Revista Árvore
ISSN: 0100-6762
r.arvore@ufv.br
Universidade Federal de Viçosa
Brasil

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Revista Árvore, vol. 41, núm. 6, 2017, pp. 1-12
Universidade Federal de Viçosa
Viçosa, Brasil

URBAN FOREST COMPONENTS INFLUENCING MICROCLIMATE AND COOLING POTENTIAL[1]

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[1] Received on 20.02.2017 accepted for publication on 07.06.2017.
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ABSTRACT – Planting areas with arboreal vegetation has been proposed as a way to improve the climatic conditions of cities. However, it is not yet known which components of urban forest provide more satisfactory effects. The main goal of this study was to determine which components of the landscape provide greater influence on the microclimate and the cooling potential of the urban forest. For this, areas of different types of urban forest were selected. Using the fixed points method, the microclimate of the areas was analyzed, and by means of mobile transects walking a route of 500 m in an adjacent street, it was possible to analyze the influence in the immediate environment, determining the potential of cooling. The results indicated that the number of individuals and the tree density of the areas showed a statistically strong correlation with the temperature and relative humidity values, as well as with the cooling potential. In addition, it was found that 70% of the influence that the urban forest provides on the immediate surroundings can be explained by the number of trees. It is concluded that the number and density of individuals were the components of urban forest typologies that exerted greater influence on the microclimate, as well as on the cooling effect.

Keywords: Temperature decrease; Urban microclimate; Afforestation.

OS COMPONENTES DA FLORESTA URBANA QUE INFLUENCIAM NO MICROCLIMA E NO POTENCIAL DE ARREFECIMENTO

RESUMO – A implantação de áreas com vegetação arbórea tem sido proposta como forma de melhorar as condições climáticas das cidades. Contudo, ainda não se conhece quais os componentes da floresta urbana proporcionam efeitos mais satisfatórios. O objetivo da pesquisa foi determinar quais os componentes da paisagem proporcionam maior influência no microclima e no potencial de arrefecimento da floresta urbana. Para isso foram selecionadas áreas de diferentes tipologias de floresta urbana. Com o método de pontos fixos foi analisado o microclima das áreas e por meio de transectos móveis, um percurso com 500 m de caminhamento em rua adjacente, foi possível analisar a influência no entorno imediato, determinando o potencial de arrefecimento. Os resultados indicaram que o número de indivíduos e a densidade arbórea das áreas apresentaram forte correlação estatística com os valores de temperatura e umidade relativa, bem como com o potencial de arrefecimento. Além disso, verificou-se que 70% da influência que a floresta urbana proporciona no entorno imediato pode ser explicado pelo número de árvores. Conclui-se que o número e a densidade de indivíduos foram os componentes das tipologias de floresta urbana que exerceram maior influência no microclima, bem como no efeito de arrefecimento.

Palavras-Chave: Diminuição da temperatura; Microclima urbano; Arborização urbana.

http://dx.doi.org/10.1590/1806-90882017000600003

INTRODUCTION

Climate can be seen as one of the most important natural resources, and it must be understood and properly managed to contribute to the sustainable development of humanity (Alcoforado, 2006). It is an important factor responsible for the variation of landscapes and biological diversity on Earth, and in cities it influences the development of typologies and architectural variations, as well as different habits and customs of the population (Basso and Correa, 2014).

Many inhabitants of cities around the world suffer from health problems and discomfort caused by urban areas overheating, and there is compelling evidence that these problems will be intensified by global climate change (Brown et al., 2015). Another aggravating factor is that cities generate their own climate, a result of the interference of all the factors acting on the urban boundary layer, which act to change the climate on a local scale (Amorim, 2010), making the urban climate particular to each urbanized environment (Lima, 2011).

The urban climate is responsible for effects that are felt more and more by the population, as it generates a thermal discomfort that directly affects the lives of the inhabitants (Lima, 2011). Thus, the possibility of controlling the climate is a focus of interest of planners involved in designing spaces that prioritize environmental optimization and human valorization in order to ensure greater environmental and emotional comfort to its users (Basso and Correa, 2014).

