PLEA 2018

VOLUME 1

34th International Conference on
Passive and Low Energy Architecture

Smart and Healthy
Within the Two-Degree Limit

Edited by:

Edward Ng, Square Fong, Chao Ren

PLEA 2018:

Smart and Healthy Within the Two-Degree Limit

Proceedings of the 34th International Conference on Passive and Low Energy Architecture;

Dec 10-12, 2018

Hong Kong, China

Organised by:

香港中文大學
The Chinese University of Hong Kong

INSTITUTE OF Future Cities

香港中文大學環境、能源及可持續發展研究所
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School of Architecture
The Chinese University of Hong Kong
AIT Building
Shatin, New Territories
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Electronic version as:
ISBN: 978-962-8272-35-8

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Design and practice are essential in implementation, while education and training stimulate innovation and empower professionals and laymen alike. With the theme "Smart and Healthy within the 2-degree Limit", the conference strives to address the different facets of smart and healthy living and aims to bring together designers, academics, researchers, students, and professionals in the building industry in the pursuit of a better and more sustainable urban and built environment.

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SCIENCE AND TECHNOLOGY

Vegetation as a Potential Tool for Improving Thermal Comfort and Exposure to Solar Radiation in the Streets of Quito

Comparative analysis of two streets in the center of the city

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ABSTRACT: Generating walkable cities is a major stake for urban areas and the transformation of public open spaces, as streets, is a key process for it. Solar radiation exposure may be an important parameter for comfort of public spaces users. In the case of Quito, radiation levels are so high all years long this parameter is a strong health issue. While street refurbishment based on pedestrians and bikers' requirements is still not a common practice in Ecuador, the present work proposes an approach of doing so based on simulating with ENVIMET two similar streets of Quito's centre against thermal comfort and hence indirectly radiation exposure, one being highly vegetated and the other not. Simulations evaluate the energy exchange between street components considering their thermal characteristics, indicating the potential satisfaction level of pedestrians. The influence of street vegetation, especially the presence of large covering trees, is demonstrated as being strong. It allowed to propose an improvement process for the comfort deficient street, thus offering a potential larger solution for Quito's streets configuration.
KEYWORDS: Street, Comfort, Heat island, Solar radiation, Vegetation

1. INTRODUCTION

Transportation in Quito is insured at 70% by public transport and the first metro line of the city is currently in construction. Its opening in late 2019 should further increase the level of public transport in the mobility panel of the city, also increasing the number of pedestrians in the streets reaching the bus, trolley or metro stations.

Quito is facing a strong sunny period each day, almost all year long, with one of the highest UV radiation level for a city in the world [1] due to its altitude (2800m a.s.l.) and localization on the Equator. The World Health Organization indicates an ultraviolet index of 11 as maximum tolerable limit for human beings [2]. A study [3] realized between 2009 and 2011 in Quito by the Secretaria de Territorio, Habitat y Vivienda showed this level is reached in the city more than 45% of the year, especially at mid-day. Such phenomenon should be further increased by climate change in coming years [4].

Quality of life and health are affected, and this situation can also represent a strong barrier to the development in the city of alternative open street mobility solutions like biking or walking where the exposition to climatic conditions is higher. Against this strong climate, the city did not develop any protection strategy and most of the streets lacks shading devices. As measured within the Treepedia Initiative carried out by the MIT Senseable LAB in 2015 [5,6] the city of Quito has an average green cover of 10,8% which is among the lowest of the 27 other international cities evaluated in this work.

Urban heat island effect has already been measured in Quito [7], and although it is not traduced by extreme temperatures for residents, it often means uncomfortable conditions at certain time of the day and dangerous exposure to extreme UV levels.

Natural conditions in Quito could afford much better vegetative coverage as the local permanently temperate climate is particularly propitious to plants development. Street tree planting and gardening buildings front spaces might be an interesting technique to be applied in Quito to generate comfortable public space conditions. Few streets in Quito already have an interesting highly vegetated configuration, most of them corresponding to the period of the beginning of the expansion of city outside the historical center (first half of the 20th century) and in areas greatly influenced by European architecture like the La Mariscal district [8].

