VALIDATION OF THE DEGREE-DAYS METHOD FOR CLIMATIC ZONING– INITIAL RESULTS BASED ON THE MEAN PERCENTAGE OF MISPLACED AREAS

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ABSTRACT

Climatic zoning is often adopted in building energy regulation, having therefore a direct impact in the energy performance of urban areas. Currently, most countries adopt simplified weather parameters to define their climatic zoning, being the degree-days method one of the most widely used. The widespread use of degree-days has been substantially influenced by the adoption of this indicator by ASHRAE. ASHRAE standards establish different requirements for buildings according to the corresponding climatic zone. However, there is no scientific evidence regarding the agreement between building energy performance and the ASHRAE climatic zones. In such a context, this study analyses the climatic zone described in ASHRAE 90.1-2013 using a performance-based assessment method. This method relies on building energy simulation and geographic information systems to assess the match between energy performance and zoning boundaries. The study was focused on the States of Florida, Georgia and Tennessee and climatic zoning performance indicators were calculated based on cooling and heating energy demand of four archetype buildings. Simulations were performed using EnergyPlusV8.3 and post-processed using ArcGIS. Results of this pilot study suggest that 16% of the area of these States is misclassified, potentially affecting highly populated areas. These results indicate the need for further studies using more archetypes that can better represent the whole building stock, preferably complying with the latest version of ASHRAE 90.1, supporting further improvements of this standard.

Keywords: Climatic zoning, building energy performance, degree-days.

INTRODUCTION

Climatic zonings for building energy efficiency applications has important implications in the worldwide energy consumption in the built environment [1], as such zonings many standards [2,3], certifications [4], and regulations [5] rely on them. However, most of the current climatic zonings are based on simplified weather parameters and are usually assumed to be correct and valid per se, being directly applied to building energy regulations without going through a validation process. These assumptions can lead to inconsistencies between the climatic zones and energy performance of individual buildings, consequently affecting the performance of the whole building stock.

Assessing the accuracy of climatic zoning methodologies is quite complex, as it involves several variables sparsely distributed in space and time. A recent advancement facilitating new insights in this topic is the popularization of Geographic Information Systems (GIS) coupled with building energy simulation (BES) [6–8]. These tools do not solve the methodological challenge of extracting meaningful data to perform climatic zoning validation. Nevertheless, they provide useful functions and interoperability capabilities to explore climatic zoning validation under different scenarios. Considering such potential, a method to address climatic zoning validation using quantitative procedures has been recently reported in the literature [9]. This method is based on building performance, rather than on weather data. It relies on the principle that two areas belonging to the same climatic zoning should have similar building performances for the same given building. The use of the performance-based validation of climatic zoning for building energy efficiency applications is capable of quantifying the level of mismatch between climatic zones and building energy performance. This validation method has been applied to a case study focused on low-rise domestic buildings with no Heating, Ventilation, and Air Conditioning (HVAC) in a tropical developing country [1]. The present paper reports an application of this validation method to high-rise buildings with HVAC in a developed country. The validation addresses the well-established set of climatic zones for the USA, proposed by ASHRAE based on the degree-days method.

Currently, at least 24 countries have used the degree-days approach to support their climatic zoning definition [1]. The widespread use of degree-days in many countries has been substantially influenced by the adoption of this indicator by the ASHRAE Standards and the International Energy Conservation Code (IECC) (according to criteria displayed in *Figure 1*a) [10]. The degree-days method presents a high correlation with heating, ventilation and air conditioning (HVAC) energy demand in buildings [11] and 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 applications [9,12–14].

