Habitability and Hygrothermal Comfort Analysis of Social Housing in Ecuador, Temperate Continental Climatic Zone

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Abstract. Housing sector plays an essential role in the sustainable development of the countries; however, there are significant problems in terms of its ability to access which promotes the occurrence of solutions that guide the housing deficit reduction as well as economic savings and natural resources preservation. One key strategic would be the use of social housing as a mechanism to ensure a decent house accessed by vulnerable population. The general housing design requires satisfying characteristics of indoor environmental comfort, arising the need outlook technical solutions. This research aims to propose functional and hygrothermal improvements for social housing located in a temperate continental climate zone in The Sierra region of Ecuador. The methodology was focused on energy simulations using Design Builder software and comparing the results with the application of passive bioclimatic recommendations. In addition, based on the quantitative housing deficit this research achieves qualitative contributions in order to improve the living conditions of low-income population whose get access to social housing in Ecuador. An experimental case study, located in Azogues a canton of the province of Cañar, has been selected for the simulation analysis which belongs to a housing governmental program named Manuela Espejo promoted by the Ministry of Urban Development and Housing and special designed for people with disabilities. The research has an applicative nature approach, with a sectional scope and explanatory depth, based on primary and secondary information sources; data collection techniques were social perception surveys used to determine comfort levels of the social housing users. The results show, based on the energy simulations carried out, improvements in terms of habitability conditions and an architectural proposal compiles passive bioclimatic recommendations focused on the design of social housing in Ecuador. Therefore, this research contributes to the implementation of new social housing plans that not only would help to reduce the housing deficit, but also contribute to improving the housing indoor environmental comfort perceived by the users.

1. Introduction

Historically, housing has been an important instrument in the development of societies, even it is recognized as a fundamental right. At present, it is understood as a safe and permanent living space in which the human being can, among other things, take shelter, recover and leave rehabilitated [1]. In housing context, Latin America nowadays is considered a highly urbanized region, owing to the
migration rapidly increase from the countryside dwellers to the major cities, undoubtedly generating a worrying social problem, especially from the housing point of view.

In Ecuador, access to worthy housing in a healthy environment is a recognized right by The Constitution. In consequence, public policies pose the access of the most vulnerable population to their own house, nevertheless, a large percentage of the population faces housing problems [2].

According to historical data, the quantitative housing deficit in Ecuador, recognized as the number of dwellings whose housing conditions are considered irrecoverable decreased from 21.2% in 2009 to 13.4% in 2017 [2]. It would correspond to 608,071 dwellings pursuant to the National Survey of Employment, Unemployment and Underemployment (2017).

Moreover, the increasing consumption of energy resources and greenhouse gas emissions as a consequence of HVAC systems plays at the present an important role in the sustainable development of the emerging countries. The inner performance of buildings has been studied for several years, in order to create optimal comfort conditions, example by involving different parameters such as heat with human needs. Thus, the inner housing environment is determined by the degrees of lighting, air quality, acoustic behavior and thermal comfort [3], the latter as the object of analysis of the present investigation.

The use of passive bioclimatic techniques, applied to social housing proposals, allow optimizing thermal comfort, attaining better conditions of habitability especially of low-income dwellers. This scenario, in connection with environment conditions, climate, and building envelope under a sustainability approach [4]. The applicability of basic bioclimatic concepts of "building with the climate" [5] does not require complex mechanisms, but rather the use of clear and efficient criteria that improve the internal environmental characteristics of social housing.

Social housing in The Sierra region of Ecuador, specifically in the temperate continental climatic zone corresponding to an altitude of 2000 m.a.s.l. to 3000 m.a.s.l., lacks an appropriate bioclimatic evaluation. Parameters like sunlight, ventilation, lighting, and use of suitable materials - among others, are key factors for decision-making in the design of an efficient comprehensive housing proposal.

As a Result, this research intends to recommend a sustainable architectural model, which compiles bioclimatic methodologies based on a social housing proposal, and furthermore of collaborate in the proposal of possible solutions promote the reduction of energy resources uses while contribute to the environmental indoor quality and thermal comfort of social housing.

