Building performance, climatic variables, and indices: identification of correlations for social housing across the Mexican territory

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ABSTRACT: Building energy codes rely on climate zoning to establish regional requirements and benchmarks for building performance. Nevertheless, there is neither an accepted methodology for this purpose nor a scientific agreement when considering variables that provide quantitative results. This paper explores the relationships between the environmental performance of a free-running housing prototype, simulated in 240 locations across the Mexican territory, and climatic variables :latitude, altitude, and diurnal range, as well as the climatic indices of continentality, oceanity, and aridity. Correlations were found and analysed through statistical methods to define the significance of the selected variables to be used to predict the effectiveness of a free-running dwelling. The simulation outputs were processed as the percentage of time in comfort and overheating/overcooling hours. The results proved that latitude and altitude had a stronger correlation than the diurnal range and the climatic indices which showed similar but inferior effect sizes for all cases. None of the obtained correlation effect sizes reached a strong significative value. The results demonstrate that the highest correlation values were from the variables of Latitude and Altitude, with both effect sizes within the moderate correlation range, therefore, these variables can be used as guidelines in the prediction of a general trend when predicting thermal comfort in free-running buildings.
KEYWORDS: Climate zoning, free-running buildings, Social housing, tropical climate

1. INTRODUCTION

As part of the global efforts to reduce CO^2 emissions, building energy efficiency programmes have been implemented across the world. Among the purposes of this programmes, is to regulate and distribute energy policies throughout territories using climate zoning as a mechanism. However, there is not an established method to do this. Previous studies have identified as many as 19 parameters as determining factors for developing criteria for climatic zoning methodologies for building energy efficiency applications. As a consequence, there is no consensus in which factors and how many of them should be included. Moreover, there is neither a correlation between the number of zones nor their sizes among countries [1], [2].

The most utilized zoning approaches have been developed in climates located at higher latitudes where active methods for heating and cooling are necessary means to create and maintain thermal comfort in building interiors. Consequently, the criteria in them are focused on energy-saving rather than proposing completely passive methods. The application of such methods becomes counterproductive when they are applied in warmer climates, such as the one in Mexico, where thermal comfort can be achieved by exploiting the bioclimatic potential.

Mexico occupies the 13th place in global territorial extension and it encompasses 14 of the 31 possible climates according to Köppen's climate classification. Historically speaking, vernacular architecture in the Mexican territory has been free-running, relying only on passive means to create thermal comfort. Nevertheless, nowadays due to the low quality of the novel social housing, there is a constant increase in the need and use of energy consumption for cooling purposes regardless of the mildness of the climate[3], and the fact that over 70% of the population suffers some kind of poverty [4]. This can be considered a consequence of impractical regulations, that excludes a pragmatic passive approach, as well as punitive measures or legislation to ensure its implementation.

The problem with the increasing use of Air Conditioning (A/C) is in part because of the socio-economical situation of the population, but mainly because of the wasted climate potential across the country. Recent research that evaluated the Mexican construction sector concluded that, on the longer-term, it is more profitable to make an energy-efficient modification to the building envelope of a dwelling, than the installation of an operational cost of an A/C unit [5], Other studies elaborated by [6]–[9] explore the energy-saving and bioclimatic potential of the territory through passive strategies, while further research made by [10], [11] conclude that even at the locations with the warmer climates and the most extreme conditions, there are effective and functional passive strategies to achieve thermal comfort. Moreover, it is also important to consider, that the United Nations Environment Programme (UNEP) has encouraged and suggested in different occasions the implementation and promotion of better building energy standards as means to reduce energy consumption [12], [13]

The most utilized climate zoning methodologies use different parameters such as climate variables, climate indices, and bioclimatic variables as indicators to characterize the climate. A climate variable is an average or an accumulative count of a specific variable such as temperature or rainfall. A bioclimatic variable is a value derived from a specific calculation of a climate variable through a certain period to characterize a specific aspect, such as maximum monthly temperature or a yearly diurnal index. A climate index is a value derived from a calculation involving different climate variables and/or bioclimatic variables within a formula to characterize and state the possible changes in a climate system through a location, such as continentality, oceanity, and aridity.

