Outdoor Comfort in Low-Income Housing Design

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ABSTRACT: This paper presents a thermal comfort analysis in outdoor spaces of low-income housing projects in Londrina city, Brazil. The objective is to improve the identification of client requirements in the design development process, in order to satisfy thermal comfort requisites of low-income housing users. It has been proved that human settlements quality is intimately linked with thermal comfort and users' well-being, and for this reason, it is necessary to establish requirements to improve the quality of outdoor spaces, which can also be parameters for new designs. Based on a case study in a house-building project, the research method consists of assessing the qualitative effects of design features that modify sun and wind exposure conditions. Simultaneously, a users' thermal perception evaluation in outdoor spaces was conducted, through a questionnaire. Finally, this paper presents a comparison between results of user perception and qualitative analysis in outdoor spaces, identifying, analyzing and prioritizing the final client thermal requirements. Based on the results from this research, the authors propose a set of climatic guidelines to guide the design development process of low-income housing, aiming to attend the users thermal comfort requirements.

Keywords: Low-income Hosing, outdoor thermal comfort, vertical building design, client requirements

1. INTRODUCTION

The thermal comfort evaluation of low-income house-building design is an important field of study to improve the human settlements quality, which include the thermal quality of outdoor spaces, designed for leisure and social activities.

In Brazil, recently, a trend has been observed towards verticality of low-income housing projects, through condominium organization. Therefore, the outdoor spaces are likely to become safer and more valuable for users. In this context, the aim of this paper is to propose a set of climatic guidelines for the improvement of thermal comfort of users in outdoor spaces of house-building projects.

2. BIOCLIMATIC ANALYSIS IN OUTDOOR SPACES

Some researches stress the importance of bioclimatic approach as a criterion for the design of outdoor spaces. The bioclimatic architecture can be defined as the one that optimize the energetic relationship between surrounding spaces and environment. As example, one can apply guidelines, such as to benefit from the sun in winter time and avoid it in the summer, or to make an adequate use of ventilation to reduce humidity effects and to eliminate the hot air. [1]

There is a bioclimatic analysis method that considers the three most relevant principal variables: The surface conditions, the building geometry and the existent vegetation. [2]

Concerning the surface conditions, the solar reflectance of materials applied should be evaluated. Materials like asphalt and concrete tend to absorb heat, which is stored during the day and released at night. The albedo coefficient varies between 0,05 to 0,20 to asphalt and 0,10 to 0,35 to concrete [1]. The planted areas, shrubs and trees also present low albedo coefficients, around 0,2. However, the absorbed energy is changed into chemical energy through photosynthesis, and also into latent heat through the process of evapotranspiration [3]. Therefore, the temperature of the air near the ground in vegetal surfaces is lower than over asphalt or concrete surfaces.

The building geometry influences, directly, the local microclimate. The building position causes changes in radiation, ventilation and humidity. The quantity of radiation reaching the ground can be determined by the buildings' height and the distance between them. This relationship (H/W – building's height and width of streets) can explain the influence of ground's surface in local temperature. In areas of high density (fraction H/W greater than 4) this influence is not so expressive because the portion of solar energy reflected by building is absorbed above the ground level. Meanwhile, in medium and low density areas (fraction H/W near or less than 1) most of the reflected energy reaches the ground, and is absorbed by it. [3](fig. 1).

Three patterns of ventilation can also be identified, that result from the influence of geometry. The "air flux above the building" (*Fluxo de ar acima do nível dos prédios*) occurs when the buildings are aligned, very close to each other and perpendicular to the ventilation flux. In this case, the fraction H/W is greater than 0,75. The "straw mat effect" (*efeito esteira*) occurs when the fraction H/W is greater than 0,40 e lesser than 0,75. Finally, the "isolated attrition (atrito isolado) Is likely to occur when the fraction H/W is lesser than 0,40. (fig. 2) [4].

