

# Design Guidelines for Residential Envelope Openings in the Equatorial Tropics

## Studies in Suburban Housing in the Cauca Valley of Colombia

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*ABSTRACT: The envelope openings of houses have a strong implication in the indoor environmental quality and energy consumption, however, there are no precise regulations for its design, especially in particular climate zones such as the tropics, where there are no recommendations or laws for residential architecture. This has not only deteriorated the environmental quality, but also increased energy consumption in new buildings. Therefore comprehensive reviews of some examples that may suggest general principles seem just appropriate, as well as its implementation as design guidelines. Several variables have been considered in the study of the envelope openings: natural ventilation, light and shadow management, connection to the outside and the perception of users in addition to the opening's own characteristics and their relationship with the living space. The correlation between variables resulted in the development of guidelines for the design of envelope openings in the hot and humid tropics, combining qualitative and quantitative aspects of comfort, as observed in the case studies. These guidelines have been implemented in a computer tool and will be a significant contribution for the design of sustainable housing, applying passive resources to the envelope openings granting better indoor environmental quality with low energy consumption.*

### INTRODUCTION

Presently, the facade of buildings is a growing concern in the industrialized countries where there exist standards and a realization concerning the impact of these on the environment and the people. These standards are similar to the European and North American standards in which the levels for human welfare are decided at different levels relative to the tropics [6]. There exist important international comfort standards [12] [13] [14] based on heat exchange analysis and the surrounding environment. Generally, their results come from experiments in climate chambers and are based on thermal sensations with diverse conditions to those of the tropics.

Some authors [4] have realized studies that suggest that these standards do not describe the real comfort conditions and that they should be complemented with adaptable comfort standards that are obtained from survey results practiced with the people of each locality.

The perception of comfort by people in the tropics is given by the ability and developed adaptation of long-term life with both high temperatures and high humidity. The tendency in these climates is to stay in shaded areas as long as possible and to take advantage of the breezes to stay cool [8].

In particular, there exists in the equatorial tropical climate a lack of constructive design standards for

envelope openings of houses with sustainable performance. This lack of legislation in some countries on the equatorial fringe aggravates the problem of energy consumption because in order to achieve constant relative temperatures and humidity, there is a high cost [10].

The comfort is intimately tied to the people involved, since these people contribute to the control factors of the physical environment. The design is determined by the environment, the technology, socio-cultural, functional and aesthetic aspects. The envelope openings have a great impact in the usefulness of a building and are elements that can be isolated from other more complex architectural problems. These can predict the complex interactions between light requirements and heat gains, which are converted into a field for the application of research methods and optimization of sustainable practice [2].

The climatic characteristics of the Cauca Valle of Colombia, implicate special considerations in the design of the envelope openings for the applicable equatorial tropical surroundings. The answer to these conditions is the result of natural occurrences like the amount of rain, the abundance of light, radiation, the air charged with humidity, exuberant vegetation, building characteristics

and the absence of a hermetic and shaded environment, in addition to the cultural aspects of the inhabitants.

The objective of this investigation is to develop alignments for the design process for envelope openings of tropical equatorial housing. Along with the representative case studies of the local architecture in relation to the interior environmental quality of the housing, the qualitative and quantitative aspects of comfort will be combined. The study of the importance of envelope openings is found not only in the definition of building esthetics and the energy yield of the same, but rather in the generation of housing interior comfort.

### CASE STUDIES

The selection of projects (Fig. 1) for study, illustrates the strategy, developed solutions and typologies in the both colonial architecture and contemporary architecture, with respect to the design of envelope and envelope openings. Diverse criteria were taken into account for the case selection, their historical and architectural value like “La Teja”. “Los Cuchos”, “La Queja”, “La Rebeca” and “El Nispero” are all winners of architectural awards. Some are a sample of contemporary architecture of the region, like “Casa Cárpena-Escobar”, “El Hormiguero” and “Casa del Agua”. Projects like “Club del Campo” represent the typology of urban commercial developments that have been successful in recent years. The majority of the projects are suburban units while “La Queja” and “El Nispero” are found in one of the traditional neighborhoods of the City, where the housing typology among dividing walls presents diverse solutions as to the climate conditions.