Trees have often been identified as a key element in minimizing the effects of climate change brought about by human actions, (Dimoudi and Nikolopoulou, 2003). The use of vegetation is one of the strategies recommended by the environmental project to reduce energy consumption, minimize the effects of heat island and urban pollution (Lima, 2009). Therefore, trees are pointed out as the best existing climate regulators (Leal, 2012), mainly because they are involved in cooling urban areas.

By cooling, it is understood as the potential for temperature decrease that the vegetation can provide, consisting of the difference between the temperature values of a site without vegetation and with vegetation. Taking into account the study scales of the urban climate (macroclimate, mesoclimate and microclimate), cooling potential can only be determined from microclimatic studies.

Moreover, the influence of vegetation is manifested throughout the most varied climatic scales; however, for the urban configuration of a place, the urban climate has its main degree of interference in the microclimatic scale (Silva, 2009). The microclimate therefore refers to the smaller scale of study in which the urban climate can be analyzed, being able to vary from a few meters up to 10 km (Andrade, 2010), and among the microclimatic variables of the urban environment, temperature and relative humidity of the air are those that exert greatest influence.

Trees can reduce temperatures by intercepting solar radiation and by providing shade to buildings and other surfaces (Adams and Smith, 2014). Their leaves have a low reflectance index, absorbing incident solar radiation and blocking much of the direct solar radiation (Basso and Correa, 2014). As a consequence, vegetation modifies surface temperature which also reaches the temperature of the air due to changes in the geometry and radiative properties of the soil cover (Shashua-Bar et al., 2010). In addition, trees transform a small part of the solar radiation absorbed by photosynthesis into latent heat (evapotranspiration), preventing it from being converted into thermal energy (Fryd et al., 2011; Chen et al., 2014).

The presence of trees in the urban environment is essential for the quality of life of the population. This ecosystem characterized by the presence of trees and other forms of vegetation associated to the people and their development is known as urban forest (Dwyer et al., 2000). Urban forest is understood as all vegetation cover located within the urban perimeter, it may be of public or private domain and it is divided into green areas and street trees (Biondi, 2015). It therefore includes trees planted in sidewalks, parks, squares, gardens, backyards, parking lots, cemeteries and urban forests, even if located in suburban and peri-urban areas (Araújo and Araújo, 2011).

The urban forest is expressed in several ways in a city, however, the main typologies of urban forest that can be found in Brazil are: forest remnants - areas of tree cover with altered forests, existing both in the urban perimeter and in urban-rural interface environments (Biondi, 2015); landscaped green areas - environments that present different types of vegetation including tree species, but that seem to have landscaped treatment to meet social, aesthetic and/or ecological needs (Biondi, 2015); and street trees - all vegetation of arboreal size along public roads, whether on sidewalks or in flowerbeds (Silva, 2009).

Regardless of the typology, urban forests can be used as a measurement to cool down of portions of urban areas, reducing the intensity and magnitude of the negative impacts of heat islands (Chang and Li, 2014). However, specific and accurate information regarding the climatological approach are needed in order to do so (Chang et al., 2007). There is a requirement to reinforce the need for research in this area, considering that we are still not fully aware of the benefits that trees can bring (Draper and Richards, 2009).

Understanding the microclimatic benefit provided by each typology of urban forest is of great importance for planning and managing urban forests. Thus, developing rigorous characterization of these areas through analysis of urban forest landscape components becomes essential for understanding the real benefits generated. The following elements can be considered as urban forest components: Area length, Tree cover, Sky view factor, Leaf Area Index, Altitude, Illuminance, Number of individuals, Tree density, Tree height and DBH, Canopy height, Tree spacing and Permeability.

Thus, the objective of the present study was to determine which landscape components provide greater influence on the microclimate and the cooling potential of urban forests.

2. MATERIAL AND METHODS

2.1. Study site

The study was developed in the city of Curitiba, which according to Köppen classification presents a Cfb type climate: subtropical, mesothermic, without a dry season, fresh summers and winters with frequent frosts and occasional snowfall (IPPUC, 2016).

In order to carry out this study, areas that represented the most frequent typologies of urban forest in the city were selected: Forest Remnant; Old Green Area (clusters of trees planted with eclectic landscaping); Modern Green Area (clusters of trees planted with modern landscaping); Street Trees (continuous tree clusters that follow a road system); Isolated Tree (single arboreal individual, planted isolated on the road system).

