Chapter 9
Ecuadorian Social Housing: Energetic Analysis Based on Thermal Comfort to Reduce Energy Poverty

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Abstract This document analyzes the energy behavior based on the thermal comfort of a sample house from the Ecuadorian program "Casa para Todos" in four cities of the country. It includes the modeling of the block in a software specialized in the environmental and energy simulation of buildings, DesignBuilder, studying its behavior in each locality with respect to thermal comfort in the current climate situation and in the projection of climate change in 2050.

Introduction

The real estate sector is responsible for about 40% of energy consumption worldwide. In Ecuador, the numbers reach 32% [1]. The high rates of energy consumption added to the energy crisis gave rise to the search of reducing this consumption, hence the origin of energy efficiency, which has been gaining importance since the 1990s.

There is a lot of information about methods and alternatives that promote energy saving in buildings, whose focus is given not only to the construction phase, but rather to the entire building cycle, since The use phase is one of the most important, as it is the longest period and, therefore, the one that generates the greatest consumption [1]. But it was not until the end of the first decade of the 21st century when countries,

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especially in the European Union, began to reduce the consumption of resources considerably, since energy efficiency regulations began to be implemented [2].

Latin American countries implemented these measures several years later and, in the case of Ecuador, it had to wait until 2018 for the State to place it within the Ecuadorian Construction Standard NEC [3] creating the Energy Efficiency section.

Furthermore, in recent years the concept of energy poverty has spread, affecting a great portion of the world population. After much research, it can be summarized that energy poverty is the inability of a home to reach the social and material levels of domestic energy services [4].

Low access to adequate energy consumption in many families is a problem that particularly afflicts Latin America, which, due to the housing deficit, is common for numerous promotions of low-income housing to appear that seek to reduce the number of families without access to housing, but they do not improve living conditions [5]. Many of these houses are conceived in numerous series without considering greater care of the climatic conditions in which they are implanted.

In Ecuador the story is similar, social housing developments usually have a typical design that is reproduced throughout the country, without considering the eight climate variants that the country has according to the Koppen-Geiger distribution. There is information on energy saving strategies for houses based on the weather, such as the specific cases of Zaragoza et al. [6] and Capdevila et al. [7] with Latin America studies and at the country level with various investigations in Chile [8], Argentina [9] and Brazil [10].

Because its geographical location, Ecuador should have a warm climate in general, but there are several factors that affect it, so it is considered that it has up to eight different types of climates. Among these factors we can mention the altitude, it is considered that the temperature drops one Celsius degree for every 200 meters that it rises above sea level. In addition, the presence of the Andes Mountains, which crosses the country from north to south, causes an accentuated climatic separation, which added to the variation of warm winds, humid winds and the clash between the two, generating rainfall. Ecuador has four regions differentiated by their climate, topography, and culture, which also have different types of climates, according to their geographical position and the factors that may affect each place [11].

According to the projection of the Casa para Todos Program [12] published in 2018, it was planned to build 2018 identical houses in the country between 2018 and 2020. According to the accountability report of the Public Company Casa para Todos of 2020 [13], it was indicated that 1,510 houses were fullfiled and it is planned to build 508 houses in 2021, as well as another 102 additional houses to the initial goal.

This implies that the materials and geometry of the houses are not the most appropriate, with a high thermal transmittance, which is why it is necessary to implement active cooling and heating systems according to each area, knowing that, according to the climatic characteristics, in each sector, the temperature variations are not so significant in the same region throughout the year, so that those which are needed of cooling, will not have to heat it in another season.

This problem means that a large part of the population that lives in this type of housing does not have adequate comfort conditions, since, as explained in the upper lines, many of these families do not have access to sufficient resources to be able to afford an active air conditioning system, considering the high installation, consumption and maintenance costs they present, because these homes are delivered without any type of active system installed.

This work seeks to understand the current situation about research and general information of social housing in Ecuador, as well as to analyze and reproduce adaptive comfort models for the climatic zones considered. Hence, the main objective of this study is to evaluate the energy behavior based on the thermal comfort of social housing in Ecuador through dynamic simulation considering the different climates and their future projection.

