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Evaluation of the energy consumption and overheating of homes in Miami, Guayaquil and Tenerife.

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Declaration of Authorship,

I, Sebastián Avilés, authorize Aurora Monge to sign this Statement of Authorship on my behalf.

I declare that this work is my own and that all resources used for its preparation are duly referenced and cited.

Likewise, I assure that this work has not been previously presented in any other academic institution nor has it been published in any medium.

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ABSTRACT

Year after year, global warming is elevating temperatures all over the world, causing indoor overheating environments that are inhabitable, and increasing energy demand in housing. Given this global concern, the aim of the study was to evaluate the thermal behavior of the house in the cities of Miami, Guayaquil and Tenerife, by a comparison assisted with a simulation for their indoor overheating hours and cooling demand, considering their climates, energy efficiency codes, and construction systems. These were: Miami, with two models (M1 with timber frame as the thermal envelope and M2 with a concrete block system), Guayaquil, with two models (G1 with the limitations for a dwelling with cooling system and G2 without it), and Tenerife with only one model.

As a result, was found that Miami is the case with the higher consumption, which has a higher energy demand in a house of timber wall system than in a house of concrete block system, due to the thermal inertia. Despite that both models have the same usage time for the cooling system, meaning that more power was needed to reach the thermal comfort. Then, Guayaquil and Tenerife, are the cases that follows, with less consumption.

While, according to the UNE EN 16798 methodology, in the indoor overheating hour evaluation in a year, Miami has the higher cases with a 31.43% of its hours in overheating for the timber frame system and a 22.88% for the concrete block system, followed by two cases in Guayaquil, with 4.2%, other with none, and also Tenerife with 2.43%.

Nevertheless, the study showed that energy consumption is not necessarily related to the indoor overheating hours that a house could have. Given that, in the case of Guayaquil, where it doesn’t have any indoor overheating hour in all year, while Tenerife, with a similar energy consumption, has 2.43% of its hours in overheating. Due to the different parameters that the UNE follows in comparison with the cooling setpoints given by the CTE-DB-HE all over the year for the respective cases, because of their long warm seasons. Therefore, the study analyses the limits establish by the Spanish normative in relation to overheating, showing an overestimation assessment if the results with the UNE methodology are compared.

Keywords: energy efficiency, overheating, thermal behavior, simulation

1. INTRODUCTION

The use of energy in our houses is vital to our daily lives. However, the increase in energy demand and in the cost of production is a global concern because of the scarcity of our resources. The energy efficiency in our homes is one of the main issues that should be considered in the development of housing, not only because saving energy helps reducing pollution, but also because it helps saving money and preserving the natural resources.

According to a data collection by Enerdata the electricity consumption doubles worldwide. Figure 1 shows a trend from 2000 until 2050 of electricity consumption in an EnerBlue scenario, which is a hypothetical situation of a successful achievement of the NDC's (Nationally Determined Contributions) emissions targets for 2030. This scenario leads to a global temperature rise between 2 ̊C and 2.5 ̊C. Figure 1 shows an increase in electricity consumption in every sector of the world, giving a trend about the possible continuation of this increase for the next 27 years *[1]*.

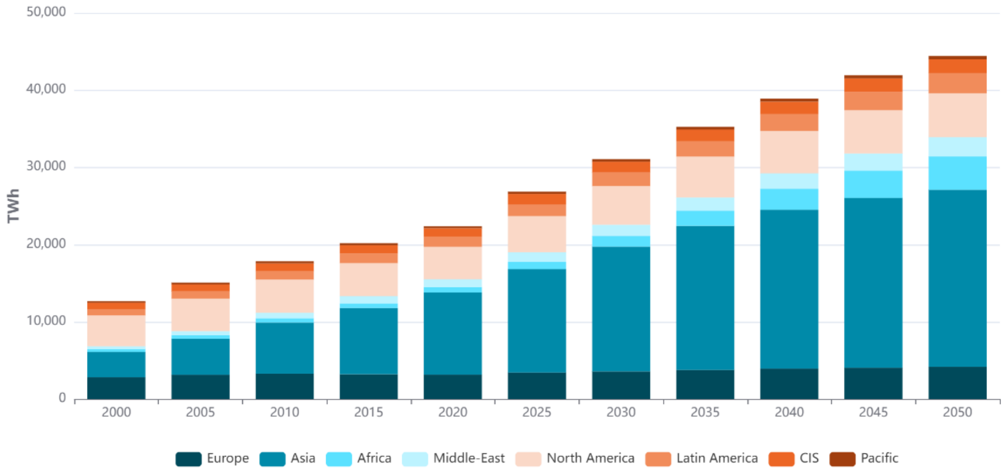

Figure 1 *Total primary energy consumption. Trend over 2000-2050 - EnerBlue scenario [1].*

The International Energy Agency (IEA) states that *"in 2019 world total electricity final consumption reached 22 848 TWh, up 1.7% from 2018"*. Given this fact, the IEA predicts that electricity demand *"is set to increase further as a result to increase further as a result of rising household incomes, with the electrification of transport and heat, and growing demand for digital connected devices and air conditioning" [2]*.

According to a world electricity final consumption done by sector, most of the growth in the OECD (Organization for Economic Cooperation and Development) countries electricity consumption since 1974 comes from the residential sector. As it is shown on Figure 2, from the data collection until 2019, the residential sector is the second sector with the highest electricity consumption with 6072TWh, after the industry sector with 9566 TWh.

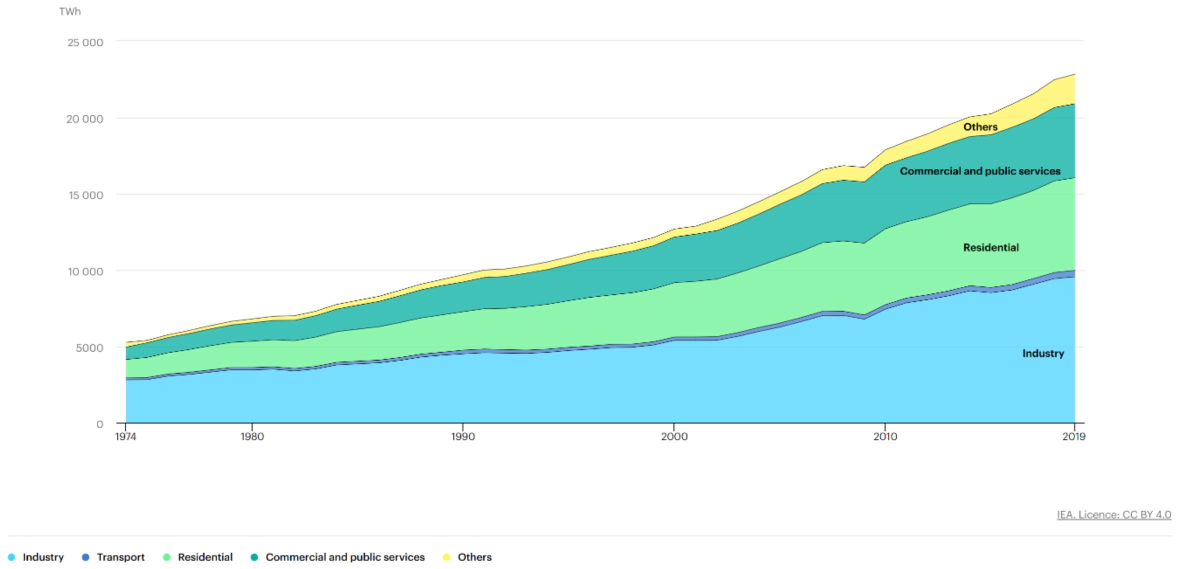

Figure 2 *World electricity final consumption by sector, 1974 - 2019 [2].*

The IEA announce that in a *"Stated Policies Scenario, global electricity demand grows at 2.1% per year to 2040, twice the rate of primary energy demand. This raises electricity's share in total energy consumption from 19% in 2018 to 24% in 2040"*. On the other hand, in a world scenario of a Sustainable Development *"electricity plays an even larger role, reaching 31% of final energy consumption…mainly due to electric vehicles-alongside the direct use of renewables, and hydrogen"*. So, either is one scenario or the other, the trend of electricity consumption is likely to increase worldwide in the residential sector, as well as the others as it is seen in Figure 3 *[3]*.

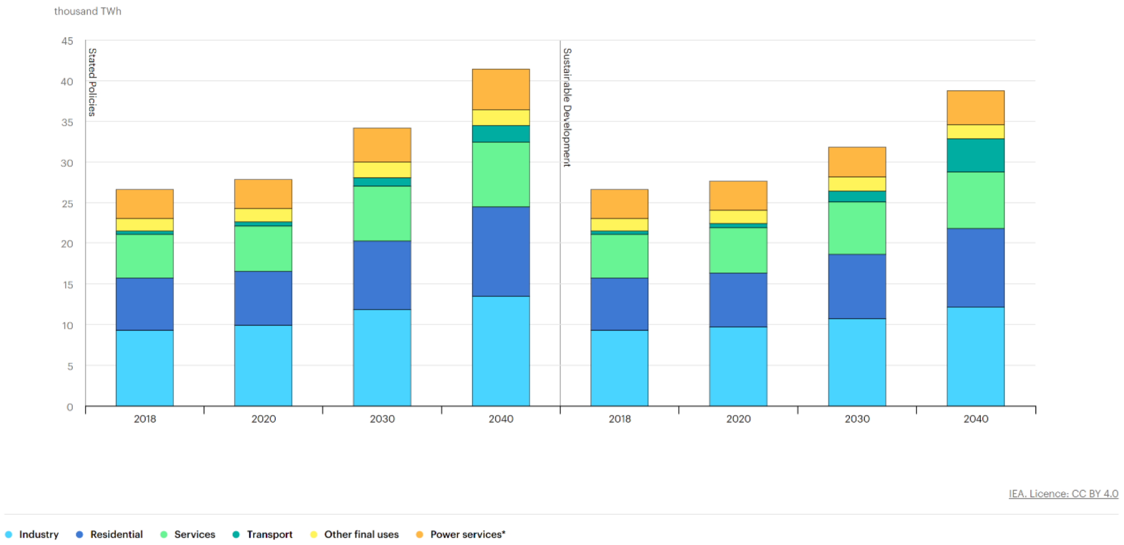

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Figure 3 *Electricity demand by sector and scenario, 2018 - 2040. [3]*

In this case, as long as the energy consumption continues to grow, pollution from fossil fuel is likely to follow the same trend. The combustion of fossil fuels for the production of electricity is responsible for more than 40% of energy-related carbon dioxide emissions. Also, about 80% of all emissions of greenhouse gases are connected to energy in the United States, and the European Union, and only 20% of total energy consumption comes as electricity.

In the United States, in states like Florida, natural gas is the main source of electricity, with a 74% of the energy generation *[4]*. Florida is the third state in the country that consumes the most energy, and despite the fact that natural gas doesn't pollute as much as the production with coal or oil, it still has significant impacts because of the methane gas for its production and transportation. However, nowadays the electricity price in Florida is around $0.16 per kWh, but it is likely to increase due to an increase in natural gas prices *[5]*.

Nevertheless, despite the fact that saving energy is not only important for the environment but also for saving money, to what extent is it possible not to use an HVAC system and achieve thermal comfort in houses?

One of the most important issues in the evaluation of thermal comfort in houses is overheating. This phenomenon occurs when excess heat builds up indoors in warm or hot seasons, where heat gains from the sun can quickly raise the temperature of the space. Solar radiation passes through windows leaving the heat trapped inside, while the high external temperatures aggravate the situation by transferring heat through the building envelope, which creates an overwhelming indoor heat situation. This could create severe consequences for people’s health as heat exhaustion, dehydration, heatstroke, respiratory or even cardiovascular problems.

According to the Council on Foreign Relations (CFR), *“the world is currently on a path that will take it high above 1.5 ˚c: temperatures are estimates to exceed 3 ˚C of warming by 2100”*. This would not only increase the global energy demand, but it will also endanger people’s health, especially in the most vulnerable sectors.

As an example, the CFR establishes that the United States *“cold endure an additional 70 percent increase in the number of days with the heat index above 32 ˚C by 2050 based on current levels of greenhouse gas emissions”*. This demonstrates how pollution not only affects the environment, but also people’s health, given that in this case *“the number of people experiencing thirty or more days with a heat index above 40 ˚C in an average year will increase from under nine hundred thousand to more than ninety million, one third of the US population” [6]*.

Given this, in this study, three cities from around the world were chosen. These cases have tropical or subtropical climates that experience warm temperature throughout the year, as well as high relative humidity, which allows a better analysis and comparison between the energy consumption and the overheating hours of the cases, considering that they have different geographical specifications.

The first city is Miami, Florida in the United States, a warm humid climate which as mentioned above, is not only part of the second sector in the world that is predicted to consume more electricity by 2050 (North America) according to Enerdata, but is also a city that is part of a state that most of its energy depends on a non-renewable source.

The second city for the study is Guayaquil, Ecuador, also a warm humid climate. Despite the fact that 92% of the country’s power generation comes from hydraulic power plants *[7]*, which allows prices not to vary so much, there are other external factors such as unemployment or constant political conflicts that don’t let people work. This became a major issue because thanks to these problems, many people doesn’t have enough money to pay for electricity.

And finally, the third case studied is Santa Cruz de Tenerife, Canary Islands, Spain. In these islands about 95% of the energy consumed comes from fossil fuels *[8]*. This generates an inconvenience with the control of energy prices, which makes it the community with the longest delays in the payment of the energy bills around Spain.

In order to do the comparison of the cases mentioned, it is important to understand that every case counts with singularities such as their own climate specification, energy efficiency codes, construction systems and other parameters that condition their indoor thermal comfort.

1.1 OBJETIVES

Energy consumption is important to have thermal comfort on homes, however, what would happen if there's an energy cut? Or, what would happen if there's a global or local crisis where people couldn't afford to pay for electricity at their homes? Given this, to what extent could people have thermal comfort in their homes? In addition, does cooling consumption gives the same information as overheating?

The study aims to evaluate and analyze the thermal behavior of the house in the cities of Miami, Guayaquil and Tenerife, by a comparison based in the calculations of the indoor overheating hours that each one may have, as well as its energy consumption for cooling.

2. STATE OF ART

2.1 Thermal comfort and climate

The concept of thermal comfort is when a situation of well-being and health is achieved in which, within the environment, there is no discomfort that physically or mentally disturbs people. Therefore, it can be said that thermal comfort means that the user is not experimenting overwhelming situations of cold or hot environments.

These conditions depend in the geographic specification of their climate zone, that involves the latitude and the altitude, which affects the solar radiation. Given that the higher the altitude, the lower is the attenuation of the sun's rays by the atmosphere, so the greater the radiation of the UV rays will be. On the other hand, the latitude will determine the inclination level of the sun, which gets closer to the vertical as it gets closer to Ecuador.

Thanks to the study of thermal comfort there are estimates for the creation of construction systems for each different type of climate, in order to give a better indoor environmental quality at homes according to the regulation of the heat exchanges between the envelope surfaces of the house. These regulations are established by the energy efficiency codes, which tries to obtain indoor thermal comfort with the less energy consumption as possible.

Nevertheless, despite the fact that thermal comfort may be relative due that not everyone has the same thermal sensation, there are parameters given by overheating standards that offer a guideline between what could be a comfort temperature or what could exceed a higher temperature, and be consider overheating.

2.2 Energy efficiency codes

The energy efficiency or energy conservation codes are used to regulate the energy consumption over a design or construction. These codes are usually dictated by the national or local government taking into account the climate zone which contains building guidelines or standards such as the requirements for insulation, cooling, heating, ventilation, minimum U factors and other regulations that help to reduce the energy costs of the building.

In the first case, Miami regulations for dwelling constructions are dictated by the Florida Building Code, Residential, that has a scope for the appliance in *"construction, alteration, movement, enlargement, replacement, repair, equipment, use and occupancy, location, removal* *and demolition of detached one- and two-family dwellings and townhouses not more than three stories above grade plant…”*. This code establishes on Chapter 11 that for energy efficiency: *“The provisions of the Florida Building Code, Energy Conservation, shall govern energy efficiency of residential construction” [9].*

The Florida Building Code, Energy Conservation *[10]*, has its bases on the ASHRAE Standards and Guidelines, from which it takes the climate zones and the minimum U factors requirements from the Standard 90.2-2018, Energy Efficient Design of Low-Rise Residential Buildings *[11].*

The second case in the city of Guayaquil, the regulations for the energy efficiency are taken by the national code called the NEC-HS-EE (Norma Ecuatoriana de la Construcción. Eficiencia Energética en Edificaciones Residenciales), which is dictated by the MIDUVI (Ministerio de Desarrollo Urbano y Vivienda) *[12]*. This code is in charge of categorizing every climate zone that Ecuador has in order to give specifications for the energy conservation of the building in each zone.

And for the case of Santa Cruz de Tenerife, the code that regulates the energy consumption is the Spanish code known as the CTE-DB-HE (Código Técnico de la Edificación. Documento Básico. Ahorro de energía) *[13]*, which is responsible for establishing rules and procedures for the energy saving. This code, counts with a classification of the Spanish climate zones in order to give details of the requirements per zone.