Three areas were selected for each type of urban forest, totaling 15 monitoring sites:

a) Forest Remnant = Parque Natural Municipal Barigüi (1); Bosque Gutierrez (2); Bosque João Paulo II (3);

b) Old Green Area = Passeio Público (4); Praça Eufrásio Correia (5); Praça Carlos Gomes (6);

c) Modern Green Area = Praça Nossa Senhora de Salette (7); Praça Alfredo Andersen (8); Jardinete Henrique Knopholz (9);

d) Street Trees = Rua Ângelo Lopes (10); Rua Brigadeiro Franco (11); Rua Guaratuba (12);

e) Isolated Tree = *Lagerstroemia indica* L. located on Rua Sant'Ana n°. 395 (13); *Lafoensia pacari* A.St.-Hil. Located on Rua Brasílio Itiberê n°. 295 (14); *Handroanthus chrysotrichus* (Mart. ex A.DC.) Mattos located on Rua Cel. João da Silva Sampaio n°. 648 (15).

2.2. Microclimate assessment

The microclimate of the different urban forest typologies was analyzed based on meteorological data collected according to the fixed point method. The meteorological variables collected with Hobo® RH & Temp. (Onset), data loggers were temperature (°C) and relative air humidity (%).

Hobo® Data Loggers were installed in the center/ within of each area of interest in mini meteorological shelters 4 m above the ground. The mini shelters were made from a section of PVC pipe 150 mm long and 100 mm in diameter, with openings on the sides and covered externally with foil and closed by two lids. They were fixed on the tree trunks in an upright position with the aid of nylon clamp tape.

Monitoring the meteorological variables was carried out simultaneously among the fifteen selected areas from February 20 to 22, 2014 (summer), and from July 28 to 30, 2014 (winter). The dates were selected based on the city's climatic history. Due to safety issues and other possible human interferences, the collection of meteorological variables lasted 48 hours, with continuous shooting at 1-minute intervals starting at 12 p.m. and totaling 2882 readings. The days were characterized as clear skies with no forecast of rain.

2.3. Assessment of cooling potential

Cooling potential was obtained from different meteorological data collection, which in this case was by mobile transects. This method consists of collecting meteorological information from equipment in continuous movement. Thus, an adjacent street from each area was selected which allowed for a 500 m path to be covered; the distance covered was 50 m for isolated trees.

The influence of urban forest typologies on its immediate surroundings was analyzed on different days due to the equipment availability. Meteorological data from one of the selected areas was collected on each day. This procedure was repeated for both summer (February and March) and winter (July and August). The collection days varied according to the climatic conditions, due to the need of clear skies during the moment of data collection between 12 and 1 p.m. (corrected to 1 p.m. and 2 p.m. during daylight saving time).

For data collection, two Kestrel® 4200mini-stations maintained at a height of approximately 1.50 m were used. One mini-station was kept under observation of a researcher in the center of the area, while the other was used for the mobile transect and was covered on foot by another researcher. Meteorological data (temperature and relative humidity) were simultaneously collected between the equipment located in the center of the area and the equipment used in the mobile transect, since they were programmed to collect information at every minute.

The intensity of the influence of different urban forest typologies on the immediate environment (cooling) was calculated based on the difference in temperature and relative humidity from the data measured from the interior of the typology and the mobile transect, for each distance of separation. In addition to temperature (more usual for cooling studies), relative humidity was also considered, since it is known that the presence of vegetation provides a more humid environment, which can also influence lower temperatures.

2.4. Assessment of urban forest components

Characterization of the areas carried out around the meteorological monitoring points by image processing and field collection allowed us to define the elements that compose the different urban forest typologies.

Image processing consisted of using images from a GeoEye-1 satellite provided by Grise (2015) for determining the tree cover, and carried out using Quantum GIS 2.8.6 software (QGIS Team Developer, 2016), which consisted of manually allocating polygons, corresponding to any continuous area of arboreal vegetation around the points of meteorological data collection. Numerical determination of the area was obtained from the program's attribute table. The area length was measured from a horizontal line drawn from end to end.