Description of the Object of Study

The study is based on the analysis of a housing block within the "Casa para Todos" national plan of the Republic of Ecuador. This prototype bears the name of 4D Multi-family Blocks, which is divided into four housing units, two on the ground floor (Fig. 9.1) and two on the upper floor (Fig. 9.2). The typology has been reproduced in 12 provinces of Ecuador, having developed 4174 housing units. Each house is

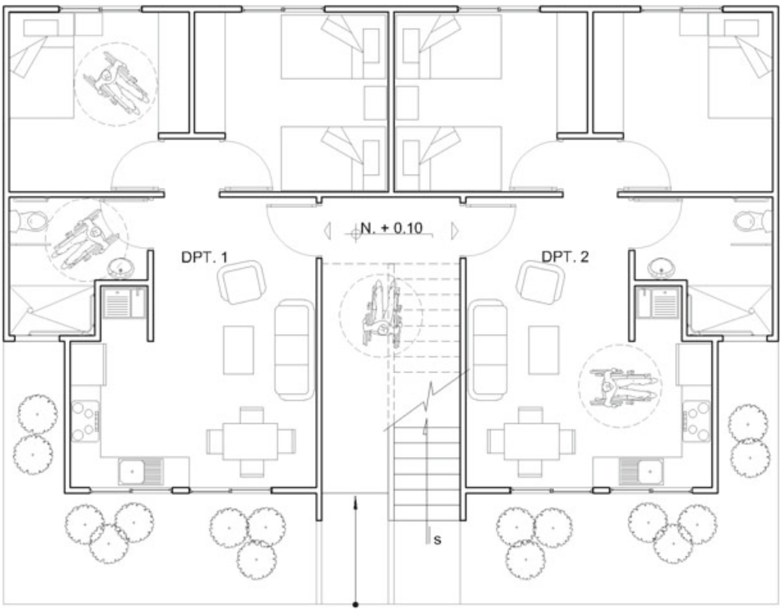

Fig. 9.1 Multi-family block ground floor (Ministry of Urban Development and Housing)

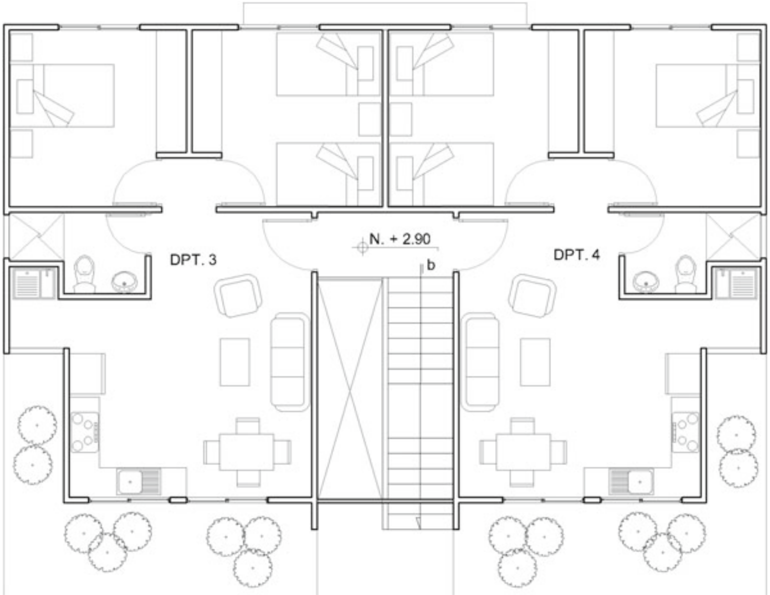

Fig. 9.2 Upper floor multi-family block (Ministry of Urban Development and Housing)

52 m^2 in area and is divided into two bedrooms, a bathroom, a kitchen, and a living room—dining room

The housing block is built as follows:

Main structure of load-bearing reinforced concrete walls with 8 cm thick (Fig. 9.3), with an interior plaster coating and exterior with a paint finish.

Fig. 9.3 Block of flats under construction, reinforced concrete walls

Fig. 9.4 Plastering building, carpentry installed

The floor corresponds to a 10 cm thick concrete subfloor and a ceramic interior finish. While the cover is made of 4 mm thick sheet metal and covered in the lower part with 5 mm of polyurethane.

The Carpentry consists of exterior aluminum windows and 4 mm thick clear glass (Fig. 9.4). While the entrance doors to each house are metal and the interior doors are made of drum-type wood.

Methodology

Thus, studying the climatic zones present in the Ecuadorian territory, it has been possible to establish those with the highest population density, because even though the variety of climates is high for a small area, some of these areas are sparsely inhabited, or completely uninhabited.

Figure 9.5 shows the climatic distribution of Ecuador, also indicating the location of the seven most populated cities in the country, where it can be observed that the climatic zones are clearly defined by the influence of the Coastal, Andean, and Amazonian zones especially, being thus other transition zones between them.

For the present study, it was decided to choose a city for each climatic zone, considering those with the highest population density in each sector and, therefore, the largest number of dwellings, thus obtaining four locations, such as Quito, Portoviejo, Esmeraldas, and Nueva Loja. The location of the cities according to the climatic zones is observed in Table 9.1.