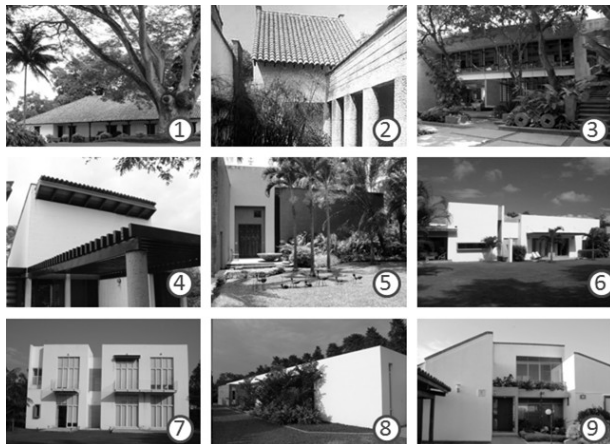


Figure 1: Selection of Housing. 1 La Teja, 2 La Queja, 3 El Nispero, 4 Casa del Agua, 5 La Rebeca, 6 Los Cuchos, 7 El Hormiguero, 8 Cárpena-Escobar, 9 Club del Campo.

The value of this small and simple factor is the wealth, depth and quality of the information that is

presumed to be found in each case. There is a great variety of envelope openings to show (Fig. 2) and the distinct perspectives of the problem to study. The purpose is to document the diversity, to find the differences and coincidences, the patterns and particularities. Even though some cases share similar traits for this investigation, nine (9) structures and sixteen (16) spaces in total have been selected. From each one of the cases one or two envelope openings were selected that represented the diversity of utilized strategies by the architect in the composition of its facades, the distribution and characterization of its spaces and climate management.

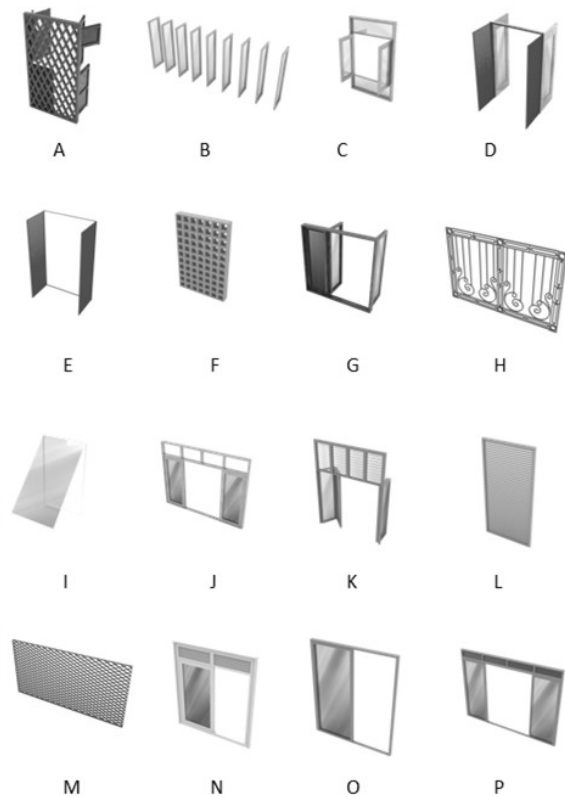


Figure 2: Selection of Case Studies. A La Teja, B-C El Nispero, D La Queja, E- F Casa del Agua, G-H La Rebeca, I-J Los Cuchos, K-L El Hormiguero, M-N Carpena Escobar, O-P Club del Campo.

### METHODOLOGY

In order to reach the proposed objective in this investigation, once the case studies were selected; standards were defined and adopted to be compared with the case measurement readings as to the thermal, lighting, and psychological comfort realized in each housing structure. Furthermore, a geometric study of spatial relations was realized. For each case there was a thermal aspect reading during 24 continuous hours.

Later, the performance was evaluated of each envelope opening as to the comparison and correlation of the obtained data and finally the guidelines were prospected for the envelope opening designs in the tropics.

Thermal comfort standards are necessary tools for the architect to provide for the building interior an environment that has a comfortable thermal level. This definition is very important not only so that spaces may possess the adequate conditions for the users, but also because this decision defines the energy consumption and its effects on the environmental sustainability [4] [5]. The exterior readings of temperature, relative humidity, and wind velocity were obtained from different meteorological stations located near each one of the case studies. They were contrasted with the one realized the same day inside each housing structure with a portable Kestrel 4500 meteorological station. Nicol (2004) determined an algorithm that predicts the comfort temperature in terms of exterior temperature. The author shows evidence that the comfort temperature in the naturally ventilated building depends on the exterior temperature. In this investigation, this algorithm has been adopted and applied in order to define the comfort standard in the study zone and it was established in Jamundí and Cali that the comfort zone is between 22.8 °C y 27.7°C. The Relative Humidity Standard defined for the study zone was determined between 50 and 80%. As for ventilation, it was estimated that for the similar climatic conditions, winds higher than 3m/s could restore comfort. [8]. Being able to use and take advantage of natural lighting can mean a reduction in the energy consumption for the housing, even more when the geographical location of the study zone is found in the equatorial zone in where the amount of daylight hours is 12 hours a day on average. The objective of this process consists in measuring the light received on a horizontal surface in the middle of the interior space to characterize and evaluate the natural light conditions. The utilized standard for the comparison of the measurement results is the standard UNE EN 12464-1 of 2003. The levels of natural interior light were measured with a digital Lutron LX-105 lux meter (ISO 9001-CE-IEC), with a range from 0 to 20,000 lux.

