Application of a performance oriented climatic zoning for buildings in Nicaragua.

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Abstract

Climatic zoning for building energy efficiency purposes is an important element in building energy policy; however, there is no consensus about the most appropriate methodology for its definition. Most methods currently used are based on few parameters, leading to an oversimplification and ignoring several aspects that are essential for building energy efficiency. In this context, this paper presents a novel approach, consisting on intensive use of archetypes, building performance simulation and geographic information system to facilitate the development and validation of climatic zoning. Results on this paper provide preliminary indications of the large potential of this approach to support informed decision making in the climatic zoning process.

Introduction

Climatic zoning for building energy efficiency purposes is a key strategy to improve thermal performance of buildings. This strategy has been widely implemented all over the world since 1949 (DIN 1960; RSAS 1960). Today several countries are subject of climatic zoning for analyzing energy efficiency in buildings, however, there is evidence of the lack of consensus regarding the appropriate methodology to conduct its definition.

This lack of consensus is noticeable by the large number of climatic zoning methodologies, variables and parameters currently applied by different countries to define climatic zones (IRAM 2011; ADEREE 2011; de la Flor et al. 2008; Moral et al. 2016; ANER 2004; Arenes and Elias 2003; Park et al. 2015; Evans, Shui, and Takagi 2009; ANSI/ASHRAE/IESNA 2010; CEC 2016; Dascalaki et al. 2012; Lau, Lam, and Yang 2007; Huang and Deringer 2007; Roriz, Ghisi, and Lamberts 1999; Rakoto-Joseph et al. 2009; Khedari, Sangprajak, and Hirunlabh 2002; Pusat and Ekmekci 2016).

The use of few aspects to defined climatic zones prevails in most countries nowadays. According to a recent review, four out of five countries used only up to three variables/techniques/parameters to define their climatic zoning for building energy efficiency purposes (Walsh, Cóstola, and Labaki 2017b). This reduced number of variables leads to an oversimplification that may induce problems in climatic zoning, consequently compromising energy policies based on them (Ware and Bozorgchami 2013; Bawaneh, Overcash, and Twomey 2011; Martins, Bittencourt, and Krause 2012; Carpio et al. 2015; Rodríguez-Soria et al. 2014).

One of the most widely used climatic zoning methods is degree-days. This approach has been used in more than 24 countries in the world to support climatic zoning definition (Walsh, Cóstola, and Labaki 2017a). The use of degree days in climatic zoning for building energy efficiency purposes is mainly stimulated by its high relation with heating, ventilation and air conditioning (HVAC) energy demand in buildings (CIBSE 2006). At the same time it is considered simple to calculate due to its reduced input data required. However, this simplicity come at the cost of disregarding several aspects that are important for building energy efficiency calculation.

The use of degree-days as indicator of energy demand of buildings has been target of criticism (Makhmalbaf, Srivastava, and Wang 2013; Ware and Bozorgchami 2013). Those critics highlight limitations that are particularly relevant in tropical climates where in many cases buildings have no HVAC systems. Those buildings have a stronger interaction with climate when compared with those having HVAC systems and high-insulated envelopes. In such a context, climatic zoning entails additional challenges, as climatic variables such as wind speed; relative humidity and solar radiation play and important role in building energy balance (Rackes, Melo, and Lamberts 2016). Those variables are not always capture by the most used methodologies for climatic zoning nowadays. The inclusion of those variables in climatic zoning process is quite complex as these variables interact with several factors in the building energy balance (Clarke 2001; Makhmalbaf, Srivastava, and Wang 2013).

More thorough approaches for climatic zoning have been under development in recent years (ADEREE 2011; Walsh, Cóstola, and Labaki 2016; Bodach and Lang 2016). Such approaches make use of dynamic simulation, parametric analysis and computer programming (Nguyen, Reiter, and Rigo 2014) to drive the climatic zoning process, avoiding arbitrary decisions based on predefined bins of weather parameters (ASHRAE 2013). The application of those methods has proven great potential in order to define predictive-based and performance-based requirements for building energy efficiency programs (Crawley 2008; ADEREE 2011).