To carry out the simulation, it was necessary to establish certain programming conditions that would allow obtaining results closer to the real situation of the same. For this, it was obtained that the number of members of an average family in Ecuador

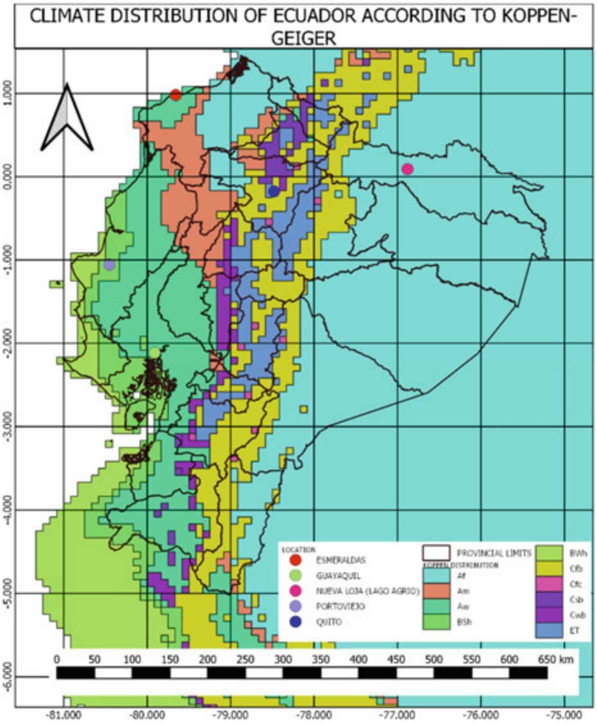

Fig. 9.5 Identification of the cities with the highest population density according to each climatic zone

Table 9.1 Identification of the cities to study according to each climate zone

Classification	Köppen-Geiger	City of study
Rainforest climate	Af	Nueva Loja
Tropical savanna climate	Aw	Esmeraldas
Hot semi-arid climates	BSh	Portoviejo
Oceanic climate	Cfb	Quito

is four people, two adults and two children of school age [14]. Thus, it is considered that between 7:00 p.m. and 6:00 a.m., the house is 100% occupied. Then, taking into account the working and educational hours of the country, it is assumed that from 6:00 a.m. to 2:00 p.m. a single person would be available inside of the house, with 25% occupancy, which becomes 75% between 2:00 p.m. and 7:00 p.m. (Fig. 9.6).

Regarding ventilation, two different profiles have been considered configured with a programmed ventilation the first one for the climatic zones Af, Aw, and BSh, which correspond to places with high temperatures throughout the year, providing the opening of windows every day of the year (Table 9.2). While for the Cfb zone, with lower temperatures, a profile has been arranged with opening windows during

Fig. 9.6 House occupancy graph according to average family

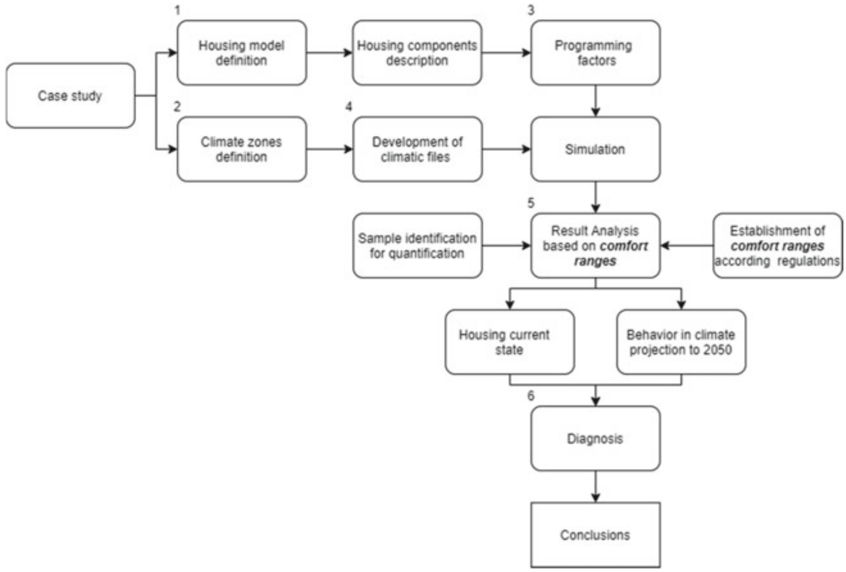

Fig. 9.7 Methodological workflow for obtaining results through simulation

the warmer months, that is, from June to September, while it is considered that users prefer to keep the windows closed during the remaining months of the **year**.

