648: Evaluation of the radius of influence of different arboreal species on microclimate provided by vegetation

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Abstract

The aim of this work is to investigate the effect of vegetation as a means of controlling solar radiation. A method is proposed to investigate different tree species and their efficiency in controlling incident solar radiation on urban environment, as well as the radius of influence of the species in the provided microclimate. This radius of influence is important information which allows quantifying the necessary number of arboreal individuals to achieve the best thermal comfort conditions in urban areas. The study was carried out in the city of Campinas, Brazil. Data were collected beneath the crowns of the studied trees, and in the open simultaneously. Attenuation of solar radiation was analysed as a percentage of integrated daily radiation under the trees in relation to the measured values in the sunlight. Evapotranspiration was analyzed through the method of Priestley-Taylor, adjusted to the local climate conditions. Air and globe temperatures, relative humidity and wind speed were measured at different distances from the tree trunk, to North direction. The analyzed species are those more frequently used in the tree-planting program of the Campinas city government. Obtained results will allow a planning of tree planting in urban areas of the regions, aiming thermal comfort in open spaces. A peculiar behaviour at a distance of 10m from the tree trunk is observed, with an increase of relative humidity, which decreases again at greater distances.

Keywords: thermal comfort, evapotranspiration, solar radiation.

1. Introduction

The accelerated expansion of urban centres brings as a consequence the occupation of green areas with construction and buildings. The climatic changes due to thermal characteristics of different kinds of surfaces present in urban spaces and by their behaviour with respect to the incident solar radiation represent serious impacts on the equilibrium of the environment. These impacts lead to undesirable consequences, reducing thermal comfort and increasing the potential of health impairment of urban populations. By observing the importance of vegetation in the control of the incident solar radiation and as a regulator of the urban climatic changes, it becomes meaningful to qualify and quantify how the vegetation and its influence on environmental parameters such as air temperatures and relative humidity attenuate this radiation. This knowledge permits to obtain guidelines for the elaboration of plans and projects aimed to the improvement of urban thermal comfort.

Several authors have pointed out the benefits of vegetation in improving city climate. Bueno-Bartholomei [1] evaluated the attenuation of solar radiation by different isolated tree species, showing that this attenuation is due to specific characteristics of the analysed species and to individual sample characteristics like structure and density of the treetop, size, shape and colour of the leaves, tree age and stage of growth.

Grimmond et al. [2] observed that the water evaporation on the surface of leaves mitigates air temperatures, due to the loss of latent heat. The so called evapotranspiration, an indirect process includes two biophysical phenomena: the water evaporation of the soil and the transpiration, loss of water in the tree leaves [3].

The purpose of this article is the evaluation of the radius of influence of some arboreal species in the microclimate, through the measurements of environmental parameters and comparison of direct and indirect biophysical effects of vegetation.

2. Methodology

In this research, the microclimatic and instantaneous scales are adopted. This choice of scales allows to analyse *in loco* the degree of influence through mitigation of air temperature and solar radiation incident on individuals and groups of trees.

2.1 Selection of species

The criteria for the choice of species was among those most used in tree planting programs by the city government in the city of Campinas, Brazil. Three arboreal individuals were selected: Ipê-amarelo (*Tabebuia chrysotricha*); Jambolão (*Syzygium cumini*); Mangueira (*Manguifera indica),* (figures 01, 02 and 03).

Fig 1. Ipê-Amarelo (Tabebuia chrysotricha), in leaves, in flowers and leafless

Fig 2. Jambolão (Syzygium cumini*)*

Fig 3. Mangueira (Manguifera indica)

The trees should fulfill such conditions as: to be adult in age, to have representative physical characteristics of the species, and to be located in areas with the adequate conditions for measurements: no shading by other trees or buildings; topography of the ground around the species; accessible area for the measurement equipment; no interference of other people; uniformity of conditions around the trees. These criteria were analyzed according to Lorenzi [4,5]

2.2 Equipment

The equipment used for experiments were two sets of tube solarimeters, type TSL (Delta-T Devices). Sensors from the tube solarimeters were connected to a logger, model DL2, also from Delta -T. One set of equipment was installed at the middle of the tree shadow, while the second one was installed at sun. Data are collected beneath crowns of studied trees and in the open simultaneously. Measurements started at about 7:00 a.m. and finished at about 5:30 p.m. Solar radiation was recorded each ten minutes. This equipment measures average irradiance (in kW/m^2) in situations where the distribution of radiant energy is not uniform, such as beneath tree crowns and greenhouses. The spectral response corresponds to visible and near infrared radiation (350 nm to 2500 nm).