The original definition of the ASHRAE climatic zones was made considering several aspects in addition to the climate itself [10]. These practical considerations, such as administrative divisions for code compliance and the pursuit of continuity of zones, were some of the drivers in the definition of boundaries between zones [10]. These criteria lead to a few climatic zones having clearly cohesive boundaries (no discontinuity) in an ascending order from south to north, like displayed in *Figure 1*b. There are concerns about the appropriateness of this approach, which can be exemplified by the comparison between the low-resolution USA zoning with the high-resolution zoning adopted by the State of California. This State has climatic zoning containing 16 zones [15], with climate zones defined by energy use [16]. The average area per climatic zone varies by a factor of 20 between these two climatic zoning schemes, from 26.10^3 km² in California State to 5.10^5 km² in the U.S. nationwide classification (See Figure 2). The building requirements will depend on the zoning used as a reference, being in some cases, contradictory [13]. This lack of agreement is the key driver for the present study.

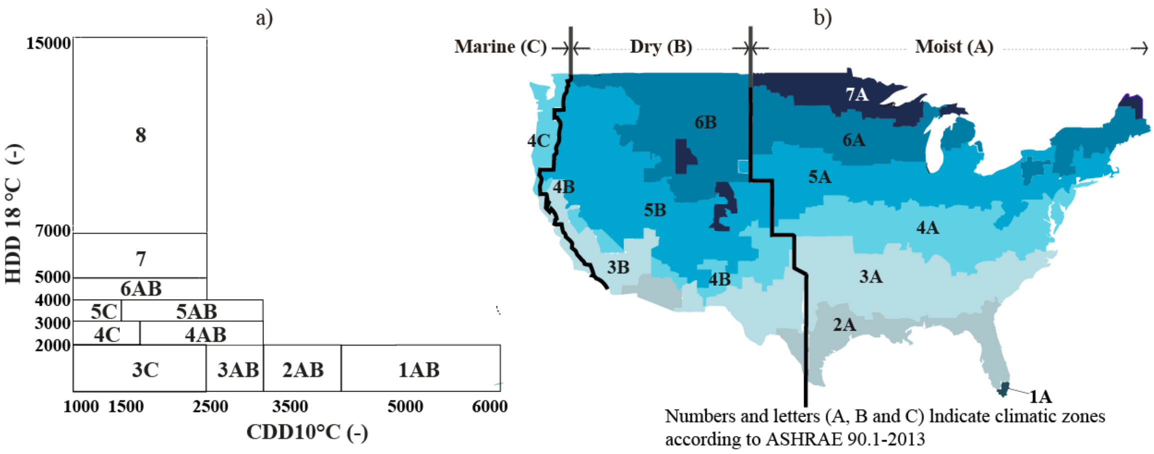


Figure 1 a)ASHRAE climate zones as function of heating and cooling degree-days [17], b) U.S ASHRAE90.1-2013 climatic zoning map [17]

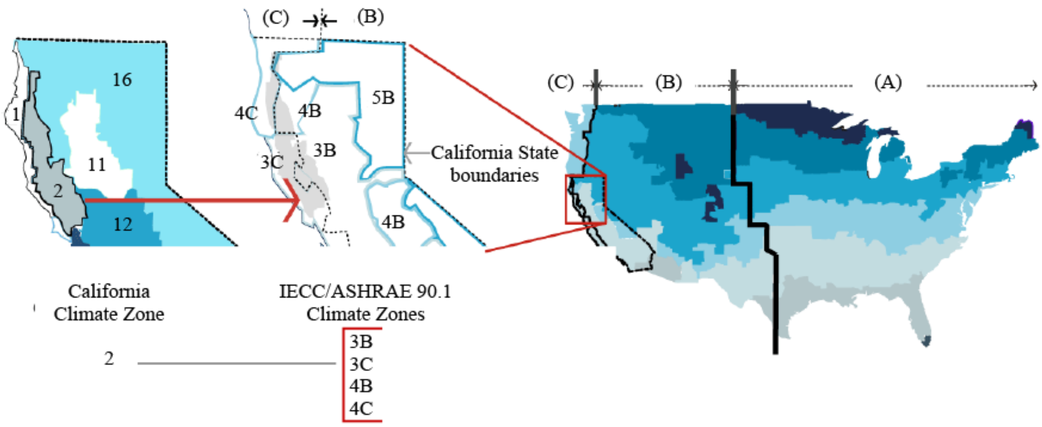


Figure 2: Different requirements for the same region of California [1]

