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BIOCLIMATIC ANALYSIS OF MECHE'S HOUSE: A CONSTRUCTION ALTERNATIVE

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Meche´s House is an alternative post-disaster construction, and this is the study of its bioclimatic approach showing that social and post-disaster buildings also need this kind of research. Tropical climate conditions lead to buildings having a high energy consumption for cooling loads. In Ecuador, the energy consumption of the residential area is 28.78% of final demand. Also, there is very little relevant information on the analysis of bioclimatic design in buildings, as well as specific analysis of interior comfort. The carried-out analysis process considered methods of bioclimatic evaluation, which mainly focuses on building the user's comfort. For this reason, in the first place, the site climatic conditions and possible passive intervention strategies were determined. Followed by the evaluation of natural ventilation with which it was possible to evaluate the effectiveness of natural ventilation through simulations in Computational Fluid Dynamics program. Furthermore, thermal comfort analysis using an Energy Plus program is used for comparing the internal temperature ranges versus indoor natural ventilation. Finally, the data is discussed under an adaptive comfort and user perception of satisfaction. This research confirms the need to carry out bioclimatic evaluations of projects conceived under a good line of architectural design, since only in this way will it be possible to demonstrate that the proposed considerations and strategies have positive or negative outcomes.

Keywords: Indoor comfort, Tropical climate, Ecuador, Natural ventilation, Bamboo.

1 INTRODUCTION

Under tropical climate conditions, lead buildings having a high energy consumption, specifically for cooling loads (Al-Obaidi *et al.* 2014). They have several problems in terms of the materials that are applied. The energy consumption of non-residential and commercial buildings in countries that are in this region is approximately "a quarter of the total consumption of electric power" (Rattanongphisat and Rordprapat 2014). In Ecuador, the energy consumption of the residential area is 28.78% of final consumption and commercial, and public services are 21.78% (Iea.org 2018). This demand could be mitigated by a passive strategy well executed in buildings and, especially in a tropical climate. Especially with an adequate bioclimatic design, it is possible to easily save 30% of the energy produced by the energy demand by active cooling systems (Sadineni *et al.* 2011). Within the process of architectural design and construction process, the key elements to reach a suitable bioclimatic design are the materiality, orientation, and shape of the building. In terms of materiality in tropical climates, the most common and suitably used are: clay, wood, bamboo, and mainly other local materials (Al-Obaidi *et al.* 2014); unfortunately, today these materials are short in supply or non-existent. Cities that are developing in this geographic location have triggered the use of industrial materials such as steel, concrete, glass, light metals, and others which are more suitable for other contexts. With a correct passive design of the building in a said geographical area (Rattanongphisat and Rordprapat 2014), the performance could be substantially improved, and the demand for energy reduced to achieve a structure with a low carbon impact (Yeang and Yeang 2006) (Roslan *et al.* 2015). The buildings located within tropical climatic conditions generate a high energy consumption due to the cooling loads used (Al-Obaidi *et al.* 2014). In the same way, the materials used in the construction of low quality, allow a higher energy transfer. Therefore, the interior temperature is increased by thermal gains by radiation and convection, decanting in the use of mechanical cooling. The architectural design plays an important role when using appropriate processes framed in parameters of bioclimatic design that allow ensuring a proper application of passive strategies to regulate the conditions towards the interior of the architectural space (Sadineni *et al.* 2011) (Yeang and Yeang 2006). In Ecuador, there is poor relevant information on the analysis of bioclimatic design in buildings, as well as specific analysis of interior comfort with the use of specialized programs such as Energy Plus. This premise revalues this research because of the high degree of certainty that can be obtained from specialized models such as those developed under this process. Within the little that exists, the authors Calle *et al.* (2013) conclude that it is possible to successfully apply energy efficiency strategies in buildings in Ecuador whenever they are carried out in early stages of design, conclusion based on the study of a prototype building located in the province of Imbabura. A similar conclusion was presented when analyzing the variation of the materiality of the envelope of a minimum dwelling; where important comfort percentages were reached, which were between 79% and 95% of the total hours analyzed (Miño *et al.* 2013). Finally, from the study of a university building in the tropical zone of Ecuador, where the analysis of natural ventilation was included, it is concluded that it is possible to reduce energy consumption by 10% when combining the cross-ventilation strategy or solar chimney (Kastillo *et al.* 2015).

