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# THE MICROCLIMATE OF DIFFERENT LANDSCAPE ARRANGEMENTS IN STREET TREES OF CURITIBA-PR STATE

## O MICROCLIMA DE DIFERENTES ARRANJOS PAISAGÍSTICOS NA ARBORIZAÇÃO DE RUAS DE CURITIBA - PR

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## ABSTRACT

Microclimate improvement is frequently stated as one of the benefits generated by urban forestry. However, there are still few studies that quantitatively approach this issue. The goal of this study was to quantify the microclimatic difference between streets with and without trees, for each season and landscaping type. For this, three locations were chosen. Each location showed different species composing landscaping types: *Tipuana tipu, Handroanthus chrysotrichus,* and *Lafoensia pacari* with *Parapiptadenia rigida*. A Kestrel® mini station was placed on a street with trees and another one on a street without trees. The daily period for collecting this data was from 9 a.m. to 3 p.m., with monitoring intervals of 1 minute, repeated during the four seasons of the year, beginning in the winter of 2011. The microclimatic variables analyzed were temperature, relative humidity and wind speed. The results indicated that the streets with trees always had lower temperatures and greater relative humidity values than the streets without trees. The greatest temperature difference was observed in the summer (2.5 $^{o}$C) and the smallest one in the winter (1.2 $^{o}$C). For relative humidity, the differences were between 6.4% (spring) and 5.6% (winter), and for wind speed the greatest difference was found in the winter (0.17m/s). Landscaping that uses *Tipuana tipu* on both sides of the street, planted in a way such as to make their canopies entangle and form a tunnel, is the best choice for a more pleasant microclimate in all seasons of the year.
**Keywords**: microclimate; streets with trees; landscaping types.

## RESUMO

A melhoria microclimática é frequentemente apontada como um dos benefícios gerados pela arborização urbana. No entanto, ainda são poucos os estudos que abordam quantitativamente essa questão. O objetivo dessa pesquisa foi quantificar a diferença microclimática entre ruas arborizadas e sem arborização, para cada estação do ano e arranjo paisagístico. Para isto foram selecionados três locais, contendo um trecho de rua com e sem arborização. Cada local apresentava diferentes espécies compondo os arranjos paisagísticos: *Tipuana tipu*, *Handroanthus chrysotrichus* e *Lafoensia pacari* com *Parapiptadenia rigida.* Para o monitoramento das variáveis meteorológicas, uma miniestação da marca Kestrel® permaneceu na rua arborizada e a outra na rua sem arborização. A coleta desses dados foi das 9 às 15 horas, com intervalo de monitoramento de 1 minuto, repetida nas quatro estações do ano, com início no inverno de 2011. As variáveis microclimáticas analisadas foram: temperatura, umidade relativa e velocidade do vento. Os resultados indicaram que a maior diferença de temperatura foi observada na estação do verão (2,5°C) e a menor no inverno (1,2°C). Para a umidade relativa, as diferenças ficaram entre 6,4% (primavera) e 5,6% (inverno) e para a velocidade do vento a maior diferença foi encontrada na estação do inverno (0,17 m/s). O arranjo paisagístico que

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utiliza o plantio com *Tipuana tipu* nos dois lados da rua, plantadas de modo a fazer com que suas copas se entrelacem e formem um túnel, é a melhor escolha para se buscar um microclima mais agradável em todas as estações do ano.
**Palavras-chave**: microclima; arborização de ruas; arranjos paisagísticos.

## INTRODUCTION

Trees are considered a fundamental element to minimize the effects of climate change in cities due to the actions of mankind, through air cooling, increased relative humidity and changes in ventilation patterns (DIMOUDI; NIKOLOPOULOU, 2003). Another significant benefit of the presence of urban forestry is the capacity for interception of rain, which reduces the volume of floods caused by storms, contributing to the hydrologic cycle and redistribution of moisture (MCPHERSON; SIMPSON, 2002).

According to Mahmoud (2011), the effect of trees on the microclimate is related to the reduction of sunlight reaching the ground. Another form of action is evapotranspiration, which is the process of water transfer from the vegetated soil to the atmosphere by vaporization of liquid water (JENSEN; BURMAN; ALLEN, 1991).

In the summer, the vegetation works as a true natural air conditioner, for it lowers air temperature through evapotranspiration (HEISLER, 1974). Grey and Deneke (1986) stated that an isolated tree can transpire 380 liters of water per day on average, which causes cooling equivalent to five average air conditioners operating for 20 hours.

Streiling and Matzarakis (2003) demonstrated that a small group of trees, or even a single tree, can have a positive impact on urban climate. Souch and Souch (1993), in a study of different types and planting conditions, observed a decrease in temperature and an increase in humidity under the foliage of trees. In the Mexico City, Jauregui (1990/1991) found that temperature in Chapultepec Park was of 2 to 3°C lower than in the surrounding constructed areas. Kurbán et al. (2002), in San Juan, Puerto Rico, demonstrated that the effect of urban forestry resulted in a decrease of 2.1°C in temperature and an increase of 5.2% in relative humidity. In Freiburg, Germany, Streiling and Matizaski (2003) found differences between areas with and without trees of 2.2°C for temperature and 5 to 7% for relative humidity. Smith et al. (2011) and Armson, Stringer e Ennos (2012), both in region 55 of Manchester, England, found that shading caused by trees reduced the temperature by 1 to 2°C.