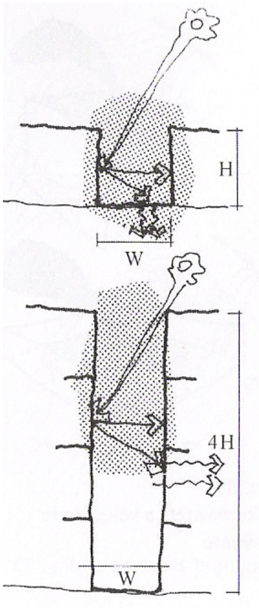

Figure 1: Influence of geometry on radiation. [1]

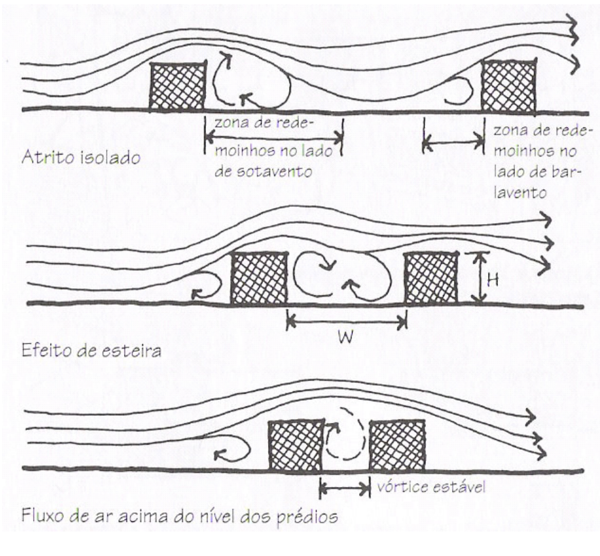

Figure 2: Influence of geometry on ventilation. [4]

The variable "existence of vegetation" focuses principally to assess the shaded areas in outdoor spaces and the quantity and location of trees.

The qualitative analysis for the assessment of the thermal conditions of outdoor spaces can also be combined with an evaluation of human thermal perception. Some studies show good integration of ventilation, solar radiation, humidity, and air temperature effects, with human perception. For this reason the thermal quality analysis, according to user's thermal perception, can provide thermal comfort parameters. [5]

In a user's thermal perception evaluation in outdoor spaces, it is important to consider that a physiological approach is not enough to characterize the outdoor thermal comfort conditions. The psychological adaptation including available choices, environmental stimulation, thermal history, memory effect and expectations, can also influence the human thermal comfort parameters. [6].

3. RESEARCH METHOD

Case studies in two high-rise residential buildings in the city of Londrina, Brazil, were developed for the evaluation of outdoor comfort in low-income housing projects and improvement in the identification of human thermal comfort parameters.

The research method consisted in a qualitative analysis, combined with an evaluation of user thermal perception. In this analysis, the comfort requisites were identified, analyzed and prioritized, than changed into design solution through climatic guidelines proposition to attend users of low-income housing.

With the requisites and a set of guidelines previously selected, a validation of this solution was undertaken through the development of a third case study. The low-income housing selected for this validation presented most of the comfort requisites identified in this paper. The validation was made through the evaluation of users' thermal perception about the outdoor spaces, and consisted of checking if the set guidelines identified could be introduced in the design development process of low-income house-building projects.

3.1 Qualitative analysis

The authors adopted a qualitative analysis method, due to the difficulties in developing local instrumental thermal measurements.

At first, data related to the project were collected, concerning building heights, vegetation, ground surfaces, through a field work and virtual design. In the field work routes and resting places were also evaluated.

The study of building geometry consisted of analyzing buildings' position and their influence on solar radiation and wind direction. Concerning solar radiation, a shading study for the summer period (22 of December) and winter period (22 of June) was developed based on the determination of azimuth angle and solar height for the following hours: 9h, 12h e 15h. The angles were found with the aid of a solar chart for Londrina's latitude (23°30S). The shading of summer solstice day in 12 hours was not applied because the position of the sun is at the zenith. The shading was drawn manually, without the use of simulation software.

The wind effects were evaluated through building position, verifying the dominant wind direction of the city and estimating the air paths influenced by geometry.

3.2 Human thermal perception

A questionnaire survey was developed comprising an evaluation of human thermal sensation combined with a psychological approach.

The questionnaire survey includes questions about expectation, habits, satisfaction degree and thermal sensation of users in outdoor spaces inside the condominium. For the summer period, the scales adopted were very hot, hot, little hot and comfortable. Thirty users were interviewed for each case study. The users answered the questionnaire survey inside their apartments or on outdoor space. However, they were asked to describe a general sensation of thermal conditions in outdoor spaces, and not the thermal sensation at the moment of the interview.

Having finished the analysis, the aim was to identify comfort requisites and then turn them into a set of design guidelines.

