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Green networks as a key of urban planning with thermal comfort and wellbeing

Dr Ornella Iuorio

University of Leeds

Leeds

LS2 9JT

United Kingdom

o.iuorio@leeds.ac.uk, +4407946346748

Dr Loyde A. Harbich

Graduate Program of Cities and Design, School of Architecture and Urbanism

Federal University of Goiás

Goiânia,

Brazil

loydeabreu@gmail.com

Abstract

This chapter discusses the interactions between vegetation and the urban environment to improve human thermal comfort, as well as guarantee the well-being of people. A network of green spaces can promote wellbeing benefits, including: recreation, healthy living, reducing flooding, improving air quality, cooling the urban environment, encourage-aging walking and cycling, and enhancing biodiversity and ecological resilience. During the decision-making process, urban planning and design cannot be based only on qualitative criteria, quantitative analyses of the benefits associated with green networks need to be considered at the various scales of the urban form. The aim of this chapter is to present quantitative tools that

can be used for the evaluation of urban thermal comfort at different scales of urban planning and design. The tools briefly described in this chapter consist in field measurements, field survey, analysis of real situations and future scenario analysis. In particular, Envi-Met model is employed for the detailed evaluation of future scenarios with case studies from Brazil and the United Kingdom. Not only do these case studies demonstrate how green networks are able to make urban spaces more attractive, improving human experience, but also how green networks can play a fundamental role in promoting thermal comfort in cities.

1. Introduction

Urban vegetation can improve the thermal, psychological and physiological comfort of the individuals (Oke, 1989; Santamouris, 2001). Today, fast urban population growth coupled with urban sprawl and reduction of green spaces tends to lead to dangerous modifications of urban climatic conditions, especially in Global South countries such as Brazil (Lombardo 1985). Tree shading reduces air temperatures (Akbari and Taha, 1992; Abreu-Harbich, Labaki, & Matzarakis, 2015), providing improvements to urban thermal comfort (Lin et al. 2010). Urban green networks regularly inserted in urban infrastructure is a good practice, not only for their cooling potential in pedestrian areas, but also for the control of longwave and shortwave radiations.

To employ green networks as key strategy for improving urban climate, promoting thermal comfort and quality of life, it is necessary to treat urban areas as green infrastructures (GI), where GI are intended as a network of protected land (green) and water bodies (blue) that supports a wide range of ecosystems services (Benedict and McMahon, 2006). For this to occur, urban planners need to consider the type and density of vegetation, their space distribution, water permeability, and green connections between public spaces.

Recent urban studies have begun to employ ecological rationality in planning cities and have therefore introduced techniques, methods and tools to integrate natural elements within the urban environment as part of the whole complex urban system. Climatic information can be analysed in various ways such as temperature and surface variation, wind and turbulence, energy balance (Ketterer, Matzarakis, 2014). For this, it is possible to configure computational patterns for wind tunnel assays or computational models such as Computational Fluid Dynamics (CFD). In the microclimatic studies, one of the most used computational models is ENVI-MET (Bruse & Fleer, 1998), because it is capable of analysing the interaction between soil, surface and atmosphere, and is based on the fluid mechanics. As well as models and computer simulation can be used in various studies to evaluate the benefits of green roofs in mitigating UHI, combined with urban design parameters as height of buildings, albedo, material typology, roughness, presence of trees, green walls and roofs (Song, Wang, 2015).

In the following sections we will discuss the impact of urban vegetation on combating effects of climate changes (section 2), focusing on the impact of trees on urban canyons and parks (section 3), and the effect of green walls at street level and on indoor spaces (section 4).

2. The Impact of Urban Vegetation On The City Climate

Urban design features, such as urban form, roughness, construction density, the shape of buildings, materials used on pavement and façades, are among the most important factors that can modify microclimate and influence urban climate. The differences in air temperature between city centers and their surrounding non-urban areas is called Urban Heat Island (UHI). This phenomenon is characterized by an increment in air temperature that can affect thermal comfort and the health status of people in urban locations, and it is mostly observed during the night. UHI is the most documented phenomenon of climate change and it is affecting significantly energy uses and quality of life in cities.