2.3 Overheating standards

The overheating standards are used as guidelines for the calculation of overheating spaces, which has their own estimation to establish the limits of a comfort temperature that should not be exceeded by the operating temperature of the spaces. In case these exceeds the limitation, it is considered overheated. Even though it depends in the standard if the accumulation of those periods is enough to consider overheating in a home. To analyze the overheating at homes three different overheating standards were studied.

The first overheating standards that was studied is in the European and Spanish regulation, called the UNE EN 16798 for energy performance of buildings *[14]*. This is a methodology that follows an adaptive model with a metric since the limits depend on the outside temperature. This methodology code follows a parameter according to the indoor air quality classified by the level of expectation that occupants may have: high (IEQ_I), medium (IEQ_{II}), moderate (IEQ_{III}) and low (IEQ_{IV}).

Since the code establishes that for the calculation of overheating, the daily outdoor temperature should not be used, but rather the average exponential outdoor temperature, it gives two formulas. The first formula dictated by the UNE EN 16798, is a weighted average for "x" number of days, given like this:

$$\Theta_{rm} = (1 - \alpha) \cdot \{\Theta_{ed-1} + \alpha \cdot \Theta_{ed-2} + \alpha^2 \cdot \Theta_{ed-3} \dots\}$$

Where "Θ_{rm}" is the average outdoor operating temperature for the day under consideration, "Θ_{ed-1}" the daily average outdoor air temperature of the previous day and "α" as a coefficient of 0.8

On the other hand, the standard also establishes a formula for the maximum allowable operating temperature, which depends on average outdoor operating temperature according to the same category as the level of expectation that occupants may have.

Nevertheless, this code does not establish what is the percentage that must be exceeded to consider overheating in a home. Given this, it is not possible to say according to this method which house are considered overheated, but is useful for the comparation. However, in the CTE there is nothing that specify about if there is overheating neither. Here it establishes that if there's no cooling system it should not have less than a 4% of the hours out of consignment.

The second standard studied is the American, dictated by the ANSI/ASHRAE Standard 55, called *"Thermal Environmental Conditions for Human Occupancy" [15].* This code, as well as the UNE, is a metric that follows an adaptive model, since the limits depend on the outside temperature. In contrast with the UNE, for the calculation of the comfort temperature, it establishes that it shall be based on no fewer than seven and no more than thirty sequential days prior to the day in question. This is because, the further away the days of the analysis, the less is the influence on the comfort temperature.

As for the maximum allowable operating temperature, it establishes a formula where the upper 80% acceptability limit in Celsius is equal to 0.31 $t_{pma(out)}$+21.3.

In contrast with the UNE, the America standard establishes a lower maximum allowable temperature, which makes it more demanding. However, like the UNE, the AHSRAE does not establish what is the percentage that must be exceeded to consider overheating in a home, hence this code doesn’t classify a house like overheated.

Finally, the third overheating standard that was studied is the English code given by the CIBSE TM59, called *“Design methodology for the assessment of overheating risk in homes” [16].* This code is aimed at homes with mechanical ventilation and with good opportunities of natural ventilation in summer. However, it should be evaluated by taking into account the adaptative method based in the CIBSE TM52 *[17].*

This English code establish two different criteria for homes predominantly naturally ventilated. The first criteria are according to the living rooms, kitchen and bedrooms, in which the number of hours during the change in temperature is greater or equal to 1 (°K) during the period from May to September, and will not exceed 3% of the busy hours.

The second criteria are only for bedrooms, in order to guarantee comfort during sleeping hours. This standard establishes that the indoor temperature from 22:00 until 07:00 will not exceed the 26°C for more than 1% of annual hours.

As for homes criteria, predominantly mechanically ventilated, it says that all occupied rooms should not exceed an operative temperature of 26°C for more than 3% of the annual occupied hours.

It should be understood that the CIBSE is an English code that it only takes into account the summer season, which is the period of the year that is likely overheated. This is why the percentages per year are really small, due that they don’t have long summers or high temperatures all year long.

However, once the standards and codes are known, each case is studied by a methodology according to its climate data and a proper model with active and passive parameters for the search of the willing to know their energy consumptions and the overheating hours that they may have. Therefore, it was decided to simulate all models with the adaptive methodology of European UNE EN to be able to compare them.

3. METHODOLOGY

3.1 Climate data of the cases studied

First of all, the different climates from the case studies are analyze and compare, for further understanding of their climate zones and the thermal transmittance regulations of their envelopes.

3.1.1 Miami

For the weather conditions of Miami, the "USA_FL_MIAMI_AP_TMY3.epw" file from climate series from 1990 to 2005 was used. According to the file, it is a very hot-humid city with a Köppen classification = Aw, of tropical, wet and dry. The city of Miami, Florida, in the United States, is located at latitude 25 ° 82'N, with an altitude of 11m. classify

Miami has a warm humid climate with an average annual temperature of 24.5 ̊C. The city does not experience major changes between seasons like other cities due to its geographic characteristics. Instead, Miami only counts with two main seasons: summer, with the hottest months from May until October, with July as the hottest with an average maximum temperature of 28.1 ̊C; and a windy winter with the coolest months, from November until April, with January as the coolest with an average minimum temperature of 19.4 ̊C. Also, despite the fact that relative humidity is present all over the year, it has a higher level on the months from July until December.

3.1.2 Guayaquil

For the weather conditions of Guayaquil, the "Guayaquil_Ecuador-hour.epw" file from the climate series from 1990 to 2005 of Meteonorum was used. According to the file, Guayaquil is also a very hot-humid climate with a Köppen classification = Aw, of tropical, wet and dry. This is a city located in the Ecuadorian coast at latitude 2 ° 10'S, with an altitude of 11m.

Guayaquil, as well as Miami, have only two seasons. The first is the wet season, which have the hottest months and the highest relative humidity of the year, due to its constant precipitation. The wet season goes approximately from December until May, and have January and May as the hottest months with an average maximum temperature of 26.3 ̊C. The second is the dry season, which is characterized by having less relative humidity and the coolest months from June until November approximately, with August and September as the coolest months with an average minimum temperature of 23.5 ̊C.

3.1.3 Santa Cruz de Tenerife

While, for the weather conditions of Santa Cruz, the “ESP_TENERIFE_SWEC.epw” file from the climate series from 1980 to 2005 was used. According to the file, the city is hot-humid, and has a Köppen classification = Cfa, humid subtropical (warm summer). Santa Cruz de Tenerife is the capital of its namesake, which is the largest island of the Canary Islands. This island is located in the Atlantic Ocean above Africa and the capital is at latitude 28 ° 28’N, with an altitude of 46m.

As well as the other two cases, Santa Cruz de Tenerife also have two main seasons all over the year. However, unlike the other cities, the highest temperatures seen on summer from June until September, doesn’t match with the highest months of relative humidity, which are from October until December. Nevertheless, it has a higher average temperature difference than Guayaquil, with January as the coolest month with an average temperature of 17.9 ℃, and August as the hottest with an average temperature of 25.1 ℃.

3.1.4 Comparative analysis of climate

According to the climate files and description given above, the following figures shows a comparison between the dry bulb temperature and the relative humidity of the cities of Miami, Guayaquil and Santa Cruz de Tenerife.

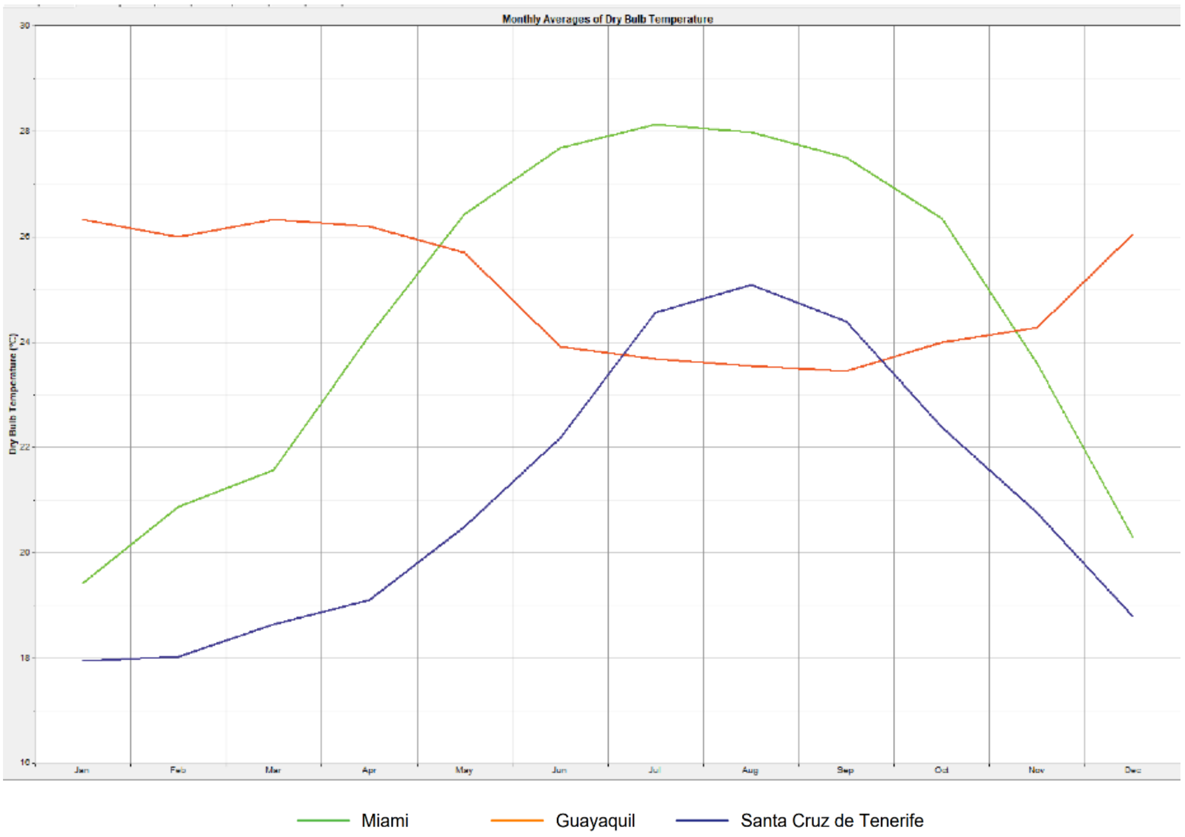


Figure 4 *Dry Bulb Temperature in a year of Miami, Guayaquil and Santa Cruz de Tenerife. Source: Own elaboration from climate files*

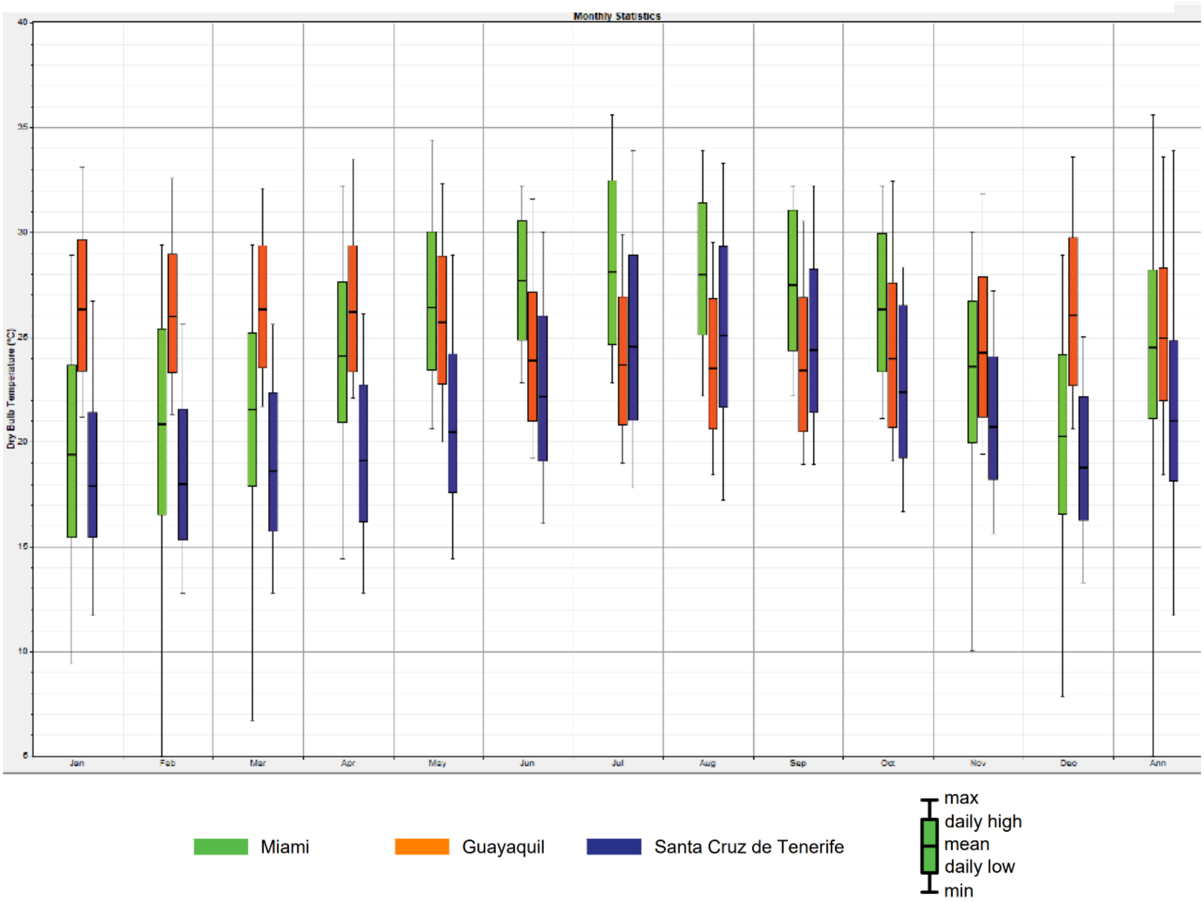


Figure 5 *Box-plot of Dry Bulb Temperature in a year of Miami, Guayaquil and Santa Cruz de Tenerife. Source: Own elaboration from climate files*

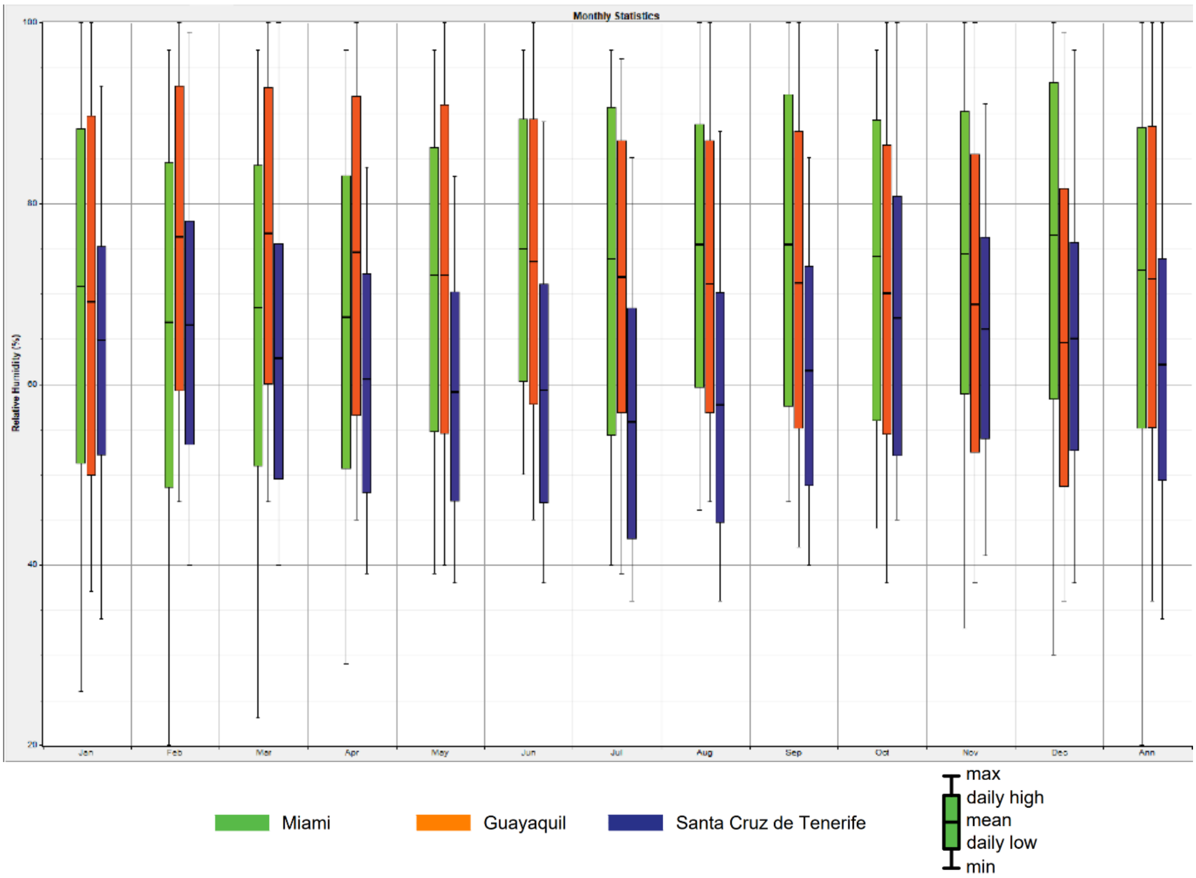


Figure 6 *Box-plot of relative humidity in a year of Miami, Guayaquil and Santa Cruz de Tenerife. Source: Own elaboration from climate files*

Finally, the Cooling degree days (in base 20 ̊C) and the Heating degree days (in base 15 ̊C) were calculated for each location, giving an idea of the severity of the climates, which are summarized in Table 1.