By using a research methodology, of mixed behavior, clear results are expected by the application of bioclimatic concepts. The results supported by the design of a virtual social housing model located in a temperate continental climate zone allow to simulate the housing conditions according to Ecuadorian regulations for sustainable construction.

2. Methodology

Based on analysis criteria, the research was developed under an applicative experimental approach through the interior environmental conditions perceived by the users of social housing, additionally it adopted a sectional scope and explanatory depth, carried out through a specific time study of variables such as climate, hygrothermal comfort and construction materials [6][7].

An analysis of the literature was carried out based on the compilation of qualitative and quantitative information; as well as social perception surveys execution which determined guidelines for strategic decisions making. Particularly, the social perception procedure allowed to obtain relevant data regarding
thermal and construction conditions aside from the functional conditions of the living spaces which consolidate enough arguments that support the investigation.

Likewise, energy simulation techniques were carried out using DesignBuilder software to conceptualize passive bioclimatic techniques and contrast reached hygrothermal comfort levels with those expected in the formulated architectural model.

The research was developed in the canton of Azogues in the province of Cañar and consider as an object of study ten social housing of Manuela Espejo 2018 program executed by the Ministry of Urban Development and Housing of Ecuador (MIDUVI), aimed for people with disabilities.

The temperate continental climatic zone in study contemplates an average annual temperature between 14 °C and 17 °C corresponding to sites whose altitude ranges between 2000 m.a.s.l. and 3000 m.a.s.l. with a relative humidity average between 59 % and 66% [8].

The social housing in study contemplates a construction area of 36 m2 and considers the following interior spaces: two bedrooms, one living room, one kitchen and one bathroom. Figure 1 shows the architectural spatial distribution while figure 2 exposes the exterior front view.

![Figure 1. Architectural plant](image1.png)

![Figure 2. Exterior front view](image2.png)

Table 1 exposes buildings materials and envelope characteristics identified according with field gathered information. Thermal transmittance values has been set according to the Ecuadorian Construction Standard defined by the Energy Efficiency in Residential Buildings section [9].

Social perception surveys exposes the predominant family composition varies between 4 and 5 people on average, in accordance with the general family composition in Ecuador which reaches 4 people per household [10]. Figures 3 and 4 detailed below expose surveys data which indicates that 60% of surveyed households consider the home somewhat uncomfortable, while 40% believe that the home is usually comfortable. Alike the 50% of surveyed households consider the living spaces somewhat
small, followed by 40% who consider the living spaces exceedingly small and remaining 10% state that the home has a regular space.

| Constructive element | Materiality                     | Characteristics                      | U factor (W/m2-K) |
|----------------------|--------------------------------|--------------------------------------|-------------------|
| Exterior masonry     | Interior plastering            | Cement and sand mortar, e=15mm       | 2,35              |
|                      | Lightweight concrete block     | 150mm x 200mm x 400mm                |                   |
|                      | Exterior plastering            | Cement and sand mortar, e=15mm       |                   |
|                      | Interior plastering            | 150mm x 200mm x 400mm                |                   |
|                      | Lightweight concrete block     | Cement and sand mortar, e=15mm       | 2,35              |
|                      | Interior masonry               | Ceramics                             |                   |
|                      | Exterior plastering            | 30 x 30mm, e=7mm                     |                   |
|                      | Floors                         | Concrete                             | 2,88              |
|                      | Cover                          | 210Kg/cm², e=100mm                   |                   |
|                      | Windows                        | Fiber cement sheet                   | 3,1               |
|                      | Doors                          | Iron and glass                       | 5,89              |
|                      |                                | Wood                                 |                   |
|                      |                                | 40mm                                 | 2,56              |

Thermal perception by social housing users was also assessed both during the day and at night. Findings reveals that during the day scenario 40% of households perceive little cold, 30% normally perceive cold, followed by 20% who feel some cold, while the remaining 10% feel very cold. In contrast, during night scenario, 40% of households feel usually cold, while 30% feels some cold, while the remaining 30% claim to perceive a lot of cold. Figure 5 and figure 6 shows graphically the results obtained.
These statistical data conclude as results the need of social housing reform including further functional and friendly spaces with optimal hygrothermal comfort conditions. These changes would lead to trial-and-error tests by applying passive bioclimatic techniques which promote indoor hygrothermal improvements.