It is also known that oscillations in temperature are smaller in areas with trees than in areas without trees, especially because radiation emitted by the ground during the night is reflected back to the ground by the foliage, and during the day, the vegetation stops direct radiation from reaching the ground (OCHOA DE LA TORRE, 1999). Huang et al. (2008a), studying Nanjing, China, observed that temperatures in the shade from trees were stable on the microclimatic scale, while environments with the presence of cement were more easily influenced by atmospheric conditions, wind speed and solar radiation. Furthermore, lack of vegetation reduces the process of evapotranspiration and consequently impedes cooling by evaporation (PINHO; ORGAZ, 2000).

According to Leal (2012), the creation of parks and the planting of groves and street trees are the most efficient measures to promote change, especially in urban microclimates. Yu and Hien (2006) emphasized that when vegetation is well distributed, the balance of energy of the entire city can be modified by adding more evaporative surfaces and that more absorbed radiation can be dissipated in the form of latent heat, thus reducing urban temperature. In this context, Huang et al. (2008b) stated that research on urban climate should be stimulated to help in the many decisions of environmental planning and rehabilitation of urban areas.

In the composition of street trees, ornamental trees are used, selected for their particular qualities of size, shape, texture and color of leaves, flowers and fruits (HARRIS, 1992). Hence, the influence of vegetation in a microclimate varies according to the different characteristics of the species present.

Microclimate is one of the scales on which urban climate can be studied. According to Silva (2009), the influence of vegetation can be measured by various climatic scales, although for urban areas, the microclimatic scale is most appropriate.

Research on urban microclimates is increasingly important, although frequently the findings are not considered in city planning. Nor have the urban climatic conditions resulting from the interaction of nature and society received due importance (DUMKE, 2007). Therefore, our main goal in this study was to quantify the microclimatic difference between streets with trees and streets without trees, for each season of the year and landscaping type.

## MATERIALS AND METHODS

The study was carried out in the city of Curitiba, Paraná, Brazil. The landmark zero of the municipality is located at latitude 25 ° 25 '40 "S and longitude 49 ° 16' 23" W and the average altitude is 934.6 m. The Köppen classification is type Cfb, subtropical humid, mesothermal, no dry season, with cool summers and winters with frequent frosts (INSTITUTO DE PESQUISA E PLANEJAMENTO URBANO DE CURITIBA, 2011).

Between 1998 and 2010, the average annual temperature was 17.8ºC, ranging from 13.4ºC in the coldest month to 21.8ºC in the hottest month. Average annual precipitation during the period was 1403.30 mm and relative humidity was 79.4%. The predominant winds were from the East (E) with an average speed of 2.04 m/s (INSTITUTO DE PESQUISA E PLANEJAMENTO URBANO DE CURITIBA, 2012).

According to Bobrowski (2011), the most common tree species found along streets in Curitiba are: *Lagerstroemia indica, Ligustrum lucidum, Handroanthus chrysotrichus, Tipuana tipu, Handroanthus albus, Lafoensia pacari, Parapiptadenia rigida, Acer negundo, Poincianella pluviosa var. peltophoroides, Cassia leptophylla, Handroanthus heptaphyllus, Hibiscus rosa-sinensis, Melia azedarach, Syagrus romanzoffiana* and *Libidibia ferrea* var. *leiostachya*.

Three sampling sites were established in Curitiba, called Alto da Rua XV, Hugo Lange, and Bacacheri. Each spot has a stretch of street with trees and another without trees, structurally similar, close to each other and in the same geographic direction (Figure 1).

The Alto da Rua XV site is formed by a section of Marechal Deodoro Street without trees and Fernando Amaro Street, which has *Tipuana tipu* (Benth.) Kuntze trees, a deciduous species. The stretch of Mal. Deodoro Street has a raceway 13 m in width and 2.4 m sidewalks on each side. In turn, Fernando Amaro Street has a raceway 7 m in width and 5.40 m sidewalks on each side, of which 3.4 m are covered by grass. Thus, the two stretches of streets have the same width, the raceway is paved with asphalt and the sidewalks are covered with concrete slabs. The structures are mainly single-story houses. The treed portion of Fernando Amaro street has 32 trees with an average height of 20 m, average circumference at breast height (CBH) of 2 m and average crown area of 200 m². Thus, the tree cover of this street is 100%. On average, the vehicle traffic observed was lower than on Mal. Deodoro Street.