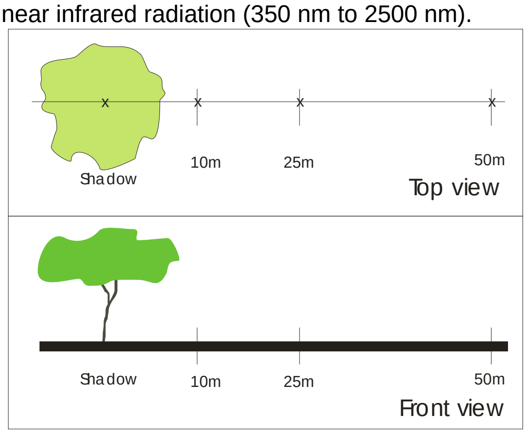

Fig 4. Distance of the measurement points from the tree trunk

For the collection of the data of the environmental parameters (air temperature, relative humidity, globe temperature) sensors were fixed to a tripod at different distances (in the shadow, at 10m, 25m and 50m): In each set there was one temperature and humidity recorder, model Testo 175-1; and a globe temperature recorder, model Testo 175-T2, connected to a temperature sensor, placed in the interior of the globe. All recording sets were protected from solar radiation through especially prepared shelters for this research outdoors (figures 4 and 5)

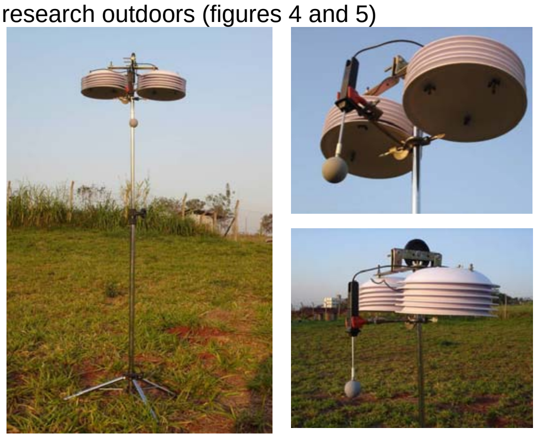

Fig 5. Tripod with the settled protections

Data for wind speed were collected with a Testo anemometer, model 0635-1549, connected to a multifunction recorder, model 445. These data were collected each 10 minutes, during 12 hours throughout the day.

2.3 Methods for analysis of the results

The percentage of radiation attenuated by each the tree and grouping trees is gotten by the methodology of Bueno-Bartholomei (2003). It consists of simultaneously making measurements of solar radiation in the shade and another in the sunlight, in accordance with expression:

$$AT = \frac{S_{sun} - S_{sh}}{S_{sun}} \times 100 \qquad \text{(Eq. 01)}$$

where:

- AT: solar radiation attenuation (%);
- S_{sun}: area that gives the total incident energy (kWh/m2), collected by the solarimeter in the sunlight, in the time interval considered;
- S_{sh}: area that gives the total incident energy (kWh/m2), collected by the solarimeter in the shade, in the time interval considered.

The transpiration rate is calculated through the Priestley-Taylor method adjusted to the local climate conditions by Villa Novas [6]:

$$To = 0{,}0011 \times N \times T_m \times \ln\left(\frac{UR}{100}\right) Af \qquad \text{(Eq.02)}$$

where:

- T_o : daily water consumption (l/day)
- N : photo period (length of the day) = 12 h
- T_m : daily average air temperature (^oC)

UR: daily average relative humidity
Af : estimated foliar area (m^2)

The potential transpiration EP_0 is given as a percentage of water vapour removed from the environment in relation to the maximum capacity of evaporation.

$$EP_0 = \left(\frac{Q_t}{Q_0 * A_{crown}} \right) \times AT \qquad \text{(Eq. 03)}$$

where
- Q_t: Daily energy consumption by the tree (MJ/day);
- Q_0 : Hourly energy consumption by unitary foliar area (MJ/m^2 . h)
- A_{crown}: tree crown area (m^2)
- AT: solar radiation attenuation by tree (%);

3. Results

Figures 6 to 8 show the graphics of the attenuation of solar radiation for the deciduous species *Ipê-Amarelo (Tabebuia chrysotricha)* in three situations: in leaves, leafless and in flowers.