Urban vegetation contributes significantly to cooling our cities, conserving energy and providing solar protection to individual homes, while evapotranspiration can reduce urban temperatures. Vegetation and in particular trees also absorb sound and rainwater, filter pollutants, reduce air velocity, and stabilise the soil by preventing erosion. Evapotranspiration provided by trees, water bodies and urban agriculture (green roof, lawns) have a great potential to reduce urban and global temperatures. In additional, evapotranspiration contributes to create spaces with milder temperatures within towns. For instance, Paris introduced “oasis” to mitigate extreme temperatures (Lambert-Habib et al 2013). “Oasis effect” refers to the phenomenon of cooling effect caused by vegetation, due to crown shading and evapotranspiration cooling (Oke, 1989). Indeed, the combination of these strategies can reduce urban temperature by 0.5 to 4.0°C (Qiu et al., 2017).

Urban trees can reduce air temperature, increase air humidity, reduce wind speed, as well as air pollutants (Streiling and Matzarakis, 2003). In Brazil, it was observed that certain isolated trees species as *M. indica, C. pluviosa and L. glyptocarpa* can reduce air temperature of 7.4–17.5 ◦C from 10:00 AM and PET (Physiological Equivalent Temperature) of 12-16ºC (Abreu-Harbich, Labaki, & Matzarakis, 2015).

The tree canopy is a major component that contributes to microclimatic environments because it can attenuate solar radiation and control the wind speed (Steven, et al. 1986). Bueno-Bartholomei and Labaki (2003) observed that some tree species can reduce solar radiation up to 87%.

3. Green Walls And Roofs For The Mitigation of UHI

Vegetated surfaces are particularly appropriate to reduce surface and air temperatures in cities that are densely populated, and where it is difficult to integrate proper green public spaces. In these cases, the combination of trees, living green walls and green roofs are an appropriate strategy for reducing the negative effects of UHI and improve human thermal comfort.

Alexandri and Jones (2008) simulated the cooling effects of green roofs and green walls on the built environment in different climates and concluded that plants on the building envelope can be used to tackle the heat island effect. Green roofs add thermal resistance to the building, with consequent cooling effects of the building in summer months. The green roof layers, indeed, absorbs fewer solar radiations than the other types of roofs, with consequent monetary savings associated with cooling of the spaces under green roofs A study from the Japan revealed that green roofs can reduce the surface temperature from 30 °C TO 60 °C (Yang 2011).

Green walls are becoming popular in both warm and cold climates for multiple purposes such as aesthetic improvements, reduction of UHI effects and air quality improvement, among others. In the last decades, different technologies and species of plants have been implemented for the design of green walls.

In the summer months, green walls are particular effective in cooling interior spaces, in turn contributing to the reduction in the use of air conditioning (Kwong, Lam, & Hang, 2017). In Brazil, Matheus et al. (2016) observed that living green walls in borders can reduce 2 ºC of indoor air temperature and shoots structure improve wall thermal inertia. Morelli and Labaki (2014) observed that green façade in vine structures can reduce superficial temperatures around 0.5º C. In cold climates as in Berlin, façade greening contributes to a slightly reduction of heat stress of building façades (Jänicke et al 2015). These studies show that plants can thermo-regulate the superficial temperature of wall and improve indoor thermal comfort. At the same time, green walls can reduce heat gains and improve microclimate along pathways.

The potential of green roof and green walls to combat UHI and improve thermal comfort, is becoming well known, so that policies are starting to be implemented in many countries. For instance, in 2015, São Paulo municipality approved a law (city ordinance n. 55994) for the application of living green walls on external surfaces. One of the selected areas for implementation of green walls was near Presidente João Goulard Elevated Highway. Due to a lack of urban parks in the city centre, people use this area as an urban park during all day on Sundays and holidays when the highway is closed to car traffic. This highway is 3.5 kilometres long and was built in 1970 to connect the city centre to the west of the city and relieve traffic congestion in central São Paulo. Because of traffic noise, this highway is closed between 9:30am and 6:30pm every day, as well as during weekends. Field studies, undertaken before the implementation of green walls show that there is discomfort during all day with air temperature about 30.5º C and PET 45.6º C in the afternoon (Abreu-Harbich et al 2016), while new studies, undertaken in the same area, demonstrate that green walls can cool surface temperatures by up to 3 º C (Brocanelli 2017).