A comfort temperature range has been defined, the criterion of which is evaluated using static models, as opposed to adaptive ones. To achieve this range, what is indicated by the National Institute of Energy Efficiency and Renewable Energies [5] has been considered, where it is stated that between 18° and 23° is an acceptable range in winter, and for summer between 22° and 26° C. Therefore, it has been decided to establish the comfort temperature ranges between 20° and 25° C for the Af, Aw and BSh zones, and between 20° and 24° C for the Cfb zone. For these results, each of

Table 9.2 Natural ventilation profile for dwellings in climatic zones Cfb, Af, Aw, and BSh

Month	Window opening by climatic zone			
	Cfb	Af	Aw	Bsh
January	Closed	9:30–17:30	9:30–17:30	9:30–17:30
February	Closed	9:30–17:30	9:30–17:30	9:30–17:30
March	Closed	9:30–17:30	9:30–17:30	9:30–17:30
April	Closed	9:30–17:30	9:30–17:30	9:30–17:30
May	Closed	9:30–17:30	9:30–17:30	9:30–17:30
June	9:30–17:30	9:30–17:30	9:30–17:30	9:30–17:30
July	9:30–17:30	9:30–17:30	9:30–17:30	9:30–17:30
August	9:30–17:30	9:30–17:30	9:30–17:30	9:30–17:30
September	9:30–17:30	9:30–17:30	9:30–17:30	9:30–17:30
October	Closed	9:30–17:30	9:30–17:30	9:30–17:30
November	Closed	9:30–17:30	9:30–17:30	9:30–17:30
December	Closed	9:30–17:30	9:30–17:30	9:30–17:30

the living rooms of the dwellings has been considered as a sample, being A and B on the ground floor and B and C on the upper floor.

As previously indicated, the study is based not only on the current behavior of the dwelling in each of the climatic zones, but also its projection to climate change for the year 2050. Thus, three different scenarios have been considered to establish a relationship between them, obtaining data for scenarios A2, B1, and A1B. These projection climate scenarios for climate change have been chosen because they are the most accepted in the scientific community and for the diagnosis, they will be compared between them in order to determine a behavior according to the average results of all possible projections.

To continue with the simulations, it was necessary to model the block of houses with the original characteristics in DesignBuilder software (Fig. 9.8) configuring the programming, conditioning factors, and then modifying each of the climatic files for each location, current situation, and projected to 2050, which were created by extrapolating existing climate data made with the Meteonorm software. The process is described in Fig. 9.7.

Results

To describe the results obtained after the simulations in each location, a table has been made detailing the number of hours below, within and above the comfort ranges established for each z**one**.

In the city of Quito, a sample of the Cfb climate zone, oceanic climate, it has been obtained that the ground floor rooms do not have hours above the comfort

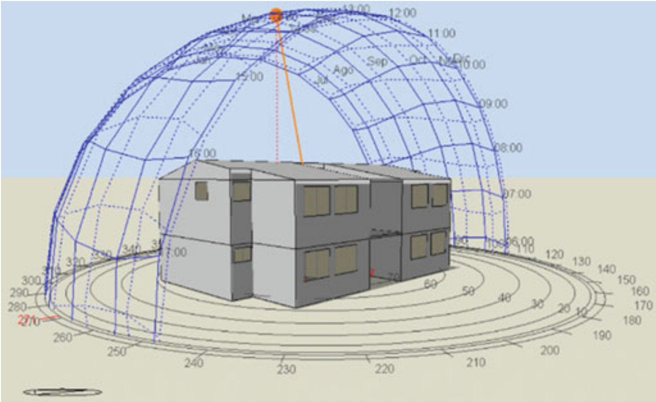

Fig. 9.8 House modeling in DesignBuilder

ranges, the most critical situation being the largest number of them below the range, as described in Table 9.3. On the other hand, the difference in temperatures between the ground floor and the upper floor is notable, since rooms C and D have, although in low amounts, hours above the comfort ranges. Regarding the climate situation projected to 2050, it is observed that the most critical situation with respect to the increase in temperature is the A1B scenario, in which case, for the climate zone Cfb it is favorable, because the hours within the comfort range, they are increased by approximately 1000 units, also finding that an average of 140 h would be available above the ranges (Fig. 9.9).

Table 9.3 describes the situation of the city of Portoviejo, a sample of the Bsh climatic zone, hot semi-arid, where it has been obtained that throughout the year, the internal temperature is never below the comfort ranges, being available of a considerable variation between the spaces of the dwellings on the ground floor and the first floor and, despite the fact that in rooms A and B there is an average of 8400 h within the range in the current climate situation, in rooms C and D, this amount decreases until 2100 h. Regarding the situation projected to 2050, the most critical scenario is A2, where a considerable increase in temperature is evidenced, indicating that by 2050, the home will have 1000 h less within the comfort range (Fig. 9.10).

Table 9.3 describes the data obtained in the city of Nueva Loja, belonging to the climatic zone Af, tropical forest. It is observed that the homes on the ground floor have an average of 8500 h per year within the comfort ranges, decreasing by 200 units in the projection to 2050, with the A1B scenario being the most critical. On the other hand, upstairs homes present only 2600 h within the range in the current climate situation, while, in the projected situation, it is evident that temperatures rise, as they increase 600 h above the comfort range (Fig. 9.11).