Hence the present research is focused on assessing in this district the potential of vegetation as a tool to prevent outside comfort issues and radiation exposure.

2. EXPERIMENTATION

The La Mariscal district is a central area of Quito for its location and for its importance in terms of touristic and economic activities. It is also a key transport hub and hence a strategic place to improve smooth mobility patterns in the city.

Land use in the district is diverse as it includes public equipments, residences, commercial areas, hotels, health establishments and schools. As shown in Figure 1, construction profile is also quite diverse with highest buildings reaching 20 floors (80m high), buildings in the main streets being 16 floors high as an average and buildings in secondary streets, representing 82% of the constructed lots, being 3 to 6 floors high. For its representativeness of the district, but also of the whole city, the present study focuses on this last typology.

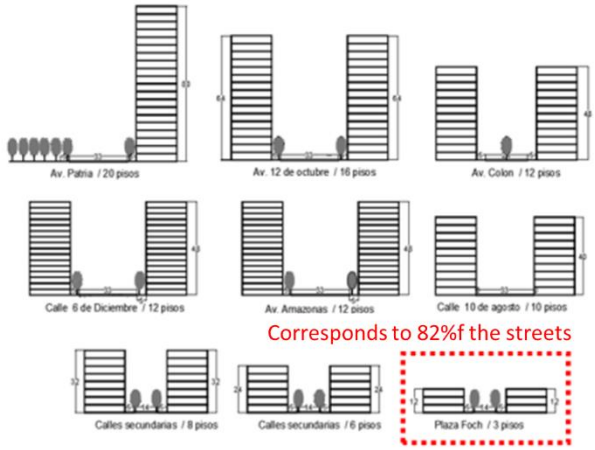

Figure 1: Building height and streets' profiles in the La Mariscal district in Quito

Further to an extended street configuration analysis in the district, comparing streets in terms of architectural configuration and presence of vegetation, the present study focused on analyzing two parallel streets of this same district showing similar characteristics in terms of buildings and size but having a different vegetal configuration. This district has a lot typology repeated in multiple areas, and this lot is very characteristics of the neighborhood.

Figure 2: Pictures of Lizardo Garcia Street (left) and Juan Rodriguez Street (right) in the district of La Mariscal in Quito

The first street is Calle Juan Rodriguez, where a regular tree coverage (sycamore tree - Platanus acerifolia) on the public sidewalk produces large areas of shade throughout the day and increases the relative humidity of the environment preventing excessive evaporation. Although it is considered as an exotic species in Quito, this type of tree can grow up to 20 m high and live 300 years in the city. The second street is Calle Lizardo Garcia, just next to Calle Juan Rodriguez and with a similar size, proportion, orientation, buildings' scale and street width. This second street has however suffered from important modifications on the type of buildings (flat roof modern buildings have replaced half of the existing large houses), the use of vegetation for the front garden often replaced by asphalted parking lots, the street pavement was modified and above all the tree covering has diminished to almost zero has shown in Figure 2.

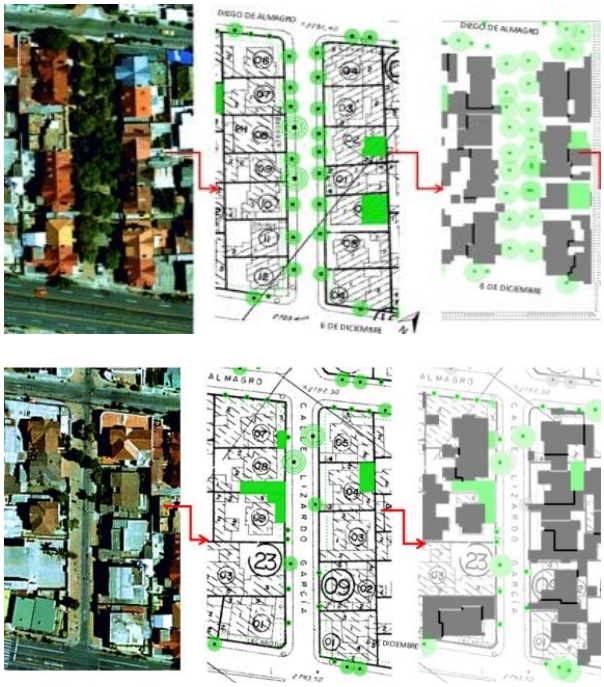

Figure 3: ENVI_met modelling of Juan Rodriguez (a) and Lizardo Garcia (b) including streets, buildings, vegetation covers pavement surface and roads. From aerial photo to 3D model process