4. Impacts Of Trees in Urban Street Canyons And Parks

Promotion of green areas, street trees, green walls and roofs can mitigate the negative effects of UHI. Case studies from Brazil and the United Kingdom are discussed in this section to demonstrate the importance of tree shading and green areas in improving thermal comfort.

4.1 Brazilian case studies

To understand the effect of green spaces in mitigating UHI effects in tropical climates, two different cities with distinct climates were selected as study cases: Santos which is a tropical rainforest (23º 57' 39" S; 46º 20' 01" W; 2 m elevation), (Af; Kottek et al., 2006) and Campinas which is a subtropical climate (22◦48’57’’ S; 47◦03’33’’W; 640 m elevation), (Kottek et al 2006). Santos daily maximum temperatures (T_{max}) usually peaks in February with a mean of 40°C, and relative humidity (RH) around 75%-80%. In Campinas, daily maximum temperatures (T_{max}) usually peaks in December with a mean of 37°C, and relative humidity (RH) around 62%-77%.

Although Campinas has population greater than Santos, both cities have similar construction density in the central areas. Indeed, Santos has 1548.92 hab/km² and Campinas 1482.48 hab/km² (IBGE, 2017). Of these two cities, this study focused on areas of approximately 9 hectares, which are broadly rectangular in shape, and have similar density construction zones, same materials used on pavement and façades, proximity of green areas and streets with same orientation. In the study, high density construction zone are considered as areas with tall buildings, predominantly between 30 and 120m, and low-density zones as areas with low-rise buildings, with height up to 15m. High resolution digital images were used to classify land use and occupation in the following four classes: buildings, vegetation, asphalt paving and water. In particular, MultiSpec© software and the algorithm ECHO (Extraction and Classification of Homogeneous Objects) were used for the automatic classification. The digital images for the 4 analyzed area are shown in Figure 1, and the percentage of buildings, vegetation and asphalt paving are recorded in Table 1.

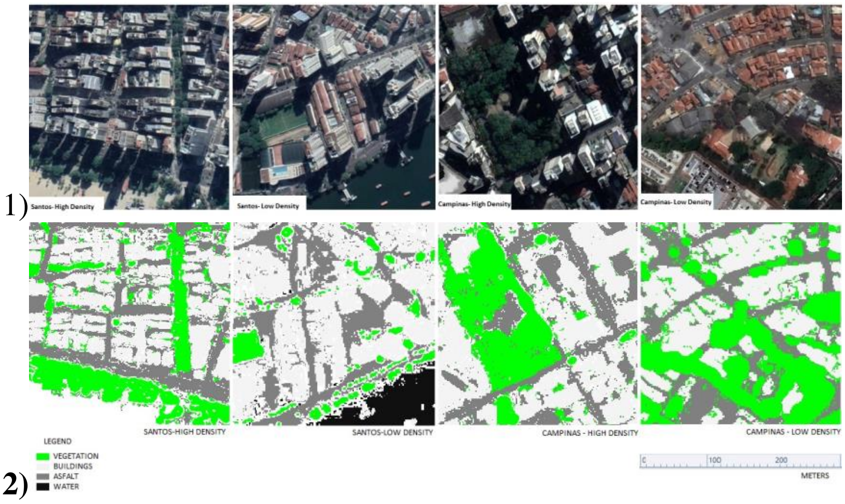


Figure 1. Aerial views of high and low density (1) and results of MultiSpec analysis (2) in Santos and Campinas, Brazil.

