387: Improving outdoor thermal comfort in warm-humid Guayaquil, Ecuador through urban design

Johansson E.[1]*, Yahia M. W.[2]

Housing Development & Management, Lund University, Sweden[1]*
erik.johansson@hdm.lth.se
Housing Development & Management, Lund University, Sweden[2]

Abstract

Many tropical cities suffer from increasingly higher temperatures due to both global and urban warming. Often the thermal conditions are worsened by poor urban design including lack of vegetation and shade in general. This paper deals with the outdoor thermal comfort in a newly built residential low and middle-income area in the warm-humid city of Guayaquil, Ecuador. The area has low-rise buildings (one or two storeys) with fairly wide streets and is practically devoid of vegetation. The aim of this study, which was based on field measurements and simulations, was to study to what extent thermal conditions could be improved through modifications of the urban design. A parametric study was performed with the numerical model ENVI-met in which the influence of parameters such as building height, shading devices and vegetation as well as surface colours was simulated. The measurements showed that the thermal conditions are very poor in general and far above normal thermal comfort limits, especially in the afternoon when the physiologically equivalent temperature (PET) reaches above 40°C. The simulations showed that the outdoor thermal conditions could be greatly improved by adding one or two storeys and/or by providing shading through trees or any type of horizontal shading devices. Such improvements led to a decrease of PET of up to 10°C. The results in this study give advice for a climate-conscious design to urban planners and designers in Guayaquil.

Keywords: Climate-conscious design, Computer simulations, Guayaquil, Microclimate measurements, Outdoor thermal comfort, Urban design

1. Introduction

Many tropical cities suffer from increasingly higher temperatures due to both global and urban warming. This has adverse effects on health and well-being of urban dwellers. Studies in several warm-humid countries have shown that the outdoor environment is very uncomfortable during daytime, especially between 11:00 and 16:00, e.g. [1,2,3,4,5]. Often, the thermal conditions are worsened by poor urban design including lack of vegetation and shade in general [2,3,5].

Fig. 1. Typical street in the housing area Mucho Lote, Guayaquil.

This paper deals with the microclimate and outdoor thermal comfort in Mucho Lote, a newly built residential low and middle-income area in the warm-humid city of Guayaquil, Ecuador. The area, which has about 14,000 plots, all of the size 6 m x 12 m, has low-rise buildings (one or two storeys), see Fig. 1. The distance between buildings vary between 8 and 20 m and the area is practically devoid of vegetation. The plots are built with terraced houses leaving a 2 m wide strip in front of the houses and a 1 m wide strip behind the houses resulting in a distance of only 2 m between the rears of the houses.

The aim of this study, which was based on field measurements and simulations, was to study to what extent the microclimate could be improved through modifications of the urban design.

2. The climate of Guayaquil

Guayaquil is the largest city of Ecuador with about 2.4 million inhabitants. The city is situated at sea level near the equator at latitude 2.11°S and longitude 79.53°W.

As the rest of the coastal zone of Ecuador, Guayaquil has a warm humid climate. Precipitation, however, is limited to the period December to April. Nevertheless, the humidity remains high all year round due to the proximity to the Pacific Ocean. The climate is very stable

over the year with daily mean maximum temperatures of 28–30°C and minimum mean temperatures of 21–24°C (the higher values occur during the rainy season). The daily mean relative humidity is around 70% during the dry season and 75% during the wet season. See Fig. 2. The wind speeds are low, especially during the rainy season; monthly averages range from 1.5 to 3.2 m/s. The wind speed in urban areas is even lower. The prevailing wind direction is SSW.
Thermal comfort is poor due to a combination of high temperatures, high humidity and low wind speeds. The situation is worsened by the solar radiation; in spite of a high amount of cloud cover there are periods of clear and partly cloudy skies, even during the rainy period. The rainy season has the worst thermal conditions since both temperatures and humidity are higher.

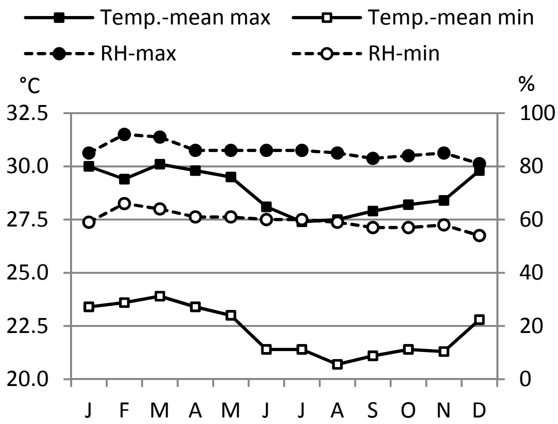

Fig. 2. Climate of Guayaquil.[4]

3. Methods

A combination of microclimatic field measurements and computer simulations was used.