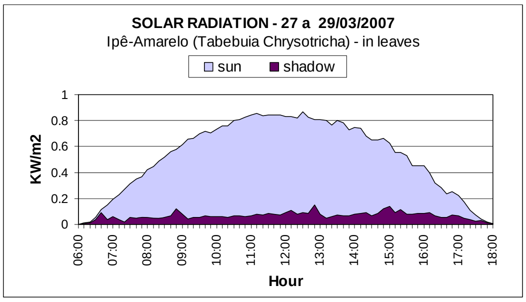

Fig 6. Solar radiation: Ipê-Amarelo (Tabebuia chrysotricha) in leaves

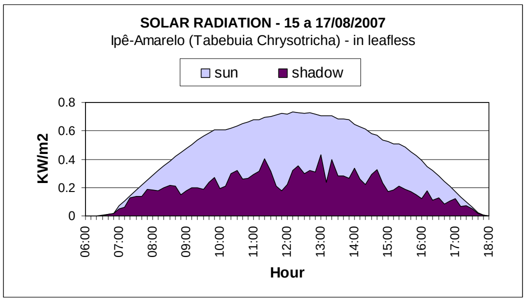

Fig 7. Solar radiation: Ipê-Amarelo (Tabebuia chrysotricha leafless

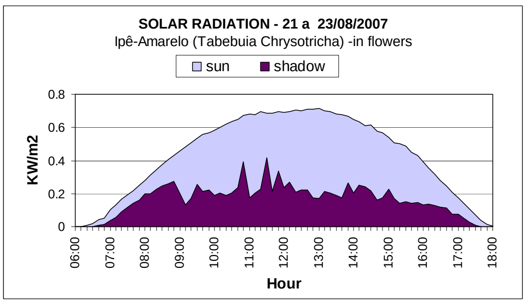

Fig 8. Solar radiation: Ipê-Amarelo (Tabebuia chrysotricha) in flowers

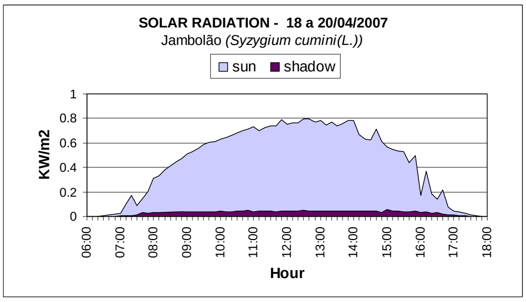

Fig 9. Solar radiation: Jambolão (Syzygium cumini(L.))

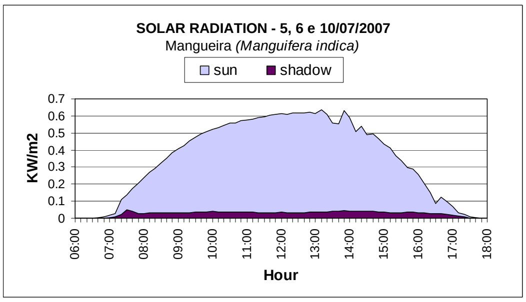

Fig 10. Solar radiation: Mangueira (Manguifera indica)

Figures 9 and 10 respectively show the attenuation of solar radiation for species Jambolão (*Syzygium cumini (L.)*) and Mangueira *(Manguifera indica)*.

Table 1: Results for attenuation of solar radiation

Species Arboreal Analyzed		Solar Rad. (%)	(α)
Ipê-amarelo (*Tabebuia chrysotricha*)	in leaves	81,7	± 1,24
	leafless	46,1	± 1,10
	in flowers	51,4	± 1,07
Jambolão (*Syzygium cumini*)		89,1	± 0.21
Mangueira (*Manguifera indica*)		88,6	± 1.67

Table 1 and figure 11 show the results for attenuation of solar radiation. The best performance for mitigation of radiation is that of Jambolão *(Syzygium cumini)*, 89.1%, followed by Mangueira *(Manguifera indica)*, 88.6%. The deciduous species Ipê-amarelo (*Tabebuia chrysotricha*) presents a high attenuation in the summer, 81.7% and 46.1% in leafless condition.

