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SOCIAL HOUSING IN THE DOMINICAN REPUBLIC, A STUDY ON THERMAL COMFORT

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ABSTRACT

The accelerated growth of cities entails challenges in all sectors, and specifically, it has a close relationship with the construction sector. The Dominican Republic is a country where urban growth is increasing considerably, representing a problem of great magnitude in terms of the construction of social housing to reduce the housing deficit. In the social housing projects in Santo Domingo, the energy conditions are non-existent. There are no previous studies on the thermal comfort of those buildings. For this reason, this study seeks to analyze thermal comfort and energy efficiency in these types of housing through an energy simulation.
The energy simulation is carried out through OpenStudio, which uses the Energy Plus calculation engine. A type of model was analyzed for the determination of temperatures and ranges of thermal comfort to evaluate its behavior for 24 hours in different months. The calculations obtained from the energy consumption due mainly to the variation of the comfort temperature indicate that the temperature variation is very similar in the selected months, with a maximum temperature of 27.3ºC in the hottest month and a minimum temperature of 26 .8ºC in the coldest month. Finally, due to the warm climate that prevails in the area, a high comfort temperature is recorded in these types of dwellings. To improve the comfort conditions in this type of dwelling, it is necessary to add thermal insulation and control the solar gains effectively.

KEYWORDS

Thermal comfort; energy simulation; natural ventilation; thermal analysis; OpenStudio.

1. INTRODUCTION

In developing countries, especially in the countries located in Latin America, the rapid growth of urban areas has caused in recent decades complex social problems that significantly affect the city and the environment. This urban growth is directly driven by the population growth due to the increasingly high natality rates and, therefore, by the higher housing demand. In modern society, most human activities take place inside buildings, both homes, and offices. Homes need to provide a safe and livable environment to ensure the well-being of its inhabitants (Observatorio de Políticas Sociales y Desarrollo 2017). However, new buildings have consequences beyond the environmental impact of their construction process. The energy consumption during the use phase of the building is probably the most impacting process that buildings entail. Researchers claim that buildings consume between 30 and 40% of the total primary energy worldwide and between 40 and 50% of the greenhouse gases worldwide (Ramesh, Prakash, and Shukla 2010).
Several strategies have been used to reach higher indoor comfort levels over the years. The climate

conditions in most parts of the world require the dwellers to use high quantities of energy, either highering or lowering the temperature through HVAC systems. The incipient effects of climate change are already altering the weather conditions and causing a higher energy demand for refrigeration in some locations.

Social housing policies in Latin America and the Caribbean have focused on tackling the housing shortage while not paying enough attention to the deficiencies in quality that lead to lower comfort levels and higher carbon emissions ("El Problema de Vivienda de Los 'Con Techo'" 2004). According to a study published by the Office for National Statistics (ONE), 71.4% of the housing stock in the Dominican Republic lacks adequate infrastructure and quality materials. The National Housing Institute (INVI) is currently working on offsetting this deficiency. either highering

In countries with areas with warm and humid climatology, as is the case of the Dominican Republic, the effects of overheating and moisture accumulation directly affect the comfort inside the dwellings. Furthermore, the Dominican Republic is not only located in a seismic epicenter but also has seasons with a permanent incidence of hurricanes and tropical storms. Due to those climate conditions, it is necessary to bear in mind that the structure and the other building elements should be designed to resist those phenomena.

1.1. Goal

This study focuses on analyzing the thermal comfort conditions and the energy efficiency while trying the reach the levels required by international standards without using mechanical ventilation. A social house prototype located in Santo Domingo city is used as a case study.The main objective of this study is to analyze the existing problems related to ventilation in the case study, which directly affect thermal comfort. The purpose is to estimate the difference between the current state of the building and the ideal comfort temperature range and propose solutions to improve this and other similar buildings without using HVAC systems.

2. METHODOLOGY

This work is structured as a case study. The thermal performance of an apartment building constructed in the context of a national social housing program in the 80s was studied.

2.1. Case study

A residential building located in the Invivienda sector, East Santo Domingo province, was chosen as the object of this case study. This building was constructed as a part of a national housing program in the 80s. Figure 1 shows the ground plant of the building and its different architectonic spaces. Figure 2 shows the plant of one of its housing units. The building has four floors. Each one of the floors has four housing units. Each of the sixteen housing units has a living room, three bedrooms, a bathroom, and a laundry room, accounting for 75 square meters. Each apartment has only one access door, one auxiliary door, and eight windows, each made of the same materials.

