps of current bioclimate analysis and projections for 2050 for Spain, allowing the determination of current conditions and comparison with changes due to climate change. For the 2050 projection, representative concentration pathways (RCPs) reported in the IPCC reports (2014) were considered. The RCP 2.6 scenario represents the most optimistic prediction, where measures taken by governments to mitigate emissions would lead to a reduction in greenhouse gas emissions released into the atmosphere. On the other hand, the RCP 8.5 scenario depicts a situation where levels of atmospheric pollution continue to rise followings current trends.

National-level bioclimate studies have not been conducted, or are not available in search engines accessible to the general public. However, there are precedents for studies on a smaller scale, carried out in specific localities or provinces. Examples include the study by Rodríguez Algeciras and Matzakaris (2016) for Barcelona and that of Pérez, Ladrón de Guevara, and Boned (2015) for the Malaga Costa del Sol. Furthermore, on a larger scale, Giannaros et al. (2018) examined the bioclimate of the European Mediterranean area as a comparative study of Southern European countries.

METHODOLOGY

The methodology followed for the study of bioclimate was proposed by Morillón (2004), which was based on the bioclimatic chart by Olgyay (1963), Auliciems (1990), etc. The process was carried out using the Biosol software (2013). In this program, bioclimate analysis was conducted using minimal available meteorological information, such as average maximum and minimum temperatures.

CLIMATIC INFORMATION

The analyzed locations (see figure 1) were chosen based on the availability of meteorological stations from AEMET, while also considering criteria such as population importance, tourism, and/or cultural significance. The goal was to uniformly cover the entire national territory, representing all climates of Spain according to the Köppen classification as documented in the Iberian Climate Atlas (AEMET-IM, 2011).

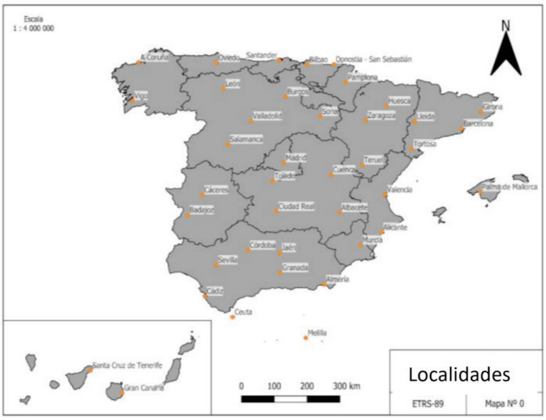

Figure 1. Location of meteorological stations in the studied regions (author's own elaboration).

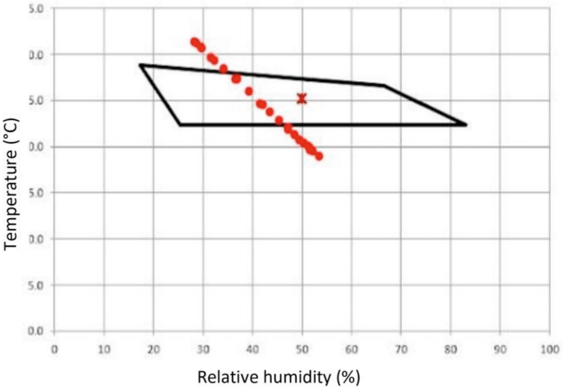

Figure 2. Bioclimatic chart adapted from Olgyay for the month of August in Madrid.

From the study locations, climatological information was obtained from AEMET (2022). The World Meteorological Organization determines that a location's climate is determined by the average of climatological values during the period 1981-2010. Thus, monthly averages of relative humidity, as well as maximum and minimum temperatures, were taken from each location. For the 2050 projection, representative concentration pathways (RCPs) reported in the IPCC reports (2014) were considered. The RCP 2.6 scenario represents the most optimistic prediction, where measures taken by governments to mitigate emissions would lead to a reduction in greenhouse gas emissions released into the atmosphere. On the other hand, the RCP 8.5 scenario is one in which levels of atmospheric pollution continue to rise with the current trend. For the prospective scenario in 2050, and the two RCP conditions, data were obtained using the Meteonorm software for each location in Spain.