The collection of field information was carried out at different moments. Determination of altitude and illuminance were concomitantly carried out to the meteorological data collections by mobile transects. It is known that the atmospheric temperature decreases with increasing altitudes, and that surface temperature influences the atmospheric temperature, which is lower according to the degree of shading. The altitude was determined with a Kestrel® 4200 Pocket Air Flow Tracker, and based on the average recorded at every minute for both seasons, summer and winter; while illuminance within each typology was obtained with a digital lux meter (MLM-1011), positioned on the ground and recorded at least ten times over the monitoring period.

In order to characterize the other variables collected in the field, a circular plot of 250 m² was established around the place where the meteorological equipment was positioned. The variables collected in this stage were: vegetation type (native or introduced – whether exotic or native), total number of individuals with DBH > 5 cm, average tree height and canopy height (visually estimated), average spacing between the trees (measured with a measuring tape), amount of impermeable area (measured with a measuring tape) and type of soil cover.

In addition, photographic registration of the areas was also carried out in this stage, which included photos taking with a fisheye lens. Images were obtained with a Canon EOS Rebel T2i digital camera with 0.42 x Fish Eye w/macro lens coupled to Ef-s 18-55 mm F/3.5-5.6 lens. The camera was attached to a leveled tripod, kept 1.50 m above the ground with the lens aimed towards the sky, 1 m away from the tree where the meteorological equipment was installed. This photo was taken in order to calculate the sky view factor and Leaf Area Index.

To calculate the sky view factor, the photos taken with the fisheye lens were processed in RayMan 1.2 software, developed by Andreas Matzarakis, and available at Urban Climate (2016). According to Minella (2009), this program is very useful for climatological and urban planning studies, as it considers complex urban structures.

The image was saved in bitmap format and edited for sky removal with the use of Photoshop online. In the RayMan program, the *Input* toolbar *Sky View Factor* (SVF) was selected. Using the *Open Horizon Limitation* tool, the image was imported and then the Monochrome tool was selected, which leaves areas of obstruction in black using the Cut off and Close functions. A window then automatically opens with the result (Minella, 2009; Ferreira, 2015).

According to Ferreira (2015), the SVF value can range from 0 (zero) to 1, in which 1 corresponds to an area without any obstacle standing between the chosen point and the sky. For the present study, an area with a lower sky view factor also corresponds to an area with a greater density of tree cover.

The photos obtained with the fisheye lens were also used for determining Leaf Area Index, according to the indirect method. In the RayMan program it is also possible to determine the amount of obstacles on the horizon by performing the procedure already described for determining SVF, which corresponds to the amount of canopy in the photograph. For greater result accuracy, obstacles that did not correspond to canopy were (digitally) removed from the photos. Thus, Leaf Area Index (LAI) was calculated as determined by Watson (1947) for the ratio between the canopy leaf area and the unit of surface projected in the soil (m^2/m^2).

The components of the urban forest measured to characterize the areas were first correlated with the averages for temperature and relative humidity, and then used to characterize the microclimate (fixed point). This analysis was performed using the Excel software through the simple correlation function for a total mean value and values separated for each station. The same procedure was subsequently performed using the data differences (mobile transect) to analyze the cooling effect promoted by the urban forest. All correlated data were classified regarding their intensity according to Prestes (2015), who defines the correlation intensity classes as: null (0.001 –l 0.03); weak (0.03 –l 0.35); medium (0.35 –l 1.65); strong (0.65 –l 1.95); very strong (0.95 –l 0.99); perfect (1.00).

3. RESULTS

3.1. Characterization of urban forest typologies

Characterization of the areas was fundamental for better understanding the influence that urban forests exert on the microclimate (Table 1). For each urban forest typology, the table was classified from the largest to the smallest area of tree cover. Thus, area 1 has the largest amount of tree cover, area 2 has an intermediate amount, and area 3 has the smallest amount of tree cover.

Among the areas that characterize Forest Remnant, it can be noted that *Parque Barigüi* had the thinnest trees with only a few individuals over 5 cm of DBH and expressive understory density. On the other hand, *Bosque do Papa* was the area that presented individuals with the higher DBH and tree height values, with little expressive understory.