Table 9.3 describes the results obtained in the Aw climatic zone, tropical savanna, of the city of Esmeraldas. It is observed that on the ground floor there is an average

Table 9.3 Results obtained in each climate zone. Percentage of hours within the comfort range

Cfb	Stage			
	2020	A2—2050	B1—2050	A1B—2050
ROOM A	11,73%	20,72%	17,65%	44,50%
ROOM B	11,70%	20,79%	17,79%	21,06%
ROOM C	31,37%	42,28%	38,59%	44,17%
ROOM D	31,39%	42,84%	38,93%	44,50%
BSh	**Stage**			
	2020	**A2—2050**	**B1—2050**	**A1B—2050**
ROOM A	96,13%	86,24%	89,25%	86,77%
ROOM B	96,28%	85,79%	88,81%	86,20%
ROOM C	24,29%	6,86%	9,32%	7,25%
ROOM D	23,93%	6,54%	8,85%	6,86%
Af	**Stage**			
	2020	**A2—2050**	**B1—2050**	**A1B—2050**
ROOM A	97,38%	94,73%	94,66%	93,35%
ROOM B	97,26%	94,72%	94,75%	93,35%
ROOM C	30,40%	28,05%	28,17%	23,45%
ROOM D	29,89%	27,38%	27,63%	22,83%
Aw	**Stage**			
	2020	**A2—2050**	**B1—2050**	**A1B—2050**
ROOM A	97,38%	94,97%	94,74%	93,44%
ROOM B	97,26%	94,75%	94,65%	93,30%
ROOM C	30,40%	21,31%	21,90%	18,60%
ROOM D	29,89%	20,70%	21,28%	18,02%

of 8525 h within the comfort range in the current climatic situation, while, in the projected situation, these hours suffer a decrease of more than 300 units. The situation on the upper floor is repeated, observing that, of the total hours, 6100 are above the comfort ranges in the current situation, and that, with the climate situation projected in the A1B scenario, being the most critical, the hours above the range are increased by more than 1000 units, having only 1600 h of comfort (Fig. 9.12).

When taking the results to the percentages indicated in Table 6, it is observed that in the current climatic situation of the city of Quito there is a difference of 20 points between the ground floor and the upper floor, the latter being the one with the greatest amount hours of comfort; while, in the situation projected to 2050, there is a homogeneity of the times within the comfort range with an average of 44%, with the exception of room B which continues with a percentage below 25 points (Fig. 9.13).

The situation of the climatic zones Bsh, Af, and Aw is similar, when noting a difference of between 60 and 70 points between the ground floor, with greater

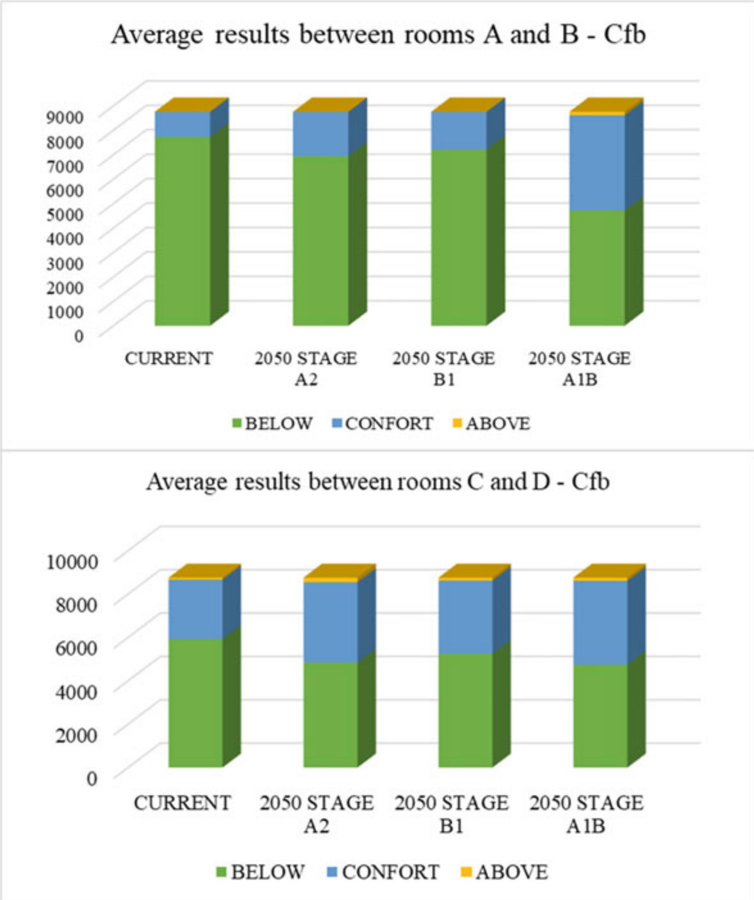

Fig. 9.9 Results obtained in the city of Quito, climate zone Cfb

comfort, and the upper floor, which is available for the greatest amount of time above the ranges. When looking at the data from the projection to 2050, the most critical situation is for the climate zone of the city of Portoviejo, by reducing the percentage of hours within the comfort range in scenario A2 by more than 17 points. The Af and Aw zones show A1B as a critical scenario, varying the percentages by 7 points for Nueva Loja and 12 for Esmeraldas (Fig. 9.13).