METHODOLOGY

This section describes the procedure, assumptions and sample of simulations used to apply the performance-based validation concept to the climatic zoning of the ASHRAE Standard 90.1-2013. This validation procedure consists in generating performance maps showing how a set of chosen indicators, such as energy consumption or thermal comfort, vary throughout the territory (country or region) for given archetype buildings, for a typical year of climatic data [9]. These maps can be produced using building performance simulation, addressing each relevant archetype in the building stock and adopting climate files for various locations in the territory. The building performance is then linked to each climatic zone under study and areas with conflicting performance results are identified, leading to the calculation of the Mean Percentage of Misplaced Areas (MPMA). The performance-based validation method is illustrated in Figure 3, and further details can be found in ref. [9]. The next paragraphs report the area covered in this study, the archetype buildings and settings adopted in the energy simulations.

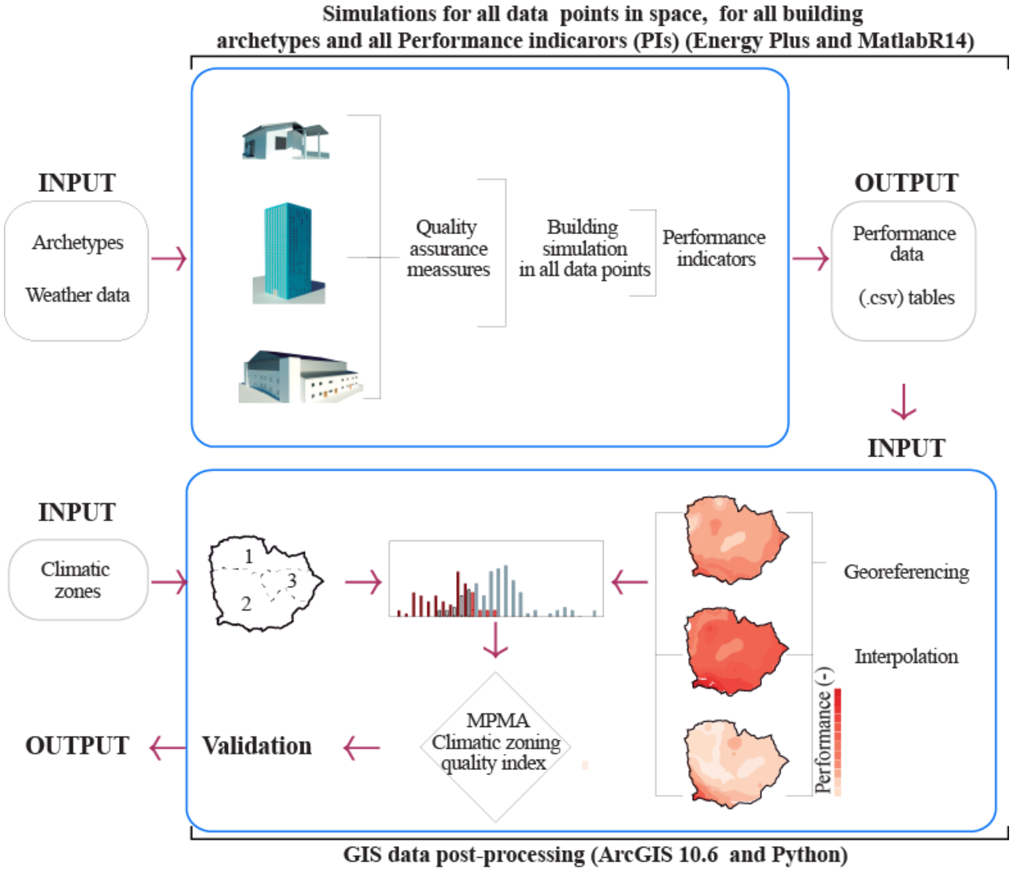


Figure 3 Methodological workflow of this study

Area of study

This study covers the area within the States of Florida, Georgia and Tennessee (Figure 4). This region extends over four climatic zones according the ASHRAE Standard 90.1-2013. From 1A (Very Hot and Humid: typical city Miami), 2A (Hot: typical city Houston), 3A (Warm – Humid: typical city Memphis) to 4A (Mild and Humid: typical city Baltimore). This area covers around 433 365 km^2 and host almost 32 million people. Some of the largest cities in the area of study are Jacksonville, Nashville, Memphis, Atlanta, Miami, Tampa, Orlando, Augusta, Columbus, and Knoxville.