Bioclimate study Based on monthly average ambient temperatures, hourly average temperatures were calculated for each month using the procedure of Tejeda and García (2002). Additionally, with the monthly mean temperature ($\bar{T}$), the temperature of the center of the comfort zone (T_n) is determined according to the equation of Auliciems (1981).

$$T_n = 17.6 + 0.31\bar{T}\ [°C] \qquad (1)$$

With a relative humidity of 50% (ASHRAE, 2023), and the T_n adapted from the comfort zone on Olgyay's chart (1963), the analysis of hygrothermal comfort conditions is then conducted by observing these charts (see Figure 2). Thus, having the average temperature and relative humidity for each hour of the month, it is associated with a thermal sensation (warmth, comfort, or cold). The red dots represent each hour and correspond to environmental conditions experienced by a human, such as thermal comfort or discomfort. Points within the comfort zone correspond to thermal comfort conditions, those above the comfort zone correspond to the sensation of warmth, and points below it to cold. All this information is compiled into a bioclimate study diagram (see Figure 3). It illustrates the predominant thermal sensation in a location for each hour and month of the year.

Map elaboration: To create the database used to generate the maps, a single thermal sensation for each month needs to be determined. For this purpose, the prevailing sensation during daylight hours was selected, as this is experienced by the inhabitants of a location. By correlating the base thermal sensation per month across all study locations, bioclimate information will be represented in a geographic information system. The map used is provided by the National Center for Geographic Information (CNIG, 2022), which also outtlines the division by autonomous communities.

The analysis of the bioclimate study diagram allows for the specification and quantification of hours of comfort, warmth, and cold in a location. In the case of Seville (see Figure 3), it can be observed how throughout the year, this city would experience warmth for 11.46% of the year, during which buildings would require cooling or air conditioning, and 64.58% of cold, requiring heating. However, the remaining 23.96% of the time, the comfort conditions of the environment can be utilized to climate-control the buildings.

BIOCLIMATE ATLAS IN SPAIN

The bioclimate atlas of Spain consists of 12 maps, one for each month, showing or presenting the predominant thermal sensation in each area of the country throughout the year, for current conditions and scenarios in 2050, for RCP 2.6 and 8.5.

APPLICATION

The analysis of these maps allows us to observe which thermal sensation predominates in each location and for each month of the year. Due to Spain's location at latitudes far from the tropics, the transition of seasons is clearly marked. Thus, the winter months are generally characterized by a sensation of cold. Spring is marked by comfort, which extends from south to north across the peninsula. It is not until June that warmth is observed, peaking in August, which is the hottest month in the country (65% of the analyzed locations experience warmth during this month). In September, temperatures drop, leading to

Hour/Month	January	February	March	April	May	June	July	August	September	October	November	December
00:00	-1	-1	-1	-1	-1	-1	0	0	-1	-1	-1	-1
01:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
02:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
03:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
04:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
05:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
06:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
07:00	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
08:00	-1	-1	-1	-1	-1	0	0	0	-1	-1	-1	-1
09:00	-1	-1	-1	-1	0	0	0	0	0	-1	-1	-1
10:00	-1	-1	-1	-1	0	1	1	1	0	-1	-1	-1
11:00	-1	-1	-1	0	0	1	1	1	0	0	-1	-1
12:00	-1	-1	0	0	0	1	1	1	1	0	-1	-1
13:00	-1	-1	0	0	0	1	1	1	1	0	-1	-1
14:00	-1	-1	0	0	0	1	1	1	1	0	0	-1
15:00	-1	-1	0	0	0	1	1	1	1	0	0	-1
16:00	-1	-1	0	0	0	1	1	1	1	0	0	-1
17:00	-1	-1	0	0	0	0	1	1	1	0	0	-1
18:00	-1	-1	-1	-1	0	0	1	1	1	0	-1	-1
19:00	-1	-1	-1	-1	0	0	0	1	0	0	-1	-1
20:00	-1	-1	-1	-1	-1	0	0	0	0	0	-1	-1
21:00	-1	-1	-1	-1	-1	0	0	0	0	-1	-1	-1
22:00	-1	-1	-1	-1	-1	0	0	0	0	-1	-1	-1
23:00	-1	-1	-1	-1	-1	-1	0	0	0	-1	-1	-1

-1	FRÍO	0	CONFORT	1	CALOR

Figure 3. Diagram of the current bioclimate study of Seville.