3.1 Field measurements

The field measurements took place sometime between 13:30 and 15:30, i.e. during the warmest period of the day, and last about one hour. Two measurement campaigns took place during the dry season (June, 2009) and one during the wet season (March 2010). During the measurements the weather varied from clear to partly cloudy and overcast.
Four micrometeorological variables that affect thermal comfort were measured: air temperature (T_a), relative humidity (RH), globe temperature (T_g) and wind speed (V_a). The type of sensors and their accuracy are shown in Table 1. The sensors were connected to a data logger to which 1-minute averages was sampled.
The measurements were taken at the height of 1.1 m, i.e. at body height. The temperature and relative humidity sensor was covered by a white, naturally ventilated radiation shield. The globe thermometer, which consisted of a flat grey painted table tennis ball, was exposed to solar radiation during the measurements.

Table 1: Measurement equipment and its accuracy. (Ta = air temperature; Tg = globe temperature; RH = relative humidity; Va = wind speed.)

Variable	Sensor	Accuracy
Ta	Rotronic Hydroclip S3	±0.3°C
RH	Rotronic Hydroclip S3	±1.5% RH
Tg	AMR Pt100 PK 24	±0.3°C
Va	Gill windsonic anemom.	±2% @ 12 m/s

The mean radiant temperature (MRT) – which considers both short-wave and long-wave radiation and represents the weighted average temperature of an imaginary enclosure that gives the same radiation as the complex urban environment – was derived from the globe temperature and the wind speed as described in [4].

3.2 Simulations

A parametric study was performed with the numerical model ENVI-met in which the influence of parameters such as building height, shading through covered walkways and vegetation as well as surface colours was simulated. ENVI-met 3.1 [6], which uses a 3D computational fluid dynamics and energy balance model, has a high spatial and temporal resolution enabling a detailed study of how the microclimate varies within the studied space over time. One of the limitations with the model is however that the thermal mass of the buildings is not considered.

3.2.1 Simulated site

A part of the Mucho Lote neighbourhood consisting of about 4,500 m² was studied, see Fig. 3. The area consisted of a street crossing of a major 10 m wide road (including pavements) aligned by two storey (7 m high) buildings and a narrower 8 m wide road aligned by one storey (4 m high buildings). The terraced buildings were 6 m x 10 m; the distance from the back of the buildings to the back of the neighbouring buildings was 2 m.

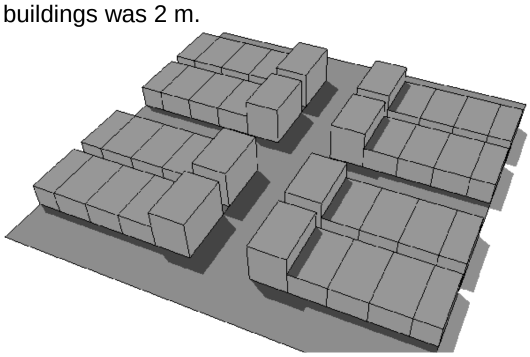

Fig. 3. SketchUp perspective view showing the simulation model used in ENVI-met.

3.2.2 Parametric study

In the first stage, ENVI-met simulations were run for the base case (actual situation) plus a number of cases with modified parameters. The sky conditions were assumed to be fairly cloudy.

General input data for all the simulated cases as well as data for the existing situation (base case) are shown in Table 2.

The cases of the parametric study are shown in Table 3. The modified parameters were surface albedo, building height, orientation, horizontal shading devices over the pavements and shading trees along the street. Based on the results of the parametric study, further simulations were performed in which positive results were combined, see Table 4.

Table 2: General input data for the simulations.

Wind speed in 10 m above ground [m/s]	1.5
Wind direction [°] (0: N, 90: E, 180: S, 270: W)	215
Initial temperature of the atmosphere [K]	301
Specific humidity at 2500 m [g water/kg air]	18
Relative humidity at 2 m [%]	90
Fraction of low/medium/high clouds [octas]	2/2/2
Factor of shortwave adjustment (0.5 to 1.5)	0.9
Albedo of the walls/roofs	0.5/0.3
Albedo of the ground: asphalt/pavement	0.2/0.4
Orientation [°] (0: N, 90: E, 180: S, 270: W)	0

Table 3: The cases of the parametric study.