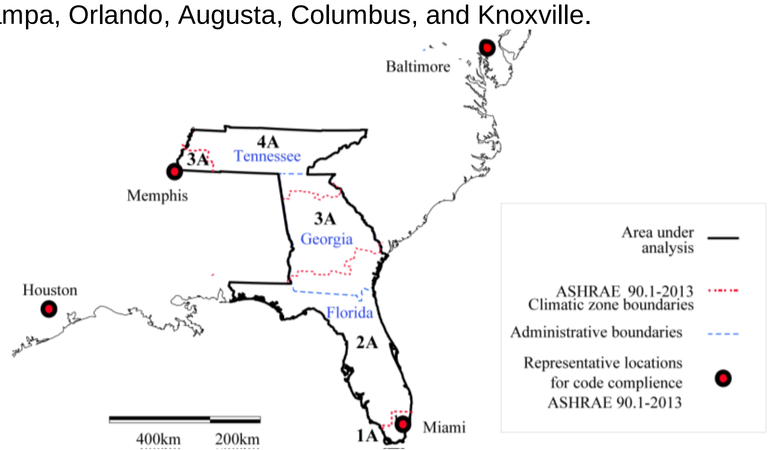


Figure 4 Area under analysis

Building archetypes

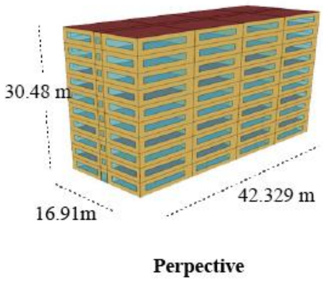
The Department of Energy of U.S. has defined 17 archetypes for the development of the building energy code [18], largely corresponding to a classification scheme established in the 2003 DOE/Energy Information Administration (EIA) Commercial Building Energy Consumption Survey (CBECS) [19]. These 17 archetypes represent 70-80% of the U.S. building stock. Such building models have been used to analyse the effects of energy efficiency code updates, to develop prescriptive new construction standards, to improve retrofit design guides, to create scales for asset scoring, to develop typical energy conservation measures, among other applications [20].

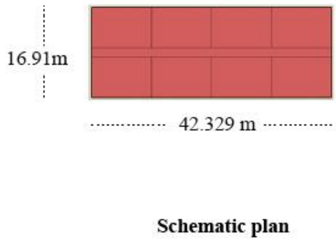
This study adopts updated versions of the DOE archetypes (see ref. [21]) representing high-rise apartments complying with the ASHRAE Standard 90.1-2013 of four climatic zones. Models represent a 10-floors multifamily building, with eight, two-bedroom apartments on each floor. The ground floor has seven apartments and a lobby. The key common parameters of the models are summarized as follow.

Table 1 Common properties of the 4 archetypes archetypes

Building Archetype	High-Rise Apartment
Building Type (Principal Building Function)	Multifamily
Total floor area	7 837.301m²
WWR	South: 30%, east: 30%, north: 30%, west: 30%

Figure 5 Geometry of building





Despite having the same geometry, each model presents distinctive properties based on the building energy requirement of Zones 1A to 4A. Each model is meant to represent a building the typical city of the zone city [10] (Figure 4). The differences among the four models are related to the envelope and HVAC settings. The insulation level for the envelope (opaque and glazing) increases in colder climates. In contrast, the Solar Heat Gain Coefficient (SHGC) allowed in hotter climates is lower. Table 2 summarizes the differences among archetypes. It should be noticed that the design-days of these models was adjusted for each location under analysis, in order to support auto-sizing features adopted in the HVAC modelling. Results were analysed in terms of cooling and heating energy demand. Energy demand of fans and pumps.