1.1 Geographic Location and Weather Conditions

The project is implemented in Ecuador in the province of Esmeraldas canton Muisne, specifically in the area called Pedro Carbo between the towns of Chamanga and Mompiche. Ecuador has four natural regions that have different climates due to their difference in altitude and proximity to the Pacific coast. In general, a large part of the Ecuadorian territory, except for the Sierra region, has warm climates typical of tropical zones. According to the climate classification Köppen-Geiger (Figure 1), it is stipulated that the area of intervention of the project is considered Cfa type, which means a temperate climate without dry seasons and with hot summers (Peel *et al.* 2007).

On the other hand, and with the aim to have a deep understanding of the site's climate, the meteorological data of the population of Muisne province of Esmeraldas was considered due to its proximity to the place. In this way, valuable information on climate data was obtained, as well as the sun's path and its different angles of inclination with the horizon during the year. The relative humidity of the air fulfills a preponderant factor when assimilating and evaluating the thermal sensation and levels of human comfort both inside and outside the buildings (Cheng *et al.* 2010).

According to the information obtained in the meteorological station closest to the site, the weather station CP M0153 INAMHI was used, the humidity of the air throughout the year remains at levels very close to 85%, in this way, the ranges of sensations. They vary from the oppressive type, which is present most of the time, to the unbearable type present during the months of higher temperature and solar radiation. Finally, it is essential to understand the behavior and velocity of the air in the sector, to include said variable in the thermal analysis and evaluation of the home. According to NASA SSE (2018), the annual air velocity at 50 meters above ground level is 2.98 m / s, with minimum and maximum speed peaks during March and August with 2.19 and 3.51 meters per second respectively.

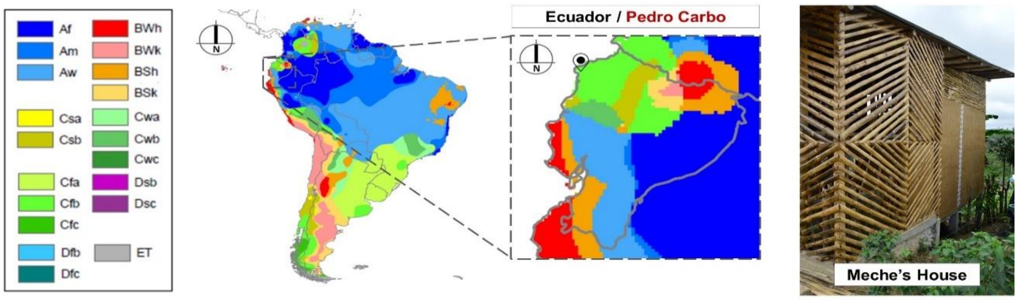

Figure 1. Climate classification Köppen-Geiger - Esmeraldas (Peel *et al.* 2007) and Meche's house façade.

2 METHODOLOGY

The analysis process that was carried out considered the methods of bioclimatic evaluation, which focuses mainly on the comfort of the user of the building. For this reason, in the first place, the site climatic conditions and the possible passive intervention strategies were determined. However, there was no data on the existence of files in format. EPW (EnergyPlus Weather file), which includes meteorological data in codes adapted for the analysis programs was used. In the same way, the tropical zones and particularly the latitude where the project is located have very little meteorological information loaded in this format. For this reason, it was necessary to generate a specific EPW file for the project considering climate data obtained from the meteorological station CP M0153 (INAMHI 2014) and mainly from NASA, to create results, close to the reality of the intervention site.