The objective of this paper is to explore the correlation between the environmental performance of a free-running dwelling and different selected parameters. These parameters are the variables of latitude and elevation, the bioclimatic parameter of diurnal range, and the indices of continentality, oceanity, and aridity. For a deeper analysis, two different versions for each climatic index will be analysed.

2. METHODOLOGY

The followed methodology was elaborated based on the work by [14] in which a set of climatic variables and indices were related to passive measures and further translated into design recommendations. For the present work, a reference building is considered, in a similar way it was done in the work by [15], [16] where a reference building was simulated in different locations and the results are used to create a zoning distribution.

As a first step, weather data from 240 locations was collected in the format of EPW weather files. The calculation periods for all the files covered a 20-year period for radiation (1991-2010) and 10 years for temperature (2000-2009). Despite the fact that all the locations were selected according to the official localization of weather stations published by the Mexican government [17], the information in them is comprised differently, 68 of them are fully equipped weather station, and the information from them is completely composed by on-site collected observations, 105 of them did not include solar radiation, therefore, these values were interpolated, and for the case of 67 of them it was not possible to obtain any data, thus the weather files were completely interpolated. All the interpolation work was done using the software Meteonorm 7.2. [18]In Figure 1, it is possible to appreciate a map of the Mexican territory with the location of the 240 weather station.

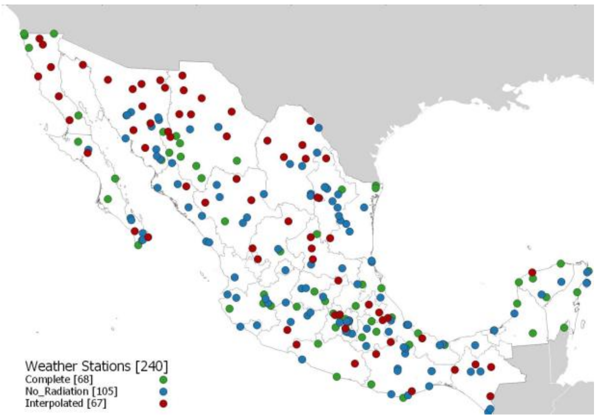

Figure 1: The location and types of the 240 weather stations where data was gathered.

As the following step, a reference building was established. The initial floor plan distribution, as well as the building envelope specifics, were taken from the Incremental Housing project elaborated by Studio Elemental [19]. The initial design of the project was originally conceived in 2003 considering Chilean socio-economic statistics for its dimensioning and constructive specifications, however, leaning on the fact that situation is similar across the Latin-American territory, in 2008 Studio Elemental created an adapted version for the Mexican context. A floor plan of the housing prototype is presented in Figure 2 and Table 1 provides a summary of the physical dimensions of the building.

Figure 2: Floorplan of the house prototype

Table 1: Physical dimensions of the housing prototype building

Area	54 m²
Perimeter	30.3 m
Volume	145.4 m³
Interior height	2.7 m
Window to Wall Ratio	0.25

Because of the predominant warmness and the tropicality of the country, the floor plan was modelled as a single and free-standing ground floor with no immediate context, assuming the worst-case scenario for overheating. The building materials were assigned considering the traditional building methods, as well as the population's poverty indicators published in the last national housing census [20]. Table 2 provides a summary of the building element's resistance values.

Table 2: Building element's resistance values of the housing prototype

	Resistance values
External Walls	3.09 W/m²K
Windows	5.20 W/m²K
Roof	3.23 W/m²K
Floor	5.53 W/m²K

The internal conditions of the dwellings were also modelled according to the last census data. It was assumed that the dwelling is occupied by a family of four people with regular daytime activities with the typical heat gains values during the occupancy and non-occupancy time. The house was modelled as naturally ventilated free-running buildings completely relying on passive strategies, considering an infiltration rate of 0.75 air changes per hour, a 50% fraction of operable window glazing area and a stack discharge coefficient of 0.25, the window opening and closing algorithm, was automated with schedules emulating the occupant's behaviour and the minimum and maximin interior temperatures for natural ventilation were programmed according to the comfort band.