Table 2 Main distinctive parameters of each model based on the complying with ASHRAE Standard 90.1-2013 requirements [17].

		Zone 1A Miami	Zone 2A Houston	Zone 3A Memphis	Zone 4A Baltimore
Envelope properties					
Roof	Solar absorptance (-)	0.45	0.45	0.45	0.70
	Thermal resistance ($m^2 \cdot K/W$)	4.32	4.32	4.32	5.30
Wall	Thermal resistance ($m^2 \cdot K/W$)	1.04	2.37	2.37	2.37
Window /	U_ value ($W/m^2 \cdot K$)	0.60	0.60	0.55	0.42
Glazing	SHGC (-)	0.25	0.25	0.25	0.40

Simulations and GIS post-processing

Simulations were carried out considering 94 locations, with weather data provided by DOE [22], using EnergyPlus V8.3. Results were post-processed using ArcGIS 10.6. The workflow was fully automated using MatlabR14 and Python scripts, producing results of percentage of misclassified points for each archetype and performance indicator. Automation included a number of quality assurance plots for each individual simulation, to allow a thorough assessment of results for each archetype.

RESULTS

Results for archetype based on requirements of Zone 1A

For clarity, this sub-section provides a detailed analysis of only one of the building archetypes adopted in this study: the one complying with Zone1A requirements (see next sub-section for aggregated results for all archetypes). Figure 6 illustrates the variation of cooling and heating energy demand over the area of study. As expected, cooling requirements are 3 to 4 times higher in southern regions, while heating requirements are higher in the northern areas and close to zero in the southern ones. These patterns are highly influenced by the latitude variation, which is also correlated with the differences of temperatures and solar radiation. Maximum heating and cooling in the whole area are in the same order of magnitude, showing that both performance indicators are relevant for this area and archetype. Results are in line with values for the same model previously reported in the literature [21].

Cooling and heating performance variation is qualitatively aligned with climatic zoning boundaries based on the ASHRAE Standard 90.1-2013. Despite such alignment, there are overlaps on the performance of this archetype obtained in different zones that can be observed in Figure 7.

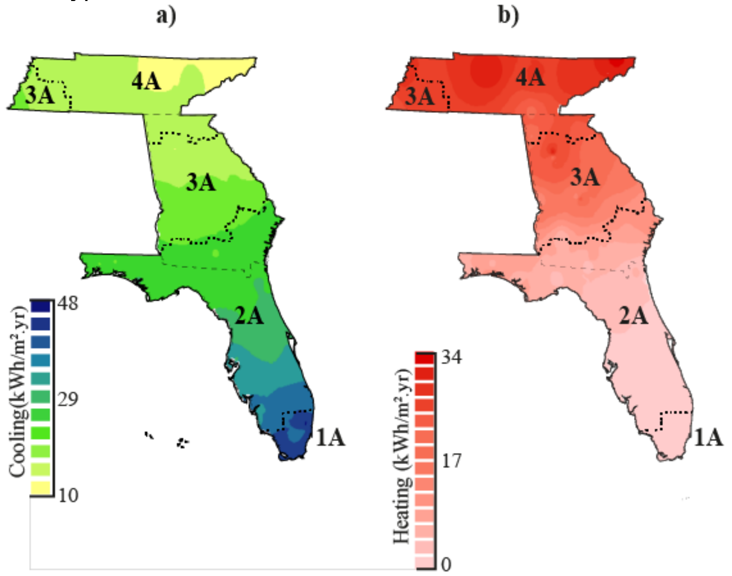


Figure 6 Performance-based maps of a) Cooling and b) Heating energy demand of High-Rise Apartments complying with Zone 1A requirements based on the ASHRAE Standard 90.1-2013.