Through the utilization of post-occupation questionnaires, a correlation was done among related aspects with the person's perception, the physical environment, and the spaces. Because the surveys were done by the housing residents, the information obtained was analyzed for the purpose of acquiring real data of comfort psychology and how measurable physical aspects impact the occupants. A value scale of 7 points was used, initiating with 1 as the lowest score, 3 as the neutral point, and 7 as very meaningful, such as has been used in different experiments [1] [11] [12].

## CASE EVALUATION

The temperature readings are qualified by taking into account if the interior temperature was in or out of the comfort zone during the 24 hours and it was compared with the exterior readings. A continuous scale of 1 to 7 was obtained, where 1 is the lowest and 7 is the highest score. According to the expressed results, the cases present unequal situations, unconnected with the housing categories. The minor qualifications obey space characteristics like a lot of permeability or absence of elements that block the passage of the exterior conditions toward the interior like glass or wood. In the morning, this situation with low temperatures makes the interior temperature fall notably.

North and south orientations with vegetation that generate shade over the face make the interior temperature lower than the comfort zone. Contrary to this, spaces with east and west orientations and an abundant shade from vegetation had temperatures inside the comfort zone. Spaces that do not offer the possibility of a permanent air exchange, due to the fact that the space has a glass window that covers 100% of the area, had high interior temperature readings, higher than the comfort zone, higher than the exterior temperature, being that this case is most critical with respect to the thermal comfort already implicated in the use of refrigeration systems (air-conditioning) to restore the interior conditions to acceptable levels.

The result of the relative humidity evaluation for each case equally had a scale of 1 to 7. The cases obtained a minor scoring where the interior relative humidity rose above the exterior or where the interior relative humidity was out of the established range between 50 and 80%. No apparent relation was found between the orientation of the spaces and the relative humidity results. It is suspected that the measurement of the space be more hermetic with importance to its orientation and that this will prevent the exterior humidity conditions affecting the space. It would seem that other characteristics like the dimension of the overhang, the absence of cross ventilation and vegetation could augment the relative humidity levels to the interior of the building.

As for the natural ventilation, it is presumed that the measurement of the interior temperature and the comfort sensation will increase in the manner the building openings permit a constant flow and exchange of air with the exterior. It was experimented during the field study that the closed spaces accumulated the heat of the entire day without the possibility of hot air renovation, producing a sensation of discomfort.

The evaluation of visual comfort was done taking into account the standard. Six of the cases registered lower

than the standard, ratifying that in the tropics some architects do not design with light but rather with shade. Even though this practice could increase the use of artificial light in some spaces to be able to realize the activities for which they were designed and consequently this will increase the electric energy consumption. The remaining ten (10) cases presented light reading above the standard.

The post-occupancy questionnaire results showed that the thermal sensation most affected by the user in the psychological comfort evaluation was heat over cold, even though the temperature readings in the majority of cases was lower than the comfort zone and not above. This could have a relation with the high social-economic level of the people surveyed who most of the time during the day would be in air-conditioned spaces and have lost the capacity to adapt to zone temperatures. For this reason, when there is a minimal temperature rise they are uncomfortable.

Table 1. Evaluation case studies results.

Facade opening	Visual Comfort	Thermal Comfort	Relative Humidity	Pshycol. Comfort	Total Comfort
A	-	7.00	4.75	6.00	5.51
B	-	3.79	3.58	7.00	3.51
C	-	7.00	4.67	7.00	5.60
D	-	1.17	2.83	7.00	1.83
E	-	5.25	4.42	6.66	4.48
F	-	3.79	4.33	7.00	3.63
G	3.50	6.42	4.58	5.60	5.97
H	3.50	2.92	3.83	6.66	3.87
I	3.50	4.08	4.17	6.50	4.60
J	3.50	7.00	4.92	6.50	6.46
K	3.50	3.50	4.33	5.00	4.13
L	3.50	1.46	4.92	6.00	3.09
M	3.50	6.13	4.50	6.00	5.83
N	3.50	6.42	5.00	4.50	5.93
O	3.50	4.08	6.17	4.50	4.70
P	3.50	2.92	7.00	3.50	4.03

Once obtained the evaluation results by parameters and factors that affect comfort, some percentages for each one of them were estimated. A value of 60% was assigned to the thermal comfort, since it was already considered that the temperature is the first aspect that determines the comfort levels in a space [7]. The visual comfort is of second grade importance. Since having low

lighting levels increases energy consumption, a weight of 25% was given. A value of 15% was assigned for the relative humidity, due to the fact that in the surveys the people did not show that the humidity outside affected the comfort inside their houses. Lastly, the psychological comfort equals 10% of the total evaluation, due to that in the surveys only one question having to do with the perception of comfort was considered.