Regarding the Old Green Area, even though *Praça Carlos Gomes* had the largest number of individuals, it was also the area with the smallest trees and the smallest tree cover. In contrast, *Praça Eufrásio Correia* was the area with the largest trees, the highest DBH and tree height and the fewest individuals.

In the Modern Green Area, *Praça Nossa Senhora de Salette* was the area with the larger individuals in height and DBH, while *Jardinete Henrique Knopholz* was the area with the largest number of individuals of smaller-sized trees.

Rua Ângelo Lopes is characterized by a greater number of individuals of smaller-sized trees, while *Rua Brigadeiro Franco* has taller trees and *Rua Guaratuba* had trees with greater DBH. Although different species of Isolated Trees were selected, their physical characteristics were quite similar, in addition to the homogeneity of their environments.

3.2. Microclimate analysis

The characteristics measured from each area were correlated with the average values of temperature and relative humidity, and were collected using the fixed point method. This correlation was applied for to the total values and for those separated by season (Table 2).

Forest remnant		
Parque Barigüi	Bosque Gutierrez	Bosque João Paulo II
		
• Tree cover: 308,700 m² • Sky view factor: 0.112 • Altitude: 895 m • Illuminance: 525 Lux • Vegetation type: Araucaria Moist Forest • Number of Individuals: 17 • Tree density: 680/ha • Average tree height: 20 m • Average DBH: 23.2 cm • Canopy height: 14 m • Spacing between trees: 2 m • Permeability: 100% • Soil cover: understory of 2 m.	• Tree cover: 25,758 m² • Sky view factor: 0.078 • Altitude: 916 m • Illuminance: 358 Lux • Vegetation type: Araucaria Moist Forest • Number of Individuals: 34 • Tree density: 1360/ha • Average tree height: 17 m • Average DBH: 20.4 cm • Canopy height: 12 m • Spacing between trees: 1.7 m • Permeability: 89.2% • Soil cover: understory with two strata, 2 m and 1 m (denser), *Iris* sp. and stone sidewalk.	• Tree cover: 54,929 m² • Sky view factor: 0.094 • Altitude: 893 m • Illuminance: 951 Lux • Vegetation type: Araucaria Moist Forest • Number of Individuals: 24 • Tree density: 960/ha • Average tree height: 25 m • Average DBH: 29.8 cm • Canopy height: 18 m • Spacing between trees: 3 m • Permeability: 100% • Soil cover: understory of 1 m.

Old green area		
Passeio Público	Praça Eufrásio Correia	Praça Carlos Gomes
		
• Tree cover: 10,745.83 m² • Sky view factor: 0.135 • Altitude: 899 m • Illuminance: 3,115 Lux • Vegetation type: Introduced (*Ceiba speciosa*, *Eugenia uniflora*, *Psidium guajava*, *Magnolia grandiflora*) • Number of Individuals: 10 • Tree density: 400/ha • Average tree height: 18 m • Average DBH: 24.2 cm • Canopy height: 12 m • Spacing between trees: 5 m • Permeability: 80.6% • Soil cover: grass, *Ophiopogon japonicus* and portuguese stone	• Tree cover: 5,066.67 m² • Sky view factor: 0.096 • Altitude: 872 m • Illuminance: 2,438 Lux • Vegetation type: Introduced (*Tipuana tipu*, *Araucaria angustifolia*, *Cedrela fissilis*) • Number of Individuals : 7 • Tree density: 280/ha • Average tree height: 20 m • Average DBH: 75.3 cm • Canopy height: 14 m • Spacing between trees: 7 m • Permeability: 98% • Soil cover: grass, *Ophiopogon japonicus* and paths of stone fine (90m²)	• Tree cover: 935.49 m² • Sky view factor: 0.117 • Altitude: 870 m • Illuminance: 3,792 Lux • Vegetation type: Introduced (*Syagrus romanzoffiana*, *Bougainvillea* sp., *Dicksonia sellowiana*) • Number of Individuals: 15 • Tree density: 600/ha • Average tree height: 9 m • Average DBH: 30 cm • Canopy height: 4.5 m • Spacing between trees: 4 m • Permeability: 47.2% • Soil cover: grass, *Hedera helix* and portuguese stone

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Table 1...
Tabela 1...