Figure 7a presents the histogram of cooling energy demand. Zone 1A which is the hottest one (red bins), presents the highest levels of cooling demand, while Z4A (orange bins), the coolest one, presents the lowest values. Let`s focus the analysis on results for Zones 3A and 4A. The cooling energy demand varies from around 14 to 24 kWh/m^2.yr in Zone 3A and from 10 to 19 kWh/m^2.yr in Zone 4A. There is a range of performance between 14 and 19 kWh/m^2.yr where buildings located in both zones have a similar performance. Points located in this range, where identical building presents the same performance while belonging to different climate zones, are the one which may have show conflict in their classification. Points related to bins that have a lower frequency in such areas are considered as misclassified. That is the case of blue bins with values between 14 and 17 kWh/m^2.yr , and orange bins with values between 17 and 24 kWh/m^2.yr, highlighted displayed in Figure 7a and b. Figure 7c show all areas that were misclassified for this particular archetype and performance indicator, totalizing a Percentage of Misclassified Areas (PMA) of 14%.

Three points on the Figure 7c were selected to further discuss the implications of misclassification (Figure 7c). Point A, which was correctly classified as Zone 2A and point B correctly classified as Zone 3A and point C, which is misclassified as Zone 3A. The classification of points A, B and C are coherent with the degree-days values of each point, however, when looking into climatic variables other than temperature, the difference among these three points take another dimension. For instance, the level of global solar radiation displayed in Figure 8 suggests that point B and C (placed in the same zone) have higher discrepancies than point A and B (placed in different zones). This difference in solar radiation affects the cooling demand, which is substantially different between points B and C (22 and 15 kWh /m^2.yr respectively), when compared to points A and B (26 kWh /m2.yr and 22 kWh /m2.yr respectively). Results of this study suggest that point A and B are well-placed points because their performance fall within the predominant range encountered on Zone 2A (23 to 39 kWh /m2.yr) and Zone 3A (17 to 23 kWh/m^2.yr). While C, is a misplaced point because its cooling performance is below the range of performance encountered in Zone 3A (17 to 23 kWh/m^2.yr) (Figure 7a). In conclusion, the degree-days criteria place buildings constructed in B and C in the same zone and consequently they must comply with the same building requirements, which may not be adequate as the performance of the building in point C is closer to the one found in Zone 4A.