The Hugo Lange site is formed by a section of Augusto Stresser Street without trees and Dr. Goulin Street with *Handroanthus chrysotrichus* (Mart. ex A.DC.) Mattos, a deciduous species. The stretch of Augusto Stresser Street has a raceway 12 m in width and 4 m sidewalks on each side, bordered mainly by single-story houses and commercial establishments. Dr. Goulin Street has a raceway 7 m in width and 6.2 m sidewalks on each side, of which 4.2 m are covered by grass, bordered mostly by single-story houses. Thus, the two stretches of streets have almost the same width. The raceways of both streets are paved with asphalt and the sidewalks are covered with slate stones. The stretch of the Dr. Goulin Street has 26 trees with an average height of 8.5 m, average CBH of 0.53 m and average crown area 24 m². Thus, the tree cover of this street is 30%. On average, the vehicle traffic observed was lower than on Augusto Stresser Street.

The Bacacheri site is formed by a section of Estados Unidos Street without trees and another with *Lafoensia pacari* A.St.-Hil., a semi-evergreen species (during this study, the trees had not lost their leaves) and *Parapiptadenia rigida* (Benth.) Brenan, an evergreen species. Estados Unidos Street has a raceway 11 m in width and 4.5 m sidewalks on each side. The raceway is paved with asphalt and the sidewalks are covered with concrete slabs, bordered with mostly single-story houses and commercial establishments. In the treed stretch, the sidewalk has strip of grass between the sidewalk and curb (3 m). On one side of the street there are 9 *Lafoensia pacari* trees with average height of 8.5 m, average CBH of 0.86 m and average crown area of 20 m². It also has 12 *Parapiptadenia rigida* trees with average height of 14 m, average CBH of 1.30 m and average crown area of 80 m². The tree cover of this street is 45% on average.

Dr. Goulin Street has a raceway 7 m in width and 6.2 m sidewalks on each side, of which 4.2 m are

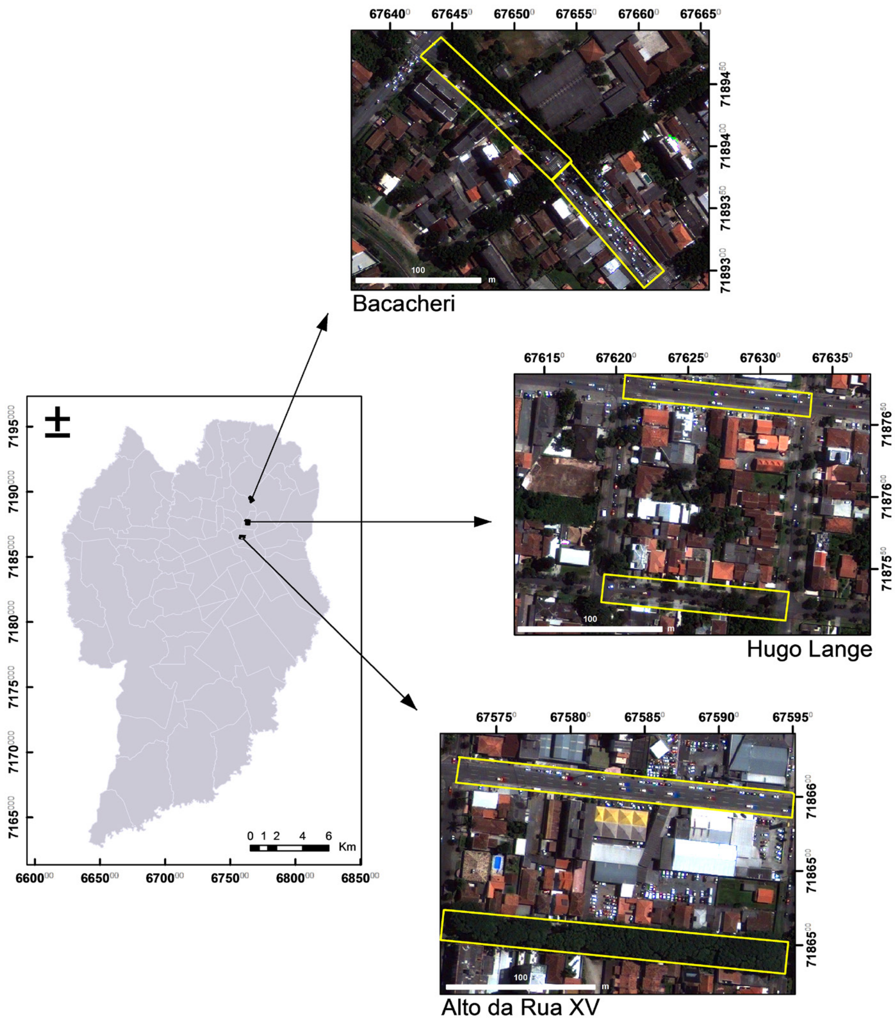


FIGURE 1: Location of the study samples in Curitiba with aerial images.
FIGURA 1: Localização das amostras de estudo em Curitiba com imagens aéreas.

covered by grass, bordered mostly by single-story houses. Thus, the two stretches of streets have almost the same width. The raceway is paved with asphalt and the sidewalks are covered with slate stones. The stretch of the Dr. Goulin Street has 26 trees with an average height of 8.5 m, CBH of 0.53 m and average crown area of 24 m². Thus, the tree cover of this street is 30%. On average, the vehicle traffic observed was lower than on Augusto Stresser Street.