Figure 1. Architectural plan of the building

Figure 2. Architectural plan of the building

The Santo Domingo province is located at 18°29'08"N latitude 69°52'24"O longitude. It has a humid tropical climate with an average annual temperature of 25ºC. Due to the oceanic current and breeze, the average temperature is around 1.5ºC lower than its latitude suggests. The highest average temperature is about 34 ºC, registered in July and August, and the lowest is around 19ºC in January and February. Intertropical locations such as Santo Doming city have high average temperatures, with low variation between night and day temperatures. There is also a relatively low seasonal variation. The high relative humidity, typical of tropical climates, makes it hard to reach adequate indoor comfort levels.

The average precipitation levels reach 1446mm. The highest rainfall incidence takes place in May and November. Santo Domingo city is in the trajectory of the northwest trade winds. The annual average wind velocity is 10.1 km/h. Near the shore, the wind direction changes direction due to the temperature differential between the land and water masses, which causes the winds to flow from the sea to the land during the day (SE), and from the land to the sea during the night (NE). That phenomenon helps mitigate the constant hot and humid conditions over the year.

Because of the proximity to the equator, the hours of daylight variate between 11 and 13. It can be stated that Santo Domingo Receives an average of 215 hours of sunlight each month with a maximum sunshine time of 62%. The solar radiation potential in the Santo Domingo Island (average solar radiation on a horizontal surface) variates between 5.25 and 5.5 kWh/m2 per day on the western side.

2.2. Simulation process

Several thermal simulations were conducted to analyze the performance of the case study building to determine the comfort temperature range. To obtain it, the period of the year with the higher temperatures and the period with the coolest temperatures were considered in a span of 24 hours. The day zone and the night zone, and one of the floor levels were also analyzed in the same period. SketchUp Pro-2021 was used for 3D modeling, one of the best computer programs for creating architectural 3D models. The thermal simulation was performed using the software OpenStudy, an open-source program that uses the Energy Plus calculation engine (United States Department of Energy 2019).

The simulation was run in two different conditions, the first one being its current state and the second one and the second one after conducting refurbishment measures.

2.3. Materials

According to the data from the National Survey of Multi-Purpose Households carried out by the National Statistics Office ((ONE) 2019), the primary materials used in the country are concrete blocks, both for external walls and partitions, zinc and concrete for the ceiling and aluminum for the windows. Table 1 shows the most typical construction materials in the Dominican Republic.

Figure 3. Simulation of the building in OpenStudio

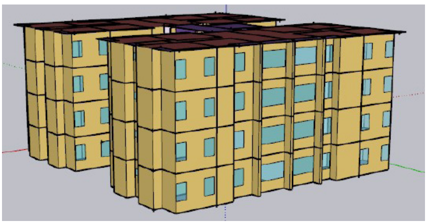

Figure 4. Simulation of the building in OpenStudio

The materials employed and the different apartments have been emulated in the thermal simulation. The building has a flat roof with a 12 cm reinforced concrete slab. Its outer face has a mortar covering and a waterproofing layer. The exterior walls and partitions are constructed with 20 cm thick concrete blocks covered with a cement mortar layer on both sides. The floor is composed of a slab of reinforced concrete and horizontal aluminum sheets distributed over all the surfaces with a ten-centimeter separation. The entrance door is made of pine wood, and the interior walls are made of plywood.
Table 2 describes the composition and the thermal properties of the materials that compose the façade, and Table 3 the layer composition of the roof.

Building elements	Thermal resistance (m² -°K/W)	Thermal conductivity (W/m °K)	U-Value (W/m² °K)
Cement mortar	0.017	1.30	5.39
Concrete block façade	0.13	1.18	3.37
Concrete roof	0.13	1.65	3.30
Aluminum windows	/	230	5.84
Wood doors	250	0.16	0.37

Table 1. Thermal properties construction materials in the Dominican Republic

Layer	Material	Thickness (m)	Thermal Resistance (m² -°K/W)	U-Value (W/m² °K)
1	Rubbed mortar	5mm		
2	Rustic mortar	15mm		
3	Façade concrete block	200mm	0.29	3.48
4	Rustic mortar	15mm		
5	Rubbed mortar	5mm		