Discussion

Based on the current climatic situation, dwelling is less comfortable in the Cfb climate zone or oceanic climate, studied with the city of Quito, since only a third of the year

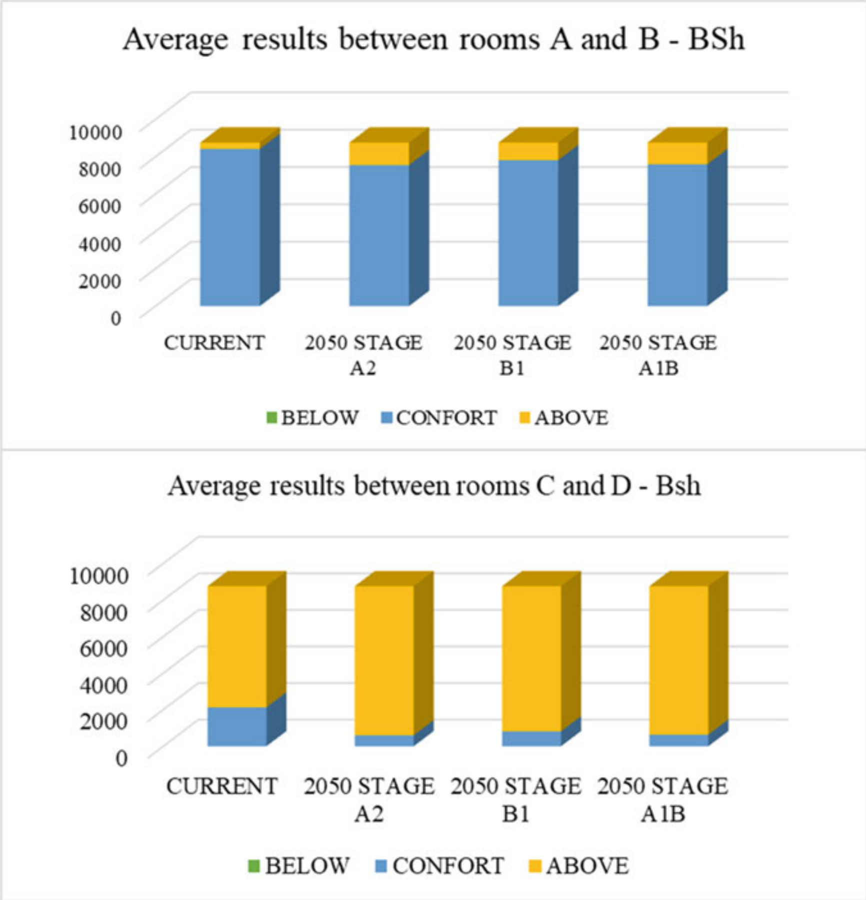

Fig. 9.10 Results obtained in the city of Portoviejo, climate zone BSh

is available within the comfort range, indicating that in most of the time, building users find themselves in a situation of thermal discomfort, which could translate into health risks due to inappropriate temperatures.

On the other hand, the results in the city of Quito for the climate scenario projected to 2050 show a favorable situation, as the number of hours within the comfort range increases.

While, in the climatic zones Af and Aw, corresponding to Nueva Loja and Esmeraldas respectively, a similar behavior is observed in the current climatic situation for both zones. Therefore, in these cities, the spaces on the upper floor will present temperatures above the comfort range 60% of the time. The ground floor areas are most of the time within the comfort temperature ranges.

In addition, it is evident that the hot semi-arid zone or Bsh, studied with the city of Portoviejo, presents the least favorable results when observing the high temperatures