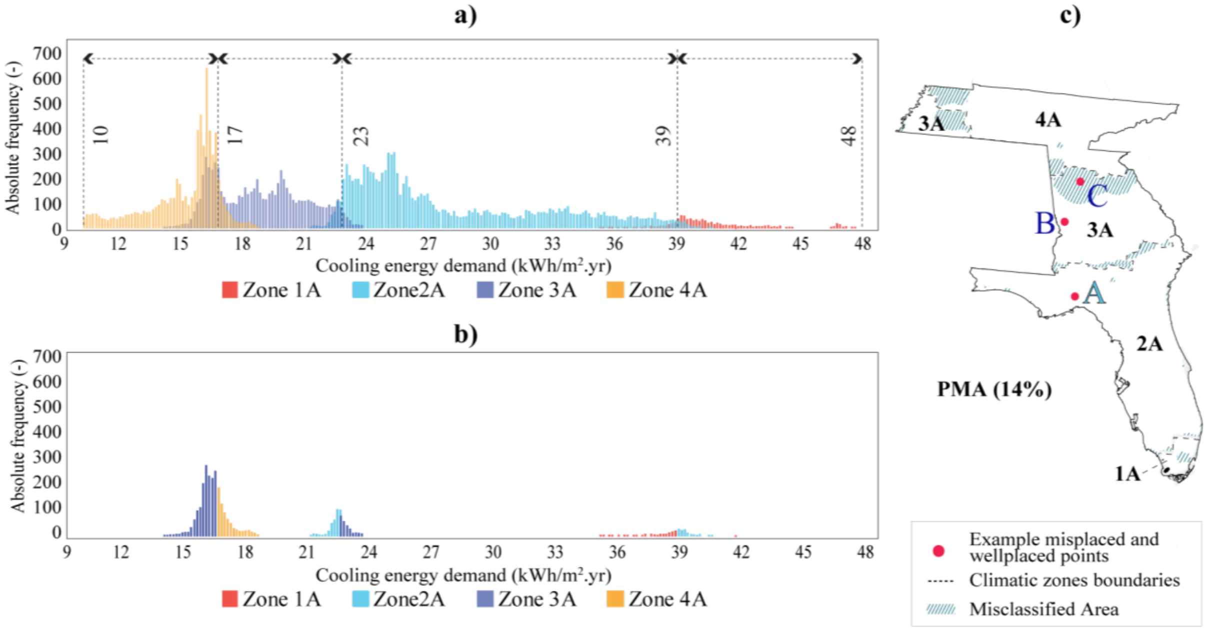


Figure 7 a) Histograms of cooling energy demand for the Zone 1A building b) frequency bars related to misplaced points and c) misplaced areas.

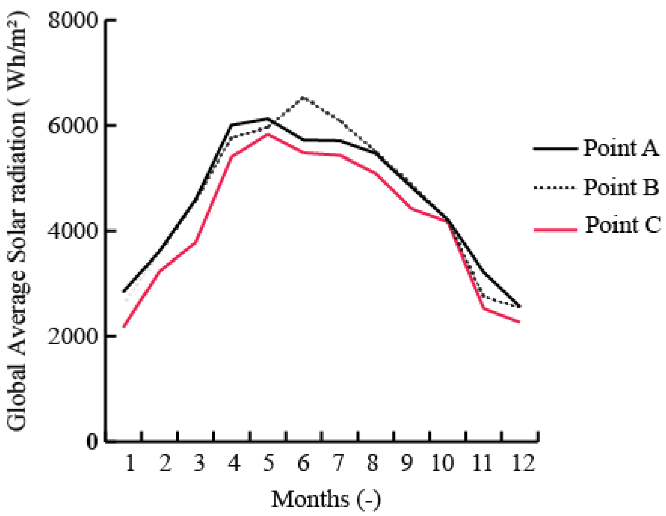


Figure 8 Solar radiation of locations A, B and C according the ASHRAE Standard 90.1-2013.

Results for all archetypes and performance indicators

PMA was calculated for each of the four building archetypes and each performance indicator (Figure 9). The average PMA based on cooling energy demand is lower (13.5%) than the PMA based on heating energy demand (19%). This could be related to the fact that zones under analysis are mainly cooling dominated, and the main indicator for climate classification is the difference of cooling degree-days rather than the heating degree-days. However, the heating overlap cannot be ignored, particularly among colder zones such as 3A and 4A. The level of misclassification become more relevant when large urban agglomerations, such as Atlanta, are located in a potentially misplaced areas (Figure 10). This could potentially affect more than 78 counties and 13 million people living in the areas of transitions between these four zones considering the area of study. The calculated Mean Percentage of Misplaced Areas (MPMA) suggests 16% of the areas in the States of Florida, Georgia and Tennessee are potentially misclassified in the climatic zoning of ASHRAE Standard 90.1-2013.

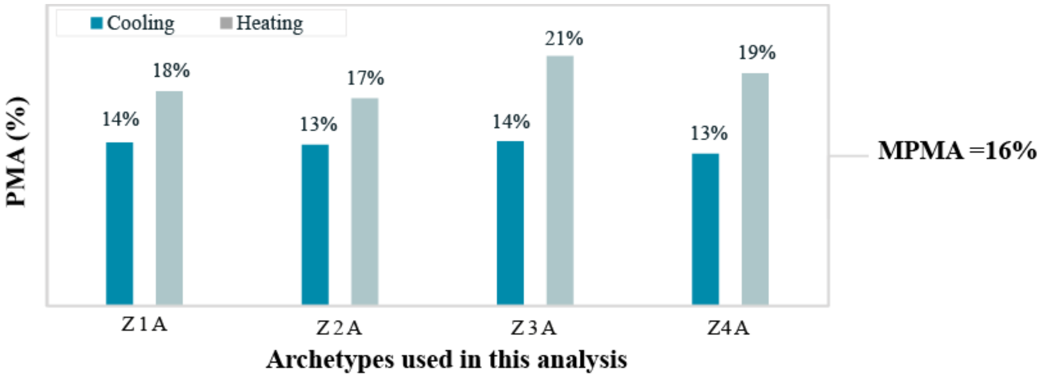


Figure 9 PMA based on cooling and heating energy demand for each archetype and MPMA results