In spite of the importance of climatic zoning related issues and the increasing tendency of the use of the simulation in many topics related to the building energy efficiency, there is no established framework to use simulation in the climatic zoning process. In such a context, this paper aims to contribute to develop this topic by means of proposing a novel approach, consisting on intensive use of archetypes, building performance simulation and geographic information system (GIS) to facilitate the development and validation of climatic zoning.

Area addressed in this study

Trends in the growth rate indicates that in 2050 the half of the world population will be living in the tropics (PNUD 2012). Most of the countries situated in this region are in development and consequently associated with lack of energy framework for buildings (Liu, Meyer, and Hogan 2010; Janda 2009; Iwaro and Mwasha 2010). Nicaragua, is an example of those countries with no energy regulation for buildings having a hot climate, and it was chosen for this study. This section briefly describes the Nicaraguan context, in order to facilitate the understanding of findings of this paper.

Nicaragua is considered as one of the least developed countries in the Americas (World Bank 2015) and has the highest housing deficit in the region reaching 78% of its total population of 6.08 million (IDB 2012). This housing deficit can be characterized into both qualitative and quantitative dimensions, which means that at least 567 079 of the existing houses need to be improved and additional 318 982 houses need to be built in order to fill this gap. In addition to this, cities are expanding exponentially as a result of population growth that implies that at least 20,000 more new houses are needed to be built every year to meet the demand of the population growth.

In order to overcome those challenges, governmental institutions and private entities embarked on a massive production of low cost housing reaching approximately 4% of the total deficit during the period of 2007-2011. Most of those new constructions are single-family detached dwellings having between $32m^2$ and $56m^2$. Those new buildings are designed without any thermal comfort criteria and replicated all across the country.

The climate

Nicaragua is the largest country of Central America and it is situated in the tropics, between 12˚ and 15˚ North Latitude and 86˚ and 87˚ West Longitude. It has an extension of 130 000 km² and it is divided into three administrative regions: the Pacific Region, Central Region and Atlantic region. Most of the population lives in the Pacific Region (65%), where the capital, Managua, is situated (Figure 1).

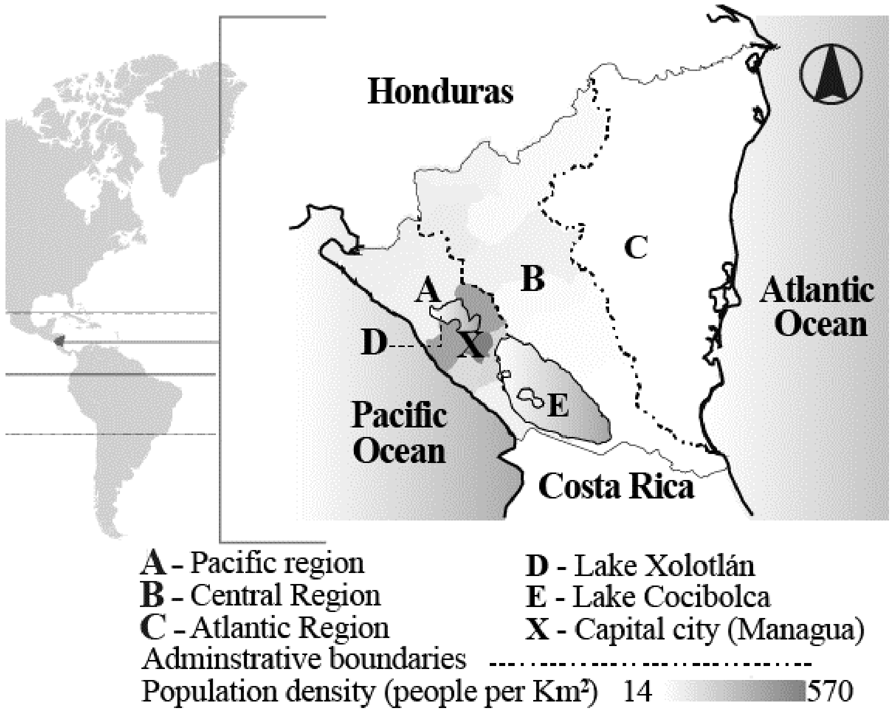

Figure 1 Nicaragua localization, population distribution and administrative division