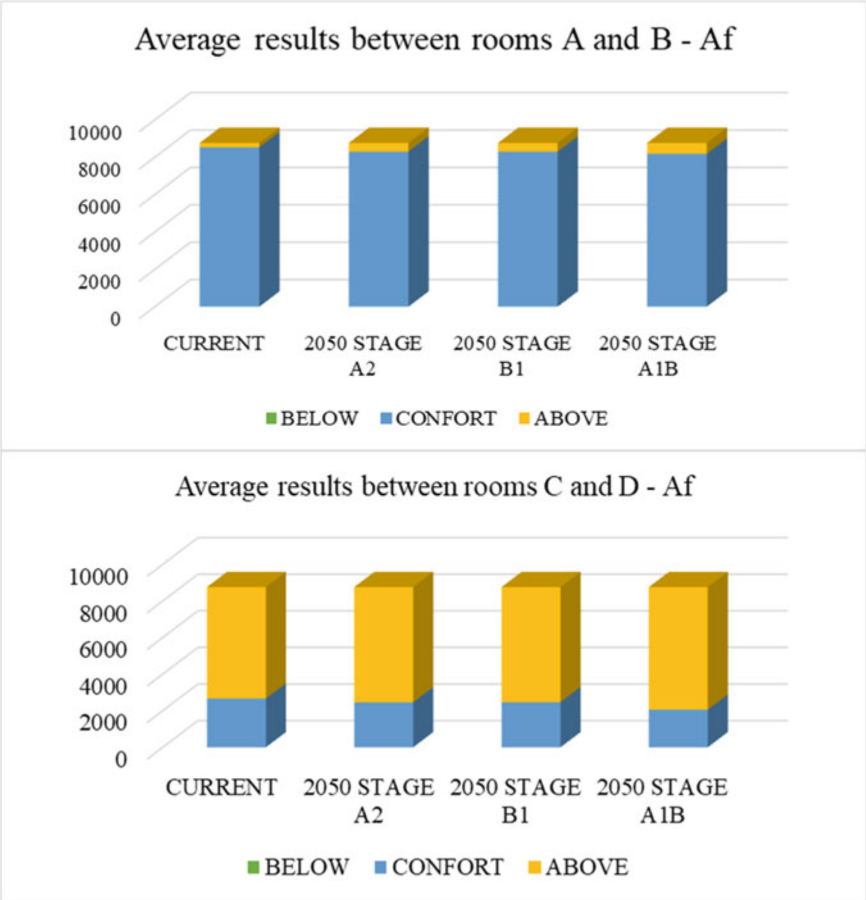

Fig. 9.11 Results obtained in the city of Nueva Loja, climate zone Af

in the upper floor rooms, having less than 25% of the time within the ranges of thermal comfort, despite the fact that the ground floor shows a similar behavior to the Af and Aw zones.

Contrary to what happens with the Cfb areas and particularly in the city of Quito, the cities of Portoviejo, Esmeraldas, and Nueva Loja are considerably detrimental in terms of thermal comfort with the projection to 2050, due to very high temperatures that make the upstairs homes are less than a fifth of the year within the comfort range.

It is added that the most affected area corresponds to that of the hot semi-arid or Bsh, Portoviejo, since, with the projection of climate change, it is obtained that the houses on the upper floor would be inadequate for their habitability when counting with less than 10% of the time within the comfort ranges.