Study Cases	Building (%)	Grassland and tree (%)	Asphaltic surface (%)
1-High-Density (Santos)	28.4	21.5	14.5
2-Low-Density (Santos)	40.5	7.1	24.9
3-High-Density (Campinas)	43	25	24
4-Low-Density (Campinas)	51.9	8.78	12.1

Table 1. Results of area images analysis for study cases

Climate data as air temperature and relative humidity, was collected each 15 min by datalogger model test H174, during a week in summer period. Other climatic data as wind speed and solar radiation was obtained by Airport Station of Santos and Campinas. Thermal comfort in outdoor area as Predicted Mean Vote Index (PMV) , Physiological Equivalent Temperature (PET) and Mean Radiant Temperature (MRT) were calculated by RayManPro. In order to compare the results of the PMV with PET, this study considers as reference the framework defined by Matzarakis and Mayer (1996) and reported in Table 2.

Thermal Sensation	PMV (Fanger, 1972)	PET range for European (ºC PET) (Matzarakis and Mayer, 1996)	PET range for Taiwan (ºC PET) (Lin et al., 2010)	PET range for São Paulo (Monteiro and Allucci, 2009)
Very cold	- 3,5	<4	<14	
Cold	- 2,5	4-8	14-18	<
Cool	- 1,5	8-13	18-22	4-
Slightly cool	- 0,5	13-18	22-26	12-18
Comfortable	0	18-23	26-30	18-26
Slightly warm	0,5	23-29	30-34	26-31
Warm	1,5	29-35	34-38	31-
Hot	2,5	35-41	38-42	>43
Very hot	3,5	>41	>42	

Table 2. Thermal sensations and PET classes for Western/ Middle European classes, Taiwan and São Paulo

Location	**Case**	**T_a (°C)**		**RH (%)**		**MRT (°C)**	**PMV**	**PET (ºC)**
		max	**min**	**max**	**min**			
Santos	High Density	32.4	24	69	40.3	47.4	1.9	32
	Low Density	37.3	23.9	73.7	42.4	48.8	2.7	35.3
Campinas	High Density	32.6	20.7	93.6	29.5	46.7	1.4	30.3
	Low Density	37.8	19.3	98.4	27.7	48.1	2.2	33.2

Table 3. Results of T_a, MRT, PMV and PPD in study cases.

Table 3 present results of mean air temperature (T_a), Relative Humidity (RH), MRT, PMV and PET for the 4 analysed areas. Differences of mean daily air temperature (T_a) between high and low-density areas was 2,4 ºC in Santos, and 1,9 ºC in Campinas. Differences of mean daily of Relative Humidity (RH) was 3,4 % in Santos and 1,5% in Campinas. Results shows that low density areas have higher average air temperatures than higher density area. This demonstrates that although high density areas have higher buildings, hosting a larger number of occupants, the fact that the buildings occupy a small surface (28.4% in Santos, and 43% in Campinas) and that good part of the other surface is used for green spaces (21.5 % in Santos and 25% in Campinas), allows cooling effects to take place with consequent benefits in terms of human thermal comfort. Hence, the results show that greening can reduce UHI, even in areas of high density. Moreover, in low density areas thermal comfort could be improved by promotion of forestry. In terms of methodology, the rapid geoprocessing technique, used as analyses method for these case studies, provides a correlation between land uses and climatic variables, such as air temperature, relative humidity and wind speed. This analyses method can be adopted by urban design experts to understand and quantify the relation between green areas and thermal climate.

4.2 Leeds Case study

To understand the effect of green spaces as mitigation of UHI effects in cold climates, a numerical model of an area of Leeds, in North of England, West Yorkshire has been studied. The site (Figure 2) measures approximately 6.3ha and is broadly rectangular in shape. At the center of the site, there is a large green expanse of 3.6ha (St. George's Field), which is surrounded by a number of buildings mostly belonging to the University of Leeds. The buildings vary in height, construction period and architecture, while the streets are made up mostly of impermeable surfaces. Leeds belongs to an Oceanic climatic region, and it is characterized by having mild summers with moderate rainfall and cold winters, occasionally resulting in snow. Daily maximum temperatures (T_{max}) usually peak in July with a mean recording of 15.1°C between 1981-2010, with a relative humidity (RH) around 62%-90%.