Nicaragua has a variety of topography, climates and microclimates, leading to different thermal comfort requirements for buildings. According to Köppen-Garcia climate classification, the prevailing climate conditions are categorised as warm sub humid (Aw0, Aw1, Aw2) and monsoon climate (Am) (Figure 2 a). In the rest of the country, there are microclimates presenting particular conditions such as warm semiarid BS1(h')w, tropical rainforest (AM(f)), semi-warm sub humid (A(C)W1, A(C)W2), temperate rainforest (C(A)Cam), and A(x'), S(x') (García 2004; INETER 2001). Table 1 synthesize the main characteristics of those climate types.

Table 1 Climatic classification of Nicaragua according Köppen-Garcia (García 2004)

Climate	Annual average Temperature C°	Annual Precipitation (mm)	P/T[1]
Aw0			< 43.2
Aw1	18-30	600-2000	43.2 - 55.3
Aw2			>55.3
Am	25-26	2000-4000	
A(f)	25 -27	5000-6000	
BS 1	23-27	650 - 800	
C [(A) Cam]	18	1000-1800	
A(C)W1/ A(C)W2	20-22	1100-1600	
A(x') / S(x')	19-21	1300-1600	

[1] ***Rainfall Index of Lang.***

Yearly mean precipitation (mm)/yearly mean temperature (°C)

Figure 2b illustrates the global solar radiation distribution in Nicaragua, which is also relevant for building energy balance, particularly in tropical climates. As it can be noticed, Pacific region of the country receives the highest levels of solar radiation, and the Atlantic region, the lowest.

Method

The new performance-based framework for climatic zoning was applied to Nicaragua following the steps indicated below. First, a definition for climatic zoning was established, secondly, a set of archetypes, thermal properties, thermal performance indicators and weather data was defined, followed by parametric simulation. Data results were geogeferenciated and compared with zones defined based on degree-days method. Each step is further described below.

Climatic zoning definition

From an energy performance point of view, climate zone can be defined as regions in which, for a set of relevant buildings, performance show:

- significant variation between points located in two distinct zones (inter-zone),
- small variation in any point of a particular zone and (intra-zone).

This definition allows the establishment of building particular prescriptive and performance requirements for buildings located in each region.

Archetype buildings

A single-detached dwelling situated in Managua the capital of Nicaragua, was selected due to its representativeness of Nicaraguan residential predominant type (Figure 3). The overall floor area of the dwelling is $56m^2$ and its occupation is determined based on the standard average Nicaraguan family size of 6 people (PNUD 2002). The framework is applicable to multiple building archetypes, but only one type of building is considered in this paper for simplicity.

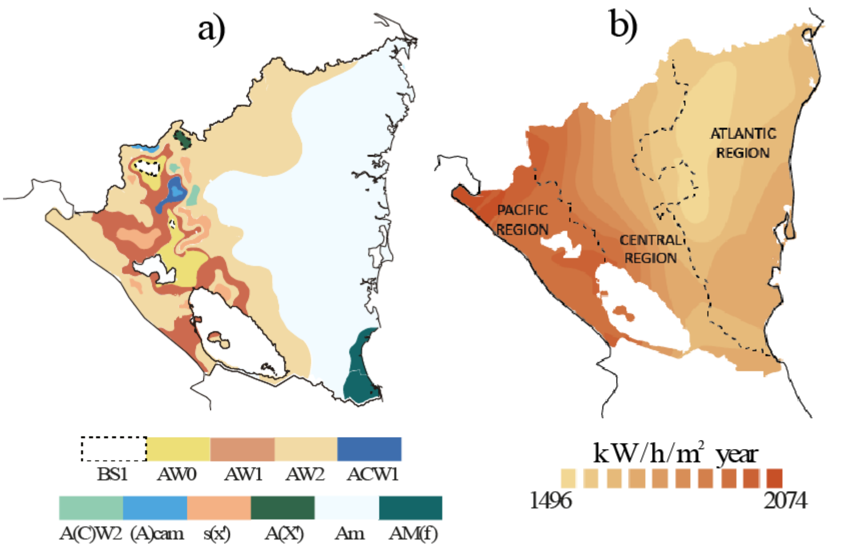

Figure 2 a)Köppen García climatic classification of Nicaragua (García 2004; INETER 2001), b) solar radiation map of Nicaragua