Table 1 *Cooling degree days (CDD) and Heating degree days (HDD) of the study cases. Source: Own elaboration*

	Miami	Guayaquil	Tenerife
Cooling degree days (20C)	1849	1812	749
Cooling degree days (15C)	42	0	8

3.2 Model for energy and thermal simulations

Then, for the analysis and evaluation of overheating and energy consumption in housing in these cities, a 3D model was created in Design Builder (Energy +). This model consists of a 2-floor detached home north-south oriented with a gabled roof, of approximately 160 m^2 built, with 80 m^2 built per floor. The first floor is an open floor plan, which is going to occupy the living room, the kitchen, the dining room and also a guest bathroom. This floor, has two windows at the front, one with a surface of $4m^2$ and other with a surface of $1.5m^2$. While, at the back of the house there are 2 windows, each with a surface of 2.2 m^2. The second floor has 3 bedrooms and 2 bathrooms. Here there are 2 windows with a surface of 2.2 m^2 at the back, two others with a surface of 4 m^2 and 1.5 m^2 at the front, and other two small windows of 0.5 m^2on the sides.

Even though, for the purpose of the analysis each of the rooms has been considered as only one thermal zone.

Given the conditions of the unique model, the energy conservation codes of each city are studied in order to know what parameters, construction systems or thermal transmittance would each case have.

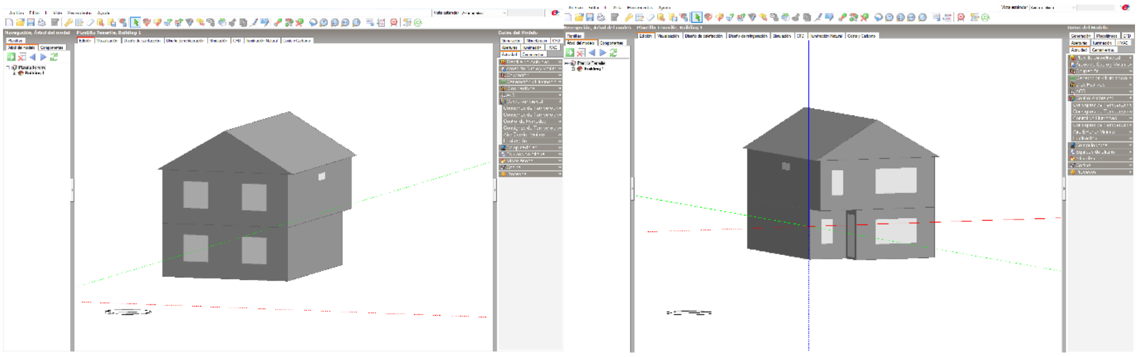


Figure 7 *Design Builder 3D energy simulation model. Source: Own elaboration*

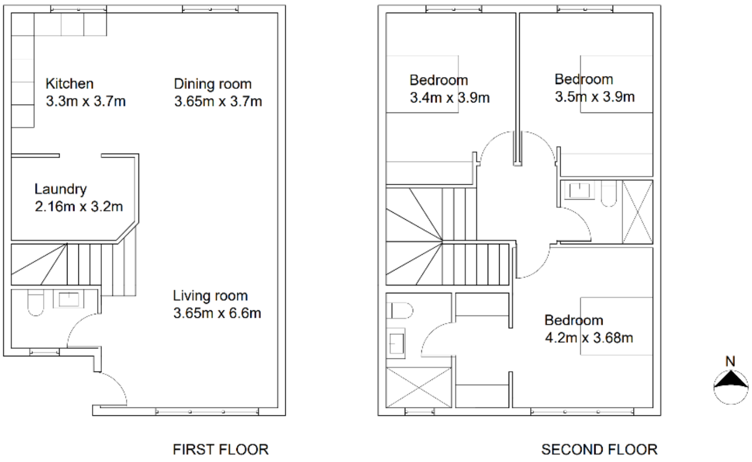


Figure 8 *Floor plans of the simulation model. Source: Own elaboration*

3.3 Active and passive measures for energy efficiency

In order to make the model more energy efficient there are two main measures that were taken into account. On one hand there are the active measures, which are the ones that try to maintain an indoor thermal comfort through mechanical systems. And on the other hand, there are the passive measures, which try to make the building more energy efficient, by integrated design strategies, such as the control of the thermal transmittance of the construction elements, and also by taking into account the natural factors to apply strategies such as the natural ventilation or the control of air leakage.

Within active measures, the mechanical system that will be use for the HVAC design of the models is a Fan Coil Unit (4 pipe), air cooled chiller. For the purpose of this evaluation, the cases will only have a cooling system in order to avoid overheating and obtain a thermal comfort, and the heating system is not considered.

Given that, every case counts with its own codes, because of their different locations. So, a study was made in order to introduce the set points for the simulation of the cooling system.

Miami, guided by the “Florida Building Code, Energy Conservation”, which has its bases on the ANSI/ASHRAE, establish in it that for the simulation of a mechanical system in a computer program you should look up into the ANSI/ASHRAE Standard I 40-2017 “Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs” *[18]*. This code presents many ways in which you could make a set up for the set points according to the temperature and the HVAC parameters. The most similar to the case study, establish that from 18:00 hours to 07:00 hours the cooling system should remain OFF, while from 07:00 hours to 18:00 hours if the indoor operating temperature is higher than 27 ̊C cooling can be turned ON.

In the case of Tenerife, it is given by the “CTE-DB-HE” (Código Técnico de la Edificación - Documento Básico Ahorro de energía). In this code it is establish the operational conditions for conditioned spaces in private residential use, according to the month, the schedule and the set temperature.

The set temperature that belongs to Tenerife matches with the schedule range from June to September, because those are the months that have higher temperature. During this period, the set points that are establish in order to turn ON the cooling system is from 00:00 to 6:59 if the temperature is equal or higher than 27 ̊C, from 15:00 to 22:59 if the temperature is equal or higher than 25 ̊C, and from 23:00 to 23:59 if the temperature is equal or higher than 27 ̊C.

In the case of Guayaquil, it doesn't have any code that specify an optimum use of a cooling system, or any set point that could help as a guideline.

So, with the purpose of a better analysis and comparison between the energy consumption of these 3 cases, the most unfavorable set points of the "CTE-DB-HE" were chosen as a unique operational parameter for the 3 cities. Nevertheless, given the fact that the months that present the higher temperatures are different in every city, the set points chosen from the Spanish code from June to September will be use all over the year in the three cases (Table 2). In addition of finding the energy consumption throughout the year, these active measures, will also help for the calculation of the total hours in a year that the operational conditions are exceed, or the percentage of hours that the cooling system is used.

Table 2 *Operational conditions of air-conditioned spaces in private residential use*

Schedule	0:00-6:59	7:00-14:59	15:00-22:59	23:00-23:59
Temperature (̊C) >	27	-	25	27

As for the passive measures, the air renewals for the indoor air quality and night ventilation were considered. Therefore, each indoor air quality regulation was searched in order to establish a unique operating parameter with the most demanding code.

For Miami, the regulation for indoor air quality in housing is given by the *"ANSI/ASHARE Standard 62.2-2013"*, referred as *"Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings"*. This code shows for our case in *"TABLE 8.2.1b (SI) Dwelling Unit Ventilation Air Requirements, L/s"*, that the minimum air renewal requirement for three bedrooms of a floor area between $47m^2$ and $93m^2$ is 28 l/s *[19].*

On the other hand, in the case of Guayaquil for indoor air quality, it is also followed by its energy efficiency code, the NEC-HS-EE. This code in point 4.4.1of Air quality (Calidad del aire), gave a formula for the calculation of the air renewals requirement for housing (Requerimientos de aire fresco para vivienda). The formula states the following:

$$Qtot = 0.15(Apiso) + 3.5(Ndorm + 1)$$

Where, "*Qtot*" is the air renewals required (l/s), *"Apiso"* is the area of the house (m^2), and *"Ndorm"* is the number of bedrooms. Considering this, the air renewals required for the house in Guayaquil would be of 24 l/s.

Despite this, with the willing of having a unique parameter for the three models it was chose the indoor air quality required of Santa Cruz de Tenerife for the three cases. This city has its regulations for natural ventilation establish in the *"CTE -DB-HS" [20].* As an approximation, taking into account the table of the code named as *"Caudales minimos para ventilacion de caudal constante en locales habitables",* it was obtained 33 l/s as the total for the air flow required. Given this, the units were transformed from l/s to ren/h, in order to take into account, the dimensions of the dwelling's volume, which gave 0.5 ren/h.

Even though, the Spanish government give another code referred as *"Condiciones Técnicas de los procedimientos para la evaluación de la eficiencia energética" [20],* where it establishes a requirement for the air flow at night to refrigerate in point 6.6 named as *"Renovación de aire. Ventilación e infiltraciones".* This table gave 4 ren/h as the air flow at night for living areas of buildings with private residential use. Therefore, for the final simulation model it was taken into account 0.5 ren/h from 8:00 until 23:59 for the indoor air quality, and 4 ren/h from 00:00 until 7:59 for the night ventilation to refrigerate. However, this condition is only considered when there is a difference between the internal and external temperature of at least 2 ̊C, with a minimum interior temperature of 24 ̊C.

Apart from this, it is very important for the simulation to focus in the envelope parameters, such as the air leakage of the façade. So, it was also proceeded to obtain those requirements from the codes of the cities.

Miami's requirements for air leakage given by the *"Florida Building Code. Energy conservation",* says on chapter 4 of *"Residential Energy Efficiency. Section R402 Building thermal envelope"* point *"R402.4.3 Fenestration Air leakage",* that *"Windows skylight and sliding glass doors shall have an air infiltration rate of no more than 1.5 L/s/m^2..., and swinging doors no more than 2.6 L/s/m^2 "[10]*

As for Guayaquil it is establish in the Ecuadorian code, the NEC-HS-EE, in section 4.3 of Air Infiltration Control, the maximum permissible infiltration rates according to the different types of joints, in which says that for aluminum frame windows and sliding doors, in the case of Guayaquil's fenestration, the air infiltration limit is 25 $m^3/h\ m$.

While, in the case of Santa Cruz de Tenerife, the air leakage requirements are given by the CTE-DB-HE, Section HE 1for the control of energy demand. Here it states on Table 3.1.3.a-HE1 the limit value of air permeability of voids of the thermal envelope, which establishes the limits per climate zone, in our case 27 $m^3/h\,m$. On the other hand, it was also important to take into consideration the pressure at which the air infiltrated, so it was seen on Table 3.1.3.b-HE1 a limit value of the air exchanges ratio with a pressure of 50Pa, taking into consideration de compactness of the dwelling by the formula V/A (m^3/m^2). As a result, this gives an estimation of 3 ren/h with an infiltration rate at 50Pa.

Due that the air leakage regulations of the cases were very similar, the limits of Santa Cruz the Tenerife (3 ren/h with an infiltration rate at 50Pa) were taken as a unique variable for the air leakage, as a simplification for the three cases for the simulation model, due that the other passive measures were also taken from this code.

In addition, with the purpose of reducing as much as possible the solar absorption of the house, it was chosen the white color, which has a solar absorption of approximately 0.5 that helps to reflect the solar rays.

Table 3 *Passive measures considered in all the simulation models.*

Passive measures		Schedule
Indoor air quality	0.5 ren/h	8:00 - 23:59
Night ventilation	4 ren/h	00:00 - 7:59[b]
Air leakage	3 ren/h[a]	-
Solar absortance	0.5	-

a. With an infiltration rate at 50Pa

b. ΔT = 2℃, if Tint is at least 24℃

3.4 Defining the construction system and calculating

When all measures are set, the energy efficiency codes of each city are studied in order to know the regulatory limits for the U factor of the envelopes. Given this, the construction systems of each city were investigated in order to get closer to the reality of the energy consumption and the indoor overheating hours in housing in those cities.

After knowing the construction systems of each city, those constructive elements are introduced into the model of Design Builder with their corresponding U factors, regulated by each of their energy efficiency codes. Once the model has all the corresponding measures and constructive element per case, the monthly/annual demand energy for cooling is calculated by the software considering the use of A/C. Also, an estimation of the exceeding hours of the cooling setpoint of CTE-HE-0 is done, by simulating the dwellings without A/C with their hourly temperature.

On the other hand, as addressed in section 2.3 of "Overheating standards", the method that was used for the calculations in all cases of the overheating hours was the UNE EN 16798-1:2020 (European Standard), because is a more permissive metric due to its higher maximum allowable temperature.

For the calculation of the overheating hours, the exterior temperature should be estimated by a weighing of the mean temperatures of the previous days. This is given by the formula stated in section 2.3 taken from the UNE EN 16798 for a "x" number of days. The calculation was done with 7 days, so it can comply with UNE standards of not making an estimation with fewer number of days than that.

Once the exponential mean temperature per day is calculated, results given from operative temperature by Design Builder are used to estimate the maximum allowable operative temperature. For this, an Environmental Category of medium level of expectation of occupants (IEQ_{II}) was chosen.

The results of overheating per hour will be given by the difference between the operating temperature of the house and the limit given by the formula of the UNE for Category II:

$$\Theta_o = 0.33\Theta_{rm} + 18.8 + 3$$

Where "Θ_o" is the indoor operating temperature (̊C) and "Θ_{rm}" is the average outdoor operating temperature (̊C). If the indoor operating temperature per hour exceeds the limit given by the average outdoor operating temperature, then it is considered an overheating hour.

Based on this, the hours of overheating for a whole year are calculated for the five cases of the three cities, considering that the house is occupied 24/7 all year, and that there's no cooling system.

4. CASE STUDIES

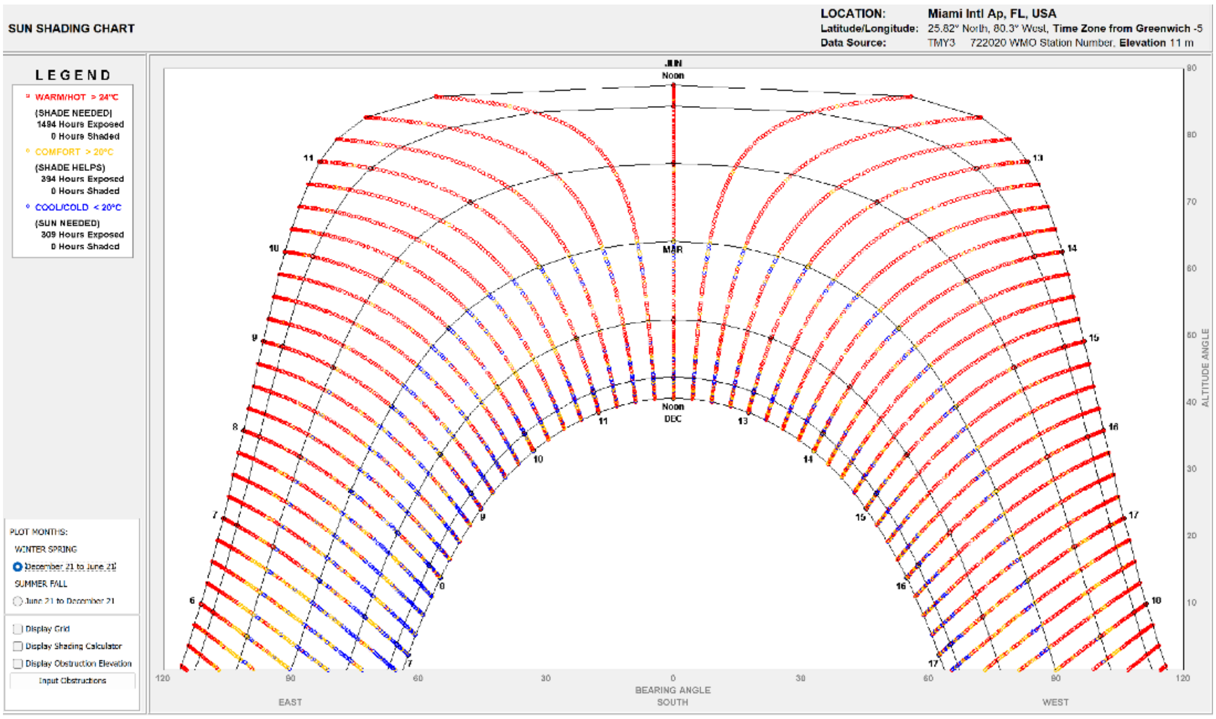
4.1 Miami

4.1.1 Analysis of sun shading chart and psychrometric chart

Before the simulation of the energy consumption of the house or the overheating hours that it may have, it is important to understand the path of the sun and the impact it has per hour over the months. This path will be conditioned by the specifications of the geographic location, such as the latitude, longitude and elevation, which will alter the bearing and altitude angle in the path of the sun.