To analyze the influence of these trees on the urban microclimate, two Kestrel® mini stations were used, fixed to a tripod, with the sensor table 1.5 m high. These devices were positioned on the south sidewalk of the east-west streets (Mal. Deodoro, Fernando Amaro, Augusto Stresser and Dr. Goulin) and on the west sidewalk of the north-south street (Estados Unidos), in order to reduce interference caused by the movement of the sun.

As described by the manufacturer, the Kestrel mini station has temperature accuracy of ± 1 °C, covering a measuring range of -29 °C to 70 °C. The relative humidity values are accurate to ± 3%, covering a range of 5% to 95% (non-condensing). Wind velocity measures have accuracy of 3%, between 0.6 m/s and 40 m/s. The instruments used were calibrated before the first collection in each season.

Monitoring of meteorological variables for each sampling site was done on different days. Thus, on each day, one device stayed on the street with trees and the other on the street without trees. This procedure was repeated in the four seasons of the year. The variables analyzed were: air temperature (ºC), relative humidity (%) and wind speed (m/s).

Monitoring was done in the winter and spring of 2011 and in the summer and autumn of 2012, with the period of data collection being from 9 a.m. to 3 p.m. (Brasília time), adjusted to 10 a.m. to 4 p.m. during daylight saving time, with a monitoring interval of 1 minute, which generated a total of 360 data readings. As each sample was monitored on different days, three days in each season were required.

An analysis of differences found between streets was made. For this, it was necessary to use the matched data, every minute, where the values found in the street with trees were subtracted from those found in the street without trees. In this way, we obtained the microclimatic difference in each season and landscaping type (composition of tree types). With this data se, a 3 x 4 factorial design (three landscaping types and four seasons) was established, and the comparison of means was done through the Student-Newman-Keuls (SNK) test at 99% significance. This test was the most sensitive among all those possible.

Landscaping for our purposes was defined as the different compositions of vegetation and the way trees were planted on the street. The analyzed landscaping types are shown in Figure 2:

Landscaping type 1 - *Tipuana tipu* on both sides of the street with canopies entangled, forming a continuous tunnel.

Landscaping type 2 - *Handroanthus chrysotrichus* on both sides of the street, without entangled canopies, spaced 7 meters apart.

Landscaping type 3 - *Lafoensia pacari* (odd side) and *Parapiptadenia rigida* (even side), with the canopies of the trees on the odd side isolated and the canopies of the trees on the even side grouped together, without entanglement over the street.

The grassy area was not taken into consideration in this composition because there were no differences between the three streets analyzed: they all have the same standard sidewalk widths, with a continuous strip of grass along the curb and another near the division with structures, these being of similar dimensions also.