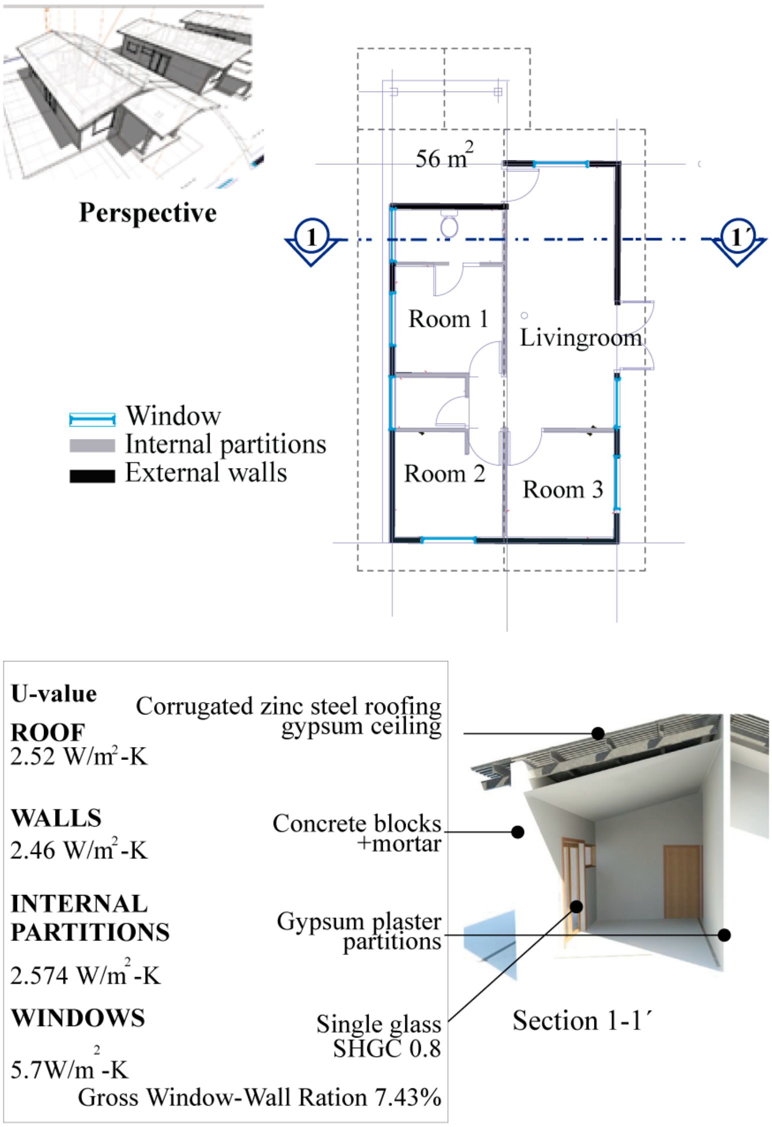

Figure 3 Base case geometry

Parametric variation

Three thermal properties of the building envelope were addressed in this study: U-Values and solar absorptance of the roof and walls, as well as the Solar heat gain coefficient (SHGC) of windows. The framework is applicable to multiple building properties/characteristics, but a limited number was considered in this study to simplify the demonstration of the method and highlight its strengths and weaknesses. Combinations of parameters were conducted simultaneously through a random choice based in the Multiplicative Congruential Method (Harris 2013).

The base case thermal properties were established according the real dwelling characteristics. Alternative solar absorptance and U-values were collected and calculated from constructions materials available in Nicaragua (Walsh, Cóstola, and Labaki 2016). Table 3 Summarizes those parameters.