The sun shading chart indicates: red as a warm/hot condition for more than 24 ˚C, yellow as comfort for more than 20 ˚C, and blue as a cool/cold condition for less than 20 ˚C.

In the first period of Miami, from December 21 until June 21, there are many morning hours from December until March in which the sun doesn't have too much impact, hence many hours are considered as comfort or even as a cool/cold condition below the 20 ˚C. On the contrary, in the afternoon hours on those months, the sun begins to have a more significant impact, so it increases the warm/hot hours above 24 ˚C. Even so, from March until June the warm/hot hours are notably higher than any other condition all over the day, with few little hours considered as comfort or cool/ cold conditions at morning. As a result of this, the city of Miami counts with 1494 hours exposed in a warm/hot condition, 394 hours in comfort and 309 hours in cool/cold condition.



SUN SHADING CHART

LOCATION: Miami Intl Ap, FL, USA
Latitude/Longitude: 25.82° North, 80.3° West, Time Zone from Greenwich -5
Data Source: TMY3 722020 WMO Station Number, Elevation 11 m

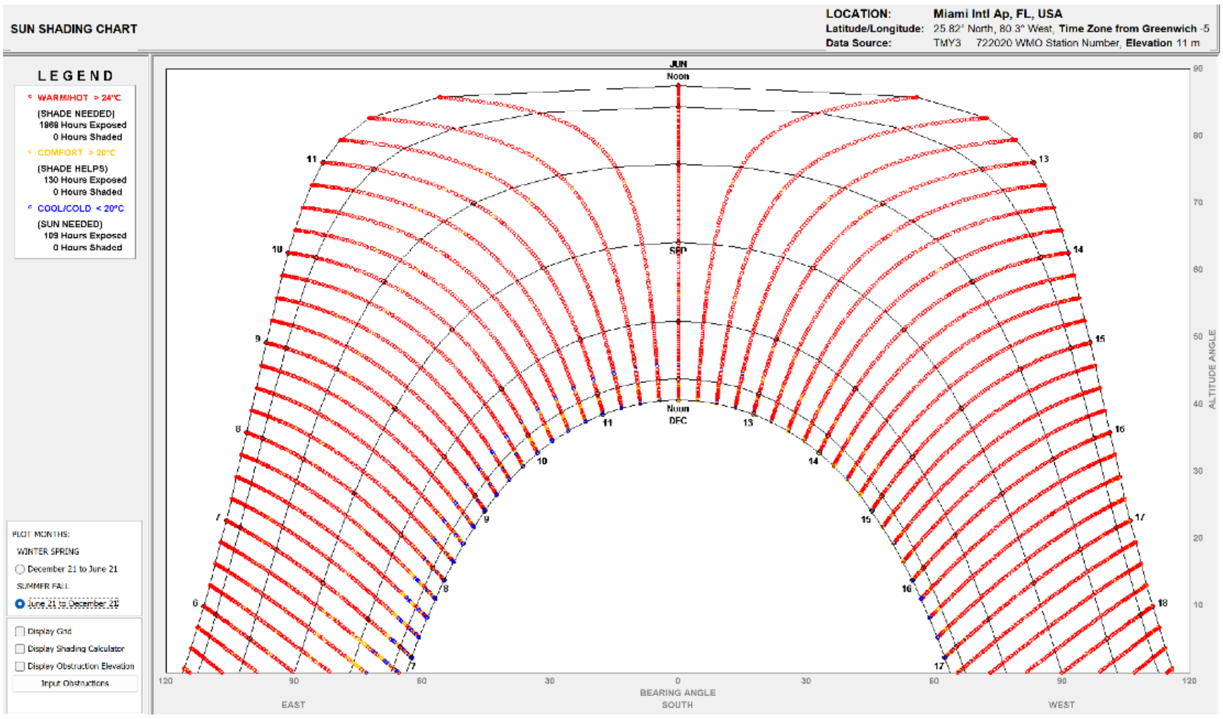
LEGEND
- WARM/HOT > 24°C (SHADE NEEDED) 1494 Hours Exposed 0 Hours Shaded
- COMFORT > 20°C (SHADE HELPS) 394 Hours Exposed 0 Hours Shaded
- COOL/COLD < 20°C (SUN NEEDED) 309 Hours Exposed 0 Hours Shaded

PLOT MONTHS:
WINTER SPRING
● December 21 to June 21
SUMMER FALL
○ June 21 to December 21

☐ Display Grid
☐ Display Shading Calculator
☐ Display Obstruction Elevation

Figure 9 Sun shading chart of Miami from December 21 until June 21. Source: Own elaboration from climate file

In contrast, in the sun shading chart from June 21 until December 21, the warm/hot hours are significantly higher all over the day on those months, except for some morning hours in November and December that could reach a comfort condition or even a cool/cold condition, below 20 ̊C. This gave a high result of 1969 hours exposed in a warm/hot condition, and only 130 hours of comfort and 109 hours of a cool/cold condition.



SUN SHADING CHART

LOCATION: Miami Intl Ap, FL, USA
Latitude/Longitude: 25.82° North, 80.3° West, Time Zone from Greenwich -5
Data Source: TMY3 722020 WMO Station Number, Elevation 11 m

LEGEND
WARM/HOT > 24°C
(SHADE NEEDED)
1969 Hours Exposed
0 Hours Shaded
COMFORT > 20°C
(SHADE HELPS)
130 Hours Exposed
0 Hours Shaded
COOL/COLD < 20°C
(SUN NEEDED)
109 Hours Exposed
0 Hours Shaded

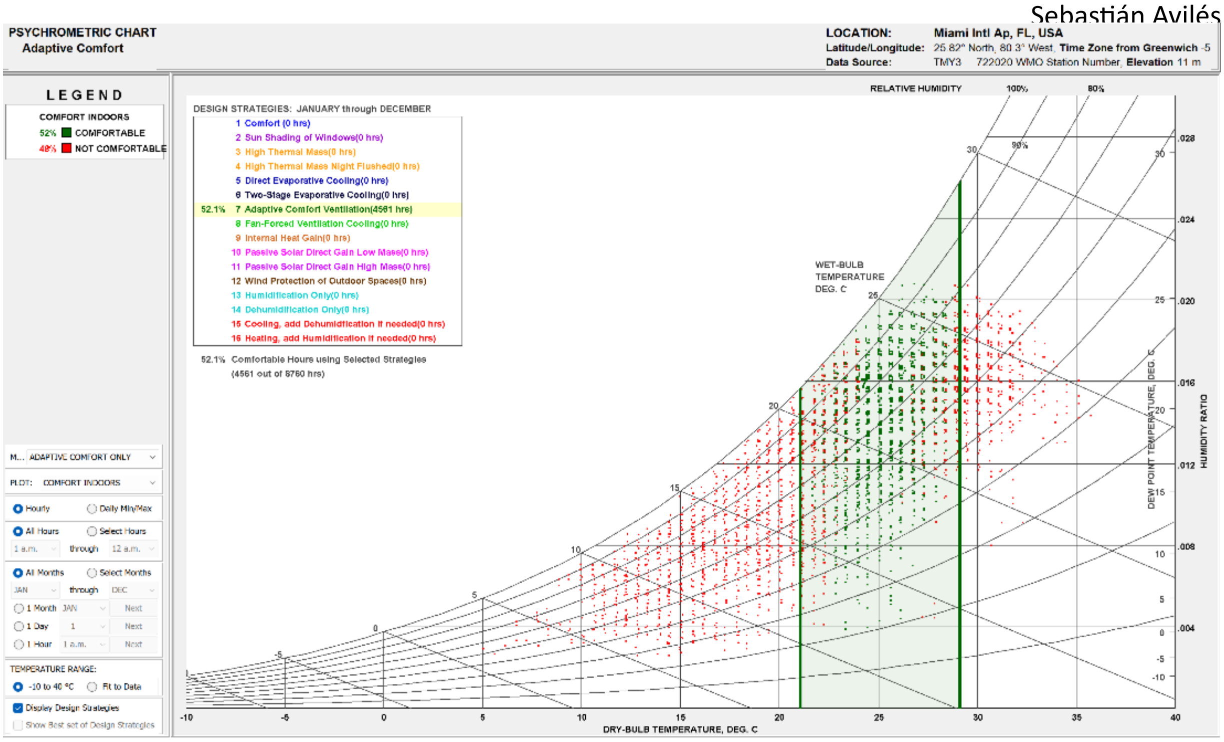
PLOT MONTHS:
WINTER SPRING
○ December 21 to June 21
SUMMER FALL
● June 21 to December 21

☐ Display Grid
☐ Display Shading Calculator
☐ Display Obstruction Elevation

Figure 10 *Sun shading chart of Miami from June 21 until December 21. Source: Own elaboration from climate file*

On the other hand, the psychrometric chart will show all the hours of the year with its dry bulb temperature, in order to know the relative humidity, the humidity ratio, the wet bulb temperature and other thermodynamical factors of the air that could disturbs the thermal comfort.

The Miami’s psychrometric chart illustrates all the hours of the year, of which 52% are comfortable with an adaptative comfort ventilation strategy and 48% them they are not. This little difference could be seen in the chart, whereas temperature rises, so the relative humidity, which could affect thermal comfort, until the point of passing the adaptative limit marked with green.



PSYCHROMETRIC CHART
Adaptive Comfort

LOCATION: **Miami Intl Ap, FL, USA**
Latitude/Longitude: 25.82° North, 80.3° West, **Time Zone from Greenwich** -5
Data Source: TMY3 722020 WMO Station Number, **Elevation** 11 m

LEGEND

COMFORT INDOORS
52% 🟩 COMFORTABLE
48% 🟥 NOT COMFORTABLE

DESIGN STRATEGIES: JANUARY through DECEMBER

1 Comfort (0 hrs)
2 Sun Shading of Windows(0 hrs)
3 High Thermal Mass(0 hrs)
4 High Thermal Mass Night Flushed(0 hrs)
5 Direct Evaporative Cooling(0 hrs)
6 Two-Stage Evaporative Cooling(0 hrs)
52.1% 7 Adaptive Comfort Ventilation(4561 hrs)
8 Fan-Forced Ventilation Cooling(0 hrs)
9 Internal Heat Gain(0 hrs)
10 Passive Solar Direct Gain Low Mass(0 hrs)
11 Passive Solar Direct Gain High Mass(0 hrs)
12 Wind Protection of Outdoor Spaces(0 hrs)
13 Humidification Only(0 hrs)
14 Dehumidification Only(0 hrs)
15 Cooling, add Dehumidification if needed(0 hrs)
16 Heating, add Humidification if needed(0 hrs)

52.1% Comfortable Hours using Selected Strategies
(4561 out of 8760 hrs)

M... ADAPTIVE COMFORT ONLY
PLOT: COMFORT INDOORS
● Hourly ○ Daily Min/Max
● All Hours ○ Select Hours
1 a.m. through 12 a.m.
● All Months ○ Select Months
JAN through DEC
○ 1 Month JAN Next
○ 1 Day 1 Next
○ 1 Hour 1 a.m. Next
TEMPERATURE RANGE:
● -10 to 40 °C ○ Fit to Data
☑ Display Design Strategies
☐ Show Best set of Design Strategies

Figure 11 Psychrometric chart of Miami of all year. Source: Own elaboration from climate file

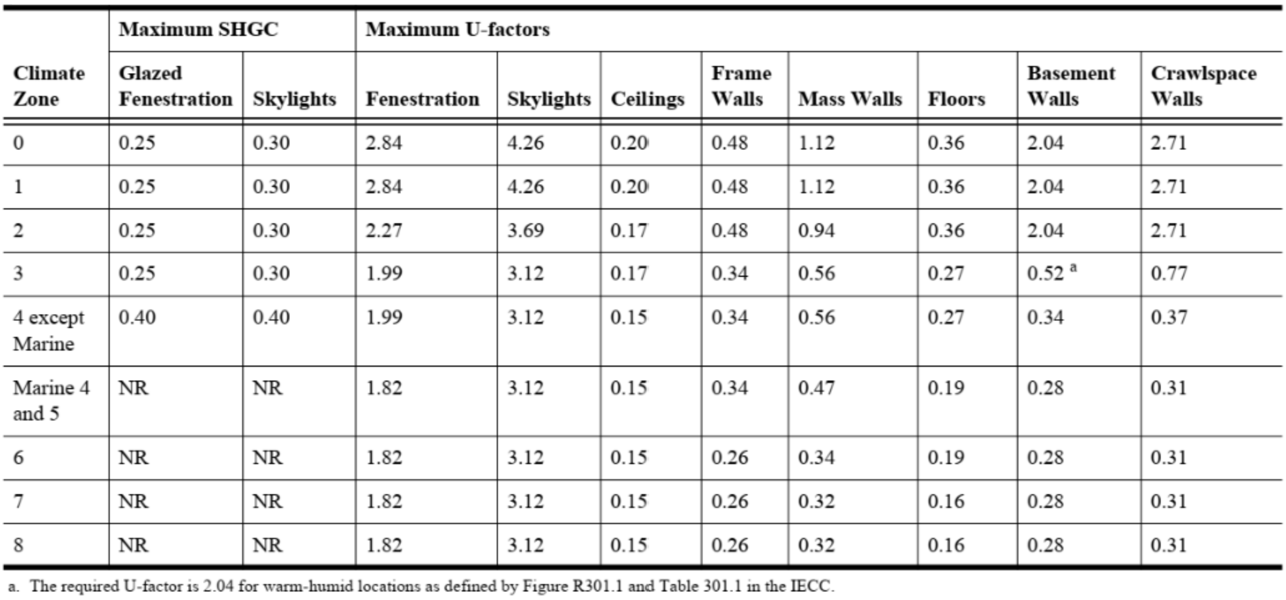
4.1.2 Climate zone according code

As mentioned before, the building regulations in the United States are dictated per state. Nevertheless, in the case of Florida, due to its size and the diversity of its climates, it classifies their cities in different climates zones. According to the *"Florida Building Code. Energy Conservation, Chapter 3, Section C301, Climate Zones"*, it categorizes Miami on Table C301.1 as a 1A climate. In which 1 stand for a thermal criterion of 5000 <CDD10 ̊C, as a measure in cooling degree days that estimates the cooling needed to a keep a comfortable temperature. While A stand for *"Warm-humid Definition: location where either of the following wet-bulb temperature conditions shall occur during the warmest six consecutive months of the year: 1. 19.4 ̊C or higher for 3000 or more hours; or 2. 22.8 ̊C or higher for 1500 or more hours" [10].*

4.1.3 Requirements for energy efficiency

Once the classification of the climate zone is known, it is necessary to figure out what are the requirements for thermal transmittance of the envelope in that climate zone, in order to comply with the building regulations for the simulation model. Because the *"Florida Building Code. Energy Conservation"* has its bases on the ASHRAE, they have the same climate zones classification and regulations for the thermal transmittance of the envelope per zone. Given this, the U factors were taken from the *"ANSI/ASHRAE/IES Standard 90.2-2018"*, called the *"Energy-Efficient Design of Low-Rise Residential Buildings"*. This code establishes the maximum SHGC (Solar Heat Gain Coefficients) and U factors for all the parts of the envelope of all climate zones, but the one for Miami's case will be the Climate zone 1 (Table 4).

Table 4 *Maximum SHGC and U-factors when On-Site Power is used (SI units) [11].*



	Maximum SHGC		**Maximum U-factors**							
Climate Zone	**Glazed Fenestration**	**Skylights**	**Fenestration**	**Skylights**	**Ceilings**	**Frame Walls**	**Mass Walls**	**Floors**	**Basement Walls**	**Crawlspace Walls**
0	0.25	0.30	2.84	4.26	0.20	0.48	1.12	0.36	2.04	2.71
1	0.25	0.30	2.84	4.26	0.20	0.48	1.12	0.36	2.04	2.71
2	0.25	0.30	2.27	3.69	0.17	0.48	0.94	0.36	2.04	2.71
3	0.25	0.30	1.99	3.12	0.17	0.34	0.56	0.27	0.52 [a]	0.77
4 except Marine	0.40	0.40	1.99	3.12	0.15	0.34	0.56	0.27	0.34	0.37
Marine 4 and 5	NR	NR	1.82	3.12	0.15	0.34	0.47	0.19	0.28	0.31
6	NR	NR	1.82	3.12	0.15	0.26	0.34	0.19	0.28	0.31
7	NR	NR	1.82	3.12	0.15	0.26	0.32	0.16	0.28	0.31
8	NR	NR	1.82	3.12	0.15	0.26	0.32	0.16	0.28	0.31

a. The required U-factor is 2.04 for warm-humid locations as defined by Figure R301.1 and Table 301.1 in the IECC.