ENVI-met (ENVIronmental-meteorology) (Huttner S & Bruse M, 2009) was selected as the analysis platform for this research project. This software is a three-dimensional (3D) non-hydrostatic model capable of reproducing microclimatic and physical behaviours in urban settings. ENVI-met previously have evaluated its performance against experimental data and confirmed its application with acceptable levels of accuracy (Kong, et al., 2016).

Figure 2. Case study: University of Leeds, with indication of the 2 measurement points.

Previous studies have demonstrated that the effects of UHI are worsened due to climate change (particularly, global warming) and are potentially mitigated with the presence of vegetation. To make an evaluation of these factors, 4 model circumstances were examined, as follows:

- Case 1: 2017 Base Case, describing the current condition
- Case 2: 2050 Base Case, where the present configuration is maintained, but an increase in temperature is considered (climate change effect).
- Case 3: 2017 Reduced Green Case, studies what would happen today if the green space would disappear (this allows to quantify the effect that green areas has today)

- Case 4: 2050 Reduced Green Case. This is the worst case scenario for UHI propagation. It considers that all vegetation is removed and climate change happens.

Table 4 summaries the 4 case scenarios and Table 5 indicates the meteorological input parameters.

Case	Year	Building coverage (%)	Grass-land and tree coverage (%)	Asphaltic surface coverage (%)
Case 1	2017	27	39	34
Case 2	2050	27	39	34
Case 3	2017	27	0	73
Case 4	2050	27	0	73

Table 4. The investigated 4 case scenarios.

	2017	2050
Wind speed at 10m height (m/s)	3.5	3.5
Wind direction	119.4	119.4
Specific Humidity at 2.5m (g/kg)	3.6	4.0
Ta (°C)	13.9	15.7
RH (%)	86.0	82.0

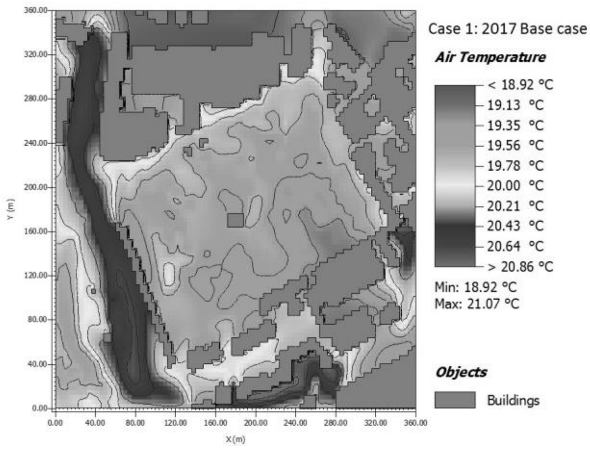
Table 5. Meteorological Input parameters

In the simulation, as for building materials, a predefined concrete option was used providing uniformity of façade and roof parameters across the simulated region. In the case of vegetation, a new grass of length 5cm was created for application to green spaces.

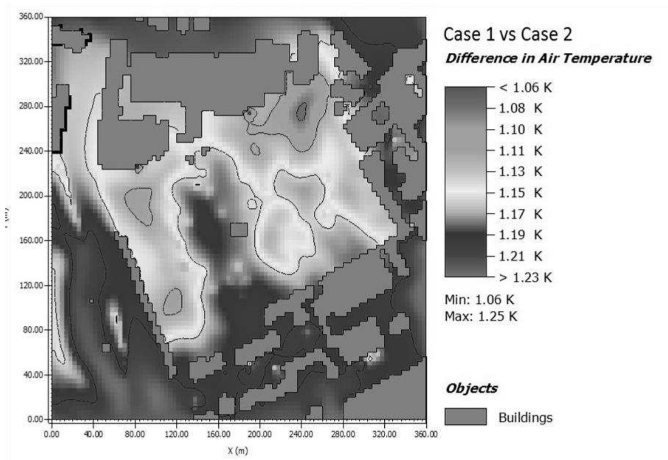
Bio-met is used for estimating thermal indices based on simulation outputs. In the case of ENVI-met Basic, the capabilities of Bio-met are limited to PMV that relates environmental conditions to human experience. It was initially introduced by Fanger (1972) for applications in interior situations, however, it has since been extended to include exterior climates and is widely used for this purpose. PMV can be extended to include the Predicted Percentage Dissatisfied (PPD).