Building performance indicators

The annual number of hours of discomfort summed in all zones of the building was used as performance indicator. Thermal discomfort was calculated using the adaptive comfort model according to Standard ASRHAE 55-2013 (ANSI/ASHRAE 2013).

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Table 2 Parameters used in this study

Input parameters		Base case energy model	Values for alternative energy models
U-Value [W/m^2-K]	External walls	2.46	1.045-2.46
	Internal partitions	2.574	1.045-3.877
	Roof	2.52	1.042-3.01
Solar absorptance	External walls	0.8	0.3-0.8
	Roof	0.55	0.3- 0.8
	SHGC	0.8	0.2 - 0.8

Two comfort regions are defined, 80% Acceptability and 90% acceptability. For this study, the 80% Acceptability status is considered, which means that upper and lower limits of the comfort region are calculated according to the next formulas.

$$\textit{Upper limit } (°C) = 0.31\ \overline{t_{pma(out)}} + 21.3 \qquad (1)$$

$$\textit{Lower limit } (°C) = 0.31\ \overline{t_{pma(out)}} + 14.3 \qquad (2)$$

Where:

t_o = The allowable indoor operative temperatures calculated as the average of the indoor air dry-bulb temperature and the mean radiant temperature of zone inside surfaces.

$\overline{t_{pma(out)}}$ = Mean daily outdoor air temperature.

Comfort hours were calculated for 24 hours of the day in order to reach a wide group of the society that has diverse occupational patterns. In Nicaragua, most of the children and elderly people stay at home most of the time.

Performance simulation program

Monte Carlo Simulation was used based on random sample in a total of 100 simulations for each weather file. EnergyPlusV8.4 was used in the simulations and MatlabR14 routines were applied in order to make the entire process automatic.

Simulation results were post-processed using the new performance-based framework for climatic zoning, based on sensitivity analysis, ranking and performance targets to be defined by policy makers (Walsh 2015).

Weather data and other boundary conditions

Weather data quality and coverage vary from country to country, and robust climatic zoning methodologies are expected to cope with this variation. The present study is not focused on data availability and treatment, therefore weather was consider a boundary condition of this work. The study was conducted using data provided by Autodesk Green Building Studio (GBS) (Malkin 2008; Hensen and Lamberts 2011). GBS weather data was chosen for being capable of providing accurate values (Degelman 2007) of several climatic variables, at high temporal and spatial resolution (hourly data for a typical year at a spatial resolution of approximately 20km for all over the world). GBS weather data is based on a combination of observational data and weather modeling using the Rapid Update Cycle (RUC) (Benjamin et al. 2004) and Mesoscale Meteorological Model version 5 (MM5) (Grell, Dudhia, and Stauffer 1994). GBS weather data is available in binary DOE2 format including hourly data of dry bulb temperature, dew point temperature, relative humidity, wind speed and direction, direct normal radiation, global and diffuse horizontal radiation, total sky cover for 8760 hours of the year. In this study, GBS weather data for 52 locations were used in the climatic performance oriented climatic zoning. (Figure 4).

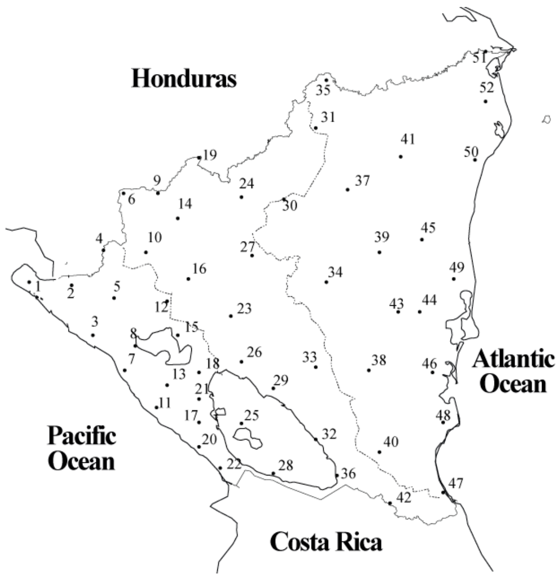

Figure 4 Simulation points

The geographical information system Arcgis10.4 (ESRI 2016) was used for georeferencing building performance results. Interpolation was performed based on inverse distance weighting method (IDW) (Li and Heap 2008). Based on this data, maps were generated using bins of 200 discomfort hours.