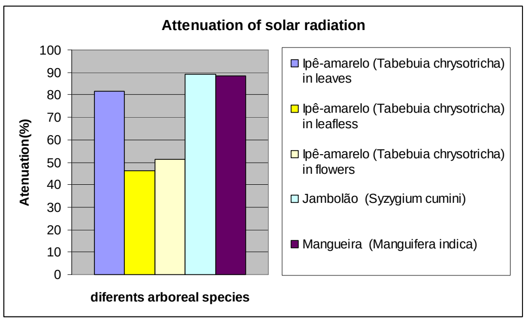

Fig.11. Results for attenuation of solar radiation

Table 2 shows the results for transpiration. The highest rate if that of Mangueira *(Manguifera* *indica)* - 137.6 litres per day and 64.1% evapotranspiration. The least rate is that of Ipê-amarelo (Tabebuia chrysotricha) in flowers, - 62.6 litres per day and 44.7%.

Table 2: Results for evapotranspiration

Species		To (l/day)	EPo (%)
Ipê-amarelo (*Tabebuia chrysotricha*)	in leaves	102.4	37.7
	leafless	70.3	54.3
	in flowers	62.6	44.7
Jambolão (*Syzygium cumini*)		114.2	45.8
Mangueira (*Manguifera indica*)		137.6	64.1

Figure 12 shows the variation of transpiration per day by the different species. The species Mangueira (*Manguifera indica*) liberates greatest quantity of water per day, consequently shows the highest capacity of environment cooling and the least energy available to environment warming.

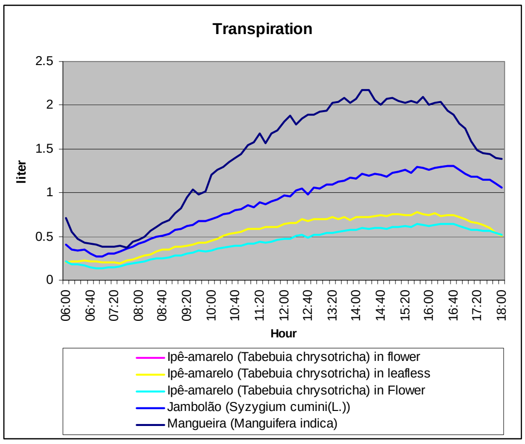

Fig 12. Comparison of transpiration per day by different species arboreal

Figures 13 through 18 show the average air temperature and relative humidity per day for Ipê-amarelo (*Tabebuia chrysotricha*) in the three situations: in leaves, leafless and in flowers.

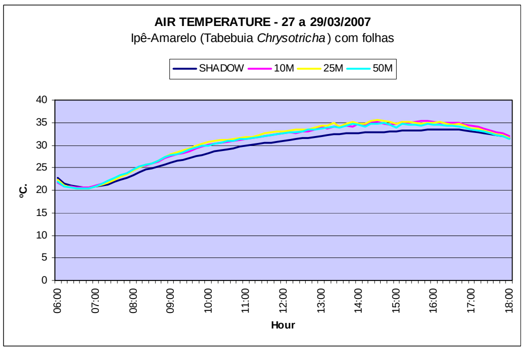

Fig 13. Air temperature: Ipê-Amarelo (Tabebuia chrysotricha) in leaves

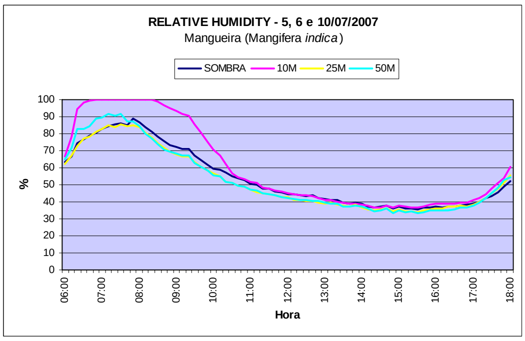

Fig 14. Relative humidity: Ipê-Amarelo (Tabebuia chrysotricha) in leaves

Through variance analysis and comparison of average data, by applying Tukey method, it was observed for Ipê-amarelo (*Tabebuia chrysotricha*) in leaves that there is no influence of distances in the temperature and humidity, with a 1.60°C variation for maximum air temperature at 15h50m, and 18.90% for relative humidity at 11h10m.