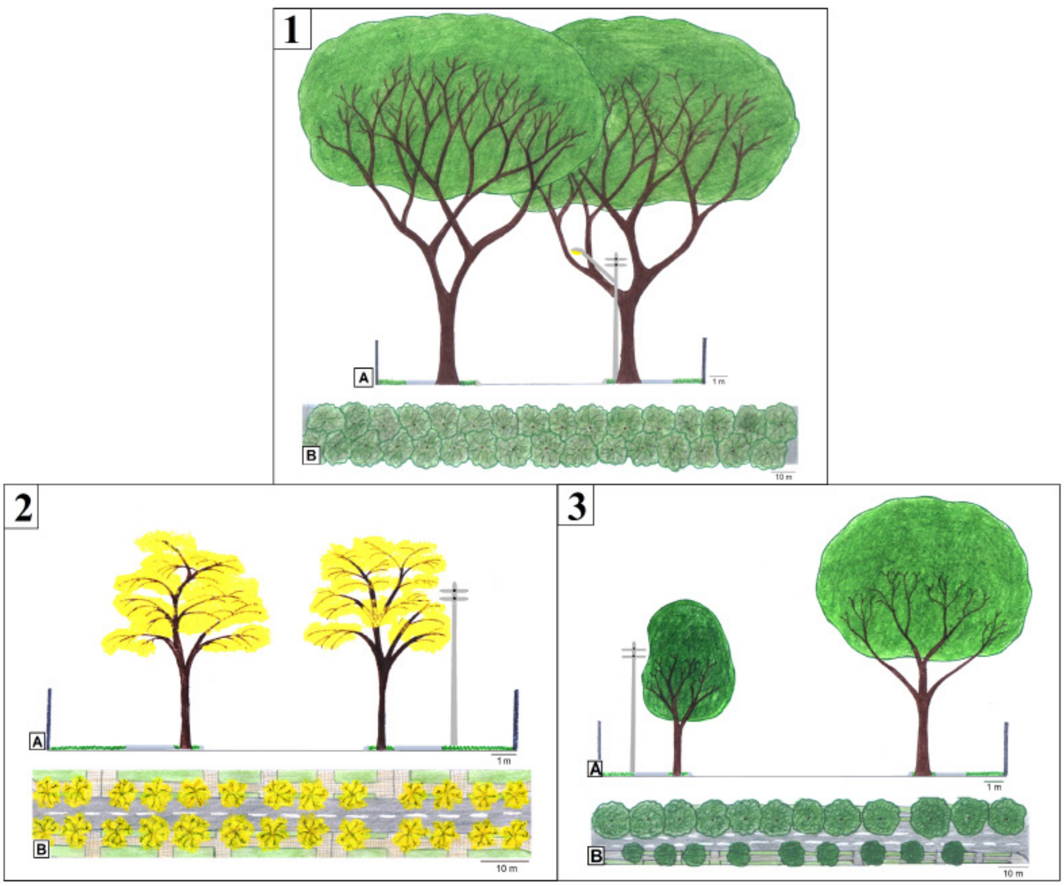


FIGURE 2: Illustration of the surveyed landscaping type (1, 2 and 3). A) street profile; B) top view.
FIGURA 2: Ilustração dos arranjos paisagísticos (1, 2 e 3). A) perfil das ruas; B) vista do topo.

## RESULTS AND DISCUSSION

The analysis of variance showed a significant difference for the means for the seasons and in landscaping types. The differences in temperature, relative humidity and wind speed between the street with and without trees in each season demonstrate the microclimatic benefits generated by street trees (Table 1).

TABLE 1: Mean difference of meteorological variables between streets with and without trees according to season.
TABELA 1: Diferença média das variáveis meteorológicas entre ruas com e sem árvores em cada estação do ano.

| Season | Temperature (°C) | | | Relative humidity (%) | | | Wind speed (m/s) | | |
|---|---|---|---|---|---|---|---|---|---|
| | without | with | difference | without | with | difference | without | with | difference |
| Winter | 13.4 | 12.2 | - 1.23 **c** | 49.2 | 54.8 | 5.59 **b** | 0.9 | 0.7 | - 0.17 **a** |
| Spring | 19.5 | 18.1 | - 1.44 **b** | 50.8 | 57.2 | 6.36 **a** | 0.9 | 0.9 | - 0.04 **b** |
| Summer | 29.8 | 27.3 | - 2.51 **a** | 38.5 | 44.2 | 5.70 **b** | 0.5 | 0.5 | - 0.03 **b** |
| Autumn | 20.8 | 19.2 | - 1.57 **b** | 65.0 | 71.1 | 6.07 **a** | 0.5 | 0.6 | 0.02 **b** |

Where: Means followed by the same letter in the column do not differ at 1% significance by SNK test. The negative signs imply that the values found in streets with trees were lower than those of streets without trees.

The average difference of temperature between the streets with trees and without trees was statistically distinct between the seasons. The greatest difference occurred in the summer (2.51°C) and the smallest in the winter (1.23 °C). The greatest difference in temperature occurred in the summer and the least in the winter and spring. This is a favorable result because it indicates that urban forestry plays an important role in attenuating high temperatures, but it does not cause substantial cooling in the winter. In the summer, the temperature in vegetated areas has a stronger effect of cooling than in the winter (CHANG; LI; CHANG, 2007). In fact, Akbari and Taha (1992) alerted that the lack of vegetation causes a decrease in temperature in the winter, due to the ease that construction materials have of losing heat to the environment where there are no natural obstacles to stop it.

The differences in temperature found in the spring and autumn were similar. This is because these seasons are similar in meteorological terms. Spring and autumn are seasons of climatic transition, thus they present, at times, the characteristics of winter and at times those of summer (SOUZA; BORSATO, 2011). According to the same authors, this variation is a circumstance of the atmospheric system in action, which can alternate frequently. In this way, the influence of tree coverage in these two seasons also remained at an intermediate level. This is contrary to the results found in another study. Dacanal, Labaki e Silva (2010), working in Campinas (Brazil), comparing the microclimate of a grove to its adjacent area, reported greater temperature differences in the autumn (2.76 °C), followed by winter (2 °C) and summer (1.76 °C).

Relative humidity in the city of Curitiba does not change much during the year. Therefore, the difference between the streets with and without trees was relatively homogeneous in the four seasons. The greatest differences were in the spring (6.36%) and autumn (6.07%), which although they are close to the smallest differences observed in the summer (5.70%) and in the winter (5.59%), are statistically different.

Relative humidity showing only small differences between the seasons. However, in a study by Dacanal, Labaki e Silva (2010), higher relative air humidity was observed in the winter (11.5%). Both results contradict the findings of Mascaró and Mascaró (2009). Those authors found the greatest differences in the summer, since this effect is proportional to the foliage density. In the spring, on the other hand, the lowest values are registered due to the action of wind and the existence of gaps in the canopy. However, in the city of Curitiba, relative humidity is typically homogeneous throughout the year.

Wind speed in the winter was statistically distinct from the other seasons, showing the greatest difference (0.17 m/s). This result may be a reflection of the greater values of wind speed among all of the collection days in this season. Nevertheless, the influence of trees on the wind speed variable was difficult to define due to the characteristics of the meteorological variable itself.