Modern green area		
Praça N. Sra. de Salette	Praça Alfredo Andersen	Jard. Henrique Knopholz
		
• Tree cover: 4,.069.91 m² • Sky view factor: 0.106 • Altitude: 876 m • Illuminance: 3,405 Lux • Vegetation type: Introduced (*Anadenanthera colubrina*) • Number of Individuals : 1 • Tree density: 40/ha • Average tree height: 30 m • Average DBH: 125 cm • Canopy height: 8 m • Spacing between trees: 10 m • Permeability: 100% • Soil cover: grass	• Tree cover: 3,836.71 m² • Sky view factor: 0.145 • Altitude: 908 m • Illuminance: 2,519 Lux • Vegetation type: Introduced (*Ficus benjamina*) • Number of Individuals : 1 • Tree density: 40/ha • Average tree height: 18 m • Average DBH: 54 cm • Canopy height: 5 m • Spacing between trees: 10 m • Permeability: 45% • Soil cover: grass and concrete walkway	• Tree cover: 1,999.70 m² • Sky view factor: 0.125 • Altitude: 883 m • Illuminance: 3,462 Lux • Vegetation type: Introduced (*Anadenanthera colubrina, Lafoensia pacari*) • Number of Individuals: 5 • Tree density: 200/ha • Average tree height: 18 m • Average DBH: 52 cm • Canopy height: 11 m • Spacing between trees: 7 m • Permeability: 95% • Soil cover: grass and concrete walkway
Street trees		
Rua Ângelo Lopes	Rua Brigadeiro Franco	Rua Guaratuba
		
• Tree cover: 408.17 m² • Sky view factor: 0.398 • Altitude: 905 m • Illuminance: 4,745 Lux • Vegetation type: Introduced (*Handroanthus albus*) • Number of Individuals: 3 • Tree density: 120/ha • Average tree height: 9 m • Average DBH: 35 cm • Canopy height: 5 m • Spacing between trees : 8 m • Permeability: 14% Soil cover: grass, asphalt and stone	• Tree cover: 1,616.61 m² • Sky view factor: 0.258 • Altitude: 902 m • Illuminance: 5,141 Lux • Vegetation type: Introduced (*Anadenanthera colubrina, Erythrina falcata*) • Number of Individuals: 1 • Tree density: 40/ha • Average tree height: 25 m • Average DBH: 90 cm • Canopy height: 18 m • Spacing between trees: 12 m • Permeability: 10.6% • Soil cover: grass, asphalt, paver.	• Tree cover: 370.70 m² • Sky view factor: 0.171 • Altitude: 918 m • Illuminance: 7,364 Lux • Vegetation type: Introduced (tipuana) • Number of Individuals: 1 • Tree density: 40/ha • Average tree height: 18 m • Average DBH: 142 cm • Canopy height: 10 m • Spacing between trees: 10 m • Permeability: 16.8% • Soil cover: grass, asphalt, paver.

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Table 1...
Tabela 1...

Isolated trees		
Lagerstroemia indica	*Lafoensia pacari*	*Handroanthus chrysotrichus*
		
• Tree cover: 24.88 m² • Sky view factor: 0.469 • Altitude: 887m • Illuminance: 40,000 Lux • Vegetation type: Introduced (*Lagerstroemia indica*) • Number of Individuals: 1 • Tree density: 40/ha • Average tree height: 7 m • Average DBH: 18 cm • Canopy height: 3.5 • Spacing between trees: 15 m • Permeability: 4.2%	• Tree cover: 21.35 m² • Sky view factor: 0.281 • Altitude: 885m • Illuminance: 11,400 Lux • Vegetation type: Introduced (*Lafoensia pacari*) • Number of Individuals: 1 • Tree density: 40/ha • Average tree height: 7 m • Average DBH: 25 cm • Canopy height: 2 m • Spacing between trees: 12 m • Permeability: 13.8%	• Tree cover: 19.13 m² • Sky view factor: 0.296 • Altitude: 905 m • Illuminance: 20,000 Lux • Vegetation type: Introduced (*Handroanthus chrysotrichus*) • Number of Individuals: 1 • Tree density: 40/ha • Average tree height: 7 m • Average DBH: 18 cm • Canopy height: 3.5 m • Spacing between trees: 15 m • Permeability: 9.8%

Table 1 – Physical characterization of each study area using fisheye photos.
***Tabela 1** – Caracterização física de cada área de estudo com foto olho-de-peixe.*

The highest correlation found for both temperature and relative humidity was between the number of individuals per sample and consequently tree density. The values indicate that these variables were the only ones that exerted a strong correlation, together with the permeability rate for the variable temperature.

