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Assessment and Proposal to Improve Hygrothermal Comfort and IAQ in Housing in Bogotá: Four Case Studies

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Abstract

Low-income housing is that which is developed to guarantee the right to housing for low-income households, the value of which does not exceed 135 minimum wages. This study was conducted as part of eEvaluation and sustainable proposal for improvement of the integral habitability of low-income housing (VIS) project in Bogota, Colombia. It provides a diagnostic and assessment plan for improving indoor air quality (IAQ) and hygrothermal comfort in terms of CO2 concentrations in four residences in Bogotá. The assessment considers the city's climate, occupancy patterns, and schedules of use within the buildings. The study confirmed results using six-month monitoring data, modeling and simulation of dwellings using Sketchup, EnergyPlus and OpenStudio plugin. These methods provided accurate modeling of relative humidity and temperature behavior. Indoor air quality (IAQ) is closely tied to hygrothermal behavior, particularly in cold weather when closed windows lead to increases humidity, and CO2 buildup. To enhance comfort levels, avoiding air infiltration and implementing hygienic ventilation practices are recommended. However, it was noted in several cases that the hygrothermal comfort standards outlined by ASHRAE were not met. As a result, passive improvements based on simulation were suggested, including the use of thermal stucco, double-glazed windows, and insulating floors, all of which improved internal comfort conditions.

1.0 INTRODUCTION

Law 46 (1918), which addressed public health issues with sanitary housing, is where the idea of habitability in social interest housing (VIS) in Colombia first emerged. Then, in accordance with the scale of the city in which it is situated, the VIS and the idea of habitability are subjugated to their economic worth connected to minimum monthly earnings under Law 9 of 1989 on Urban Reform. The Housing Policy and the National VIS System (SINAVIS), which defines the housing solution in terms of the current legal minimum salary, were established with the new Political Constitution of 1991. Another factor at play has been Law 142 of 1994, a socioeconomic stratification system that uses property observations to divide Bogotá's population's income level into six strata. Among these, strata 2 and 3 correspond to the state interventions in VIS that have remained constant over time.

The main purpose of buildings, especially housing, is to provide adequate habitability conditions. Despite human's efforts to improve environmental conditions through various technologies, there are still many shortcomings in bioclimatic and habitability aspects. These include the inappropriate use of materials, building orientation, spaciousness, among other aspects that have generated dissatisfaction with housing and a diminished quality of life (Rodríguez et al., 2019), (Mewomo et al., 2023).

Habitability in a home is an architectural concept that encompasses both the physical space and the living environment, aiming to guarantee minimal conditions of health and comfort. Comfort and indoor environmental quality (IEQ) are connected. Comfort comprises the total indoor environmental elements (i.e., ventilation, thermal comfort, noise, and lighting) within that building, while indoor air quality (IAQ) primarily focuses on the quality of air circulating within a building (Dimitroulopoulou et al., 2023).

Because of human activity, the IAQ inside the buildings might not be sufficient. Adequate ventilation is crucial for the residents' comfort and health; with natural ventilation playing a significant hygienic role. This type of ventilation, known as hygienic ventilation or winter ventilation, is required permanently, particularly in colder seasons or predominantly cold areas where windows tend to remain closed to maintain thermal comfort. Therefore, hygienic ventilation becomes essential for ensuring air quality (Scherer & Grigoletti, 2023). It is vital to guarantee that ventilation occurs at a level higher than occupants to sanitize these environments effectively (Russi & Rocha, 2014).

The most significant risk factor in homes is poor indoor air quality, often caused by inadequate ventilation (Wimalasena et al., 2021). Elevated indoor CO2 levels serve as a reference for assessing IAQ, with concentrations adversely affecting the attention and productivity of the occupants (Cao & Deng, 2019). Additionally, exposure to acute high concentrations of CO2 can cause mucosal and respiratory diseases, blood acidosis, neurophysiological consequences, and impaired decision-making in those affected (Huimin Yao et al., 2024).

Hygroythermal comfort depends on factors such as air temperature and humidity, thermal radiation, and ventilation. This is directly related to the climate of the place, occupancy patterns, and house characteristics (Espinosa Cancino & Cortés Fuentes, 2015). According to the American Society of Heating, Refrigerating and Air-Condition Engineers (ASHRAE) standards, thermal comfort "is a mental condition in which satisfaction with the environment is expressed." It is said that to reach this sensation of comfort, you must be in thermal equilibrium (Ming et al., 2023), that is, where individuals experience neither excessive heat nor cold (American Society of Heating, 2017).