4.1.4 Construction systems

Given that the study concern is about the energy consumption and the overheating hours that a house could have, the two most typical construction systems for housing of the city were chosen. Nevertheless, these two construction methods have different regulatory limits for the U factor of the walls, due that one method consists of a wood frame system and the second one consists on a concrete block system. The first case referred as "Model M1" is the timber frame system, which follows the U factor requirements of "Frame walls" according to Table 4. The construction composition of this system for the simulation model is the following:

Table 5 *Construction system of Model M1. Source: Own elaboration*

Constructive element	Description	Components	U Factor (W/m^2K)	Regulatory limit (W/m^2K)
Walls	Frame wall	Stucco Polyethylene sheet Plywood Fiberglass/wood framing (10cm) Gypsum plasterboard	0.31	0.48
Roof	Roof tile	Clay tile Air gap Roofing felt Plywood Loose fill/powders-cellulosic insulation	0.2	0.2
Floor with ground	Concrete slab	Gravel XPS (5cm) Polyethylene sheet Cast Concrete Floor screed Timber flooring	0.36	0.36
Non habitable attic	Wood truss	Loose fill/powders-cellulosic insulation Plywood Gypsum plasterboard	0.2	*Note: the regulatory limit is given as a whole with the roof*
Door	Timber door	Painted Oak	2.82	2.84
Windows	Doble pane glass	Doble Clear SolarPlus LOWe 3mm/13mm Air	1.8(SHGC=0.22)	2.84(SHGC=0.25)

While, the second case is the most typical way of housing construction in Miami. This construction system is very similar from the one just mentioned, with the only difference that it has “Walls” as a variable in the composition of the constructive elements, due that it is built by concrete blocks. This case will be referred as “Model M2”, and will follow the U factor requirements for “Mass Walls”, according to Table 4. The components of the “Walls” variable for the simulation model is the following:

Table 6 *Construction system of Model M2. Source: Own elaboration*

Constructive element	Description	Components	U Factor (W/m^2K)	Regulatory limit (W/m^2K)
Walls	Concrete block	Stucco Aerated concrete block Air gap/Metal frame Gypsum plasterboard	0.94	1.12

In contrast with the frame system of Model M1, Model M2 has a more permissible regulatory limit for thermal transmittance (1.12 W/m^2K). On the other hand, as a shading strategy, both models count with interior slat blinds in all of their windows with a set-up from 10:00 until 16:30 all days of the year.

With these construction systems, two simulation models were made for Miami, in order to compare between the two models and the ones from the other cities, what is the energy consumption in each case? And, in a hypothetical scenario; what would happen if there’s an energy cut in the state? How many overheating hours would each case have?

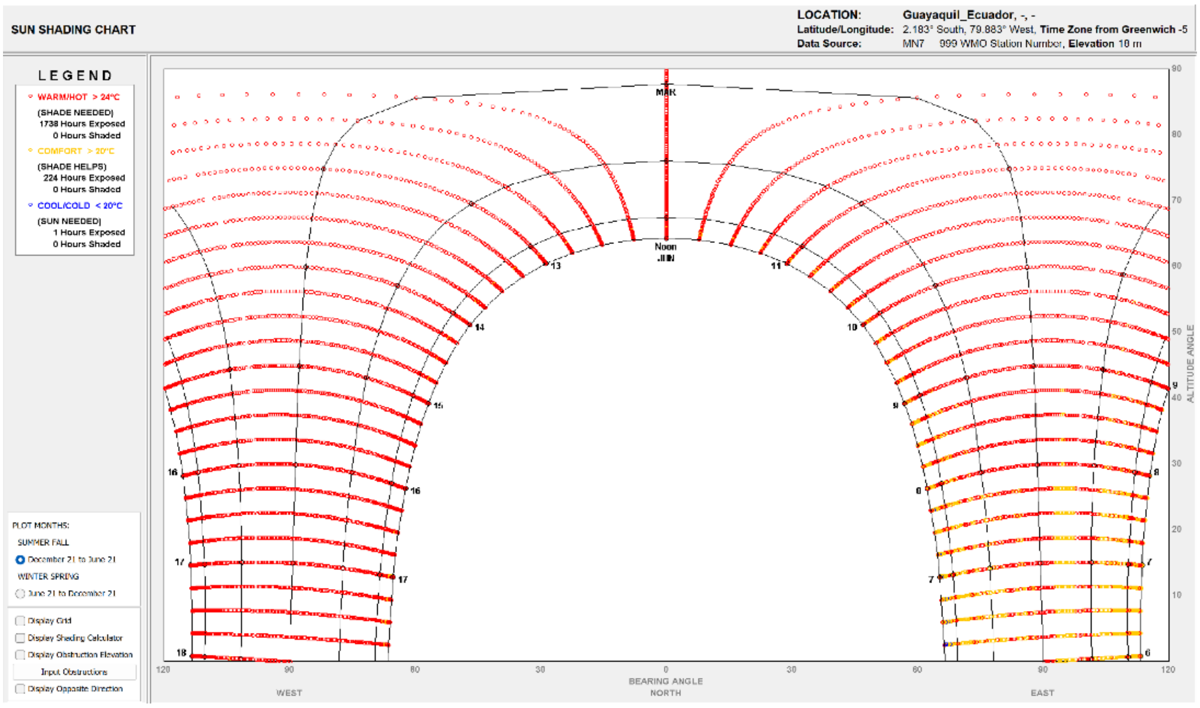
4.2 Guayaquil

4.2.1 Analysis of sun shading chart and psychrometric chart

In the case of Guayaquil, for the study of the climate before the simulation to obtain the energy consumption and the overheating hours, it could be seen the impact that the sun has per hour on the sun shading chart.

In comparison with the sun shading chart from Miami, the altitudes angles of the sun shading charts from Guayaquil are higher due to the geographic location of the city, which is closer to the equator line.

In the first period of Guayaquil, from December 21 until June 21, the warm/hot hours are extremely higher than the comfort or the cool/cold hours, leaving just a few hours under 24 ̊C but above 20 ̊C in the mornings. This leads to 1738 warm/hot hours, 224 comfort hours and only 1 hour in a cool/cold condition.


SUN SHADING CHART

LOCATION: Guayaquil_Ecuador, -, -
Latitude/Longitude: 2.183° South, 79.883° West, Time Zone from Greenwich -5
Data Source: MN7 999 WMO Station Number, Elevation 10 m

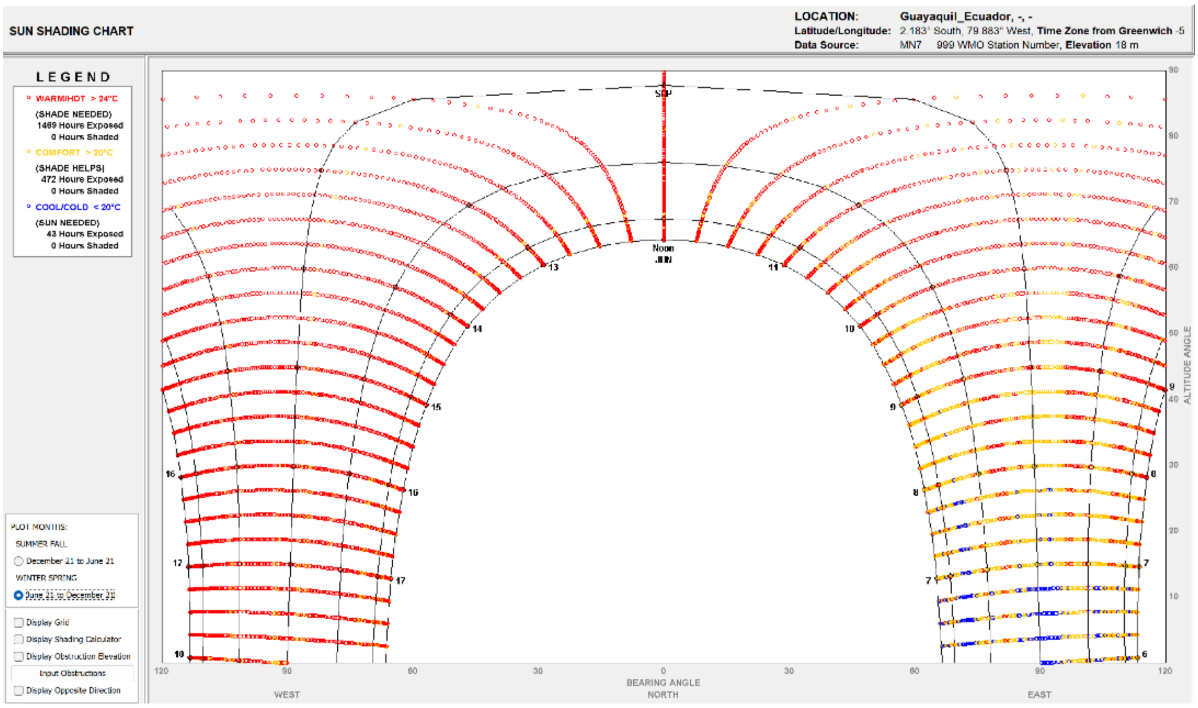
LEGEND
WARM/HOT > 24°C
(SHADE NEEDED)
1738 Hours Exposed
0 Hours Shaded
COMFORT > 20°C
(SHADE HELPS)
224 Hours Exposed
0 Hours Shaded
COOL/COLD < 20°C
(SUN NEEDED)
1 Hours Exposed
0 Hours Shaded

PLOT MONTHS:
SUMMER FALL
● December 21 to June 21
WINTER SPRING
○ June 21 to December 21

☐ Display Grid
☐ Display Shading Calculator
☐ Display Obstruction Elevation
Input Obstructions
☐ Display Opposite Direction

Figure 12 Sun shading chart of Guayaquil from December 21 until June 21. Source: Own elaboration from climate file

While, in the second period, from June 21 until December 21, even if the hot/warm hours are still more significant than the others, it appears cool/cold hours at mornings from 6:00 until 8:00, followed by prevailing comfort hours until 10:00. As a result of this period, it gave 1469 warm/hot hours, 472 comfort hours and 43 hours of cool/cold hours.



SUN SHADING CHART

LOCATION: Guayaquil_Ecuador, -, -
Latitude/Longitude: 2.183° South, 79.883° West, Time Zone from Greenwich -5
Data Source: MN7 999 WMO Station Number, Elevation 18 m

LEGEND
WARM/HOT > 24°C (SHADE NEEDED) 1489 Hours Exposed 0 Hours Shaded
COMFORT > 20°C (SHADE HELPS) 472 Hours Exposed 0 Hours Shaded
COOL/COLD < 20°C (SUN NEEDED) 43 Hours Exposed 0 Hours Shaded

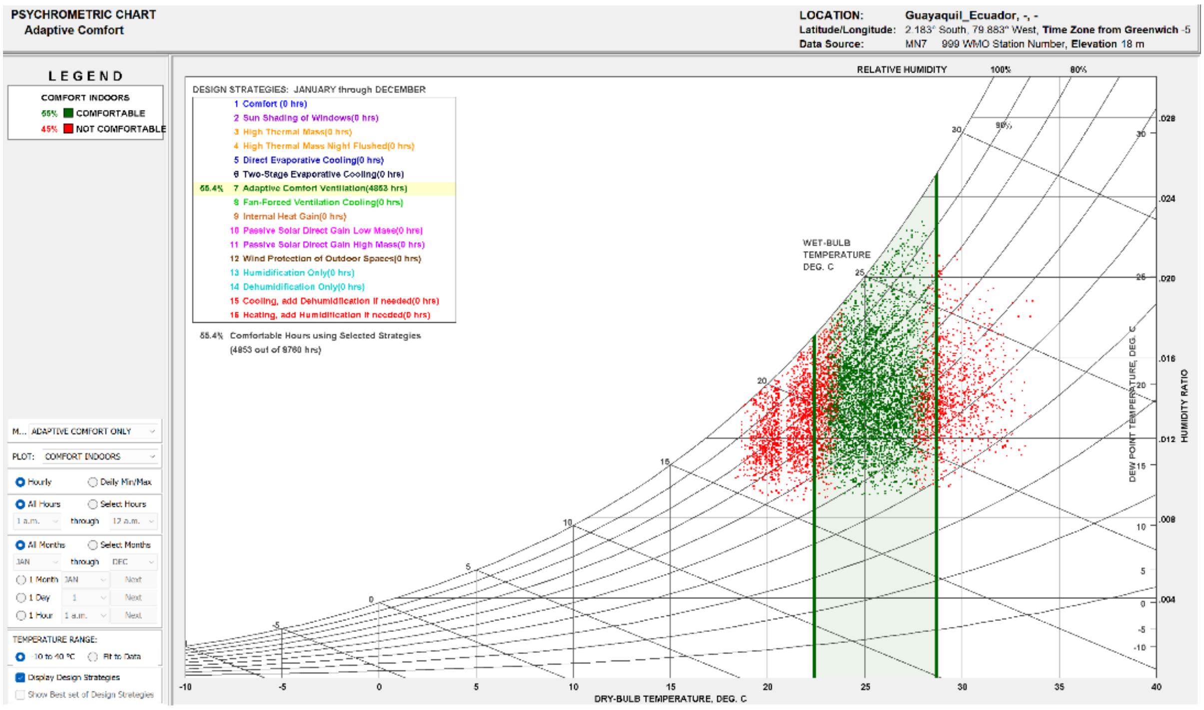
PLOT MONTHS:
SUMMER FALL
○ December 21 to June 21
WINTER SPRING
● June 21 to December 21

☐ Display Grid
☐ Display Shading Calculator
☐ Display Obstruction Elevation
☐ Display Opposite Direction

Figure 13 *Sun shading chart of Guayaquil from June 21 until December 21. Source: Own elaboration from climate file*

Apart from the sun shading charts, the psychrometric chart from Guayaquil shows the thermodynamic properties of the air and its temperature. Here it could be seen all the hours of the year and how they correspond with most of the temperatures between 20 ̊C and 30 ̊C, but with some of them reaching almost 35 ̊C. Within these hours, 55% of them are considered as comfortable, due to an adaptative ventilation strategy, and 45% are considered not comfortable, which is similar to Miami's case.

Even though, the peculiarity of Guayaquil is that all hours are very compacted in an upper part of the psychrometric chart, which means that there's not only a little variation of the high dry bulb temperatures, but also there's a little variation in the high relative humidity and humidity ratio.



PSYCHROMETRIC CHART
Adaptive Comfort

LOCATION: Guayaquil_Ecuador, -, -
Latitude/Longitude: 2.183° South, 79.883° West, Time Zone from Greenwich -5
Data Source: MN7 999 WMO Station Number, Elevation 18 m

LEGEND
COMFORT INDOORS
55% 🟩 COMFORTABLE
45% 🟥 NOT COMFORTABLE

DESIGN STRATEGIES: JANUARY through DECEMBER
1 Comfort (0 hrs)
2 Sun Shading of Windows(0 hrs)
3 High Thermal Mass(0 hrs)
4 High Thermal Mass Night Flushed(0 hrs)
5 Direct Evaporative Cooling(0 hrs)
6 Two-Stage Evaporative Cooling(0 hrs)
55.4% 7 Adaptive Comfort Ventilation(4853 hrs)
8 Fan-Forced Ventilation Cooling(0 hrs)
9 Internal Heat Gain(0 hrs)
10 Passive Solar Direct Gain Low Mass(0 hrs)
11 Passive Solar Direct Gain High Mass(0 hrs)
12 Wind Protection of Outdoor Spaces(0 hrs)
13 Humidification Only(0 hrs)
14 Dehumidification Only(0 hrs)
15 Cooling, add Dehumidification if needed(0 hrs)
16 Heating, add Humidification if needed(0 hrs)

55.4% Comfortable Hours using Selected Strategies
(4853 out of 8760 hrs)

M... ADAPTIVE COMFORT ONLY
PLOT: COMFORT INDOORS
● Hourly ○ Daily Min/Max
● All Hours ○ Select Hours
1 a.m. through 12 a.m.
● All Months ○ Select Months
JAN through DEC
○ 1 Month JAN Next
○ 1 Day 1 Next
○ 1 Hour 1 a.m. Next
TEMPERATURE RANGE:
● -10 to 40 °C ○ Fit to Data
☑ Display Design Strategies
☐ Show Best set of Design Strategies

Figure 14 *Psychrometric chart of Guayaquil of all year. Source: Own elaboration from climate file*

4.2.2 Climate zone according code

The Ecuadorian code for energy efficiency, the NEC-HS-EE, also has the ASHRAE as a reference for the parameters of the classification of their climate zones. This same classification is guided by Figure 15, where it shows the Ecuadorian map with a scale color of the climate zones classification. In the case of Guayaquil, located in coastal region of Ecuador, it is classified with the color red as a “very hot humid” climate. This description matches the same thermal criteria as Miami, by classifying it as a climate zone 1A.