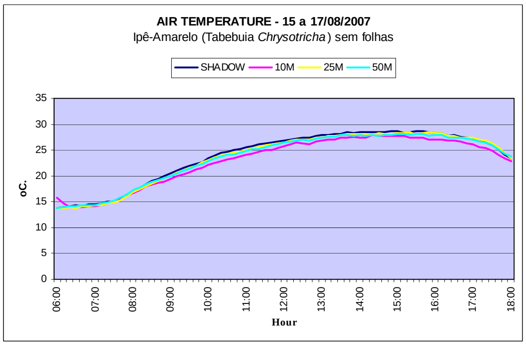

Fig 15. Air temperature: Ipê-Amarelo (Tabebuia chrysotricha) in leafless

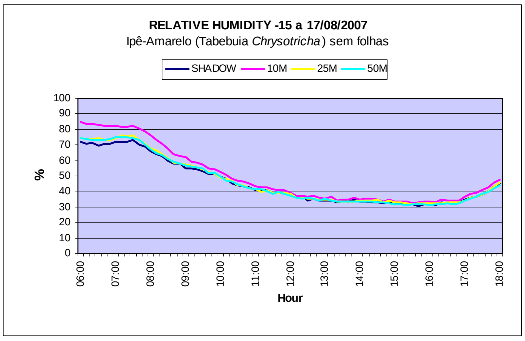

Fig 16. Relative humidity: Ipê-Amarelo (Tabebuia chrysotricha) in leafless

Analyses for Ipê-amarelo (*Tabebuia chrysotricha*) leafless shows that there is little influence of distance on temperature and humidity, with a 0.58°C variation for maximum air temperature at 15h50m, and 4.16% for relative humidity, at 11h10m.

For Ipê-amarelo (*Tabebuia chrysotricha*) in flower there is little influence of distance in temperature and humidity, with a 0.76°C variation for maximum air temperature at 15h50m, and 13,42% relative humidity at 11h10m.

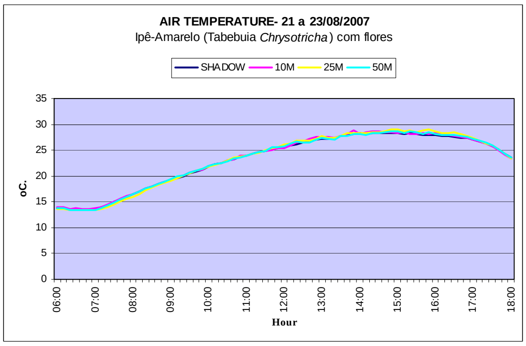

Fig 17. Air temperature: Ipê-Amarelo (Tabebuia chrysotricha) in flower

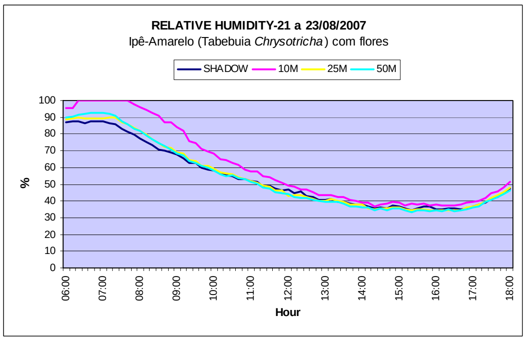

Fig 18. Relative humidity: Ipê-Amarelo (Tabebuia chrysotricha) in leaves

Figures 19 and 22 show the average air temperature and average relative humidity per day for Jambolão *(Syzygium cumini(L.))* and Mangueira *(Manguifera indica)*.

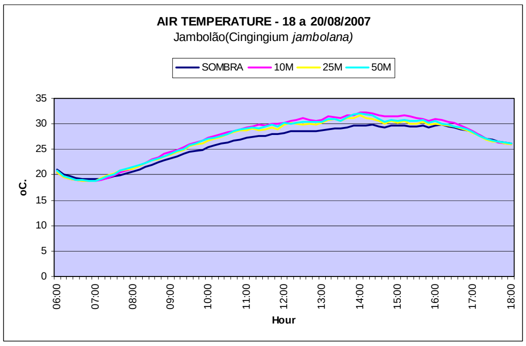

Fig 19. Air temperature: Jambolão (Syzygium cumini(L.))

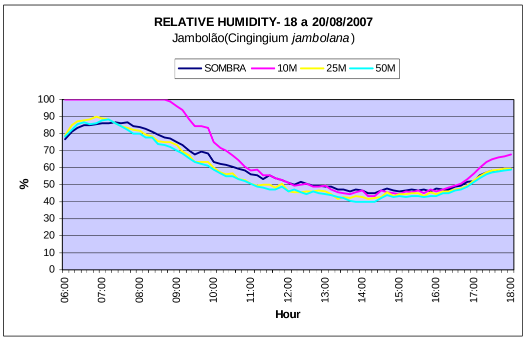

Fig 20. Relative humidity: Jambolão (Syzygium cumini(L.))