Table 2. Elements of the façade construction materials in the Dominican Republic

Layer	Material	Thickness (m)	Thermal Resistance (m² -˚K/W)	U-Value (W/m² ˚K)
1	Waterproofing	3mm		
2	Rustic mortar	50mm		
3	Reinforced concrete	120mm	0.27	3.71
4	Rustic mortar	20mm		
5	Rubbed mortar	5mm		

Table 3. Roof elements construction materials of the Dominican Republic

PARAMETER HOT DAY	
Occupant by Zone	4 PEOPLE
People Activity	80%
Time of Occupation	168 Hours per Week
Simulation Day	August 15th

PARAMETER FRESH DAY	
Occupant by Zone	4 PEOPLE
People Activity	80%
Time of Occupation	168 Hours per Week
Simulation Day	January 16th

Table 4. Parameters for openstudio simulation

3. RESULTS AND DISCUSSION

Once the simulation is complete, the results are shown by the OpenStudio viewer, which summarizes the results using tables and graphs. The simulation parameters are displayed in Table 4.

As was previously explained, two simulations were conducted. In the case of the first scenario, initial temperatures on a hot and cold day were obtained to determine the comfort range of the building. The 15th of August was chosen as the hot day and the 16th of January as the cold one. The second scenario was performed with the same parameters but added a passive natural ventilation solution to compare the temperature and comfort range.

Figure 5 depicts the exterior temperature in those periods. The maximum temperature on a hot day is 30.5ºC, and the maximum on a cold day is 29.1ºC. Figure 6 shows the average radiating temperature in those periods. In this case, the maximum temperature on a hot and cold day are 31 and 30.1ºC, respectively. The relative humidity on a hot day varies between 75 and 88%, with the average hourly being approximately 80%. For a colder day, the results oscillate between 66 and 72%, with an average of 69%.

In scenario 1, the calculations did not account for the influence of natural ventilation. Figure 7 shows that the indoor temperature reaches a maximum of 29.3ºC during the hot season and a maximum of 28.6% during the cold season. In both cases, the temperatures are outside of what would be considered comfortable.

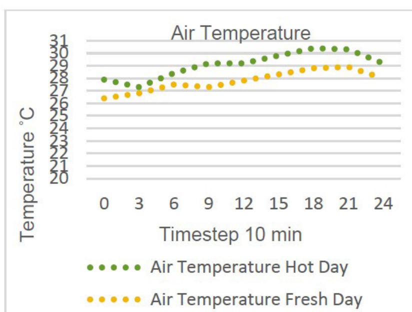

Figure 5. Air Temperature scenario 1. Own source

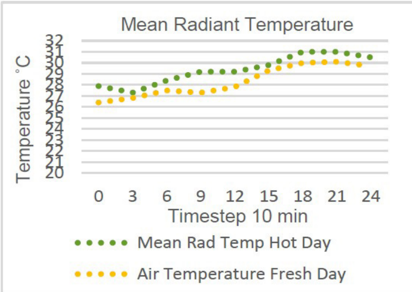

Figure 6. Mean Radiant Temperature scenario 1. Own source

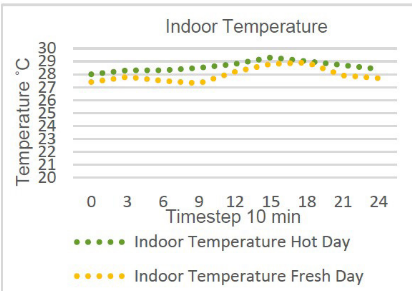

Figure 7. Indoor Temperature scenario 1. Own source

PMV	Thermal Sensation
3	Much hot
2	Warm
1	Slightly warm
0	Neutral
-1	Slightly cold
-2	Cold
-3	Very cold

Table 5. Thermal Sensation. Source (ISO 2005)

Afterward, the temperature is evaluated using the Fanger methodology, which assesses the Predicted Mean Vote (PMV) on the thermal sensation scale of a group of people exposed to a particular environment (Diego-Mas 2015). This method derives from heat transfer physics combined with an empiric adaptation to account for the subjective human sensation. PMV establishes a thermal tension based on thermal transmittance in the stationary state between the body and the environment and assigns a vote of comfort according to that tension. PMV is measured on a scale from three (much hot) to minus three (Very Cold) (Table 5). From that, it is possible to obtain the Percentage of People Dissatisfied (PPD) for each PMV. The PPD increases as the PMV moves from the neutral position (zero) to either positive or negative values. Table 6 shows the temperatures required to perform the thermal comfort calculations. The values were obtained through the simulation with OpenStudio.