The comfort assessment was elaborated according to the European Standard EN-16798 (previously EN-15251) for naturally ventilated buildings. It was decided to employ the European comfort standard, rather than the North American, following the concept that the original comfort algorithm of the EN-15251 has a higher operative temperature tolerance of 33.5°C, as a consequence of considering the exponentially weighted running mean of the past days mean outdoor air temperature (T_{rm}) rather than the monthly mean temperature (T_{om}) considered by ASHRAE, which only allows a maximum operative temperature of 31.4°C [21]. Additionally, an acceptability limit of 80% was also assumed and it was applied as a comfort band-width of 8°K. Finally, to assess the indoor thermal comfort in a quantitative way, and due to the lack of a comfort standard for free-running naturally ventilated dwellings, the general comfort assessment was elaborated following the EN-16798 standard for naturally ventilated office buildings.

In the final phase, a set of parameters were selected and the climatic indices were calculated according to each location. The parameters were:

- Latitude: The geographical latitude of the location according to the distance to the equator. This feature was selected since it is the main one used by the current Mexican normative [22] with the intention of determining its adequacy.
- Altitude: The geographical height of the locations in relation to the sea level. Previous work by [23] aimed at an Indian context, found that there is a correlation between the altitude and the environmental performance of an active dwelling. The objective is to investigate if this same relation applies to the Mexican context and for free-running homes.
- Diurnal Range: The temperature variation between the highest value and the lowest value occurring within one day. The objective is to explore to what extent this feature can predict the possible effectiveness of passive strategies, in climates characteristically arid, the diurnal range can provide the necessary means to tackle the daytime overheating with the night's coldness and vice versa [24].
- Continentality: The quantification of the degree to which a location is influenced by the surrounding landmass. The selected indices are the Johansson Continentality Index and the Conrad Continentality Index [25], [26], even when the second was intended to be an improvement of the first one, over the time, it has been found that they are equally useful for different purposes [27]. Both equations include latitude, Thermal Amplitude (T_{amp}) and arithmetic fixed values, T_{amp} is defined as the difference between the maximum monthly temperature and the minimum monthly temperature during the year. The difference between the two formulas lies in the fixed arithmetic values.
- Oceanity: The quantification of the degree to which a location is influenced by the proximity of the sea. The selected indices are the Kerner Oceanity Index and the Mars Oceanity Index

[28], [29], both in a similar condition as the previously mentioned, in which they are still used nowadays for different purposes. Their formulas follow the same general structure, and they both consider the T_{amp} in the same way. Their differences are in the fixed arithmetic values, and in the fact that Kerner's Index considers the resultant value of the subtraction of October's mean monthly temperature minus April's, while Mars consider the latitude degrees minus a fixed value [27].

- Aridity: The quantification of the degree to which a location is influenced by the lack of effective or life-promoting moisture. The selected indices are the De Martonne Aridity Index and Pinna Combinative Index [30], [31], both of them used for different purposes, De Martonne's index provides a simple general overview since it's the resultant of the division of the mean yearly values of precipitation and air temperature plus ten, while the Pinna Combinative Index provides a more accurate number with respect to the extent of the aridity since it considers the mean monthly values of precipitation and temperature of the driest months additionally to the yearly values of precipitation and air temperature.