As shown in Figure 3, we used the ENVI-met 4.2 simulation software, which is a tool that allows to model the urban structure and to analyse the microclimates and their physical foundations in a holistic way. ENVI-met was used to simulate the two streets in similar conditions, both in winter and summer seasons, with the objective to obtain the comfort potential and the useful hours of the streets in comfortable conditions, through Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indexes, as defined in ISO 7730 [9].
The modeling is based on a 40m x 100m x 35m high 3D net applied on each street with a 1,2m resolution. It composes a complete lot integrating constructions from both sides of each street and going from the Avenida 6 de Diciembre to the Calle Diego de Almagro. Although the climatic conditions are stable along the year in Quito there are some differences between the northern hemisphere summer period and the rest of the year. We focus in this paper on the results obtained for the warmer season – from June to august

- at the warmest hours of the day – between 11AM and 2PM.

3. RESULTS

Figure 4 presents the simulations results obtained for the Lizardo Garcia Street in the warm season at the warmest moment of the day. Overall temperatures are not reaching extreme values but go beyond comfortable conditions. The whole street is exposed to the same level of heat and the few trees planted in the northern part of the street are not enough to balance this situation.

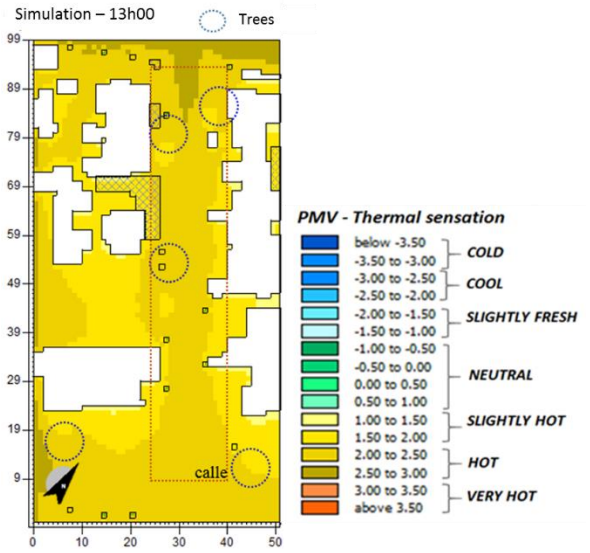

Figure 4: PMV thermal sensation simulated with ENVI-met in the Lizardo Garcia Street (Quito) during the warm period (August 2016)

A graphical representation of the average comfort values in the street among the day is presented in Figure 5. It appears clearly that the heat peak at mid-day generates an important discomfort with up to 93% in the PPV evaluation. This peak, beyond "neutral" thermal conditions as shown in Figure 5 b, last 6h20 in the case of the Lizardo Garcia street. It gets more severe from 12AM to 2PM where it reaches the level "hot" during 2h03. Hence the street cannot be a comfortable place for pedestrians or cyclist for most of the useful time of the day. The comfortable "neutral" period lasts 3h50 in this case, representing only 24% of the useful day (i.e. as night starts at 6h30 PM every day in Quito).