As part of the applicative research, one specific social housing located at 2800 m.a.s.l was analyzed. The selection obeys to its altitude that would guide to perceive the greatest hygrothermal discomfort in relation to the others. Table 2 shows the geographic location of case of study.

| Table 2. Geographical data of the home. |
|---------------------------------------|
| Direction    | Vegapamba              |
| Sector       | Vegapamba              |
| Parish       | San Miguel             |
| Canton       | Azogues                |
| Orientation  | Front facade facing south-west |
| Height       | 2800 msnm              |
| UTM coordinates | 740043 E           |
| WGS 84       | 9689822 S              |

The following recommended passive bioclimatic techniques [11], are tools to improve indoor hygrothermal comfort for social housings located in The Sierra region of Ecuador corresponding to a temperate continental climatic zone.
Table 3. Passive bioclimatic recommendations.

| Configuration | Recommendations | Outcome |
|---------------|----------------|---------|
| Implantation  | Insulation on its 4 facades | Improves hygrothermal and light comfort |
| Orientation   | Longest bay towards east - west direction | Heat gains throughout the day, contributing to hygrothermal comfort |
| Enclosure design | Compact housing | Improves hygrothermal, light and acoustic comfort |

| Envelope Recommendations | Outcome |
|---------------------------|---------|
| Architectural walls       | High storage capacity walls, brick, block, adobe | Improves hygrothermal and acoustic comfort |
| Cover                     | Coating of materials with high thermal inertia, handmade tile | Improves hygrothermal comfort |

3. Results and discussions

3.1. Functional and hygrothermal architectural proposal

The social housing studied served as the basis for the architectural proposal by maintaining its typology and including only a dining room and an additional bedroom; in conformity with the predominant family composition in Ecuador enclosed by 4 persons per family. Consequently, the construction area changes from 36 m² to 54 m² warranting its functionality.

Figure 7. Architectural plant

Figure 8. Exterior front view
Alternatively, the case study building envelope has been analyzed and compared with the functional proposal including hygrothermal improvements. This allowed to obtain reliable data that supports the investigation. The hygrothermal improvements considers both exterior and interior lightweight concrete masonry coated with expanded polystyrene and finished with plasterboard. Additionally, interior spaces were provided with a gypsum ceiling, and the existing roof was covered with clay tile.

Table 4. Building envelope materials with functional and bioclimatic improvements (54m^2).

| Element            | Description            | Characteristics          | U factor (W/m^2-K) |
|--------------------|------------------------|--------------------------|-------------------|
| **Exterior masonry** | Gypsum plate          | e=10mm                   |                   |
|                    | Expanded polystyrene  | e=50mm                   | 0,54              |
|                    | Lightweight concrete block | 150mm x 200mm x 400mm  |                   |
|                    | Exterior plastering   | Cement and sand mortar, e=15mm |               |
| **Interior masonry** | Gypsum plate          | e=10mm                   | 1,26              |
|                    | Expanded polystyrene  | e=50mm                   |                   |
|                    | Gypsum plate          | e=10mm                   |                   |
| **Floors**         | Ceramics              | 30 x 30mm, e=7mm         | 2,88              |
|                    | Concrete              | 210Kg/cm2, e=100mm       |                   |
|                    | Roof tile             | e=25mm                   |                   |
| **Cover**          | Fiber cement sheet    | e=6mm                    | 2,61              |
|                    | Gypsum plate          | e=10mm                   | 2,22              |
| **Windows**        | Iron and glass        | Clear glass, e=4mm       | 5,89              |
| **Exterior doors** | Wood                  | e=40mm                   | 2,56              |

3.2. Orientation according to thermal gains and losses

Comparative energy simulations of original orientation - southeast facade with an angle of 39 ° - and south facade orientation, according to bioclimatic recommendations, highlight the importance of an adequate orientation by allowing direct sunlight in the east west facades. Therefore, internal gains in the case study exposes slight annual improvements of 13.01 Kwh.