Case	Parameters
1.1	Albedo walls = 0.2, albedo ground = 0.2
1.2	Albedo walls = 0.5, albedo ground = 0.4
1.3	Albedo walls = 0.8, albedo ground = 0.6
2.1	Adding one storey (3 m) to the existing buildings
2.2	Adding two storeys (6 m) to the existing buildings
3.1	Site orientation 45°
3.2	Site orientation 90°
4.1	Adding external roofs of two meters width to the buildings at both sides of the streets
4.2	Adding rows of very dense trees of 10 meters height to the both sides of the streets

Table 4: Combined simulation cases.

Case	Parameters
A	Horizontal shading devices plus two storeys (6 m) higher buildings
B	Street trees plus two storeys (6 m) higher buildings
C	Horizontal shading devices plus one storey (3 m) higher buildings
D	Street trees plus one storey (3 m) higher buildings

3.3 Calculation of thermal comfort

In this study, thermal comfort was assessed using the physiologically equivalent temperature (PET). The PET, which is based on a steady-state heat balance equation of the human body, is defined as the air temperature at which the energy balance for typical indoor conditions is balanced with the same mean skin temperature and sweat rate as calculated for the complex outdoor conditions [7]. The PET index has been used widely in recent research in outdoor thermal comfort, e.g. [2,4,5,7]. It was calculated using the PC application RayMan [8]. The suggested thermal comfort zone of the PET index, applicable to Western Europe, is 18–23°C [4,7]. A recent study however showed that the thermal comfort zone for people who are adapted to local thermal conditions of warm-humid Taiwan was considerably higher: 21–29°C [7].

4. Results

4.1 Measurements

The measurements showed that the thermal conditions are very poor in general and far above normal thermal comfort limits, especially in the afternoon. Fig. 5 shows the variation of the physiologically equivalent temperature (PET) during an afternoon in June; PET reaches above 40°C during clear and partly cloudy sky conditions.

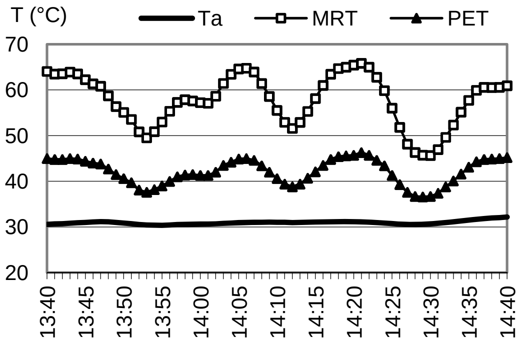

Fig. 5. Measured air temperature (Ta), mean radiant temperature (MRT) and physiological equivalent temperature (PET) in Mucho Lote, Guayaquil on 25 June 2009. Sky conditions varied from clear to partly cloudy to overcast.

4.2 Simulations

The simulated maximum air temperature (23 June at 15:00 h) was about 31°C, which agrees well with the measurements (Fig. 5). The calculated PETs – of the base case at 13:00 and 15:00 hours – are shown in Fig. 6. The results show PET values of about 40°C in places exposed to solar radiation in the afternoon which agrees well with the measurements.

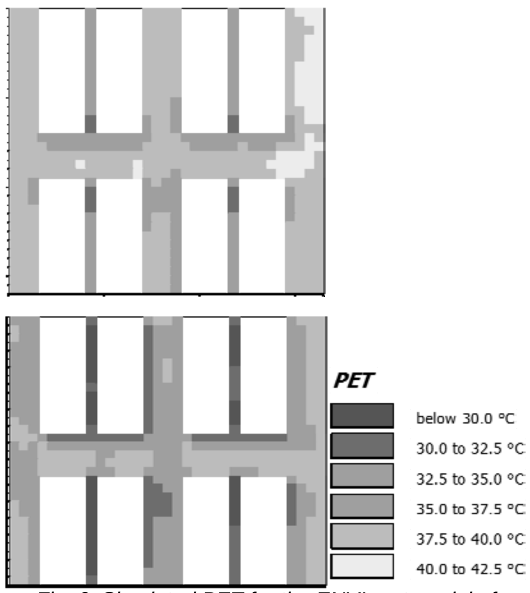

Fig. 6. Simulated PET for the ENVI-met model of existing situation in Mucho Lote (base case) at 13:00 (above) and 15:00 hours (below).

The modifications that have positive effects on the microclimate (lower PET) were increased building height (the higher the better) (Fig. 7), horizontal shading of pavements and shading trees along the street (Fig. 8). Conversely, increasing the albedo had a negative effect (higher PETs). Decreasing the albedo as well as changing the orientation of the area, which affects solar radiation and wind speed, had negligible effect. It should be noted that an increase in building height has only limited effect around noon when the solar altitude has its maximum (Fig. 7). To improve shade at this hour of the day it is thus necessary to use some kind of horizontal shading. Fig. 8 shows the combined effect of one storey higher buildings and shading trees along the streets and Fig. 9 shows the combined effect of two storey higher buildings and horizontal shading devices over the pavements.