On the other hand, an internal thermal comfort analysis using the EnergyPlus program was used to compare the interior temperature ranges versus the presence of natural ventilation. The thermal study of the project was carried out based on related evaluation processes in such a way that it is possible to determine the incidence of the architectural and bioclimatic contributions in the thermal sensation of the users; this is how three scenarios modeled in the Energy Plus program were considered, which are identifiable. The first one evaluates the project considering a typical design and construction process in Ecuador with generic materials of frequent use and acceptance. The second scenario estimates the architectural project carried out by Ensusitio Arquitectura, including data and thermal capacities of local materials such as bamboo cane and soil-concrete. Finally, the third scenario starts from the base of the built project but includes natural ventilation considering the proposals and openings of the windows, as well as the bamboo framework spans. With the aim to establish similarity to reality, the cane framework was carried out in a more non-volumetric mathematical way, and lattice properties were included for each of the window openings. Natural ventilation is based on the direction and wind speed per hour determined by the weather station and loaded into the created EPW file. The evaluation of natural ventilation, with which it was possible to assess the effectiveness of natural ventilation through simulations in Computational Fluid Dynamics (CFD), was carried out based on the parameters of natural ventilation in CFD (Gan 2016). considering stable conditions. For representing and having a better understanding of the analysis process used in this research, an orthogonal chart was made where important and determining points in the continuity of each of the methods are highlighted. See Figure 2.

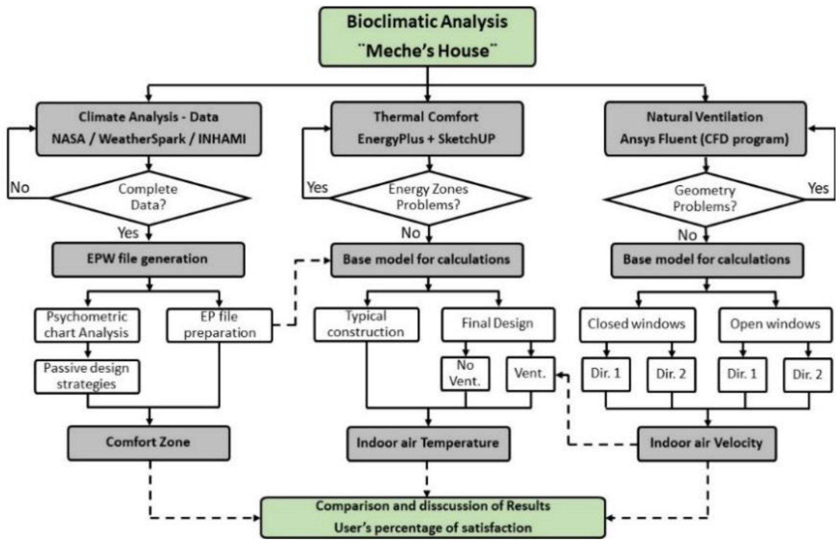

Figure 2. Orthogonal chart of the research methodology.

3 RESULTS

3.1 Natural ventilation analysis results with Ansys Fluent (CFD)

In the first analysis of the building (Figure 3), the direction of the wind is from North to South, and the building in terms of its openings is closed. There is evidence of natural ventilation even though the windows are closed, due to the materiality and configuration, which allows the passage of natural ventilation into the interior of the space with an average speed of 1.64 m/s.

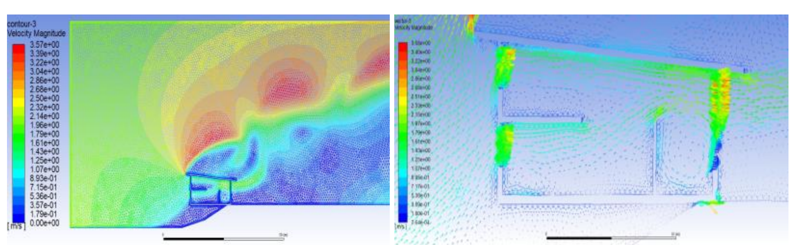

Figure 3. Natural ventilation on building CFD analysis 1.

3.2 Internal Thermal Analysis Results with Energy Plus

The average value of the interior air temperature of each space represents an excellent basis for comparing the thermal conditions of each scenario. With the aim to understand the annual behavior of them, the temperature is presented on an average day of each month. In the case of housing, the analysis shows that the construction of the project using typical materials from the area and without bioclimatic design strategies generates an interior temperature that is between 2 and 3.5 °C above the average room temperature that varies between 24 °C and 26.5 °C throughout the year. That is due to the heat gains through the materials and energy transfer from the outside to the inside. On the other hand, the same habitable space when it includes design strategies and architectural contributions decreases its temperature by at least 1.5 °C considering a traditional construction. Finally, when the passive design strategies are added plus the adaptability of the user using natural ventilation and window opening, a significant reduction of the temperature is obtained, and the internal thermal conditions are improved. Thus, the final project that includes natural ventilation manages to lower the temperature from the first scenario in a range between -1.9 °C to -3.4 °C throughout the year. This is evidenced in Figure 4.