4. RESULTS PRESENTATION AND ANALYSIS

The first case study was developed in the housing project A, composed of seven buildings with three floors, comprised of 48 apartments. The outdoor spaces correspond to 76% of total site. In this area, an average of 10% is designated for children leisure, and the remaining to vehicle and pedestrian circulation, open parking and vegetal surface. The planted areas are situated mainly in the surroundings of the condominium, and concrete and asphalt surfaces are concentrated in central areas. Paths for pedestrians are not available in outdoor spaces, which lead the users to walk on asphalt surfaces, with high thermal inertia. The shading by trees as well as sheltered social spaces are non-existent. Some trees were recently planted.

The second case study was developed in the housing estate B, composed of eleven four-storey buildings, with a total of 174 apartments. This complex has about 82% of total site destined to outdoor spaces. The leisure space contains four sheltered barbecues, one sheltered social space, one game square and two playgrounds, and it amounts 15% of outdoor spaces. The remaining area is destined to vehicle and pedestrian circulation, open parking and planted areas.

The difference between housing projects A and B is that the last one has more sheltered spaces and a variety of leisure activities addressed to children and adult users. However, the design solution to attend circulation and parking needs were the same in both projects. The asphalt surfaces for pedestrian and vehicle circulations extend as far as the parking area, without planted areas. The lack of shading by trees is visible in both projects; however, project B has more recently planted trees.

In both housing estates, the leisure and circulation spaces are faced to East. In this orientation, the asphalt receives direct solar radiation during all day, and circulation and parking areas do not have protection. Project A presents a fraction H/W = 0,75 and B fraction H/W = 1,30, with features of medium density. In those situations, the albedo coefficient of ground between buildings has an important influence on microclimatic conditions. The ground receives direct solar radiation and reflected radiation by walls (absorbance = 0,3). In the housing estate A, four out of seven buildings have asphalt surface between them. However, in project B there was plant covering that decrease the air temperature and the heat emission.

The East orientation of leisure spaces and circulation favour the incident wind (predominant direction wind to Londrina), and improve the air circulation in outdoor spaces of both case studies (fig. 3, 4, 5 and 6). The ventilation flux only has reduction in spaces between buildings. Project A presents straw mat effect “efeito esteira”, and B, air flux above the building “fluxo acima do nível dos edifícios”. This reduction of wind flux doesn’t influence the comfort conditions of outdoor spaces, but reduce the internal ventilation efficiency.

In both case studies, there was a lack of trees that make shade and protect the asphalt surface against direct solar radiation. Some trees were planted in project B, near the buildings. However, they are distant from circulation and leisure spaces. Thus, the shading areas provided by vegetation are null, yet, in both projects, and this leads users to look for protection in building shadows, as it occurred in case A, as well as in the shaded social spaces present on case B.

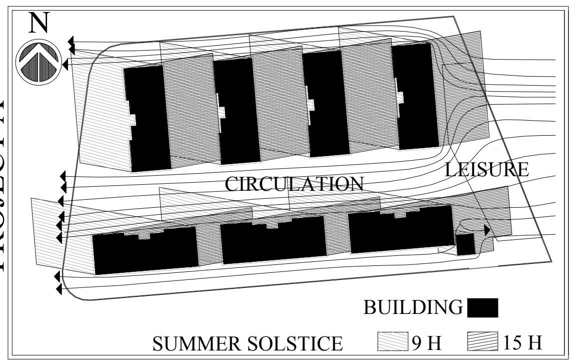

Figure 3: Shading and ventilation in the summer solstice day in house-building A.

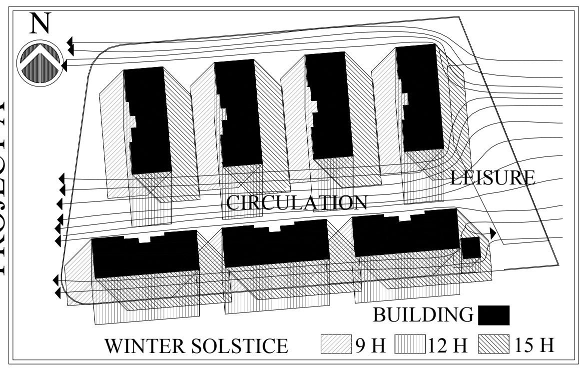

Figure 4: Shading and ventilation in the winter solstice day in house-building A.