According to Varejão-Silva (2000), near the surface-atmosphere interface, the wind is highly influenced by geometric characteristics and by the state of heating of the subjacent surface. Therefore, according to Mascaró and Mascaró (2010), cities have complex forms of responding to wind. However, efficiency in reducing wind speed depends on the placement of individual trees in open spaces (WATANABE et al., 2006). Some factors that also affect the ventilation conditions of an environment are the characteristics of the tree species, such as size, shape, permeability, period of defoliation, and age (MASCARÓ; MASCARÓ, 2010).

The influence of street trees on temperature, relative humidity and wind speed varied according to the different landscaping types studied. The statistical analysis applied to these differences of temperature and humidity, found between streets with and without trees, shows a significant difference between all landscaping types (Table 2).

TABLE 2: Mean difference of meteorological variables between streets with and without trees according to landscaping type and season.

TABELA 2: Diferença média das variáveis meteorológicas entre ruas com e sem árvores em cada arranjo paisagístico e estação do ano.

| Landscaping type | | Winter | Spring | Summer | Autumn | Mean |
|---|---|---|---|---|---|---|
| Temperature (°C) | | | | | | |
| 1- *Tipuana tipu* | with | 10.1 | 18.5 | 28.7 | 19.8 | -2.12 **a** |
| | without | 9.7 | 16.2 | 25 | 17.7 | |
| | difference | -0.4 | -2.3 | -3.7 | -2.1 | |
| 2- *Handroanthus chrysotrichus* | with | 13.8 | 21.5 | 30.5 | 23.8 | -0.97 **c** |
| | without | 13.8 | 21.7 | 28.7 | 21.5 | |
| | difference | -0.0 | 0.3 | -1.8 | -2.4 | |
| 3- *Lafoensia pacari* and *Parapiptadenia rigida* | with | 16.3 | 18.5 | 30.3 | 18.7 | -1.97 **b** |
| | without | 13.0 | 16.3 | 28.2 | 18.5 | |
| | difference | -3.3 | -2.3 | -2.1 | -0.2 | |
| Relative humidity (%) | | | | | | |
| 1- *Tipuana tipu* | with | 61.2 | 53.8 | 38.7 | 68.7 | 6.80 **b** |
| | without | 65.4 | 64.3 | 46.2 | 73.7 | |
| | difference | 4.2 | 10.5 | 7.5 | 5.0 | |
| 2- *Handroanthus chrysotrichus* | with | 33.4 | 46.9 | 34.7 | 52.2 | 3.89 **c** |
| | without | 34.5 | 46.1 | 40.1 | 61.9 | |
| | difference | 1.1 | -0.8 | 5.4 | 9.7 | |
| 3- *Lafoensia pacari* and *Parapiptadenia rigida* | with | 53.1 | 51.7 | 42.2 | 74.2 | 7.10 **a** |
| | without | 64.5 | 61.1 | 46.3 | 77.6 | |
| | difference | 11.4 | 9.3 | 4.2 | 3.5 | |
| Wind speed (m/s) | | | | | | |
| 1- *Tipuana tipu* | with | 0.8 | 0.7 | 0.6 | 0.4 | 0.13 **a** |
| | without | 0.7 | 1 | 0.6 | 0.8 | |
| | difference | -0.2 | 0.3 | -0.0 | 0.4 | |
| 2- *Handroanthus chrysotrichus* | with | 1 | 1.2 | 0.2 | 0.1 | -0.17 **b** |
| | without | 0.4 | 0.6 | 0.2 | 0.7 | |
| | difference | -0.6 | -0.6 | -0.0 | 0.5 | |
| 3- *Lafoensia pacari* and *Parapiptadenia rigida* | with | 0.8 | 0.7 | 0.8 | 1.1 | -0.13 **b** |
| | without | 1 | 1 | 0.7 | 0.2 | |
| | difference | 0.2 | 0.2 | -0.1 | -0.8 | |

Where: Means followed by the same letter in the column do not differ at 1% significance by SNK test. The negative sign imply that the values found in streets with trees were lower than those of streets without trees.

There were statistical differences among landscape types. Landscaping type 1 provided the greatest difference in temperature (2.12° C), followed by type 3 (1.97° C) and type 2 (0.97° C). The greatest difference in relative humidity was found in landscaping type 3 (7.1%), followed by 1 (6.8%) and 2 (3.9%). Finally, the difference in wind speed in landscaping type 1 was statistically distinct from the others, with the mean found on the streets with trees showing higher values than the streets without trees.

These results occurred mainly in response to the different characteristics of the species. The canopy, for example, when too dense, retains more water and increases the relative humidity of the air underneath it. The same is true of the foliage, which is also important to control air humidity (MASCARÓ; MASCARÓ, 2010).

Kurbán et al. (2002) highlighted that vegetation introduces differentiated conditions from absorption of solar radiation related to the volume of the canopy, the surface and density of leaves, colors, and foliation cycle. The species in this study have very different characteristics. *Tipuana tipu* and *Parapiptadenia rigida* present a large canopy area, with small leaves, but with great density, which results in a high absorption of radiation, in contrast to *Handroanthus chrysotrichus*, which has a small canopy area, with medium leaves and low density. Both of these species are different from *Lafoensia pacari*, which has a medium canopy and leaves and high canopy density.