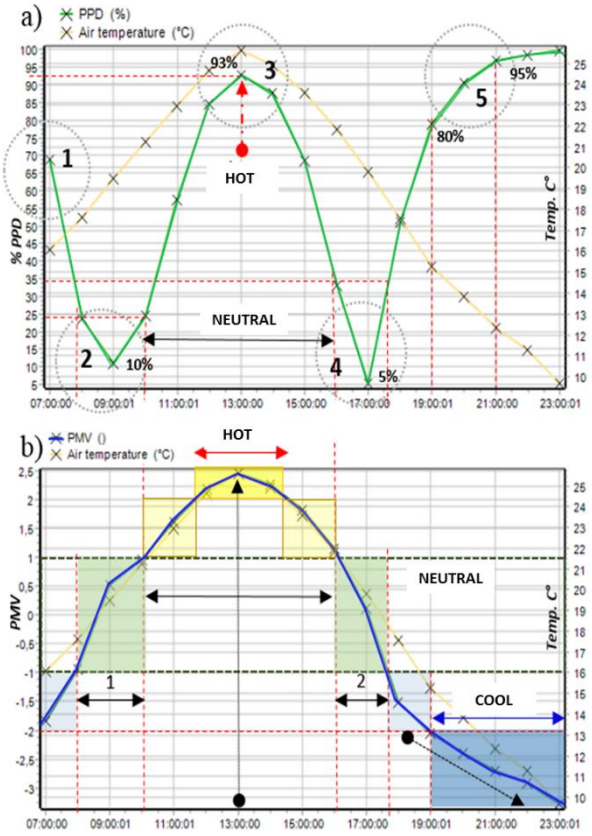

Figure 5: Thermal comfort conditions among the day evaluated from the ENVI-met simulation of Lizardo Garcia Street during the warm period (August 2016)

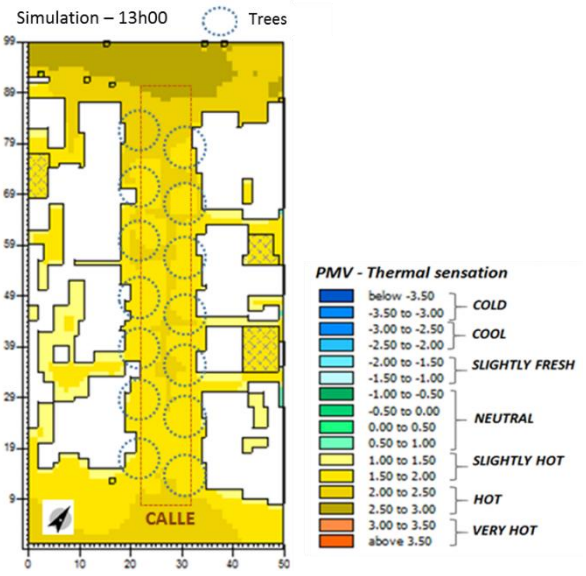

Figure 6: PMV thermal sensation simulated with ENVI-met in the Juan Rodríguez Street during the warm period (August 2016)

Similar analysis was realized for the same conditions of the same day in the case of the Juan Rodriguez street, as shown in Figure 6. At the warmest time of the day, the thermal sensation is "slightly hot" in most parts of the street. Simulation shows that in the center of the

street, where the crown and foliage of the trees do not generate optimum shade coverage, they produce changes in thermal sensation indexes compare to the public sidewalk where the shadow zone generates greater coverage and trees prevent the pavement to be hot. Although this is not a crucial issue as the central axe of the street is not often used by pedestrians and cyclists.

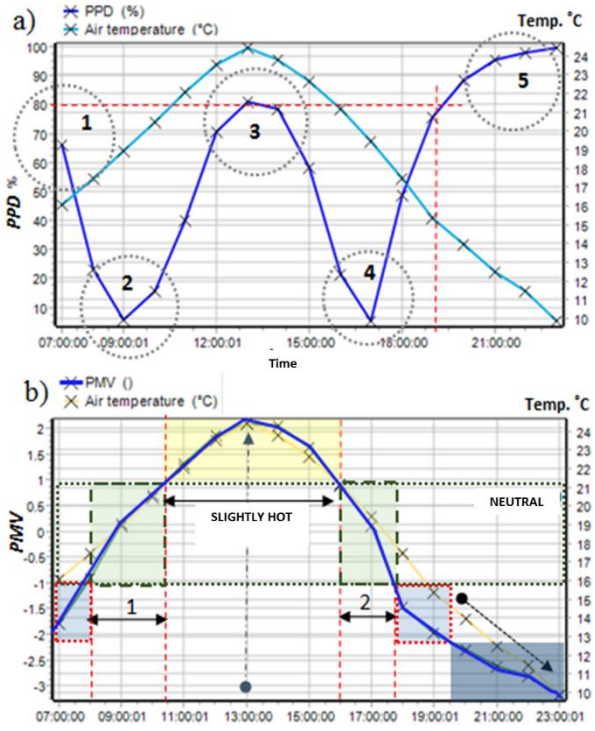

Figure 7: Thermal comfort conditions among the day evaluated from the ENVI-met simulation of Juan Rodriguez Street during the warm period (August 2016)