Comparison of results with previous climatic zoning

Performance oriented climatic zoning was compared with degree-days climatic zoning previously defined for Nicaragua (Walsh, Cóstola, and Labaki 2017a). Degree days climatic zones are defined according to the ASHRAE Standard 169-2013 (ASHRAE 2013) (Table 3 and Figure 5).

The main analysis of this paper was concerned with the identification of areas of the country where the two different climatic zoning methodologies provide the same classification. The percentage of these areas was then calculated and reasons for such agreement were discussed.

Table 3 ASHRAE climate zones based on precipitation (ASHRAE 2013)

Classification	Criteria
C - Marine	Locations meeting all four of the following criteria: • Mean temperature of the coldest month between -3°C and 18°C • The warmest month mean temperature less than 22°C • At least four months with mean temperatures over 10°C • Dry seasons in summer. The month with the heaviest precipitation in the cold season has at least three times as much precipitation as the month with the least precipitation in the rest of the year. The cold season is October through March in the Northern Hemisphere and April through September in the Southern Hemisphere.
B - Dry	Locations that are not Marine and that meet the following criterion: • $P < 2.0 \times (T + 7)$, where: P = annual precipitation [cm] T = annual mean temperature [°C].
A - Moist	Locations that are not Marine nor Dry based on criteria above.

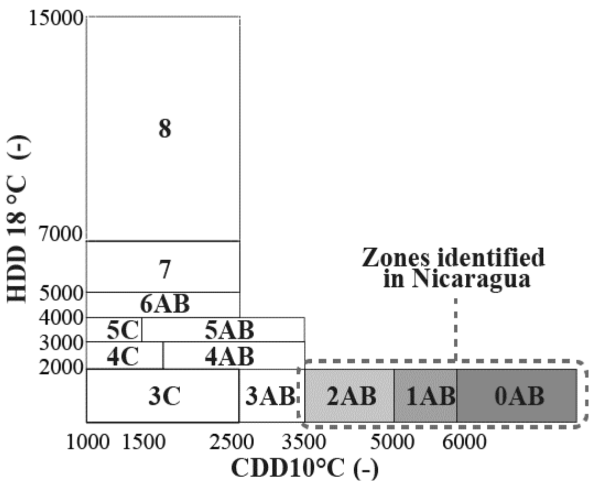

Figure 5 ASHRAE climate zones as function of heating and cooling degree-days (ASHRAE 2013)

Results

Simulation results in terms of comfort were analyzed in order to explore an overall pattern of thermal behavior encountered in typical dwellings constructed in Nicaragua using combination of parameters based on local available construction materials. Average values of simulation results varies along the country from 550 to 1220 hours of discomfort which is equivalent to 6% up to 14% of the year.

Those simulation results were plotted in a map and interpolated using the IDW method. Results were classified into three zones using boundaries every 200 discomfort hours (Figure 6 a).

As in can be noticed, regions presenting the highest values of discomfort hours are located in the Pacific region, where most of the population lives (65%). In contrast, the lowest values of discomfort hours are encountered in the north central and north atlantic region, which are more humid and higher altitudes. Those results are contrasted with degree days zone map shown in Figure 6 b.

According to ASHRAE Standard 169-2013, Nicaragua presents three climates classifications: 0A, 1A and 2A, numbers indicate the amount of CDD10 and the letter (A), the climate type according to precipitation further detailed in Table 3. Letter A indicates that Nicaragua is considered a moist climate.

Both maps present similarities, as the most extreme hot and less hot weather are located in the same area, but also have certain differences, mainly in the less hot region and Atlantic coast of the country.

Those differences can be explained by the influence of climatic variables that are not capture by degree days approach. For example, solar radiation, relative humidity and wind velocity.