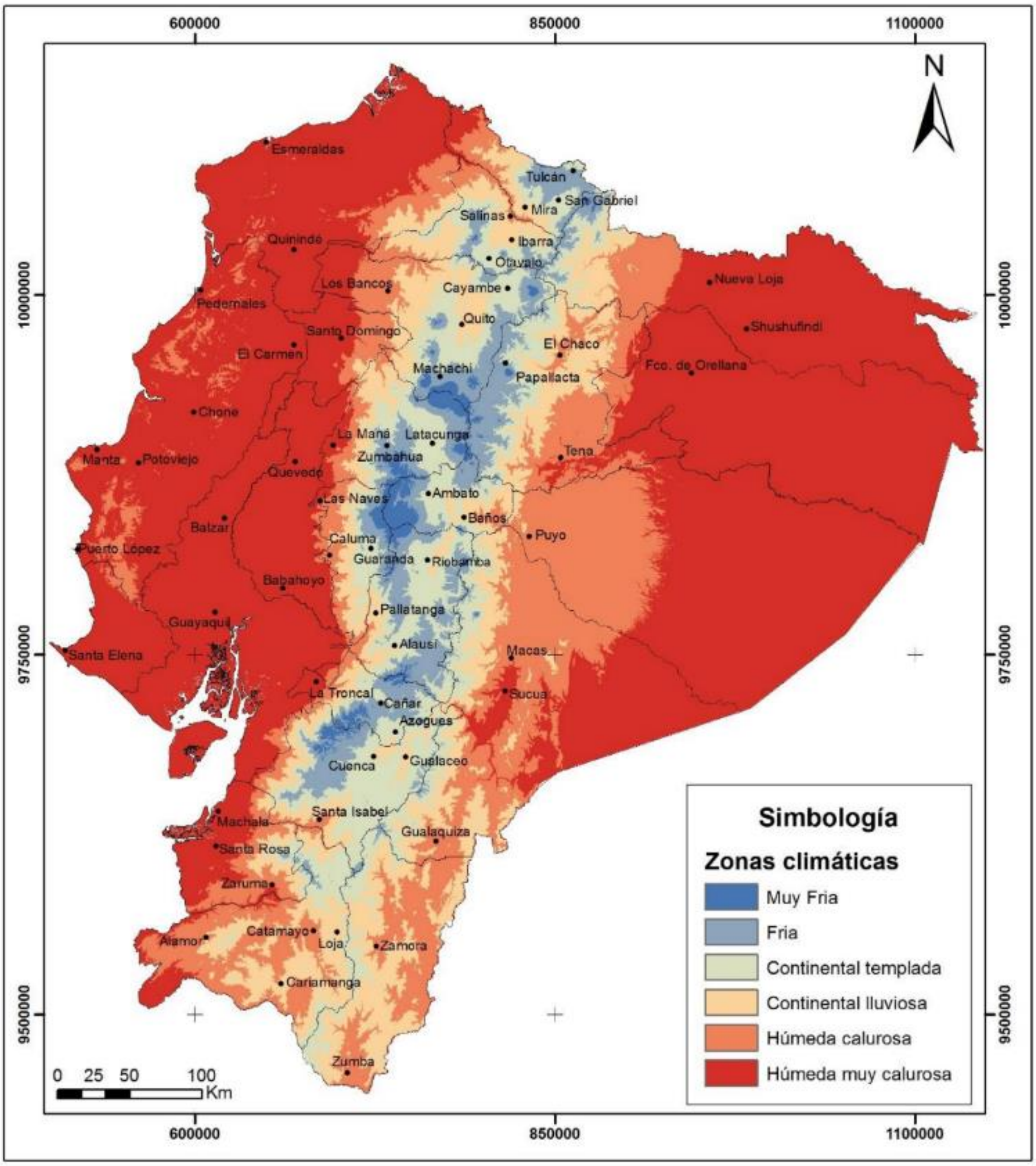


Figure 15 *Climate zone map of Ecuador [12].*

4.2.3 Requirements for energy efficiency

After knowing the climate zone, the regulations for climate zone 1 is chosen from the same code. In comparison with Miami, the classification for the thermal transmittance of the constructive elements is classify by "Habitable" and "Not habitable". Within the area of interest for the study the classification of "Habitable" is chose for the analysis, which have two other classifications inside it, according to the use of the space (Table 7). The first classification is "Air-conditioned", referring to a space that is intended to have a mechanical system for the thermal comfort. While, the other classification is "Not air-conditioned", meaning that is a space that would not have an HVAC system. Besides thermal transmittance, Table 7 also collects the limits of the SHGC.

Table *7 Envelope requirements for climate zone 1of NEC-HS-EE [12]*

	U factor Regulatory limits (W/m^2K)	
Opaque elements	**Air-conditioned**	**Not air-conditioned**
Roofs	0.273	3.5
Walls	0.857	4.61
Floors	1.825	3.4
Doors	3.2	3.2
Windows	6.81 (SHGC=0.25)	3.84 (SHGC=0.77)

Within the requirements for the energy efficiency there are also special regulations for the solar reflectance of products for covering roofs. Which are taken from the NEC-HS-EE (Table 8), where it specifies the reflectance according to the deck slope of the roof, where lower or equal to 2:12 is a low slope and higher or equal to 2:12 is a high slope. Also, another consideration for the reflectance of the roof is if it is a new installation or an old one. In these cases, it is considering an initial solar reflectance of 0.25 for a new gable roof.

Table 8 *Requirements for solar absorptance of the roof of NEC-HS-EE [12].*

	Slope	**Initial solar reflectance**	**Aged solar reflectance (three years after installation)**
Low slope roof	< 2:12	Equal to or greater than 0.65	Equal to or greater than 0.5
High slope roof	> 2:12	Equal to or greater than 0.25	Equal to or greater than 0.15

4.2.4 Construction systems

The most common construction system of housing in Guayaquil is the construction by concrete blocks. Therefore, for the analysis of the energy consumption and the overheating hours in different housing situations, two simulation models were developed.

The first Guayaquil model, named as "Model G1", respond to the requirements for an "Air-conditioned" space, which is supposed to be specified prior to construction. The construction composition of this system for the simulation model is the following:

Table 9 *Construction system of Model G1. Source: Own elaboration*

Constructive element	***Description***	***Components***	***U Factor (W/m^2K)***	***Regulatory limit (W/m^2K)***
Walls	Doble concrete block	Cement sand render Aerated concrete block (15cm) Aerated concrete block (10cm) Cement/plaster/mortar	0.794	0.857
Roof	Roof tile	Clay tile Air gap Polypropilene sheet EPS (12cm) Plaster OSB	0.26	0.273
Floor with ground	Concrete floor	Gravel Polyethylene sheet Cast Concrete Floor screed Ceramic/clay tiles	0.97	1.825
Door	Metal	White painted steel Air gap White painted steel	2.84	3.2
Windows	Doble pane glass	Doble Clear SolarPlus LOWe 3mm/13mm Air	1.8(SHGC=0.22)	6.81(SHGC=0.25)

On the other hand, the second model, called "Model G2", is based in the most typical way of housing development, where instead of having a doble concrete block wall, it only has one. This model responds to the requirements for a "Not air-conditioned", which have higher limitation values for the U factors in all of the envelope elements, with the exception of the thermal transmittance for the windows, which is more regulated. Even though, the SHGC regulations for a "Not air-conditioned" space is still lower than the SHGC from a "Air-conditioned" space. The construction composition of this system for the simulation model is the following:

Table 10 *Construction system of Model G2. Source: Own elaboration*

Constructive element	***Description***	***Components***	***U Factor (W/m^2K)***	***Regulatory limit (W/m^2K)***
Walls	Concrete block wall	Cement sand render Aerated concrete block Cement/plaster/mortar	1.185	4.61
Roof	Roof tile	Clay tile Air gap Polypropylene sheet OSB	2.036	3.5
Floor with ground	Concrete floor	Gravel Polyethylene sheet Cast Concrete Floor screed Ceramic/clay tiles	0.97	3.4
Door	Metal	White painted steel Air gap White painted steel	2.84	3.2
Windows	Doble pane glass	Doble clear 3mm/13mm Air	2.71(SHGC=0.76)	3.84(SHGC=0.77)

As seen in Table 10, every regulatory limit has changed due to the "Not air-conditioned" space parameters. Even though the constructive elements of the floor with ground and the door remains the same, as it is the most common way of doing it. However, in "Model G2", the components of the roof change due that the regulatory limits are more permissible, so it can be done without the EPS insulation. On the contrary, despite the fact that the regulatory limits for windows are more flexible for "Model G1", it has a higher regulation in the SHGC, hence the u factors of the windows are lower than the windows of "Model G2".

In addition, in terms of shading strategy, it was used the same as Miami for both models, with interior slat blinds in all of their windows with and a set-up from 10:00 until 16:30 all days of the year.

Given this, two simulations models were made with the willing to know not only what is the energy consumption of "Model G1" for an "Air conditioned" space, but also what would happen if "Model G2" decided to have a cooling system; what would be the energy consumption in that case?

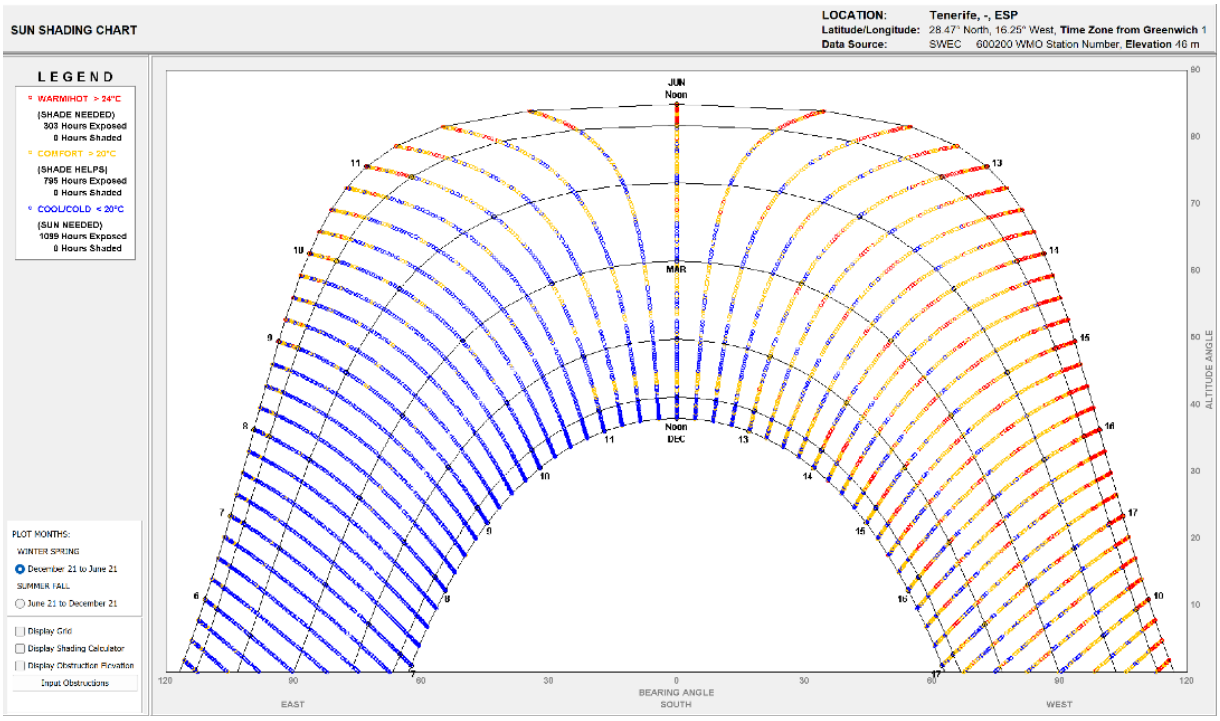
In addition, as an estimation for the overheating hours, the study also wonders; how many overheating hours does these models have, in case there is no cooling system at all.

4.3 Santa Cruz de Tenerife

4.3.1 Analysis of sun shading chart and psychrometric chart

The third case of the city of Santa Cruz de Tenerife, presents a smaller difference between the distribution of hours in the consideration of a warm/hot condition, a cool/cold condition and a comfort condition. Also due to its slightly difference in latitude with Miami, the path curve is very similar, which means that the altitude angle of the sun will affect more or less in an equal way.

In the first period of the sun shading chart, from December 21 until June 21, in comparison with the other cases, the cool/cold hours are higher than the warm/hot hours or the comfort hours all over the day, showing specifically a higher impact in the morning of all of those months. On the other hand, the warm/hot hours and the comfort hours appears more in the afternoon from March util June on the chart. Consequently, it gave only 303 warm/hot hours and 795 comfort hours, while the cool/cold condition below 20 ̊C gave 1099 hours.


SUN SHADING CHART

LOCATION: **Tenerife, -, ESP**
Latitude/Longitude: 28.47° North, 16.25° West, **Time Zone from Greenwich** 1
Data Source: SWEC 600200 WMO Station Number, **Elevation** 46 m

LEGEND
WARM/HOT > 24°C
(SHADE NEEDED)
303 Hours Exposed
0 Hours Shaded
COMFORT > 20°C
(SHADE HELPS)
795 Hours Exposed
0 Hours Shaded
COOL/COLD < 20°C
(SUN NEEDED)
1099 Hours Exposed
0 Hours Shaded

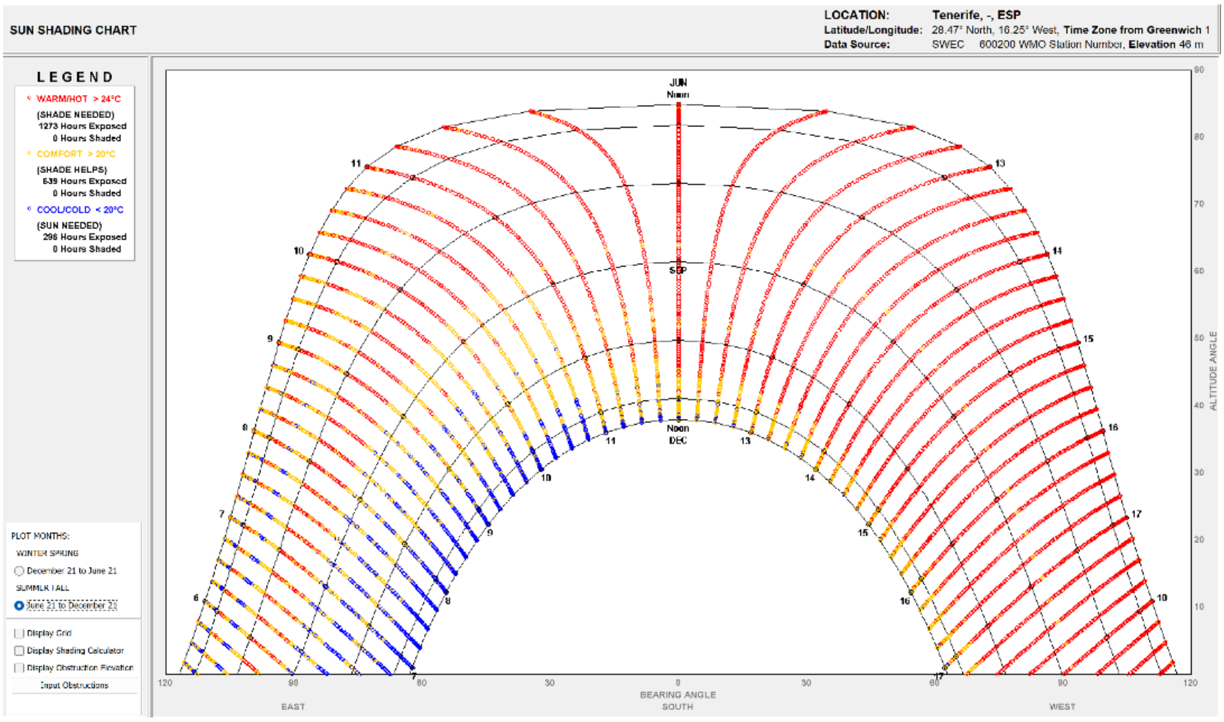
PLOT MONTHS:
WINTER SPRING
● December 21 to June 21
SUMMER FALL
○ June 21 to December 21

☐ Display Grid
☐ Display Shading Calculator
☐ Display Obstruction Elevation

Figure 16 *Sun shading chart of Santa Cruz de Tenerife from December 21 until June 21. Source: Own elaboration from climate file. Source own elaboration from climate file*

On the contrary, in the second period, from June 21 until December 21, the sun shading chart shows a bigger difference due that the warm/hot hours are now higher than the comfort and the cool/cold hours.

As revealed by the sun shading chart the cool/cold hours appear in the mornings from September until December, followed by some comfort hours in the afternoon on those months. Which gave a result of 1273 warm/hot hours, 639 comfort hours and only 296 cool/cold hours.