3. RESULTS

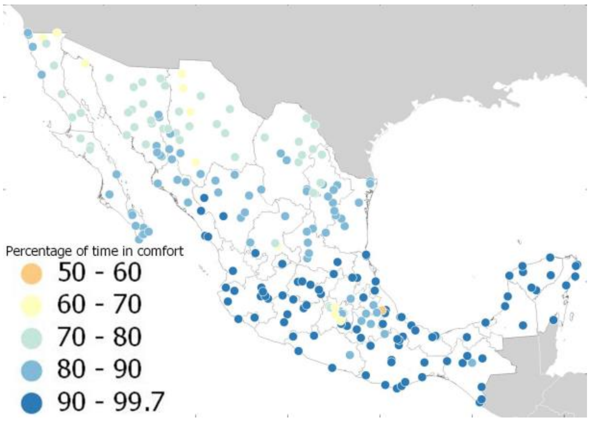

Figure 3: Percentage of time in comfort of each location

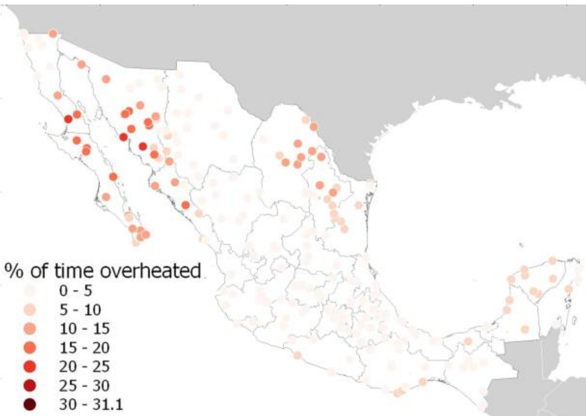

Figure 4: Percentage of time in overheated of each location

The simulation results were processed according to the resultant Operative Temperature (T_o). The total percentage of time in comfort (figure 03) was calculated as well as the percentage of time overheated, or above the upper comfort limit (figure 04), and the percentage of time overcooled or below the lower comfort limit (figure 05). A dataset was created including the station's general information, the selected parameters and simulation results.

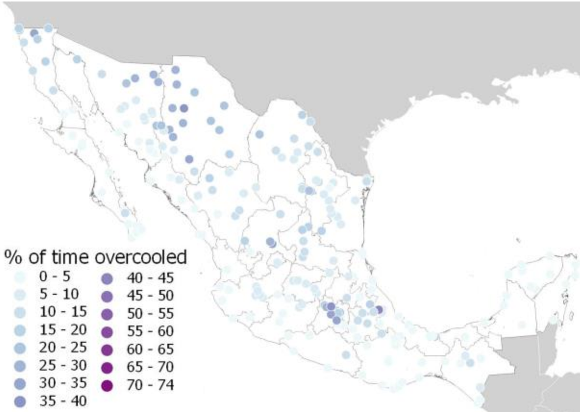

Figure 5: Percentage of time in overcooled of each location

Table 3: r values of Spearman's rank correlation coefficient test results

	% in comfort	**Overheating hours**	**Overcooling hours**	**Average effect size**
Latitude	-0.71	0.38	0.50	0.53
Altitude	-0.32	-0.73	0.67	0.58
Diurnal range	-0.53	-0.36	0.68	0.52
Johansson's Continentality	-0.65	0.42	0.45	0.50
Conrad's Continentality	-0.67	0.41	0.47	0.52
Kerner's Oceanity	-0.06	0.65	-0.29	0.34
Marsz's Oceanity	0.65	-0.42	-0.45	0.51
De Martonne's 's Aridity	0.51	-0.50	-0.22	0.41
Pinna's Aridity	0.49	-0.48	-0.21	0.39

For the statistical analysis, the simulation results were considered as dependent variables and the selected parameters were considered as independent variables. As a first step, a Shapiro-Wilk test together with a non-parametric Kolmogorov-Smirnov test were performed to all elements of the dataset. As a result, it was established that all of the elements of the dataset were non-normally distributed. Sequentially, with the interest of establishing the relation between the dependent and independent variables, Q-Q plots were elaborated followed by the Spearman's rank correlation coefficient test. The resultant correlation coefficients were tabulated (Table 3) and the effect sizes were interpreted following the recommendations of [32], [33], where an effect size value of 0.1 to 0.2 is considered as very small, 0.2 to 0.5 as small, 0.5 to 0.8 as medium and 0.8 to 1 large. All the resultant effect sizes determined that none of the tested correlations presented values above -0.73, positioning all the effect sizes in the medium, small, and very small categories. None of the independent variables demonstrated a constant medium effect or higher size across the independent parameters.