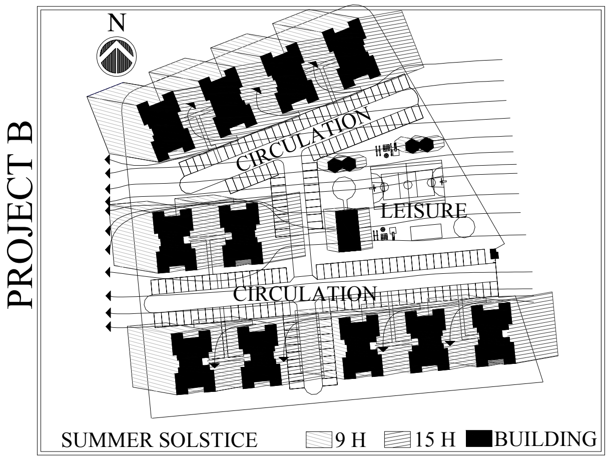

Figure 5: Shading and ventilation in the summer solstice day in house-building B.

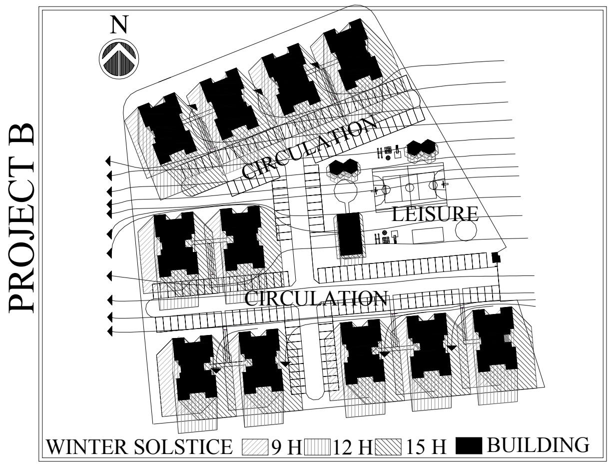

Figure 6: Shading and ventilation in the winter solstice day in house-building B.

The qualitative analysis showed that both projects have good ventilation conditions in outdoor spaces due to the configuration of buildings and outdoor spaces. The influence of geometry favours shading of spaces between buildings but does not guarantee solar protection on circulation areas. Precisely in the circulation, the surface is covered by asphalt and shading by trees is not available. It was not possible to identify if only the ventilation (efficient in both case studies) is enough to compensate for the lack of shading and to promote good conditions of thermal comfort.

The surveys applied to users provided a good understanding of thermal perception on outdoor spaces. Through the surveys it was identified that most of the 60 users have a sensation of a "very hot" outdoor space (fig. 7). Many of the users emphasized the lack of shading and vegetation as cause of discomfort conditions.

The good ventilation condition in outdoor spaces in both case studies is highly appreciated by users and it was pointed out as a positive feature by them (fig.8). The lack of vegetation is noticed too, but as a negative aspect (fig.9).