According to Mascaró and Mascaró (2010), trees, especially the large ones as is the case of the *Tipuana tipu*, give the environment more thermal capacity, promoting daily decrease in temperature values. We observed this throughout the monitoring period and in all seasons.

We also highlight that the differentiated conditions of solar radiation absorption are influenced by the planting arrangement of these species. In landscaping type 1, *Tipuana tipu* was planted to form a tunnel, due to the entangled canopies, and thus offered greater barriers to the arrival of solar radiation at the surface. In landscaping type 2, the opposite is the case, as the exemplars of *Handroanthus chrysotrichus* were planted so that the canopies remained separated, favoring the entry of radiation. In an intermediate scale is landscaping type 3, where one side of the street showed isolated canopies and the other entangled canopies.

Furthermore, deciduous species, as is the case of *Handroanthus chrysotrichus* and *Tipuana tipu*, are frequently indicated for regions that have well-defined seasons. These species are especially functional, for during the hottest period they provide shade and during the coldest period, when they lose their leaves, they allow the incidence of sunlight, warming the atmosphere (OCHOA DE LA TORRE, 1999).

Using species with dense foliage, which will permit the absorption of solar radiation and cooling of the air, increases the differences in temperature (MASCARÓ; MASCARÓ, 2010). However, according to Ochoa de La Torre (1999), evergreen species can function both as elements of shade as well as wind deflectors. They maintain their leaves during the entire year, which can also lead to negative effects, such as when deflecting necessary wind in the summer or providing unnecessary shade in the winter. The species that make up landscaping type 3, as the literature indicates (LORENZI, 2008), are semi-deciduous, although the trees had leaves on every collection day.

The behavior of these microclimatic differences between streets with and without trees throughout the entire collection period, separately for each season of the year, provides more detailed and relevant information about the influence that each landscaping type has on the microclimatic environment (Figure 3).

In all seasons of the year, the behavior of differences in temperature caused by each landscaping type is similar to the behavior of differences in relative humidity. The variation curves of these differences follow the same pattern for both of these variables. According to Soares and Batista (2004), relative air humidity presents an inverse daily course from temperature, because relative humidity is inversely proportional to the pressure of saturation of water vapor, which in turn, is directly proportional to temperature. In this way, relative air humidity tends to increase when there is a decrease in temperature and decrease when there is an increase in temperature (LAMBERTS; DUTRA; PEREIRA, 1997).

Furthermore, we found an increased difference in temperature in the first hour of monitoring in some situations. Lima (2009), in the parks of Maringá, Paraná state, also found the greatest difference in temperature between environments (under vegetation/ exposed to direct radiation) in the summer, at 9 a.m.

In the summer, landscaping type 1 presented a very pronounced difference in temperature in the first hour of monitoring (6°C on average). The same can be said for landscaping type 2, to a lesser extent,