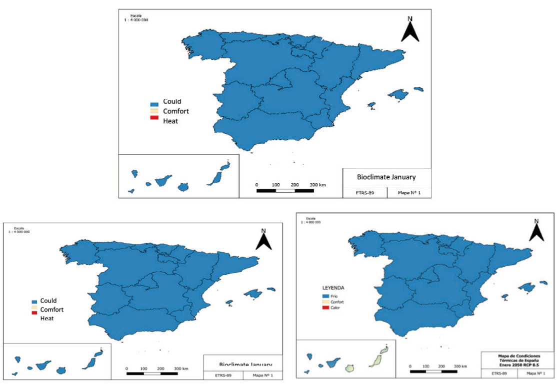

Figure 4. Bioclimate of Spain for January; current and in 2050 (RCP 2.6 and 8.5).

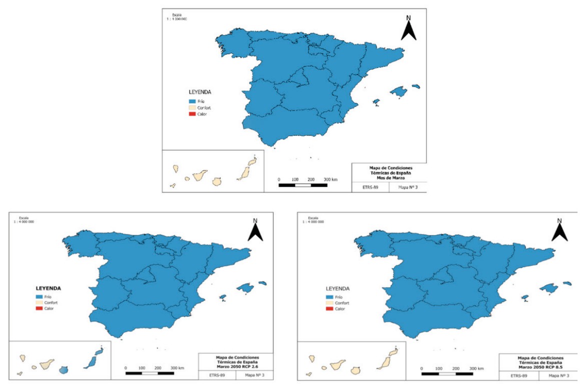

Figure 6. Bioclimate of Spain for the month of March; current and in 2050 (RCP 2.6 and 8.5).

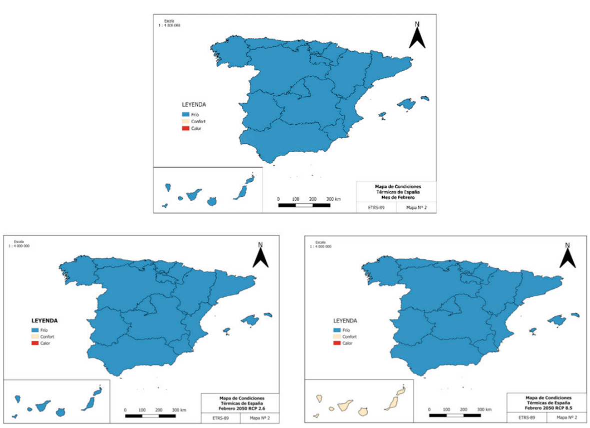

Figure 5. Bioclimate of Spain for February; current and in 2050 (RCP 2.6 and 8.5).

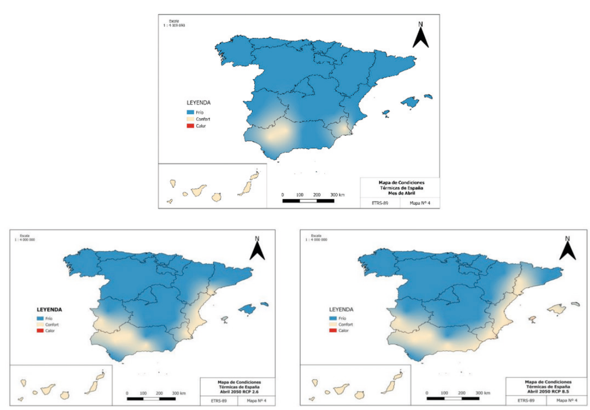

Figure 7. Bioclimate of Spain for the month of April; current and in 2050 (RCP 2.6 and 8.5).