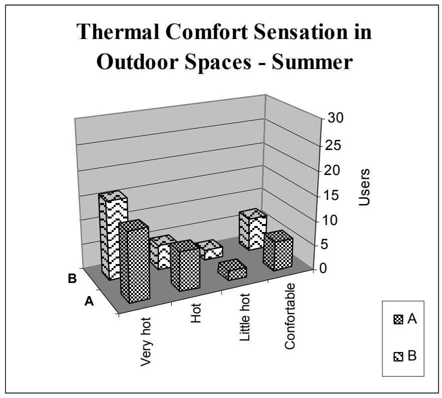

Figure 7: Thermal comfort sensation in the summer

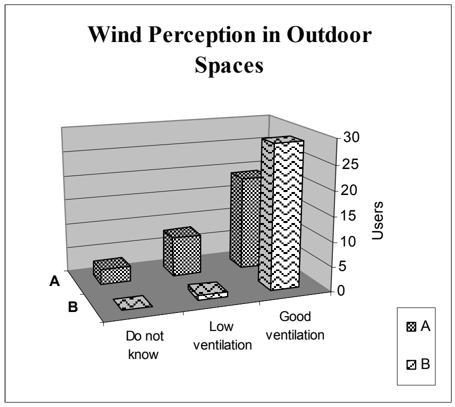

Figure 8: Wind perception by users

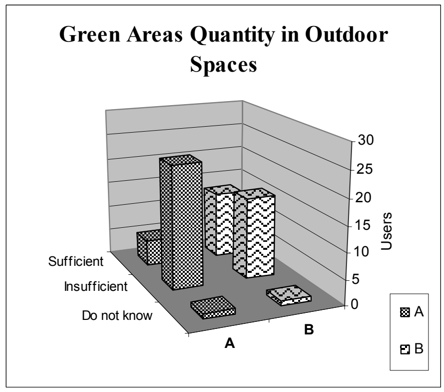

Figure 9: Vegetation perception by users

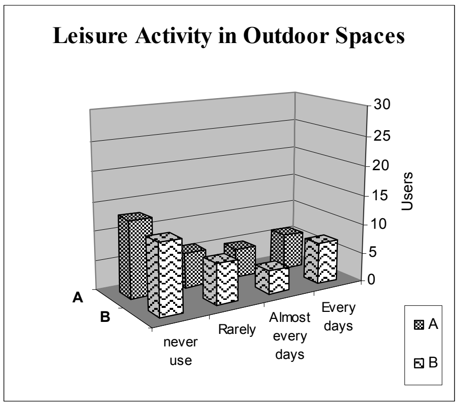

Figure 10: Frequency of leisure activity

The study also showed that, although project B presents a diversity of leisure activities, the majority of the users do not use the outdoor space (fig.10). It was observed too that the majority of the users did not have the habit to develop leisure activities in condominiums before moving to the housing estate B (fig.11). This information improves the understanding that offering children and adult leisure areas could not stimulate the use of these spaces, independently of thermal conditions.

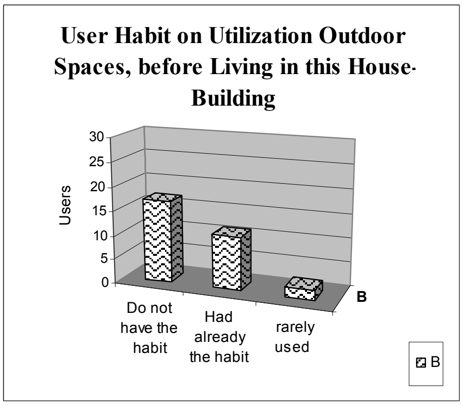

Figure 11: Users' habit on utilization outdoor spaces

Considering that most of the users do not spend time in outdoor spaces and, even so, have a perception of a very hot space, one can conclude that this discomfort sensation occurs when they are arriving or leaving the condominium, using pedestrian and vehicle circulation areas.

Through the survey, thermal comfort requisites were identified in both case studies. The vegetation was the requisite most mentioned by users followed by sheltered social spaces and than sheltered parking areas. The last one, the third most mentioned, is an important requisite, not only for protecting vehicles, but also because of the thermal discomfort inside them. A few users specified improvement measures for the general quality of the project. Most of the users were satisfied with outdoor spaces.

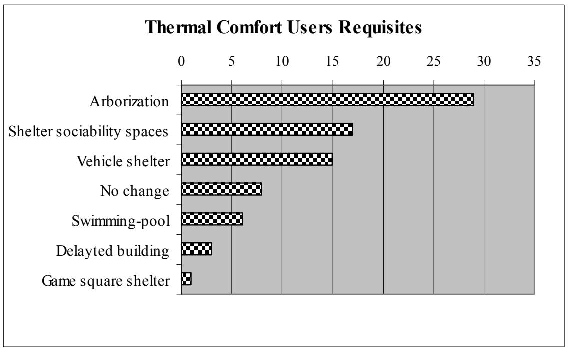

Figure 12: Thermal comfort requisites

Based on the requisites identified, the objective was to answer the research question: What are the guidelines that should be prioritized in low-income housing projects? The qualitative analysis combined with a human thermal perception study established the outdoor thermal comfort requisites. The definition of those requisites can support studies on design solutions, especially because that kind of project is mainly limited by production costs. Next, the prioritized requisites are described:

1 – Thermal protection of pedestrian external circulation: This requisite was not directly mentioned by users. However, the qualitative analysis showed that the lack of a thermal comfort in circulation areas forced pedestrians to take an alternative way over non-paved surfaces. As a consequence, most of the users have an outdoor sensation of a very hot space. Thus, the guideline for this situation is **the use of vegetal surfaces and trees**, in order to protect the pedestrian circulation against solar radiation and to reduce air temperature at this space.