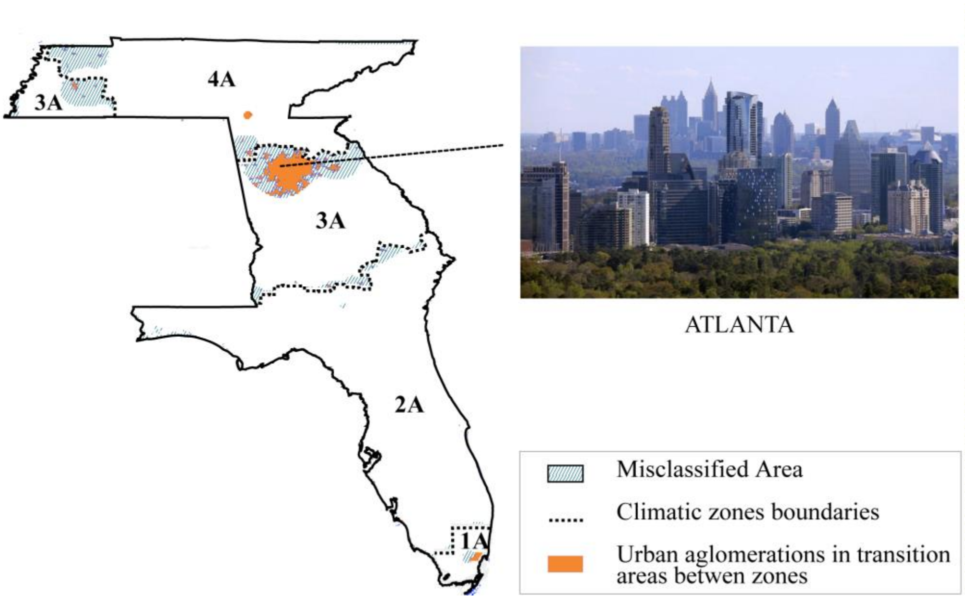


Figure 10 Example of cities located in transition areas between zones (Atlanta) and misplaced areas calculated for one building archetype.

It is important to highlight that maps illustrating misclassified areas in this study are just a way of graphically representing the magnitude of the mismatch between climatic zoning and performance, with no intention of indicating the actual most adequate position for boundaries between zones. Further research is needed to define the appropriate ranges of performance variations in the zones, zoning resolution (number of zones), definition of zone boundaries under uncertainty and its implications in policy-making, as well as continuity constraints in zoning and the implications of all these decisions in building energy codes.

CONCLUSION

A performance-based validation method was applied to the climatic zoning on the ASHRAE Standard 90.1-2013, using four archetype buildings complying with building energy requirements of Zones 1A to 4A. The study covered the range of weather conditions within the States of Florida, Georgia and Tennessee. This area covers around 433 365 km^2 and host almost 32 million people.

The applied method was capable of quantifying the level of agreement between climatic zoning and building performance in terms of cooling and heating. Results suggest that, in spite of the strong correlation between degree-days and the energy consumption of the models under analysis, there are important overlaps of performance among zones, mainly when considering heating energy demand of buildings.

The MPMA of this case study suggest that 1 out of 6 areas (16% of the territory analysed) could have been misclassified in ASHRAE Standard 90.1-2013. This misclassification could have an economic impact on the building industry and performance of buildings considering that around 13 million people live in the areas of transitions between zones. Future studies should expand the present analysis by considering a wider range of archetype to better represent the building stock.

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