SUN SHADING CHART

LOCATION: Tenerife, -, ESP
Latitude/Longitude: 28.47° North, 16.25° West, Time Zone from Greenwich 1
Data Source: SWEC 600200 WMO Station Number, Elevation 46 m

LEGEND

● WARM/HOT > 24°C
(SHADE NEEDED)
1273 Hours Exposed
0 Hours Shaded

● COMFORT > 20°C
(SHADE HELPS)
639 Hours Exposed
0 Hours Shaded

● COOL/COLD < 20°C
(SUN NEEDED)
296 Hours Exposed
0 Hours Shaded

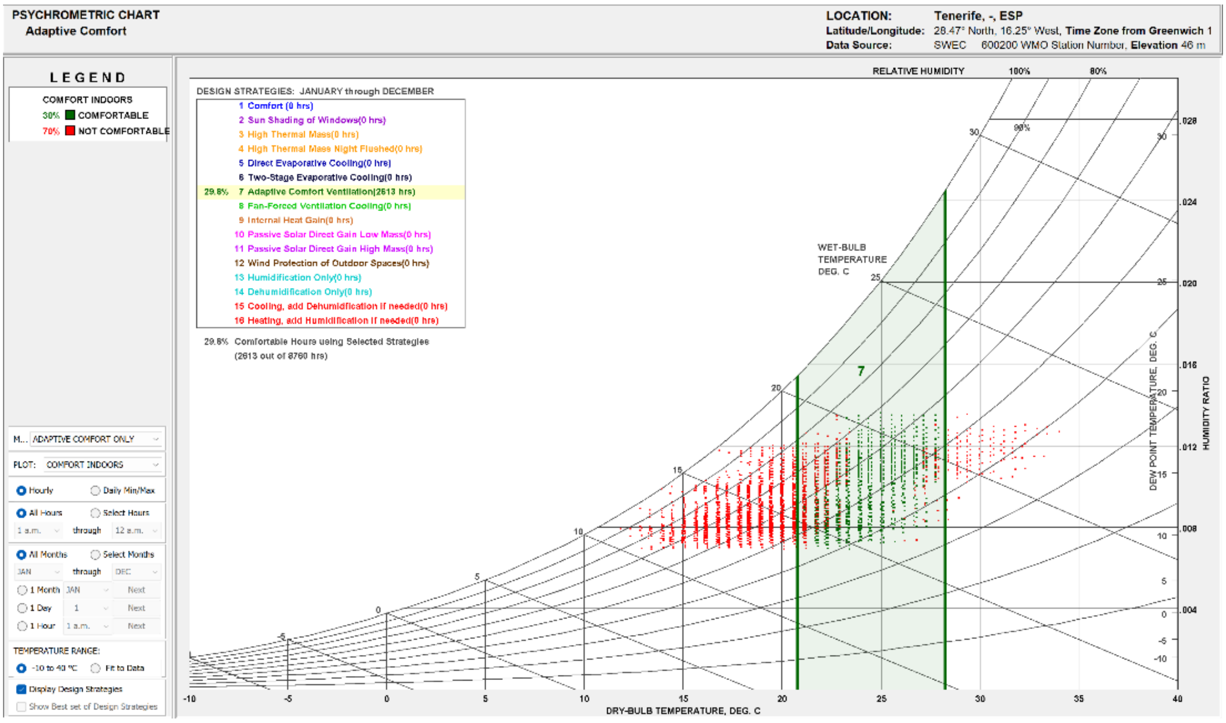
PLOT MONTHS:
WINTER SPRING
○ December 21 to June 21
SUMMER FALL
● June 21 to December 21

☐ Display Grid
☐ Display Shading Calculator
☐ Display Obstruction Elevation

Figure 17 Sun shading chart of Santa Cruz de Tenerife from June 21 until December 21. Source: Own elaboration from climate file. Own elaboration from climate file

On the other hand, the psychrometric chart from Santa Cruz de Tenerife shows how the difference in the dry bulb temperature is bigger than in Guayaquil but not as bigger as in Miami. However, despite the fact that the humidity ratio is lower than Guayaquil, it is still constant among all the hours of the year, staying approximately between 0.8 and 0.12. According to the strategy of an adaptive comfort ventilation, only 30% of all the hours of the year could be comfortable.

In contrast with Guayaquil or Miami, Santa Cruz de Tenerife doesn't have many hours that exceed the adaptative comfort range. Even though, part of the study is to figure out if those hours that are not comfortable could reach the overheating and until what point is a mechanical system needed in order to satisfy the thermal comfort on all the hours of the year.



PSYCHROMETRIC CHART
Adaptive Comfort

LOCATION: **Tenerife, -, ESP**
Latitude/Longitude: 28.47° North, 16.25° West, **Time Zone from Greenwich** 1
Data Source: SWEC 600200 WMO Station Number, **Elevation** 46 m

LEGEND

COMFORT INDOORS
30% 🟩 COMFORTABLE
70% 🟥 NOT COMFORTABLE

DESIGN STRATEGIES: JANUARY through DECEMBER

	1 Comfort (0 hrs)
	2 Sun Shading of Windows(0 hrs)
	3 High Thermal Mass(0 hrs)
	4 High Thermal Mass Night Flushed(0 hrs)
	5 Direct Evaporative Cooling(0 hrs)
	6 Two-Stage Evaporative Cooling(0 hrs)
29.8%	7 Adaptive Comfort Ventilation(2613 hrs)
	8 Fan-Forced Ventilation Cooling(0 hrs)
	9 Internal Heat Gain(0 hrs)
	10 Passive Solar Direct Gain Low Mass(0 hrs)
	11 Passive Solar Direct Gain High Mass(0 hrs)
	12 Wind Protection of Outdoor Spaces(0 hrs)
	13 Humidification Only(0 hrs)
	14 Dehumidification Only(0 hrs)
	15 Cooling, add Dehumidification if needed(0 hrs)
	16 Heating, add Humidification if needed(0 hrs)

29.8% Comfortable Hours using Selected Strategies
(2613 out of 8760 hrs)

M... ADAPTIVE COMFORT ONLY
PLOT: COMFORT INDOORS
● Hourly ○ Daily Min/Max
● All Hours ○ Select Hours
1 a.m. through 12 a.m.
● All Months ○ Select Months
JAN through DEC
○ 1 Month JAN Next
○ 1 Day 1 Next
○ 1 Hour 1 a.m. Next
TEMPERATURE RANGE:
● -10 to 40 °C ○ Fit to Data
☑ Display Design Strategies
☐ Show Best set of Design Strategies

Figure 18 Psychrometric chart of Santa Cruz de Tenerife of all year. Source: Own elaboration from climate file

4.3.2 Climate zone according code

In the classification for the climate zone in the CTE-DB-HE in the Annex B, it shows a table with all the provinces of Spain classified by climatic zones depending on where the building is located and its altitude above sea level. In the case of Santa Cruz de Tenerife it has four different climate zones that depends in the elevation; α3 for elevation below 400m, A2, for elevations between 400m and 800m, B2 for elevations between 800m and 1000m and C2 for 1000m or higher. In this case study, given that the climate file gives a low altitude, the climate zone α3 is chose for the energy efficiency conditions.

4.3.3 Requirements for energy efficiency

Knowing that Santa Cruz de Tenerife is classified as a climate zone α3, for being an arid subtropical climate, it is proceeded to see the regulations of the envelope for energy efficiency that this climate zone could have. Due that the value of "k" of the elements has not been calculated, the guide transmittance values of the U factor have been chosen from the "Annex E" of the CTE-DB-HE. As a compilation of the data, Table 11 show the regulatory limits of thermal transmittance per constructive element of climate zone "α" [26].

Table 11 *Guide values for thermal transmittance of the element, according to Annex E, CTE-DB-HE [13].*

	α Winter climatic zone
Walls and floors in contact with the outside, U_M, U_S	0.56
Roofs in contact with the outside, U_C	0.5
Elements in contact with non-habitable spaces or with ground, U_T	0.8
Windows, U_H	2.7

4.3.4 Construction system

In comparison with the thermal transmittance tables of Miami, the regulatory limitations from Spain don't depend on the construction system that can be used, like the ASHRAE does, by having different U factors for "Mass walls" and "frame walls". Instead, it has a unique thermal transmittance limitation for each constructive element that it must be fulfilled. In the same way, Table 11 doesn't have a specification for an "Air conditioned" or "Not air-conditioned" space either, as the Ecuadorian code has. For these reasons, in the case of Santa Cruz de Tenerife, it would only need one simulation model, in order to realize a comparison with the other cases. This unique model for Santa Cruz de Tenerife will be named as "Model T1".

For this housing construction system, a typical concrete block system of the zone was chosen, so it could meet the regulatory limits given by the CTE-DB-HE. This components of the construction system per constructive element are the following:

Table 12 *Construction system of Model T1. Source: Own elaboration*

Constructive element	*Description*	*Components*	*U Factor (W/m^2K)*	*Regulatory limit (W/m^2K)*
Walls	Concrete block	Cement sand render Celullar concrete block EPS (4.5cm) Aerated concrete block Gypsum plasterboard	0.55	0.56
Roof	Roof tile	Clay tile Air gap Cement/plaster/mortar XPS (4.5cm) Polypropylene sheet Tablero Soporte de madera	0.484	0.5
Floor with ground	Concrete floor	Gravel Polyethylene sheet Cast Concrete Floor screed Timber flooring	0.78	0.8
Door	Timber door	Painted Oak	2.62	2.7
Windows	Doble pane glass	Doble Clear 3mm/13mm Air	2.7	2.7

In contrast with the thermal transmittance regulatory limits of the "Florida Building Code. Energy Conservation" or the "NEC-HS-EE", the "CTE-DB HE" has higher limitations in the U factors for walls, with the exception of the regulations for the frame walls in Miami's case, which is 0.48 W/m^2k.

However, as for the thermal transmittance regulatory limit of the roof, Santa Cruz de Tenerife has a higher value, meaning that the code is more permissible than most of the cases. As revealed by the other models, Miami has 0.2 W/m^2k and Guayaquil 0.273 W/m^2k for the regulatory limit of the roof, while “Model T1” from Tenerife has 0.5 W/m^2k. This means that the regulations for the u factor in roofs are more demanding than those in Tenerife. Also, unlike the other codes, Model T1 doesn’t have a regulatory limit for the SHGC of the windows.

Table 13 *Summary of the thermal transmittance per constructive element and their regulatory limits. Source: Own elaboration*

U factors of constructive elements (W/m^2K)	Model M1	Model M2	Model G1	Model G2	Model T1
U Factor Walls	0.31	0.94	0.794	1.185	0.55
Regulatory limit Walls	0.48	1.12	0.857	4.61	0.56
U Factor Roofs	0.2	0.2	0.26	2.036	0.484
Regulatory limit Roofs	0.2	0.2	0.273	3.5	0.5
U Factor Floor with ground	0.36	0.36	0.97	0.97	0.78
Regulatory limit Floor with ground	0.36	0.36	1.825	3.4	0.8
U Factor Doors	2.82	2.82	2.84	2.84	2.62
Regulatory limit Doors	2.84	2.84	3.2	3.2	2.7
U Factor Windows	1.8 (SHGC=0.22)	1.8 (SHGC=0.22)	1.8 (SHGC=0.22)	2.71 (SHGC=0.76)	2.7
Regulatory limit Windows	2.84 (SHGC=0.25)	2.84 (SHGC=0.25)	6.81 (SHGC=0.25)	3.84 (SHGC=0.77)	2.7

5. RESULTS AND ANALYSIS

5.1 Energy consumption

Each model was created and analyzed with its specification in Design Builder. From the simulation, results are obtained for the cooling demand of the dwelling in the models of each city.

Through the results obtained from the different models, the energy consumption in each case was compared.

As it is seen in Table 14, the city that has the highest energy demand is Miami, with an annual demand of 60.1 kWh/m^2 for Model M1, and 58.77 kWh/m^2 for Model M2. This variation of energy consumption is due to the different construction systems that each model has. Despite the fact that Model M1 consist on a frame wall system, with a lower regulation limit for the U factor of 0.48 W/m^2k, it still has a higher energy demand than Model M2, which is a concrete block system with a higher regulation limit of 1.12 W/m^2k. This is due to the thermal inertia of the walls, which is the capacity to store and release energy. This depends in the properties of the materials, like the mass, the specific heat and the coefficient of thermal conductivity. This helps reducing the amount of energy that is need for thermal comfort, given that the system would not have to increase so much its power to reach the willing temperature.

Despite the difference, the energy demands in Miami are considerably high all year long, and the months that present higher energy consumption are from April until November with July and August as the months that more energy were consumed. This data match with the hottest months of the city, meaning that more energy was needed in order to reach the thermal comfort in those months.

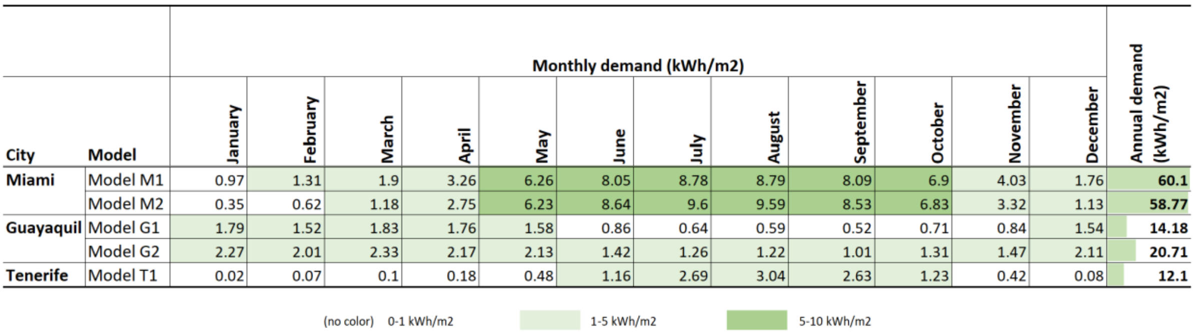
The second city that presents more energy demand for cooling was Guayaquil, with an annual demand of 14.18 kWh/m^2 for Model G1, and 20.71 kWh/m^2 for Model G2. The difference in the energy consumption between these two models is due to the different construction systems that are used. For instance, Model G1 has a lower U factor, hence it counts with a doble concrete block wall, an insulated roof and a window with very low thermal transmittance, and a low solar heat gain coefficient. These characteristics allows the house to have less heat transfer from the outside, thus the house will have a lower operating temperature that could help reducing the amount of energy that is needed to reach a certain temperature for comfort.

In contrast with Miami, the months that presents the higher energy demand are from December until May, which matches the hottest months of the city. Nevertheless, despite the fact that Model G1 only counts with a significant energy consumption between those months, Model G2 has an important energy consumption all year long.

Finally, the last case of Santa Cruz de Tenerife, named as "Model T1", has an energy consumption similar to Model G1. Unlike the Guayaquil model, Model T1 only has five months, in which its energy consumption is significant. In contrast with Guayaquil, this period is part of the summer season, from June until October.

Despite the fact that Santa Cruz de Tenerife has lower temperatures in winter than Guayaquil, it also has a lower regulatory limit for the U factor of the walls than Model G1. This, as explained before, helps in the energy efficiency of the house, due that it will need less energy to achieve the wishing temperature.

Table 14 *Cooling demand per month of the case studies. Source: Own elaboration*



		Monthly demand (kWh/m2)												Annual demand (kWh/m2)
City	**Model**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	
Miami	Model M1	0.97	1.31	1.9	3.26	6.26	8.05	8.78	8.79	8.09	6.9	4.03	1.76	**60.1**
	Model M2	0.35	0.62	1.18	2.75	6.23	8.64	9.6	9.59	8.53	6.83	3.32	1.13	**58.77**
Guayaquil	Model G1	1.79	1.52	1.83	1.76	1.58	0.86	0.64	0.59	0.52	0.71	0.84	1.54	**14.18**
	Model G2	2.27	2.01	2.33	2.17	2.13	1.42	1.26	1.22	1.01	1.31	1.47	2.11	**20.71**
Tenerife	Model T1	0.02	0.07	0.1	0.18	0.48	1.16	2.69	3.04	2.63	1.23	0.42	0.08	**12.1**

(no color) 0-1 kWh/m2   ░ 1-5 kWh/m2   🟩 5-10 kWh/m2

5.2 Hours exceeding the cooling setpoint following CTE-HE-0

Table 15 shows the percentage of hours in a year, in which each model has to turn on its cooling system to reach thermal comfort. For this, once the operative temperatures of each simulation model are obtained, it is calculated how many hours exceed the setpoints of Table 2 in all year.

Equally to the results in Table 14, the cases that consumed more energy for cooling are the same that have more hours exceeding the cooling setpoint. In the case of Miami, from all the hours of the year, 36% of them have the cooling system turned on in Model M1 and Model M2. In contrast with their energy consumption, even if the models of Miami have different thermal envelopes, they still have the same number of hours exceeding the cooling setpoint. This means that even if they have the cooling system turned on the same amount of time, Model

M1 is still consuming more energy than Model M2 in that period in order to reach the willing temperature.

As for Guayaquil, Model G1 has evidently less hours exceeding the cooling setpoint than Model G2. This is because the envelope from the first model has more demanding thermal transmittance regulations, which allows the house to have more comfort hours in which there is no need of a cooling system.

While, in the case of Tenerife, as it is similar in the energy consumption to Model G1, it is also closely related to the exceeding hours that it has, due that while 15% of the hours of Model G1 is using a cooling system, Model T1 is using it in a 12% of their hours.