We can observe on the graph in Figure 7 that the level of dissatisfaction potential (PPD) rises at mid-day but does not reach so high level as it does in Lizardo Garcia Street. PMV evaluation over the day does not reach the "hot" level in this case. The thermal condition is "neutral" during most of the day (30,4% of the useful day, i.e. 4h51min), except in the early morning where it is "slightly cold" and between 11 AM and 4 PM where it is "slightly hot" (i.e. lower than 26°C).

4. DISCUSSION

These values demonstrate a clear difference as for thermal conditions for the two neighbor streets during the same day. Vegetation, being the principal difference factor between them, allows an opportune and efficient protection against solar radiation and local overheating. The use of trees with a high covering potential like sycamore trees proved to be an efficient tool for insuring pedestrian comfort and supporting soft mobility in Quito. Other species may insure similar effect while being more representative of the local flora. Native trees like the "algarrobo" (*Mimosa Quitensis*) or the "arrayan de Quito" (*Myrcianthes Hallii*), both declared as "emblematic specie of the city of Quito" could also insure similar effect while preserving and showing the genuine local nature within the urban area.

Based on these results an improvement strategy was defined for a potential refurbishment plan of the Lizardo Garcia Street (Table 1).

Table 1: Street improvement measures evaluated against feasibility and impact factors

FACTORS	Viability Yes = 2 Limited = 1 No = 0	Cost Low = 3 Medium = 2 High = 1	Implementation time 6 - 12 months = 3 1 - 2 years = 2 3 - 5 years = 1 5 - 10 years = 0	Impact on urban space quality From 1 to 5	Impact on thermal comfort From1 to 5	Global evaluation
Change of pavement material	1	1	1	1	3	7
Tree planting (covering trees)	2	3	3	3	4	15
Street pedestrianisation (limited access to autos)	2	1	2	4	1	10
Introducing vegetation bands in the street and in private front gardens	2	3	2	4	3	14
Intoducing water based components (rain water retention basins for example)	2	2	2	3	3	12
Generating more compact urban tissue	0	1	0	2	3	6
Eliminating massive and closed private-public separations	2	3	2	2	3	12

Considering factors of viability, cost, implementation time and impact potential, a set of measures was analyzed for improving thermal comfort and generating further impact on urban space quality. Assessment was realized with a group of expert using qualitative values for each measure/factor. As shown in Table 1 tree planting comes as one of the most pertinent option for street improvement in the present context. It can be combined with the other solutions judged as the most pertinent, i.e. introducing low vegetation in public and private areas, introducing water based elements and eliminating/reducing separation between private and public areas. Such pool of simple nature-based solutions would give a complete added value on urban quality and comfort in street of Quito.

5. CONCLUSION

The present study focused on the impact generated by two different street configurations in the case of Quito, the main difference being in the level of vegetation covering. For this purpose, two neighbor and similar streets, one vegetated and the other almost not, were analyzed using the ENVI-met simulation tool aiming at evaluating the outdoor comfort indexes in both cases. It demonstrated the strong impact of vegetation with 20% comfort in the case of the vegetated street. As mentioned earlier the natural context in Quito would allow quite easily to implement much more vegetation in the streets than what they have today, allowing a higher quality of life and insuring better protection for pedestrians.

Climatic data used in the present study are statistical data from past years measures realized in the available meteorological stations located in the city and solar radiation levels were calculated by the ENVI-met solution. Simulation data would gain in value if it could be compared to real measures. Hence a future study will complete the presented results with on-site measurements in both streets, on a representative time frame.

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