The results indicate that cases like A, C, G, J, M and N that obtained an evaluation above 5, on the scale of 1 to 7, can be considered exemplary cases with respect to the comfort and some of its characteristics and the geometric relations could be considered to determine design guidelines of residential openings for the tropics.

### DATA CORRELATION

The statistical correlation and significance were realized utilizing software Stata® (Data Analysis and Statistical Software), which evaluated the association grade between different types of comfort and the geometric aspects of each case. The results demonstrate that the opening area-space plan area/thermal comfort relation has a correlation of -0.6799; the overhang depth/comfort visual has a correlation of -0.5225. Another significant correlation registered was the space height/thermal comfort, with a value of 0.5841. The results of the correlations of this investigation have a partial explicative value, since the relation among some aspects gives only certain information.

### DESIGN GUIDELINES

The guidelines are the result of geometric analysis of the outstanding cases and their relations, aside from the orientation recommendations, use of vegetation and solar protection (overhang and louver), obtained through observation during visits and comparative analysis. The temperatures in the study zone are not very high during the entire year, which allows building plans to develop and permeate very freely that allow the circulation of air in the day as well as at night. Promoting shade in all of the spaces is of vital importance in the four orientations. It is recommended to orient the long and open facades toward the north and south, in order to minimize the heat gains because of exposure to the sun. The spaces toward the east and west require special conditions of solar protection due to the symmetry of the sun path. It was found in this study that east and west orientations could offer high levels of comfort, depending always on the complementary strategies like solar protections and the vegetation.

One of the characteristics of the tropics is that vegetation is varied and exuberant during the whole year.

This is a resource very easily utilized and combined with the building to create one entity. The vegetation can be used even in less favorable orientations (east and west), since they absorb the radiation and contribute to improving the air movement through thermal differential.

The use of overhangs, louvers and side fins on all of the facades in the tropics can be an effective resource in terms of control of solar light penetration and temperature gains, besides avoiding reflections and glare that produce discomfort. The most effective protections are the exteriors, even though this type of solution can affect the visibility toward the exterior. The distribution of the natural light in the interior and the spaces require precise considerations related with the depth of the facade opening in the building.

It is recommended to maintain an area of the window with permanent openings in order to maintain the interior air quality and to remove the humidity. Constant air movement by operating the windows during the day is needed in the hottest hours (14:00 to 17:00 hours), and the possibility of closing the openings in the hours in which the relative humidity reaches 100% (4:00 to 7:00 hours).

The variations are not linear and differing between them. Because of this, they cannot be implemented with prescriptive measures or in an intuitive manner in the project process, but rather more efficiently through parametric relations in a design system. In this investigation, the design guidelines have been implemented in a generative parametric tool that optimizes the facade openings of the housing as a support during the design process. Tools such as Rhinoceros, Grasshopper and Galapagos were utilized for the implementation and optimization of the guidelines as can be observed in Figure 3.

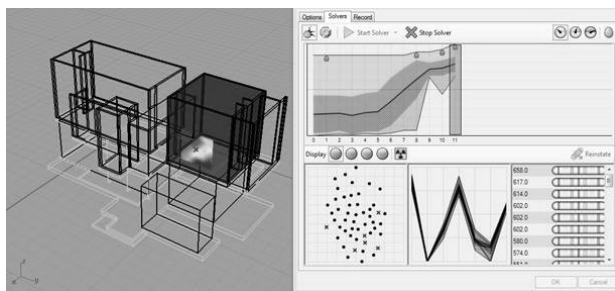


Figure 3: Optimized space utilizing parametric and generative tools.

## CONCLUSION

The characteristics of the facade openings depend on the requirements of the space, people and style of each

architect. It would not be prudent to propose only one applicable solution to all spaces in a housing structure, the desirable conditions of thermal, visual and psychological comfort also vary with the use of the space.

In conclusion, there is no evidence of an apparent relation between the space orientation and the interior temperature. This seems to be more related to the envelope opening characteristics like permeability and the protection that overhangs, louvers and vegetation may have.

There are three aspects related to the envelope openings and comfort in tropical housing that are considered important to keep in mind during the design process and that are related: the relation between the facade opening area and space area, the permanent facade opening area and the closed opening area with the possibility to operate the windows during day and night, and finally, the freedom of orientation for envelope openings, when and always architectonic and landscaping resources protect them from solar radiation.

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