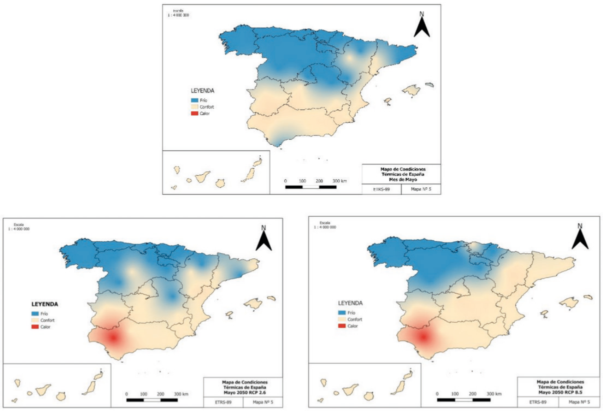

Figure 8. Bioclimate of Spain for the month of May; current and in 2050 (RCP 2.6 and 8.5).

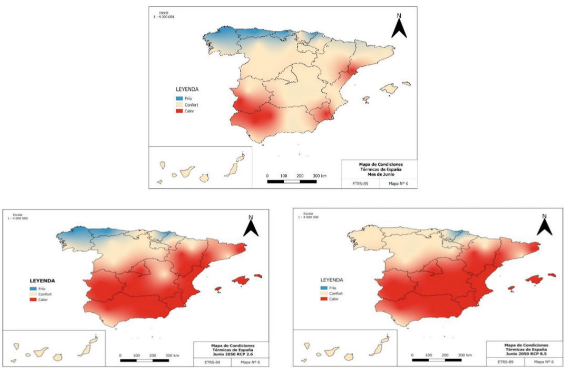

Figure 9. Bioclimate of Spain for the month of June; current and in 2050 (RCP 2.6 and 8.5).

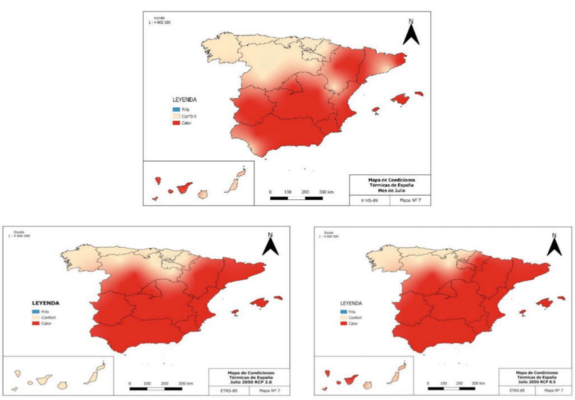

Figure 10. Bioclimate in Spain for the month of July; current and in 2050 (RCP 2.6 and 8.5).

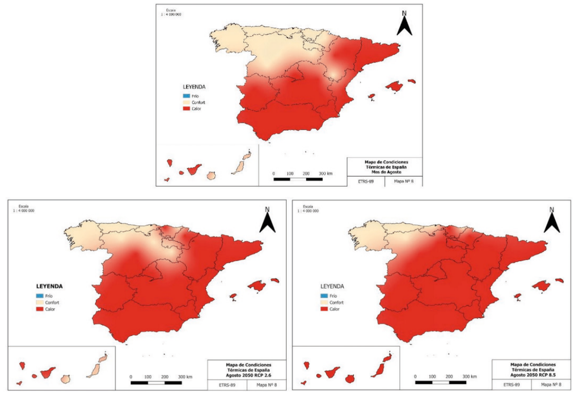

Figure 11. Bioclimate in Spain for the month of August; current and in 2050 (RCP 2.6 and 8.5).