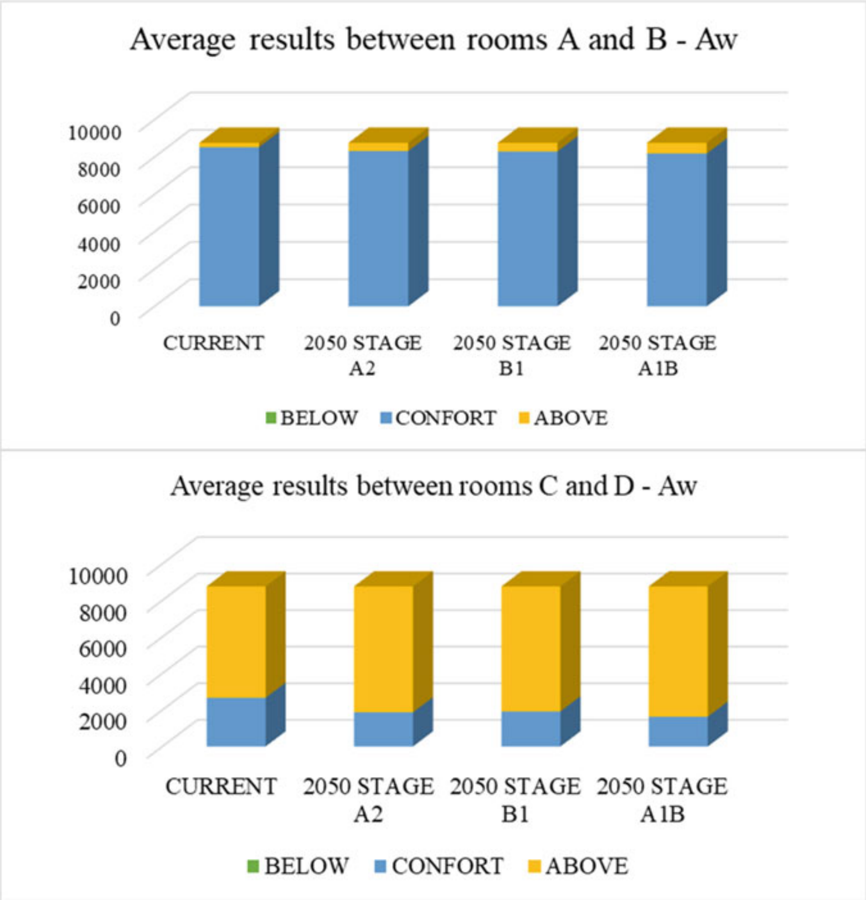

Fig. 9.12 Results obtained in the city of Nueva Loja, climate zone Aw

Conclusions

The largest amount of the country's population is available in the climatic zones Cfb, Bsh, Af, and Aw, which correspond to the oceanic climate, hot semi-arid, tropical forest, and tropical savanna, respectively, presenting the largest number of housing units studied, on which, after analyzing the results, it is evident that the construction conditions of the same are not appropriate for any of the climatic zones where they have been implanted.

The block studied adapts in a better proportion to the Cfb area, Quito, because it presents less variation in interior temperature throughout the year and less difference between the results of the ground floor and the upper floor, even though the percentages corresponding to the hours within the comfort range are kept below 50%.

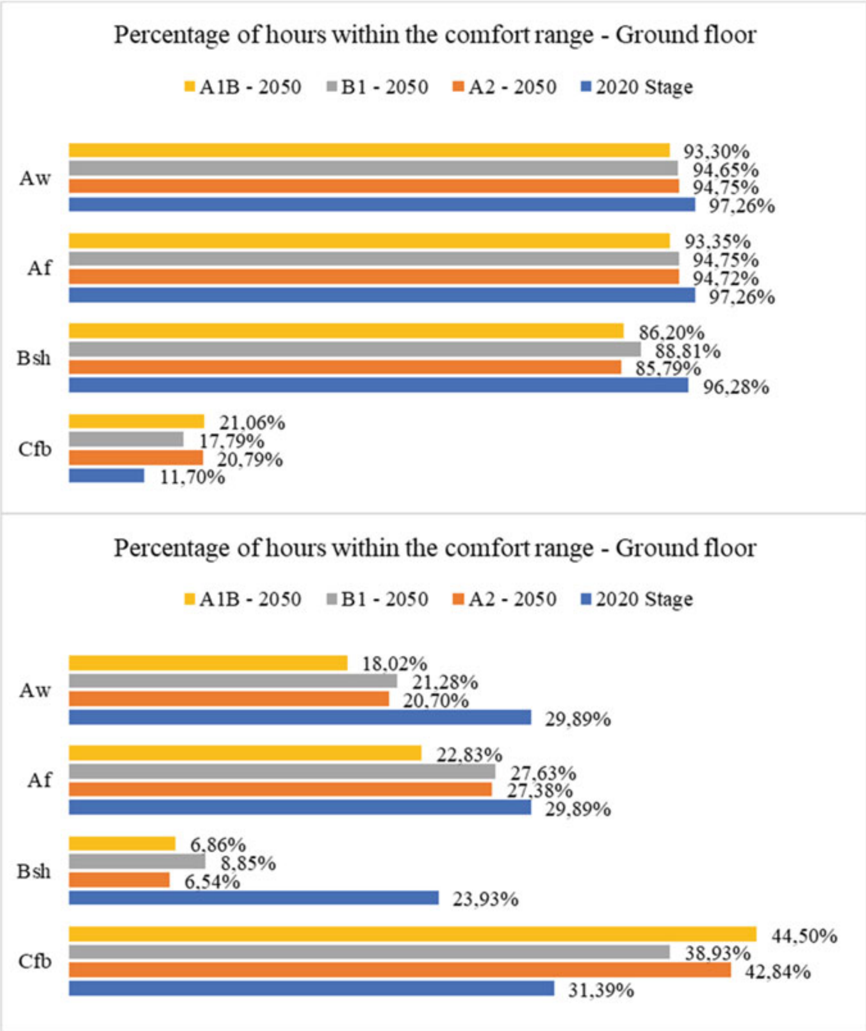

Fig. 9.13 Percentage of hours within the comfort ranges of all localities in the current and projected climatic situation

Climate change, according to the scenarios applied in this study, favors the rooms implanted in the Cfb zone, since, when the temperature rises, the number of hours in which the interior of the house is within the comfort range increases.

The climate projection to 2050 indicates that the dwellings established in the Bsh, Aw, and Af zones will be highly affected, since, according to the current situation, comfort times would drop by up to 30%, averaging only 10% of hours within ranges in the two upper floor housing units.

With these results it is expected to continue and evolve with the research developing new simulations, variations, and considering adaptive comfort to reduce energy poverty.

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