High humidity in the air and "low temperatures" inside buildings can cause water condensation on surfaces, and possible deterioration of construction materials, as well as the proliferation of mold and other microbial agents (World Health Organization, 2009), (Smith & Gorse, 2021) which can cause serious structural and health problems (Pipiriate, 2017).

In Colombia, the application of thermal comfort standards regulating in the design of buildings is advised but not mandatory within sustainable architecture policies. Regulatory frameworks are limited, and policies are relatively new compared to other countries (Medina et al., 2021). Some studies have shown that comfort levels in houses that have been built and are still being built, particularly in Bogotá, often fall below acceptable thresholds of temperature and relative humidity (Rodriguez et al., 2019), (Calderon Uribe, 2019). The situation regarding regulations for air quality is not significantly different, since it remains challenging to find standards specifically tailoredto homes.

Bogotá has a bimodal climate with two rainy periods and two dry periods annually, each of approximately three months (Cuellar & Perez, 2023). During the rainy season, there's a notable increase in cold sensations due to greater cloudiness and less solar radiation on surfaces. According to (Agudelo Varón, 2014), in at least six of the twelve months of the year, houses in Bogotá fall short of thermal comfort standards because parameters such as spatial distribution, lighting, ventilation, and materials are not ideal.

These issues stem partly from a focus on quantity over quality in housing, driven by government policies aiming for broader coverage, as well as construction companies seeking higher profits by repeating models regardless of the specific characteristics of each place, saving in costs of designs, materials and other expenses (García Ramírez, 2020). This situation generates a problem, given the city's cold weather conditions, with an average temperature of 14°C and relative humidity of 80% (Rodríguez et al., 2019), resulting in cold stress. Therefore, when inhabiting these cold and humid spaces, it can generate deterioration in health and low satisfaction, especially in social housing, where the cost of maintaining comfort attributes or making adjustments can exceed the economic capacity of residents (Rodriguez et al., 2019).

Computational modeling offers a valuable tool for evaluating buildings and propose constructive solutions. These models analyze thermo-energy behavior and its relationship with thermal comfort and air quality. While most bioclimatic and air quality analyses have been carried out with CFD-based programs, other methods like zonal and network models in software such as EnergyPlus, DesindBuilder, DOE, Transys, Esp-r, Domus Procel Edifica, among others are also common and applicable to both commercial buildings and housing (Al Ka'bi, 2020).

Notably, the U.S. Department of Energy (U.S Department of Energy (DOE), 2021) produced EnergyPlus, one of the most popular open source energy and bioclimatic simulation systems for buildings globally (Guerra García et al., 2022).

In light of these challenges, the goal of this study was to analyze hygrothermal comfort and IAQ (CO2) using EnergyPlus simulations and to propose improvements based on passive strategies for four houses in Bogotá.

2.0 METHODOLOGY

Four case studies were selected, representing houses from different historical periods of social housing in Bogotá: Antonio Nariño Urban Center Case (CUAN) (1958), Paulo VI Case (1966), Sauzalito Case (1987), and Alcalá Case (2010). The first three cases are considered Social Interest Housing (VIS) in the city (socioeconomic strata 2 and 3), while the Alcalá Case belongs to a higher socioeconomic stratum (socioeconomic strata 5). This selection provided a contrast reference, thus expanding the research framework. In Figure 1 the location and orientation of the selected dwellings is shown.

Figure 1. Location of case study homes in the city of Bogotá.

(Source: the authors)

Visits were conducted to verify planimetric data and gather input for simulations through surveys on house routines, natural ventilation, equipment usage, and lighting.

To analyze the study cases regarding their materials and configuration concerning hygrothermal comfort, simulations were carried out using the free-access program EnergyPlus and the OpenStudio plugin. These simulations were validated using data collected every 20 minutes over a period of 6 months, resulting in a total of 12,960 data collected for each variable. Data were collected using Wöhler 210 dataloggers, which recorded variables of temperature, relative humidity, and CO2 within the ranges and precision shown in Table 1.

Table 1. Wöhler 210 Parameter Ranges and Accuracy.
(Source: adapted from the team manual.)