The variables altitude and DBH presented weak correlation with the mean temperature, while the variables sky view factor, illuminance, tree height and DBH presented weak correlation with relative humidity. The other variables presented a mean correlation with temperature and relative air humidity.

The variables tree cover, altitude and DBH correlated better with relative humidity than with temperature. Overall, more expressive values were found during the summer for all variables.

The correlation analysis indicates that 75% of the temperature variation can be explained by the number of individuals, meaning by the number of trees. This element is also responsible for explaining 70% of the relative humidity variation. The other elements that most influenced the meteorological variables were permeability rate, area length, amount of tree cover, sky view factor, leaf area index and spacing between the trees.

3.3. Analysis of the cooling potential

In addition to the correlation applied between the characteristics of each area and the meteorological data collected by the fixed point method, a correlation analysis was also carried out between these characteristics and the cooling potential obtained by the mobile transect. The mean difference in temperature and relative humidity between the external area (mobile transect) and the internal area which represents the cooling potential was correlated with the total mean values for temperature and relative humidity, as well as those analyzed for each season (Table 3).

In this analysis the highest correlation was also found with the number of individuals per sample and consequently with tree density for both temperature and relative humidity. The values indicate that these

Table 2 – Simple correlation analysis applied to each composition element and meteorological variable.
Tabela 2 *– Análise de correlação simples aplicada para cada elemento de composição e variável meteorológica.*

Composition element	Temperature			Relative humidity		
	Mean	Summer	Winter	Mean	Summer	Winter
Area length (m)	-0.50	-0.53	-0.38	0.50	0.53	0.42
Tree cover (m²)	-0.45	-0.49	-0.39	0.52	0.55	0.46
Sky view factor	0.58	0.66	0.39	-0.34	-0.40	-0.23
Leaf Area Index (m²/m²)	0.51	0.59	0.32	-0.28	-0.34	-0.18
Altitude (m)	-0.31	-0.23	-0.35	0.42	0.35	0.49
Illuminance (Lux)	0.42	0.50	0.24	-0.26	-0.29	-0.19
Number of individuals	-0.75	-0.73	-0.74	0.70	0.68	0.68
Tree density (ind./ha)	-0.75	-0.73	-0.74	0.70	0.68	0.68
Tree height (m)	-0.47	-0.52	-0.19	0.32	0.40	0.18
DBH (cm)	0.07	0.06	0.18	-0.22	-0.16	-0.31
Canopy height (m)	-0.45	-0.48	-0.15	0.38	0.43	0.29
Spacing between trees (m)	0.64	0.70	0.46	-0.49	-0.53	-0.39
Permeability (%)	-0.68	-0.73	-0.49	0.47	0.52	0.37

NOTE: Negative symbols indicate an inverse relationship between the variables.

Table 3 – Simple correlation analysis applied for each composition element and the values of cooling effect.
Tabela 3 *– Análise de correlação simples aplicada para cada elemento de composição e os valores do efeito de arrefecimento.*