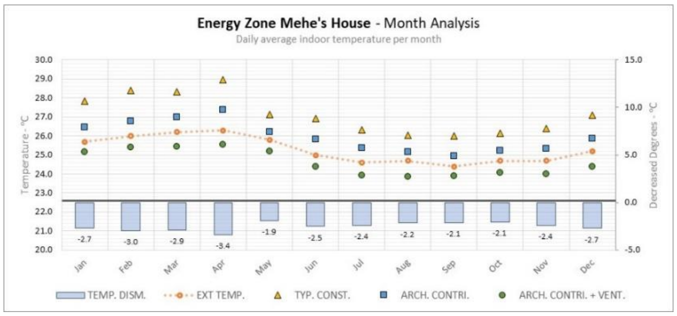

Figure 4. Indoor thermal comfort analysis (temperature) – house.

4 DISCUSSION OF RESULTS

With the aim to assess the results obtained from the natural ventilation and internal temperature analyzes, the PMVTool program developed by Marsh (2005) was used. It identifies the prediction of user satisfaction considering seven levels of complacency where 0 is comfortable, +3 is extremely hot and finally -3 is extremely cold, for this case study two scenarios were analyzed. The first evaluates average conditions during the day, which were obtained from the EnergyPlus and CFD modeling. Therefore, the inserted data is Ambient temperature 27 °C, radiant temperature 26 °C, relative humidity 80%, activity 1.61 (light), type of clothing 0.66 (Pants/short sleeve shirt) and finally a speed of wind of 2 m/s. As a result, 21% of the users could be dissatisfied with the conditions existing in the interior space, since the value obtained was +0.87, which falls outside the limit of what is considered comfortable with the beginning of heat sensations. The second analysis evaluates average conditions during the night, when the temperature of the environment is 23 °C, the radiant temperature 22 °C, the relative humidity 96%, the activity 0.77 (rest), the type of clothing 0.70 (Pants/shirt long sleeve) in case A and 1.59 (Thermal pajamas & blankets) in case B, finally a wind speed similar to 2 m/s. The variation of the cases (A/B) is generated to establish an adequate analysis with a possible adaptive comfort of the user. As a result, in case A 100% of the users could be dissatisfied since they obtained a score of -3 that represents a cold temperature sensation. On the other hand, case B with similar climatic conditions, but with the inclusion of user adaptability for the use of different clothes, a much lower percentage of dissatisfaction was obtained that was around 13.9%. It corroborates the hypothesis that the project has adaptive thermal comfort conditions.

5 CONCLUSIONS AND RECOMMENDATIONS

This work confirms the need to carry out bioclimatic evaluations to projects conceived under a good line of architectural design, since only in this way will it be possible to demonstrate that the considerations and strategies proposed have a positive result, as is the case of this project. It is evident that the morphology of the openings, as well as the materiality of the enclosure used, had a significant contribution in the reduction of thermal gains of the building and therefore the modification of internal temperature of the space; this guarantees a true adaptive comfort during the periods analyzed (between 20 °C and 28 °C) for the majority of users, as confirmed by temperature analysis and satisfaction percentage (higher than 70% of satisfied users) respectively. As could be seen, adaptive comfort (user adaptability) plays an essential role in the building in terms of thermal sensation. However, this process has a high degree of uncertainty about the average satisfaction obtained, since the conditions are assimilated differently by each user. Therefore, a more detailed analysis per hour could result in a proposal to improve the project, utilizing minimum changes in the morphology to ensure a greater interference of the volume in the internal temperature control and therefore a lower range of user dissatisfaction. Finally, as a project that has already been built, it has excellent potential to verify the results of the modeling described above and explained.

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