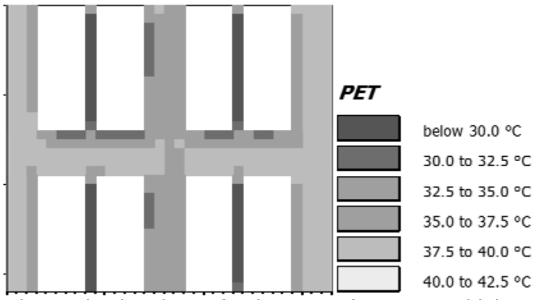

Fig. 7. Simulated PET for the case of one storey higher buildings at 13:00 hours.

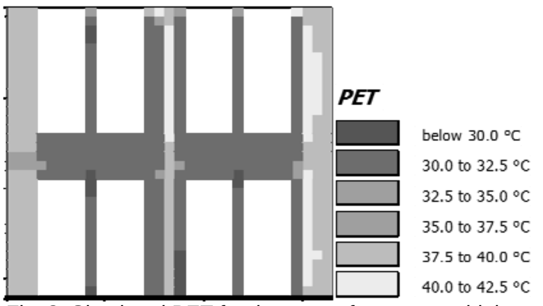

Fig. 8. Simulated PET for the case of one storey higher buildings and shading trees along the streets at 13:00 hours.

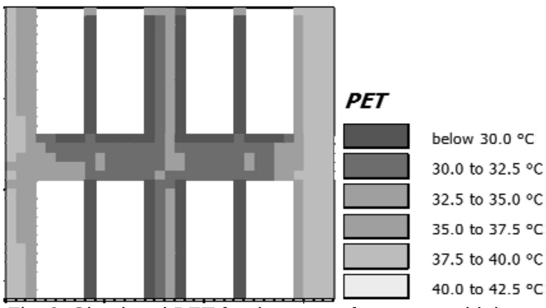

Fig. 9. Simulated PET for the case of two storey higher buildings and shading devices above the pavements at 13:00 hours.

5. Discussion and conclusions

The simulations showed that the microclimate and consequently the outdoor thermal comfort could be greatly improved by adding one or two storeys and/or by providing shading through trees or any type of horizontal shading devices. These improvements led to a decrease of PET of up to 10°C.

It should be noted however that the use of terraced buildings, and the fact that the rows of buildings are very close to each other, makes it difficult to achieve cross ventilation of the buildings which has adverse effects on the indoor climate. It would therefore have been better to use detached buildings.

Future urban design in the climate of Guayaquil should preferably swift from low-rise (one to two storeys) to medium-rise (three to five storeys) detached buildings in order to improve both shade and ventilation in urban public space as well as ventilation of buildings. Moreover architectural and urban design elements such as arcades, overhead shading devices and shading trees should be included to achieve shade around solar noon.

6. Acknowledgements

This research was supported by the Swedish International Development Cooperation Agency (Sida). The authors are grateful to Ms. Soheila Bahrami who performed the ENVI-met simulations.

7. References

1. Emmanuel, R. and E. Johansson, (2006). Influence of urban morphology and sea breeze on hot humid microclimate: the case of Colombo, Sri Lanka, *Climate Research*, 30: p. 189–200.
2. Johansson, E and R. Emmanuel, (2006). The influence of urban design on outdoor thermal comfort in the hot, humid city of Colombo, Sri Lanka, *Int. J. Biometeorol.*, 51: p. 119-33.
3. Emmanuel, R., H. Rosenlund and E. Johansson, (2007). Urban shading – a design option for the tropics? A study in Colombo, Sri Lanka, *Int. J. Climatol.*, 27: p. 1995-2004.
4. Johansson E. and M.W. Yahia, (2011). Subjective thermal comfort in urban spaces in the warm-humid city of Guayaquil, Ecuador. In *Architecture and Sustainable Development – 27th PLEA Conference*, Louvain-la-Neuve, July 13-15, Vol. I, p. 577–582
5. Ng, E., L. Chen, Y. Wang and C. Yuan, (2012). A study on the cooling effects of greening in a high-density city: An experience from Hong Kong, *Building and Environment*, 47: p. 256-271
6. ENVI-met 3.1, available: http://www.envi-met.com
7. Lin, T.-P., (2009). Thermal perception, adaptation and attendance in a public square in hot and humid regions, *Building and Environment*, 44: p. 2017-26
8. RayMan 1.2, available: http://www.urbanclimate.net/rayman/