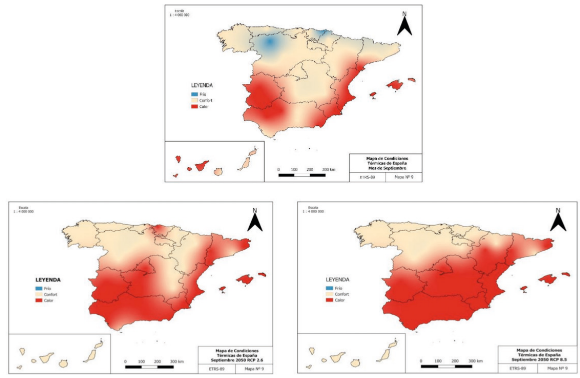

Figure 12. Bioclimate in Spain for the month of September; current and in 2050 (RCP 2.6 and 8.5).

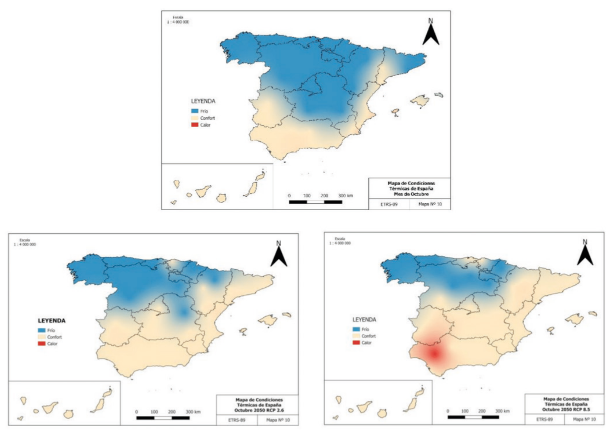

Figure 13. Bioclimate in Spain for the month of October; current and in 2050 (RCP 2.6 and 8.5).

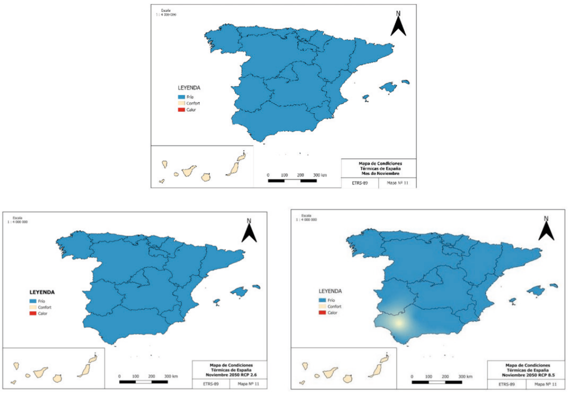

Figure 14. Bioclimate of Spain for the month of November; current and in 2050 (RCP 2.6 and 8.5).

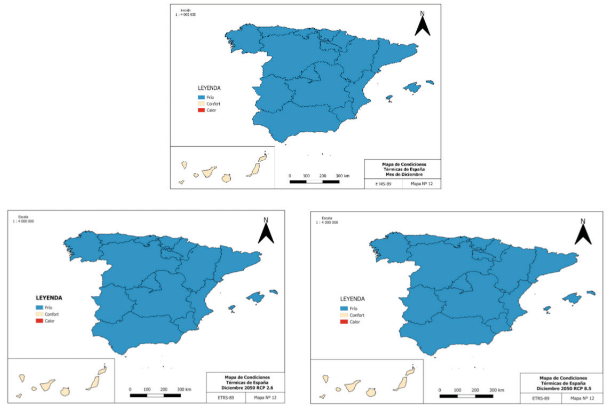

Figure 15. Bioclimate of Spain for the month of December; current and in 2050 (RCP 2.6 and 8.5).

a sensation of cold until winter arrives. It is worth noting the case of the Canary Islands, which, being situated to the south in the Atlantic Ocean off the African coast, enjoy a much more comfortable climate. Throughout the archipelago, comfort is the prevailing thermal sensation throughout the year, at 70.83%. With the exception of 16.67% of the time when it is cold and only 12.5% when it is warm, not on all islands.

The analysis of this atlas allows for determining the impact of climate change on the current and future bioclimate in Spain. In this way, it is possible to anticipate how and where there will be an increase in the energy consumption required for building climate control.