Parameter	Measuring range	Precision
CO2	0 _ 6000 ppm	± 5%
Temperature	-10 °C _ 60°C	± 0.6 °C
Relative Humidity	5% _ 95%	±3%

For each case study, 3D geometry was modelled using the Sketch up program and the Open Studio Plugin to generate an IDF-type file. The geometries created thermal zones for spaces, added boundary conditions such as sun protection, contact with the ground, and thermal zone connections, among others, and assigned names to spaces and surfaces. The model was oriented according to the corresponding case for easy recognition.

For the CUAN Case, the apparatus (data logger) was positioned at a height of 1.0 m in the study room. The geometry for the case was set up with nine thermal zones (Figure 2-A). Additionally, sun shields were incorporated into the modelling to simulate the shadows cast by the upper floor (Figure 2-B).

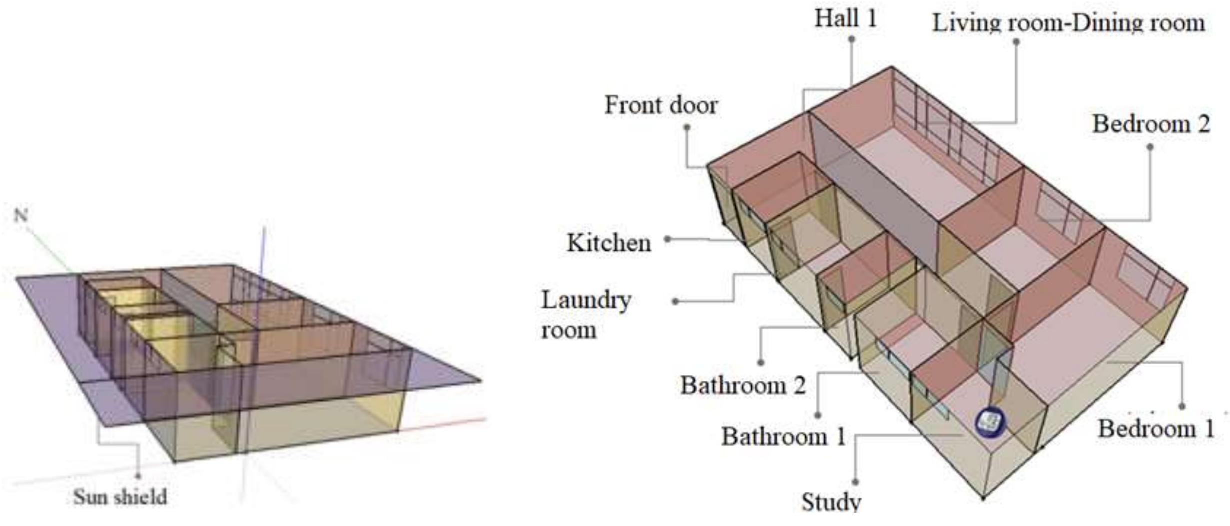

Figure 2. 3D geometry CUAN case: A. Spaces corresponding to thermal zones. B. Sun shields.
(Source: the authors)

The Paulo VI Case is a house with 2 floors, with 14 thermal zones (Figure 3). In this case, two Wöhler units were installed, one on the first floor, in the bedroom 3, and the other in the living-dining room on the second floor. A sun shield was used that recreates the parking lot door located on the first floor.