2 – Shading social spaces: Second requisite more mentioned by users, principally in project A, where sheltered leisure spaces were not available. The guideline is to protect **leisure spaces with the use of trees with perennial leaf and long top.**

3 – Adequate use of materials of low thermal capacity around buildings. Materials of high thermal capacity must be avoided in the ground surface around buildings, mainly when fraction H/W is less than 1. Materials of high thermal capacity increase the air temperature, and generate a heated air mass that could enter into apartments in low stories through ventilation. Thus, the suggestion of design guideline is **to apply planted surfaces around buildings** in order to reduce the air temperature and reflection of solar radiation.

4 – Protect Vehicles. This requisite is important to users, because of the exposure of vehicles to solar radiation. The guideline based on cost limitation is to use **low absorption materials and trees to shade the vehicles**.

All of the design guidelines for low-income housing suggest the use of vegetation. Besides being a low cost solution, the vegetation has an excellent thermal conditioning effect, and can protect buildings and pedestrians, providing a microclimate with habitability conditions higher than empty spaces [3]. However, this solution was poorly implemented in the design development process in both case studies.

5. REQUISITES VALIDATION

The case selected to validate the requisites prioritized, was a low-income housing completed seven years ago and with consolidated vegetation. It consists of two-storey attached houses. This condominium was selected because it presents integration of three requisites prioritized in this paper. The pedestrian circulation area is protected by trees and planted surfaces, the parking is sheltered and the surface around the houses is covered by vegetation. However, the negative feature of this case is that the leisure area does not have shading by trees or other shelter, and some circulation areas have a lack of trees. Even so, this low-income housing was selected due to the lack of low-income housing condominium with the four requisites in the city of Londrina.

The same questions used in projects A and B were used for this case study. The results revealed that the unprotected leisure area, composed of a game court and a square influenced the users' thermal sensation. Most of the users judged outdoor space in hot days as a "very hot" space. The good ventilation, the vegetal surfaces on pedestrian circulation and the good amount of vegetation around the buildings, does not guarantee thermal comfort in outdoor spaces. An adequate protection of social sheltered spaces is necessary.

Figure 13: Image of pedestrian circulation of case study adopted for requisites validation

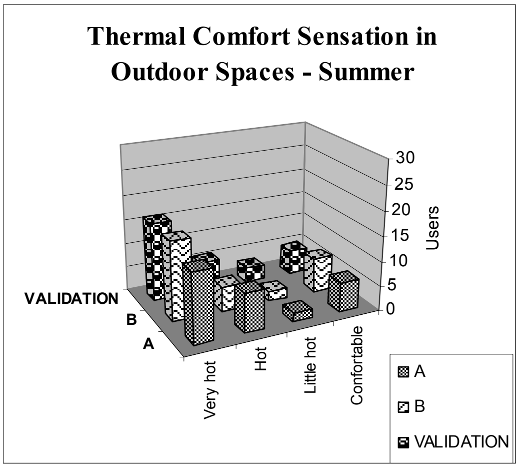

Figure 14: Thermal comfort sensation in the summer in the third case study

Although the majority of the users had answered that the outdoor space is very hot, the percentage of general satisfaction with all outdoor space is very good. Only four out of thirty users were not satisfied with outdoor spaces. This result demonstrates that the thermal comfort is not the only requisite for a general satisfaction of users in outdoor spaces.

6. CONCLUSION

Due to the hot and dry climate on intertropic regions, it is difficult to obtain a neutral thermal sensation of users in outdoor spaces. The air temperature is high in the summer months, mainly with solar position on zenith. However, it can be expected that the use of a vegetal protection, able to shade and protect most of the outdoor spaces for circulation and leisure would provide good comfort conditions, with a small percentage of dissatisfied people. But the use of the shelter provided by top of trees for the protection against solar radiation is not a usual practice in the design process.

Londrina's urban plan regulation [7] presents some environmental requisites, related to thermal comfort in outdoor spaces. Basically, that regulation presents three requisites: **1**˚: Avenues and ways should have trees in both sides and one tree for each lot, or at a minimum distance of 12 meters; **2**˚: Minimum of 20% of permeable area; **3**˚: Public's open spaces for leisure activities on outdoor spaces should amount 15% of total area inside a condominium. There is a lack of parameters related to green areas (trees and vegetated surfaces). Requisites linked to trees in leisure spaces and pedestrian and vehicle circulation areas should be better defined because they contribute to thermal comfort in outdoor spaces and to environmental sustainability of low-income housing.

The shading by trees can effectively provide thermal comfort in outdoor spaces, although ventilation has considerable influence on comfort. New environmental parameters must be clearly inserted in urban regulations of cities to benefit the microclimate regions and sustainability of cities.

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