CONCLUSIONS

Understanding the thermal sensation of a location throughout the year, using the bioclimate atlas of Spain, will enable the utilization of environmental or climatic conditions for the thermal conditioning of buildings. It also allows for the identification of cooling and heating needs of Spanish buildings according to their respective regions. Moreover, it facilitates analysis to determine which locations may experience higher or lower energy demand due to climate variations.

Importantly, conducting bioclimate analysis prior to the construction of new buildings is crucial for achieving sustainability and reducing energy consumption. The application of bioclimatic strategies in building design, based on the conditions observed in the atlas with climate projections up to 2050 for RCP 2.6 and 8.5, will help decrease expenditure on climate control, a significant portion of buildings overall consumption. Proper design and adaptation of existing buildings enable natural climate control.

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REFERENCES

AEMET, (2022), Consultado en: http://www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos

AEMET – IM (2011), Atlas Climático Ibérico

ASHRAE (2023), Handbook, Online, https://www.ashrae.org/technical-resources/ashrae-handbook

Auliciems, A (1981), Towards a psycho-physiological model of thermal perception, International journal of biometeorology, jun, 25(2), 109-22

CNIG, (2022), Consultado en: https://centrodedescargas.cnig.es/CentroDescargas/catalogo.do?Serie=CAANE

Giannaros T, Vassiliki K, Lagouvardos K. at al, (2018), Climatology and trends of the Euro-Mediterranean thermal bioclimate, International Journal of Climatology, Volume 38, p. 3290-3308.

Hernández H. Everardo (1984), A, B, C de la climatización natural mediante uso directo e indirecto de la energía solar. Información Científica y Tecnológica. Vol 6, núm 93, México.

Intergovernamental Panel on Climate Change IPCC (2014), AR5 Reports: Climate Change 2014.

Meteonorm (Versión 8) [software]. (2022), Obtenido de: https://meteonorm.com/en/

Morillón D (1993), Bioclimatica: Sistemas pasivos de climatización, Ed. Universidad de Guadalajara, México

Morillón-Gálvez, D., Saldaña-Flores, R., & Tejeda-Martínez, A. (2004), Human bioclimatic atlas for Mexico. *Solar Energy*, *76*(6), 781-792.

Morillón D, Bahena DA, Muela A y Silva R (2023), Bioclima en ciudades de Iberoamerica ante el cambio climático proyectado al 2050: Atlas del bioclima de México, Colombia y España ante el cambio climático, Ed. CEMIEO, p. 376, México

Muela A, Morillón D, Resendiz O, Galindo M, García M (2022), Atlas del bioclima de España, Memorias del XLVI Semana Nacional de energía Solar, ANES, octubre, México

Muela A y Morillón D (2022), Atlas del blioclima de España Presente y Proyección al 2050, Congreso del CEMIEO, México.

Preciado Olvera, Oscar Ulises; Morillón Gálvez, David (2013), BIOSOL: Software para el estudio del bioclima, control solar e iluminación natural. Ingeniería de la Energía Solar para la Sustentabilidad, Instituto de Ingeniería de la UNAM, México

Olgyay, V. (1963), Design with climate. Princeton University Press, Princeton. 190 p.

Pérez J.L, Ladrón de Guevara I, Boned J. (2015), Incidencia del clima local en los procesos de planificación territorial. Análisis bioclimático de la Costa del Sol Occidental de Málaga (España), EURE. 187-210 p.

Rodríguez Algeciras, J.A., Matzarakis, A. (2016), Quantification of thermal bioclimate for the management of urban design in Mediterranean climate of Barcelona, Spain. *Int J Biometeorol* **60,** 1261–1270. https://doi.org/10.1007/s00484-015-1121-8

Tejeda, A, y García, O., (2002), A comparative simple method for human bioclimatic conditions applied to seasonally hot/warm cities of Mexico, Atmósfera, Revista del Centro de Ciencias de la Atmósfera, UNAM, 15(1), México