![Thermal balance, 36m^2 house (gains and losses in kWh)](image_url)

**Figure 9.** Thermal balance, 36m^2 house (gains and losses in kWh)
3.3. Hours of hygrothermal comfort

Givoni diagram determine that the interior comfort range for the case study is between 19 °C and 25 °C. By using Meteonorm software a weather file [12] has been obtained and as a result weather condition were established which were used for energy simulations with DesigBuilder software.

Energy simulation results determine improvements in the internal hygrothermal comfort of the social house through the application of passive bioclimatic techniques. The scenario of analysis involves the original space composition of 36 m² of construction, the proposal expansion to 54 m² with and without hygrothermal improvements where it was possible to test the comfort hours rise in the coldest month of the year; from 1 to 7 of July. This reflects in the change from 24 hours to 55 hours of hygrothermal comfort, representing 56% more of comfort level in contrast to the original case study. For the warmest month, from February 1 to 7, the comfort hours remain in a range of 98 hours in all three analyzed scenarios. While the relative humidity ranges between 46% and 61% for both coolest and warmest month.

Figure 10 shows the hygrothermal comfort behavior for the three analyzed scenarios and the hours of hygrothermal comfort due to improvements in the building envelope materials is exposed in figure 11.

![Figure 10. Hours of hygrothermal comfort according to the type of home](image1)

![Figure 11. Thermal balance (gains and losses in kWh)](image2)
The difference between internal annual thermal gains increases significantly from 933.24 kWh in the first scenario – original case study – to 1452.82 kWh in the third scenario - expansion to 54 m². In summary, the research carried out encourages the proposal of functional and hydrothermal improvements in social interest housing for temperate continental climatic zone in The Sierra region of Ecuador.

Experimentally the research demonstrated the habitability conditions offered by current social housing and contrast the results based on a comprehensive architectural proposal that compiles passive bioclimatic recommendations along with the analysis of the scientific literature and energy simulation analysis. This Reveals significant improvements in the living conditions of the social housing users as is detailed below.

Table 5. Research results.

| Description                        | Original social housing, 36m² | Social housing proposal, without hygrothermal improvements, 54m² | Social housing proposal, with hygrothermal improvements, 54m² |
|------------------------------------|-------------------------------|----------------------------------------------------------------|-------------------------------------------------------------|
| Room                               | x                             | x                                                               | x                                                           |
| Dining room                        | ......                         | x                                                               | x                                                           |
| Kitchen                            | x                             | x                                                               | x                                                           |
| Bedroom 1                          | x                             | x                                                               | x                                                           |
| Bedroom 2                          | x                             | x                                                               | x                                                           |
| Bedroom 3                          | ......                         | x                                                               | x                                                           |
| Comfort Hours, February 1-7        | 98                            | 98                                                              | 98                                                          |
| (19 °C - 25 °C – warmest month)    |                               |                                                                |                                                             |
| Comfort Hours, July 1-7            | 26                            | 24                                                              | 55                                                          |
| (19 °C - 25 °C – coldest month)    |                               |                                                                |                                                             |
| Hygrothermal heat balance (gains in kWh) | 8849,55                     | 8894,55                                                         | 9003,23                                                     |
| Heat balance (losses in kWh)       | -7916,31                      | -7916,31                                                        | -7577,41                                                    |
| Difference (total earnings in KWh) | 933,24                        | 978,24                                                          | 1425,82                                                     |

4. Conclusions
The results showed that the application of passive bioclimatic techniques becomes fundamental key to achieve hygrothermal comfort conditions in social housing located in a temperate continental climatic zone of the Sierra del Ecuador region.

Likewise, housing improvements and optimal levels of hygrothermal comfort were notorious through the incorporation of mentioned passive bioclimatic techniques in the architectural design of the building.

The inclusion of passive bioclimatic considerations in public and private real estate developers should be considered as an essential basic need specially in social housing projects.

In context, improvements in the spatial functionality, orientation and characteristics of the building envelope determine optimal environmental conditions for a social housing proposal; the latter depending
on the application of bioclimatic recommendations that reach habitability and hygrothermal comfort of social housing projects in Ecuador.

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