Composition element	Temperature			Relative humidity		
	Mean	Summer	Winter	Mean	Summer	Winter
Area length (m)	0.40	0.38	0.31	0.65	0.46	0.67
Tree cover (m²)	0.43	0.34	0.42	0.70	0.49	0.74
Sky view factor	-0.35	-0.46	-0.11	-0.35	-0.39	-0.29
Leaf Area Index (m²/m²)	-0.32	-0.43	-0.10	-0.29	-0.34	-0.24
Altitude (m)0.30	0.28	0.25	0.21	0.24	0.17	
Illuminance (Lux)	-0.22	-0.44	0.14	-0.20	-0.19	-0.19
Number of individuals	0.70	0.75	0.44	0.70	0.57	0.69
Tree density (ind./ha)	0.70	0.75	0.44	0.70	0.57	0.69
Tree height (m)	0.23	0.40	-0.06	0.22	0.37	0.13
DBH (cm) -0.26	-0.10	-0.40	-0.24	0.03	-0.35	
Canopy height (m)	0.37	0.63	-0.06	0.27	0.28	0.22
Spacing between trees (m)	-0.18	-0.44	0.16	-0.36	-0.17	-0.41
Permeability (%)	0.31	0.37	0.15	0.46	0.39	0.45

NOTE: Negative symbols indicate an inverse relationship between the variables.

variables were the only ones that exerted a strong correlation in the temperature variable. Tree cover also indicated a strong correlation for relative humidity.

The correlation analysis indicated that 70% of the influence that the urban forest provides to the immediate surroundings can be explained by the number of trees. This element is also responsible for explaining 70% of the relative humidity variation. The other elements that most influenced cooling potential were: area length and amount of tree cover.

We can state that the results of this analysis were similar to those already presented for the microclimate analysis for the other variables; however, a lower interaction of the variable permeability rate is worth pointing out.

4. DISCUSSION

The importance of characterizing the study areas in detail is justified by the lack of information in this respect, especially when considering the microclimatic benefits. According to Chang and Li (2014), because urban space is often limited, small areas are more easily acquired than larger spaces. Therefore, understanding that the intensity and the extent of the increase in cooling are directly related to the size and other characteristics of green areas is important for implementing the analysis process.

Fan, Myint and Zheng (2015) claim that the potential impacts of the spatial arrangement of vegetation in the urban thermal environment have not yet been well characterized. It is known, however, that a combination of factors including the shape, size and segmentation level of vegetation fragments can influence temperature, usually with lower values associated with larger, continuous and dense vegetation fragments. Moreover, vegetation can introduce different solar radiation absorption conditions due to canopy volume, leaf surface and density, color and foliation cycle (Kurbán et al., 2002).

Determining which elements exert a greater influence on the microclimatic benefit provided by urban forests is of utmost importance. In conducting a similar study, Ren et al. (2013) found coefficients always higher than 0.56. Among the analyzed variables they found that the greatest influence was generated by canopy density, followed by the leaf area index, basal area, tree height, area of coverage, diameter at breast height, and finally tree density.

Considering all the analyses carried out, we found that larger tree cover areas do not expressively demonstrate more significant values. Thus, we can infer that larger urban forest areas are not necessary to promote microclimatic benefits in the surroundings. Despite the microclimate presenting significant differences, the environment/surroundings does not benefit on the same scale.

Therefore, from the climatic point of view, it is desirable that green areas are scattered throughout urban environments rather than concentrated on a single location, since the cooling range provided by any green area is limited to a few hundred meters (Honjo and Takakura, 1990; Hamada and Ohta, 2010). Amorim and Leder (2012) also stated that a greater distribution of small green areas throughout urban spaces produces a more efficient mitigating effect by increasing the transition area, thereby accentuating the effect observed at the edges.

5. CONCLUSION

The number and density of individuals were the components of the urban forest typologies that exerted the greatest influence on the microclimate, as well as on the cooling effect.

Regarding the urban forest influence on the microclimate in addition to these components, one can also highlight permeability rate, area length, amount of tree cover, sky view factor, leaf area index and the tree spacing. In relation to the cooling potential, the permeability rate did not prove to be a significant component; the other components that stood out were the area length and amount of tree cover.

In urban forest planning and management it is recommended that green areas and street trees contemplate as many trees as possible (greater tree density), making better use of available physical space. This measure is more significant than the creation of larger spaces. In addition, the presence of areas with extensive grassland/lawns allows better microclimatic conditions for the environment, however it does not guarantee the occurrence of cooling for the surrounding environment.

6. ACKNOWLEDGEMENTS

To the Araucária Foundation of Support to Scientific and Technological Development of Paraná (*Fundação Araucária de Apoio ao Desenvolvimento Científico e Tecnológico do Paraná*) for financing the purchase of equipment.

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