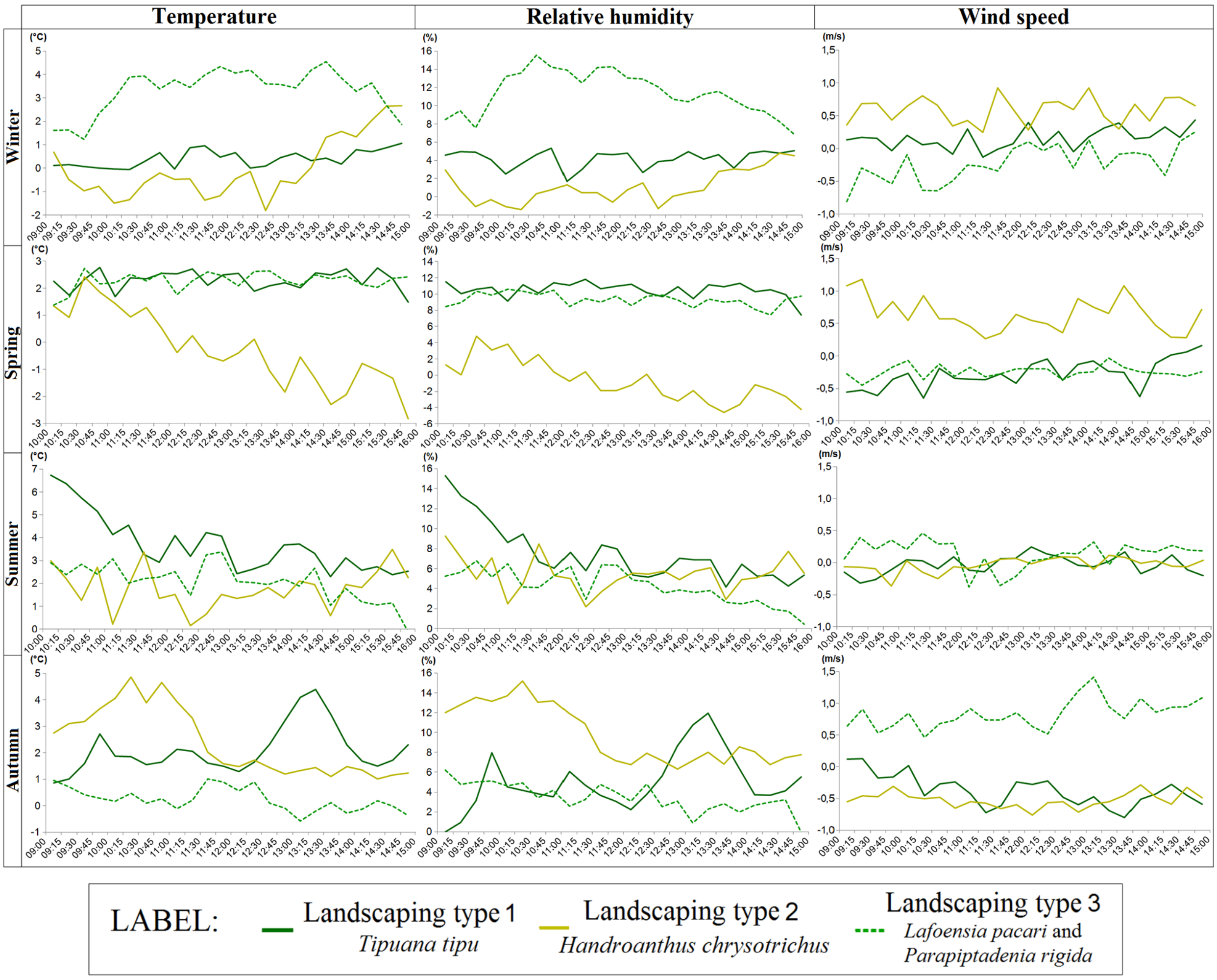


FIGURE 3: Variation of microclimatic differences of each landscaping type and season.
FIGURA 3: Variação das diferenças microclimáticas em cada arranjo paisagístico e estação do ano.

in spring and autumn. Landscaping type 1 in the winter showed the least variation in temperature (0.4°C) during the daily sampling period. The greatest differences occurred in the spring and summer, on average 2.3°C and 3.7°C respectively, and in the summer this difference was greater. In the autumn, although the greatest average difference (2.1°C) was not found, during the afternoon period this was the landscaping type that provided the greatest difference. The difference in relative humidity followed these same patterns and the difference in wind speed always remained close to zero.

Landscaping type 2, as was said before, showed certain peculiarities. However, in the winter, when there was no average difference (0 °C), this landscaping type presented different behavior throughout the period of analysis. Most of the time the difference was around 0.6°C, with the greatest values occurring in the street with trees, but this reversed in the final hours, when the difference was approximately 2.5°C. In the spring and summer this landscaping type showed the least differences throughout most of the time, 0.3°C and 1.8°C, respectively, and again with the greatest values in the spring occurring in the street with trees. The greatest average difference (2.4°C) was found in the autumn, but the behavior throughout the day was distinct. The difference in relative humidity followed these same patterns and the difference in wind speed was the greatest in the winter and spring.

Landscaping type 3 showed the greatest average difference in temperature in the winter (3.3°C). In the spring, it showed similar behavior to landscaping type 1 (average difference of 2.3°C). In the summer, it showed an intermediate difference (2.1°C) compared to other types. In the autumn, it was the landscaping type that showed the least difference (0.2°C). Among all of the landscaping types, it was the one that showed the most homogeneous differences throughout the monitoring periods. As for othe others, the difference in relative humidity followed the same patterns as temperature and the difference in wind speed was the greatest in the autumn and least in the spring.

The difference in wind speed found in landscaping type 1 was statistically different from the rest. However, it is known that vegetation produces some basic effects on wind, such as channeling, deflecting, blocking and filtering (ROBINETTE, 1972). According to the same author, this effect of wind channeling is produced when the vegetation corridor is well defined and relatively narrow, like the one found in this landscaping type.

Landscaping type 1, which uses *Tipuana tipu* on both sides of the street, planted in a way such as to make their canopies entangle and form a tunnel, is the best choice for more pleasant microclimate in every season of the year. On the other hand, using species with thin canopies and planted separately, such as the case of the street with *Handroanthus chrysotrichus*, provides a smaller influence in the microclimate.

Similar to this result, Mascaró and Mascaró (2009) highlighted that urban environments with small tree species undergo more undesirable climate effects than those that use large species, which produce milder microclimates. However, for the planting of large species on public sidewalks to be considered desirable, more research is necessary so that adequate street/sidewalk layout can be found so that these trees' root systems do not adversely affect transit and their branches do not pose hazards to structures.

## CONCLUSION

It was possible to quantify the influence that street trees exert on urban microclimates in each season of the year and the landscaping type.

The microclimatic difference between the streets showed the greatest difference of temperature in the summer and smallest in the winter. For relative humidity, the values remained between 6.4% (spring) and 5.6% (winter). The greatest difference for wind speed was found in the winter.

The landscaping type that uses *Tipuana tipu* on both sides of the street, planted in a way such as to make their canopies entangle and form a tunnel, is the best choice when seeking a more pleasant microclimate in every season of the year. In contrast, the landscaping type with *Handroanthus chrysotrichus* was the one that had the least influence on microclimate.

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