The highest correlation values obtained with respect to the simulation results were all within the medium effect size classification. The parameter of Latitude presented the highest value of the chart with a -0.71 and also with respect the percentage of time in comfort, the parameter of altitude presented a value of -0.73 with respect of overheating and for the case of overcooling the highest effect sizes were the ones of altitude of 0.67 and diurnal range of 0.68. The parameters with the highest effect sizes were Latitude and Altitude, from which it is possible to establish that there is a monotonic relationship between the latitude and percentage of time in comfort, although, it is not possible to determine accurately if this lack of comfort correspond to overheating and overcooling. On the contrary, with the resultant effect sizes of altitude, it is possible to establish that there is also a relationship between the increase of meters above sea level of a location and the overheating and overcooling hours, but not necessarily neither in an equative manner nor a proportional way according to the total percentage of time in comfort. For the case of the Diurnal range, it presented two mediums or moderate effect sizes and one small correlation value, from which we can establish that the diurnal range might predict in a non-accurate way the total percentage of time in comfort and overcooling hours, and even in a more imprecise way the overheating hours. None of the Climatic Indices, presented a strong or large correlation value, the highest averages correspond to Johansson's Continentality index, Conrad's Continentality Index and Marsz's Oceanity Index. The three of them presented a medium or moderate effect size for the percentage of time in comfort and a small correlation in overheating and overcooling with similar values between -0.42 and -0.47. Kerner's Oceanity index presented the highest correlation value among indices with a 0.65 for overheating hours and the lowest value in the chart of -0.06 for the percentage of time in comfort, being the closest value to a no-correlation result, the three values of Pinna's Aridity index remained in the small correlation category, and together with Kerner's Oceanity index presented the two lowest averages values of the table.

4. CONCLUSION

The study presented in this paper investigates the relationship between nine different variables and the time in comfort of a naturally ventilated free-running house. For the investigation, weather data of 240 different location across the Mexican territory, was collected and it was first used to calculate climate indices, sequentially; a reference free-running naturally ventilated building was simulated in these locations, and the simulation results were used to test the correlation of the environmental performance of a free-running dwelling and different climatic parameters: latitude, altitude, diurnal range and the indices of continentality, oceanity and aridity.

The study considered the Mexican territory as a single geographical area, which is in contrast to the observations of Köppen's climate classification that divides the country into three main different areas based on their climate generalities. This subdivision will be investigated in further studies since the sources of discomfort may concur according to general climate zoning. Similarly, further research needs to be followed, since the simulation results or total percentage of time in comfort together with the total overheating and overcooling time, may vary when considering a different building configuration closer to what can be found in an urban or suburban area.

The present research considered the correlation of nine different variables and thermal comfort simulation results. The highest correlation values were obtained for Latitude and Altitude. Meanwhile, the average correlation values for the bioclimatic feature of diurnal range and the climate indices are within the medium and small effect size categories. Hence their results can be considered more ambiguous and uncertain compared with Latitude and Altitude.

One of the secondary objectives of this work was to test the parameter of Latitude as it is used in the Mexican normative. In the normative Latitude is employed as the main variable to define the building envelope resistance value of a dwelling. After looking at the results obtained, it is possible to conclude that while the parameter of latitude encompasses a level of uncertainty, it showed a closer relation to predict the total percentage of time in comfort. Nevertheless, the pertinence of the building regulations' suggested resistance values remains in question since they seem to be unrelated to the socioeconomic situation and they fail to consider the typical construction systems in the country.

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