The above noted metrics were considered at 2 measurement points within the model domain and compared between cases. These points are representative of different urban contexts: point 1 (MP1) is representative of an urban canyon while point 2 (MP2) is representative of a park (Figure 3).

The variation of T_a, *MRT* and *PMV* between case 2, 3, 4 versus the case 1 (current condition) in the urban canyon (MP1) and in the park (MP2) were investigated. Evaluations have been made at a height of 2m above ground, which is considered representative of pedestrian level. The comparison is presented in Table 6. Differences in T_a between 2017 and 2050 are also indicated in Figure 5. The study demonstrates that trees are more effective than grasslands in mitigating adverse MRT, PMV and PPD. The current contribution of all vegetation within the study domain is roughly equal to the effect of climate change on PMV within an urban canyon (MP1). Contributions to thermal control offered by urban green are generally greater at close proximity (MP2).



a)



b)

Figure 3. T_a differences in: a) Case 1; b) comparison between case and case 2.

Location	**Case**	**Ta (°C)**	**MRT (°C)**	**PMV**	**PPD (%)**
	Case 2	1.16	0.71	0.28	14
MP1	Case 3	0.54	3.25	0.27	13
	Case 4	1.73	3.96	0.55	28
	Case 2	1.18	1.09	0.28	0
MP2	Case 3	0.55	36.62	1.45	25
	Case 4	1.76	37.43	1.77	42

Table 6. Variation of T_a, MRT, PMV and PPD for Case 2, 3 and 4 compared to Case 1 (Base case scenario) at the 2 measurement points.

The results of this study are helpful for urban design practitioners as, within this relatively small precinct, there is a clear indication of UHI formation. The results (Fay D., 2017) suggest that climate change and urban green mitigations are likely to have effects on urban thermal characteristics. Preservation of existing green spaces surrounding the FoE has been shown to have an important influence on the current thermal environment. This is evidenced by Case 1 vs. Case 3 comparisons. The results show a notable contribution of trees and grasslands to the mitigation of heat stress across the whole simulation area, especially within close proximities. This is explained by the blocking effect of plants against solar radiation, as well as evapotranspiration phenomena. All studied parameters are affected by the presence of trees and grasslands thus, proving that human thermal comfort and building energy consumptions can be controlled with the enactment of urban greening.

5. Conclusion

This chapter presented quantitative analyses of the benefits associated with green networks that can be used for mitigating negative effects of urban climate changes at different scales. Qualitative criteria and quantitative analyses of benefits associated with green network can be applied in urban planning and design to evaluate urban thermal comfort.

Urban vegetation provides thermal comfort in different climates due to vegetation thermoregulation capacity provided by evapotranspiration, known as the “oasis” phenomenon. This work, discusses the influence of vegetation in two distinctive climate regions, subtropical regions and Oceanic climatic regions. Two case studies in Brazil and one case study in North of England are used to analyze the impact of urban vegetation on UHI. Both study show that trees are particularly influential in mitigating UHI. In Tropical climates, results show that 21-25% of green areas in high density areas can provide cooling effects on air temperatures up to 2.4 ^{o}C and promote thermal comfort up to 4 ^{o}C PET mitigation.

In the United Kingdom, it was observed that green cover provided by trees, grasslands, shrubs, brings, can reduce effects of climate changes in cities in terms of thermal comfort, specially within urban canyons.

This study also highlights the importance of adopting green roof and green walls within cities, where large vegetated areas and park are not feasible. However, thermal comfort effects on microclimate need further investigations in different urban microclimates. Quantitative evaluation of urban open areas needs to be an intrinsic part of research on urban green areas and thermal comfort. Quantitative and qualitative tools should be adopted by urban planners and designers to make proper informed decisions to improve urban quality of life.

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