The thermal comfort was assessed using Design Building, which calculates the PMV and PPD by introducing the data in table 7. Figure 8 shows the thermal comfort on a hot day with the natural ventilation turned on. The figure shows that the operative temperature registered is 30.5ºC. The thermal sensation is 2.20, which is considered warm according to Table 5. The PPD indicates a value of 84.81% of satisfaction due to the high temperatures. Figure 9 shows the thermal comfort of a cold day. It indicates that the operative temperature is 29.4 and the thermal sensation is 1.83, which indicates that the comfort level is slightly warm, according to Table 8. The PPD is 68.38%, which is still due to the high temperatures.

Day	Air Temperature	Mean Radiant Temperature	Relative Humidity
Average Daily Max. Hot Day	30°C	31°C	69%
Average Daily Max. Fresh Day	28,8°C	30,1°C	65%

Table 6. Mean Temperatures for calculate thermal comfort scenario 1. Own source

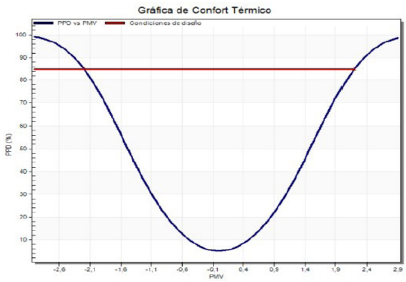

Figure 8. Thermal comfort hot dayscenario 1. Own source

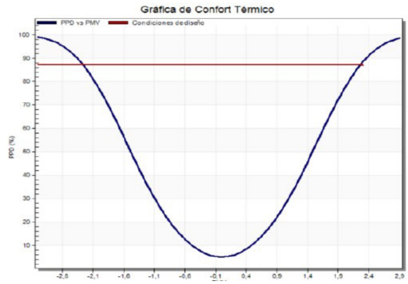

Figure 9. Air Thermal comfort fresh day scenario 1. Own source

Results	
Operating temperature ˚C	30,5˚C
PMV	2,2
PPD (%)	84,81%

Table 7. Results thermal comfort scenario 1. Own source

Results	
Operating temperature ˚C	29,4˚C
PMV	1,83
PPD (%)	68,38%

Table 8. Results thermal comfort scenario 1. Own source

The second proposed scenario takes into account the effect of natural ventilation. The simulation is configured to control the parameters of opening and closing windows according to the relation between internal and external temperature. The windows in these kinds of buildings do not have glass. The window frame only has shutters to control the airflow and light inside the house. Table 9 shows the temperature and humidity for scenario 2. Figures 6 and 7 depict the exterior temperature in those periods. The maximum temperature is 28.8ºC on a hot day, and the maximum temperature on a cold day is 27.3ºC.

Figure 10 shows a maximum average radiating temperature of 25.4ºC on a hot day and a maximum radiating temperature average of 24ºC on a cold day. The relative humidity on the hot day oscillates between 96% and 85%, the hourly average being 90%. The cold day has a relative humidity between 57% and 70%, averaging 63%. The interior temperature reaches a maximum of 26ºC in the hot season and 25ºC in the cold season. The PMV and PPD were again obtained using the data from Table 9. Figure 11 shows the thermal comfort result in a hot day with natural ventilation, showing an operative temperature of 27.1ºC. The PMV is 1.08, slightly warm according to the values in Table 10. The PPD indicates a value of 29.72%.

Day	Air Temperature	Mean Radiant Temperature	Relative Humidity
Average Daily Max. Hot Day	28,8˚C	25,5˚C	90%
Average Daily Max. Fresh Day	27,3˚C	24˚C	63%