As it can be seen in figure 2b, the global solar radiation distribution of Nicaragua presents a similar pattern distribution of discomfort hours shown in Figure 6a. Relative humidity and pluviosity also differ significantly in that region of the country, and have influence on thermal amplitude and other thermal behaviors that are not capture by degree days approach. The Atlantic region is characterized by having high levels of pluviosity and wind velocity, which also has a strong influence in natural ventilated buildings and thermal comfort perception.

Climatic zoning for building energy efficiency applications is usually adopted to define uniform recommendations or mandatory values for certain building characteristics throughout the whole area within the climatic zone. This definition based on degree days approach would not be appropiate for the Nicaraguan context considering that most buildings are natural ventilated.

Conclusion

With the use of simulation and parametric analysis it was possible to make a connection between several aspects relevant for the definition of climatic zones for building energy efficiency purpose. For instance, weather data, thermal properties of the building envelope and thermal performance targets. Those aspects can be defined according to local needs and extended to other archetypes and thermal properties of buildings.

Comparison results between degree days climatic zoning and performance oriented climatic zoning indicate that degree days approach do not illustrate a clear relationship between climate and thermal performance of

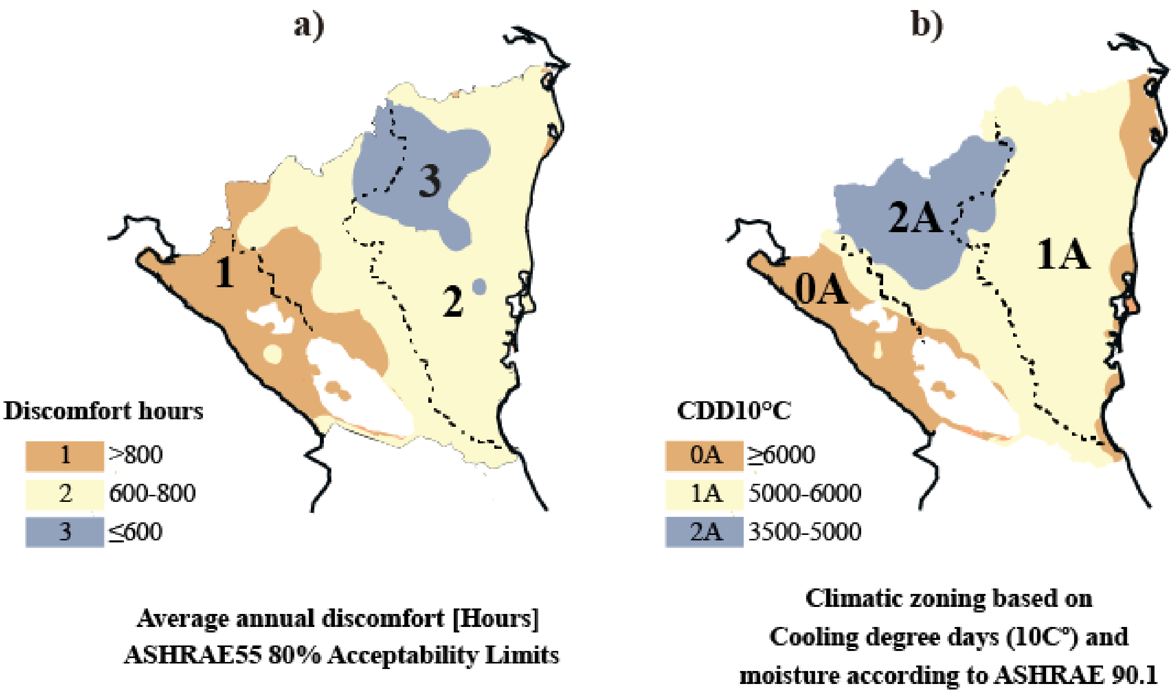

Figure 6 Comparison of climatic zoning results, of a) Performance oriented climatic zoning and b) CDD climatic zoning

naturally ventilated buildings in Nicaraguan context. Further research is needed in order to cope those limitations.

Results also provide preliminary indications of the large potential of this approach to support informed decision making in the climatic zoning process. Future studies should further extend this approach, preferably by defining a coherent framework to use simulation in the validation of climatic zoning.

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