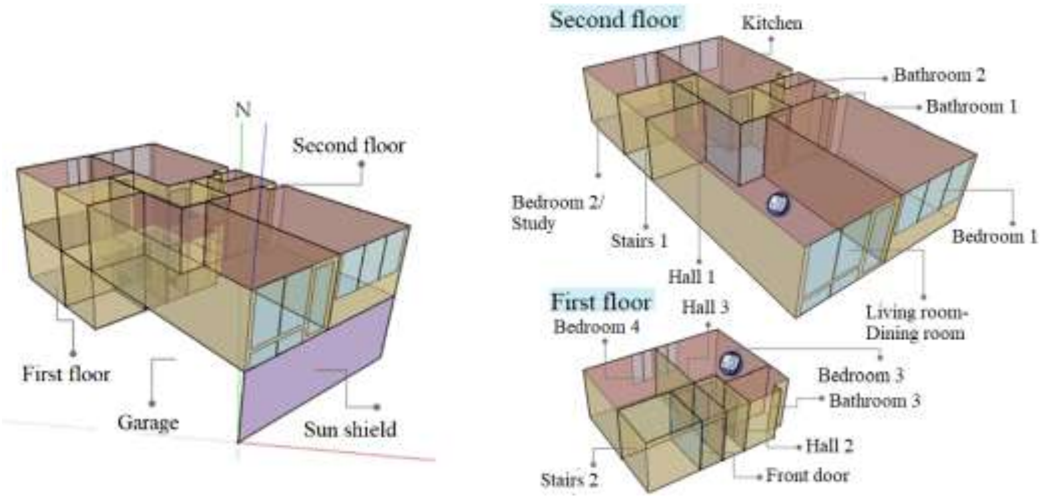

Figure 3. 3D geometry Paulo VI case.
(Source: the authors)

Additionally, the Sauzalito Case was divided into 8 thermal zones (Figure 4) and the data logger was installed in the living-dining room.

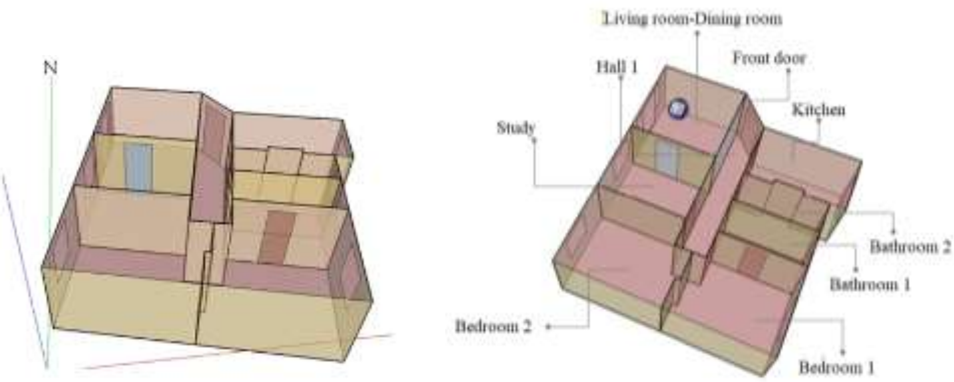

Figure 4. 3D geometry Sauzalito case.
(Source: the authors)

Finally, the Alcalá Case (second floor) was divided into 13 thermal zones (Figure 5-A). Sun shields were used in this instance to simulate the shadows cast by the cantilever on the upper floor (Figure 5-B). It is worth noting that, in this house, the first floor corresponds to the parking area.

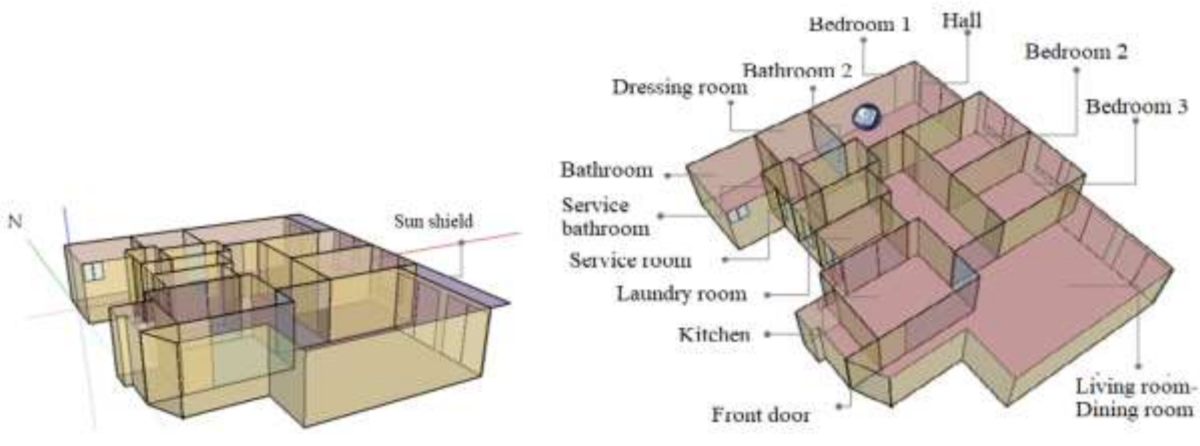

Figure 5. 3D geometry Alcalá case: A. Spaces corresponding to thermal zones, B. Sun shields.
(Source: authors)