Table 9. Mean Temperatures for calculate thermal comfort scenario 2. Own source

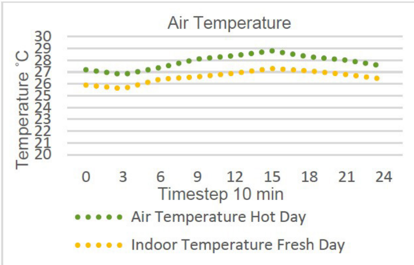

Figure 10. Air Temperature scenario 2. Own source

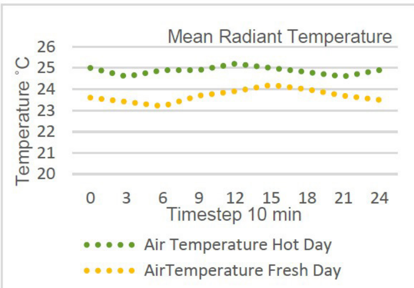

Figure 11. Mean radiant Temperature scenario 2. Own source

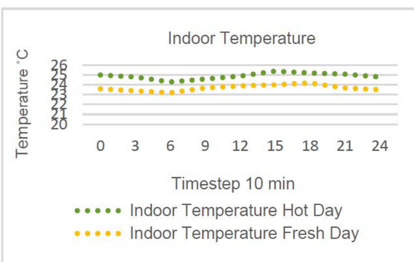

Figure 12. Indoor Temperature scenario 2. Own source

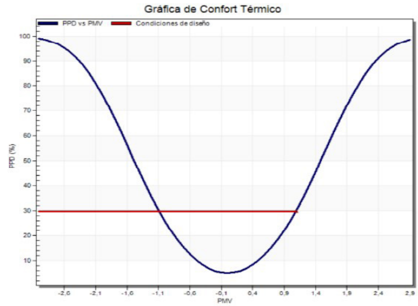

Figure 13. Thermal comfort hot day scenario 2. Own source

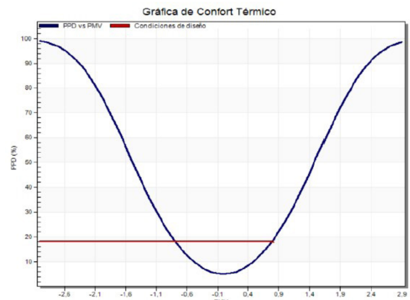

Figure 14. Thermal comfort fresh day scenario 2. Own source

Results	
Operating temperature °C	27,1°C
PMV	1,08
PPD (%)	29,72%

Table 10. Results thermal comfort scenario 2. Own source

Results	
Operating temperature °C	25,6°C
PMV	0,79
PPD (%)	18,13%

Table 11. Results thermal comfort scenario 2. Own source

Figure 14 shows the thermal comfort values accounting for the natural ventilation on a cold day. It shows an operative temperature of 25.6ºC and a PMV of 0.79, which can be considered neutral according to Table 5. The PPD is 18.3%.

As seen in scenario one, the results show that the high temperatures directly affect the thermal sensation when the space is not adequately ventilated. For that reason, the PMV is 2.2, which negatively affects the thermal comfort and the PPD, 84.81%. However, when the parameters of natural ventilation are correctly configured, in scenario 2, the temperature drops, and although the thermal sensation keeps being high, a PMV of 1.08 is obtained. This PMV is slightly warm. The PPD also drop the 29.72%. Both scenarios were calculated for August 15th.

On January 16th, the results of scenario 1 show lower temperatures. However, the thermal sensation keeps rising, with a PMV of 1.83 and a PPD of 68.38%. In scenario 2, the PMV is 0.79, considered neutral, and a PPD of 18.13%.

According to the Fanger method, for the value to be considered adequate, the PMV must be within -0.5 and +0.5. The comfort temperature should also be between 20ºC and 24ºC in the cold season and 23 and 26 in the hot season.

5. CONCLUSIONS

The study's primary purpose was to analyze the thermal comfort in a social housing project in the Dominican Republic and propose measures to improve it through passive measures. Natural ventilation, orientation, and shading are critical factors in the design strategies toward passively obtaining better thermally behaving buildings. This study allowed to evaluate the thermal comfort conditions of the building in two scenarios, one with natural ventilation and one without it. The results in neither scenario reached the minimum requirements for thermal comfort. The best obtained PMV was January 16th, in which the PMV is 0.76 with an operative temperature of 25.6ºC and a PPD of 18.13%, where the acceptable values are between -0.5 and +0.5 with an operative temperature from 24 to 26ºC. A possible solution to this problem would be to improve the thermal insulation of the building envelope. Also, it would be advisable to include glass in the windows beside the shutters. Opening the shutters at night would also help in lowering the temperature. These solutions might be a starting point for future studies and research on these building typologies.

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