Table 15 *Percentage of hours exceeding the cooling setpoint. Source: Own elaboration*

City	Model	% of hours exceeding the cooling setpoint
Miami	Model M1	36%
	Model M2	36%
Guayaquil	Model G1	15%
	Model G2	26%
Tenerife	Model T1	12%

5.3 Indoor Overheating hours (IOH)

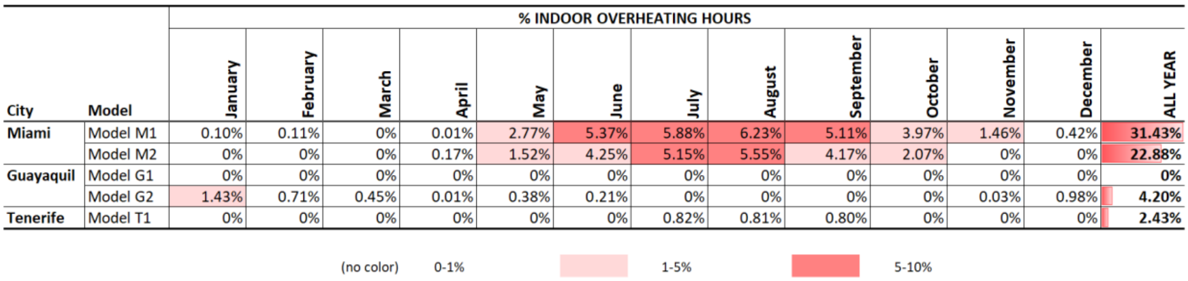
Table 16 shows the percentage of indoor overheating hours per model in a year, with the corresponding percentage per month. In the case of Miami, it is the city that has more overheating hours in their models, with 31.43% of its hours in overheating in Model M1, and 22.88% in Model M2. This gives an overheating hour difference of 8.55%. Both models have most of their overheating hours in the months from May until October, with the exception of Model M1 that also has a significate percentage of hours in November and a few more in December. This means that the Model M2 reacts better to the climate condition by having fewer overheating hours. This is also due to its construction system of concrete blocks, which in comparison to Model M1, it has more thermal inertia. Because of this, walls tend to absorb and release heat more slowly, which helps Model M2 to maintain a temperature within a more optimal range.

On the other hand, in the case of Guayaquil, Model G1 doesn't have any overheating hour in any time of the year, while Model G2 has only 4.2% of its hours in overheating. This is also because of their construction systems, which in Model G1 have less thermal transmittance due to the regulation that if follow for the U factor in its envelope. This forces it to use roof insulation and another layer of concrete blocks for the walls.

And finally, the last case of Santa Cruz de Tenerife, or “Model T1”, has 2.43% of its hours of all year in overheating. As it is seen, this percentage is very similar to Model G2, with a difference of only 1.77%. This is because of the low U factor of their envelope, which is higher in Model G2, and also due to Tenerife’s climate data that has less hours in high temperatures.

In comparison with the models of Miami or Guayaquil, Model T1 has its overheating hours between the months of July and September, while the other models, with the exception Model G1, have their overheating hours distributed almost all year long. Nevertheless, in the case of Model G2, in contrast with the other models, it has most of its overheating hours in the months from December until March.

Table 16 *Percentage of Indoor Overheating Hours (%IOH) of the study cases in a year*



		% INDOOR OVERHEATING HOURS												
City	**Model**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**ALL YEAR**
Miami	Model M1	0.10%	0.11%	0%	0.01%	2.77%	5.37%	5.88%	6.23%	5.11%	3.97%	1.46%	0.42%	**31.43%**
	Model M2	0%	0%	0%	0.17%	1.52%	4.25%	5.15%	5.55%	4.17%	2.07%	0%	0%	**22.88%**
Guayaquil	Model G1	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	**0%**
	Model G2	1.43%	0.71%	0.45%	0.01%	0.38%	0.21%	0%	0%	0%	0%	0.03%	0.98%	**4.20%**
Tenerife	Model T1	0%	0%	0%	0%	0%	0%	0.82%	0.81%	0.80%	0%	0%	0%	**2.43%**

(no color) 0-1% ▨ 1-5% 🟥 5-10%

6. DISCUSSION

Given the results of the energy consumption and the overheating hours of all cases, it is noticed how internal factors such as the thermal inertia or the thermal transmittance of the construction systems affects the thermal comfort and the energy consumption in homes. On the other hand, it is also seen how the external factors such as external temperatures, altitude or latitude given by its geographic specification and climate data, affects in a different way the energy models of each city.

As a result, most of the overheating hours are caused by an overwhelming indoor heat situation, consequence of the high external temperatures, which they also create a demand for energy. Nevertheless, despite the fact that in most of the cases as the energy consumption grow, so the overheating hours, they do not necessarily correspond to each other.

For instance, Model G1 has an annual energy consumption of 14.18 kWh/m^2, but it doesn't have any overheating hour in all year. This is because, as show before, the calculation of the energy consumption doesn't follow the same parameters as the calculation of the overheating hours. Due that the energy consumption follows the parameter shown in Table 2 with the specific limits of 25 ̊C and 27 ̊C according to the time. While, for the calculation of the overheating hours, as seen in section 5.3, it follows a limit of the indoor operative temperature given by a calculation with the exponential average of their daily temperature, and also with the coefficient of having a maximum allowable temperature.

This estimation, is because the overheating calculation takes into account a weighing of the mean temperatures of the past seven days, for the adaptation of thermal comfort in people.

This is why there is an energy consumption but there aren't any overheating hours in model G1. Because as seen in Figure 19 for Model G1, in the hottest week of the year, even if the indoor operative temperatures exceed the parameters for the cooling system, it doesn't exceed the limitations of the maximum temperature establish by the UNE in that case.

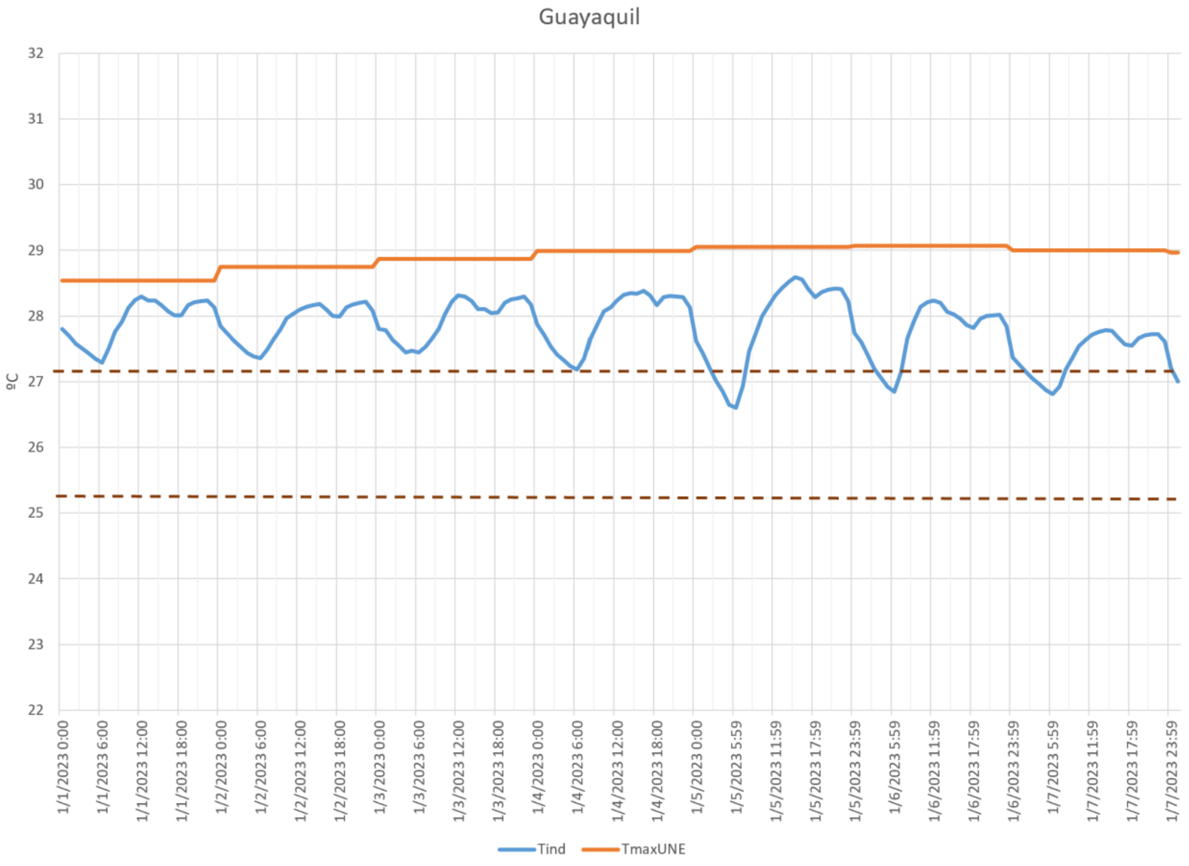


Figure 19 *The indoor operating temperature of the hottest week of the year of Model G1, with the temperature limits given by the UNE, and the limits of the operational conditions of air-conditioned spaces in private residential use. Source: Own elaboration*

Besides, it could also have a similar energy consumption while still having overheating hours, as revealed by Model T1 in Figure 20. This model in spite of having an energy consumption (12.1 kWh/m^2) lower than Model G1 (14.18 kWh/m^2), it still has overheating hours. Due that, as shown in the hottest week of the year in Santa Cruz de Tenerife by Figure 20, many of their indoor operative temperature per hour, do not only surpass the limit temperatures for having cooling demand, but they also exceed their own limitations of the maximum temperature establish by the UNE.

Given this, it is seen that the energy consumption and the overheating hours are not necessarily related due to their different parameters, even though, both evaluations are affected by similar factors.

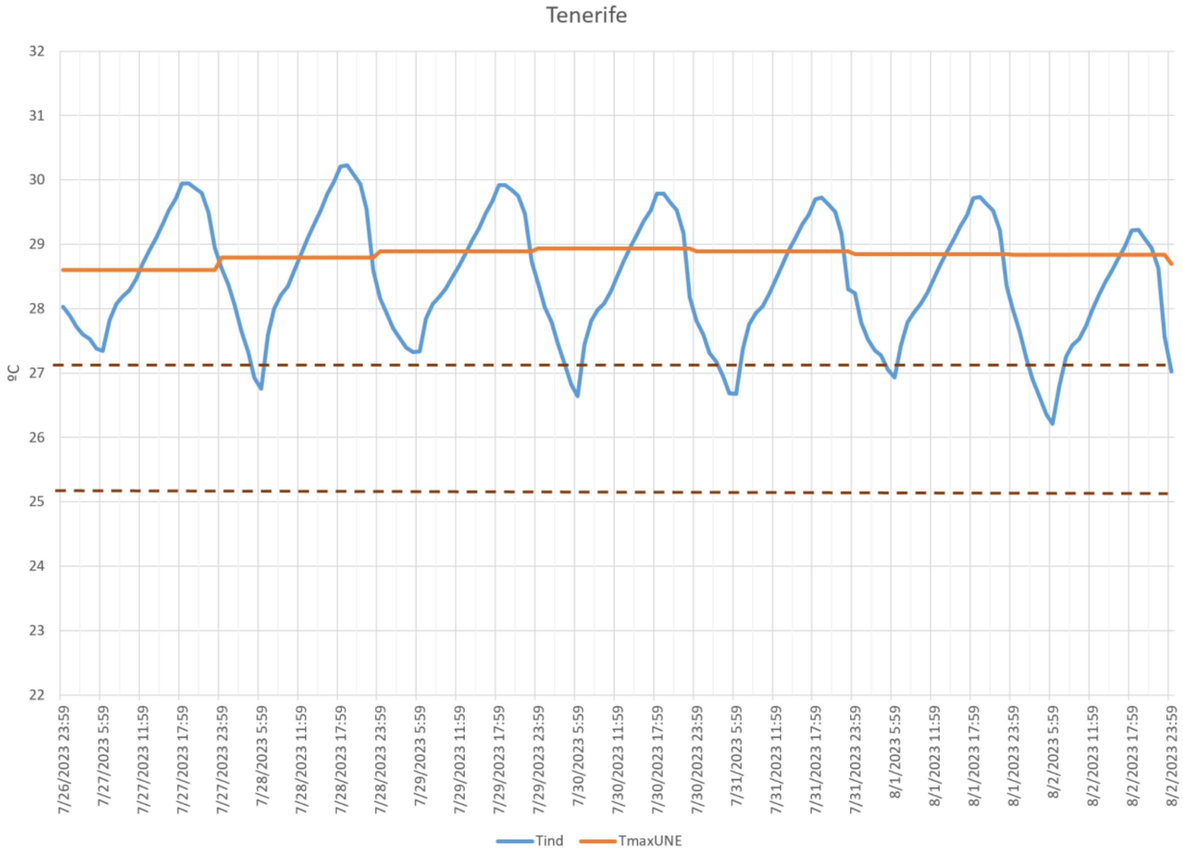


__Figure 20__ The indoor operating temperature of the hottest week of the year of Model T1, with the temperature limits given by the UNE, and the limits of the operational conditions of air-conditioned spaces in private residential use. Source: Own elaboration

However, this methodology for IOH that is widely used, does not take into account relative humidity, only indoor and outdoor temperatures, hence future research could focus in the evaluation of those aspects, which may improve or give a better approach to the calculations on energy consumption or overheating.

In addition, due that a limitation of the study was that all was calculated with the European standards and the CTE, in the future this work could do the calculations with the ASHRAE55, or even be useful as a simulation index for the estimation of energy costs in each city.

7. CONCLUSIONS

The increase in energy demand and in the cost of production is a major worldwide concern. It is very important to understand energy efficiency at homes not only as a way for saving money, but also as a way of preserving the natural resources. This demand has a significant global impact in the residential sector, which is the second sector that more energy consume, with a trend of increasing in the future. In addition, due to global warming, cooling consumption and/or overheating at homes is projected to grow exponentially.

In some places like Florida in the United States, where most of its energy depends in natural gas, or Canary Island in Spain, where most of its energy depends on fossil fuels, the energy costs are likely to grow.

In the case of the city of Guayaquil in Ecuador, despite the fact that most of the energy of the country comes from hydraulic power plants, which allows prices not to vary so much, there are still other factors that affects the possibilities of people to pay for their electricity.

Because of this, the study aims to evaluate and analyze the thermal behavior of the house in the cities, by calculating the energy consumption and the indoor overheating hours in a year to respond to questions like, what would happen if there is no electricity due to an energy cut? Or, what if people could not afford their energy bills? Given this, to what extent could people have thermal comfort in their homes without a cooling system? In addition, is the analysis of the cooling demand an adequate approximation to overheating assessment?

In order to respond these questions, the three cases of Miami, Guayaquil and Santa Cruz de Tenerife were studied for a global perspective of the problem. The methodology of the evaluation of the energy consumption and the overheating hours consisted first, in the analysis of the climates. Followed by the creation of a simulation model in Design Builder (Energy +), fixing some operational and constructive parameters for all models, like a cooling system, the air flow for indoor air quality, night ventilation, air leakage, or even the design of the solar absorptance.

Once these parameters were established, models per location were designed, following their own energy efficiency codes, in order to match the regulatory limits of each constructive element of the envelope. In summary, in this study were considered: two models for Miami (M1 with timber frame as the thermal envelope and M2 with inertia), two models for Guayaquil (G1 with the limitations for a dwelling with cooling system and G2 without it), and one model for Tenerife.

After this, the calculations for the energy consumption, plus the percentage of the hours exceeding the cooling setpoint according to CTE-HE, and the indoor overheating hours for all the models, following UNE EN 16798, were done.

As a result, the analysis shows that the city with the highest energy demand was Miami, with an annual demand of 60.1 kWh/m^2 for Model M1 and 58.77 18 kWh/m^2 for Model M2. As a result, 36% of the hours in a year required the cooling system to be turned on for both of the models, but needing more energy in Model M1 to reach a comfort temperature.

While, the second city that presented more energy demand was Guayaquil, with an annual demand of 14.18 kWh/m^2 for Model G1 and 20.71 kWh/m^2 for Model G2, with a need of a cooling system in 15% and 26% of the hours in a year respectively.

And last, Santa Cruz de Tenerife with an annual energy consumption of 12.1 kWh/m^2, which is similar to the Model G1. This model requires a 12% of the hours in a year with a cooling system in order to have an indoor comfort temperature, which is only 3% less hours than Model G1.

Moreover, the study evaluates the housing thermal behavior in each city according to the calculation of the overheating hours per each simulation model.

These estimations shows that the city with more overheating hours in a year is also Miami, with a 31.43% of its hours in overheating for Model M1 and 22.88% for Model M2. Followed by Guayaquil with the peculiarity that only Model G2 is affected by overheating with a 4.2% of its hours, while Model G1 behaves very well by not presenting any.

As for the city of Santa Cruz de Tenerife, it has 2.43% of its hours in overheating. Nevertheless, in spite of having more overheating hours than Model G1 from Guayaquil, it has less energy consumption. This is because the overheating hour limitations doesn't follow the same parameters as the cooling setpoints for energy consumption. Given that, as shown in Figure 19 and Figure 20, the indoor operative temperature in the case of Guayaquil exceeds the cooling setpoint limitations, but not the limitations from the UNE. While in the case of Model T1, despite the fact that the energy consumptions are similar, it exceeds both limitations, the cooling setpoint and the maximum levels establish by the UNE in their case, hence they do not necessarily correspond to each other.

Finally, the study analyses the limits establish by the Spanish normative in relation to overheating, showing an overestimation assessment if the results with the UNE methodology are compared.

Overall, this study shows the importance of designing energy-efficient houses that takes into account the climate condition of the location and their geographical specifications, by providing valuable information of the energy consumptions and the overheating hours of a model with the common construction systems of each city. This is especially interesting for architects, engineers, developers, policy makers, or anyone involved in housing, who want make informed decisions to save as much energy as they can and avoid overheating as much as possible.

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