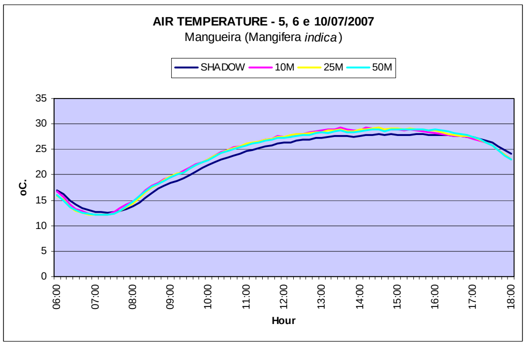

Fig 21. Air Temperature: Mangueira (Manguifera indica)

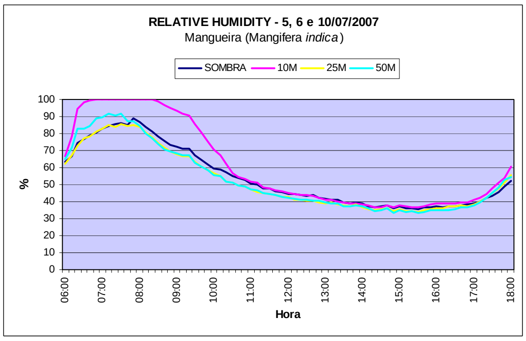

Fig 22. Relative humidity: Mangueira (Manguifera indica)

Through variance analysis and comparison of average data, by applying Tukey method, it was observed for Jambolão *(Syzygium cumini(L.))* that temperatures are influenced by distances at 10m, 25m and 50m and for humidity at 10m and 50m. For Mangueira *(Manguifera indica)*, temperatures are influenced at 10m, 25m and 50m, and humid at 10m.

Figures 23, 24 and 25 show the relation between temperature and relative humidity at different distances for deciduous species *Ipê-Amarelo (Tabebuia chrysotricha)* in the three situations: in leaves, leafless, in flowers. Figures 20 and 21 respectively, show the relation between temperature and relative humidity at different distances of species Jambolão (*Syzygium cumini (L.))* and Mangueira *(Manguifera indica).*

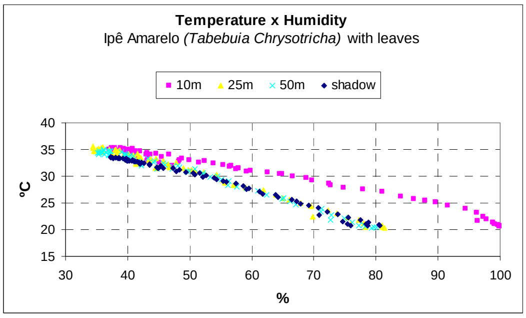

Fig 17. Temperature X relative humidity for Ipê-Amarelo (Tabebuia chrysotricha) in leaves

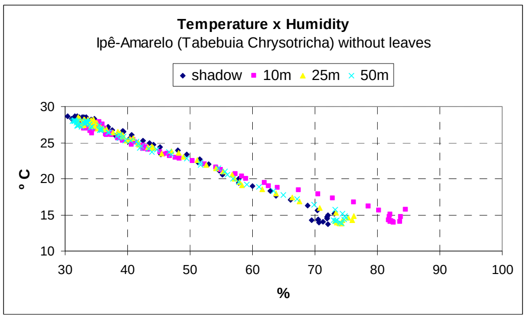

Fig 18. Temperature X relative humidity for Ipê-Amarelo (Tabebuia chrysotricha) leafless

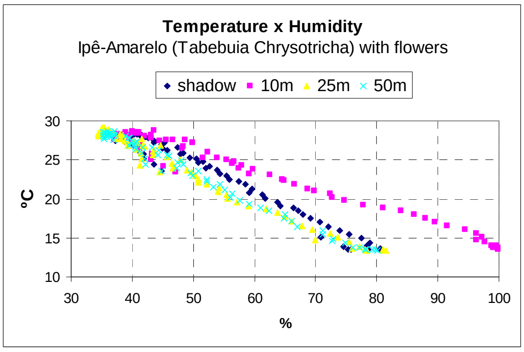

Fig 19. Temperature X relative humidity for Ipê-Amarelo (Tabebuia chrysotricha) in flowers

The average difference between temperatures at sun and in the shade is about 2ºC, during the day. The highest temperature measured for Ipe-amarelo *(Tabebuia chrysotricha)* is at the point located 25 m from the tree trunk. In general, the temperatures measured at 10 m from tree are higher than for the other simultaneous measurements.

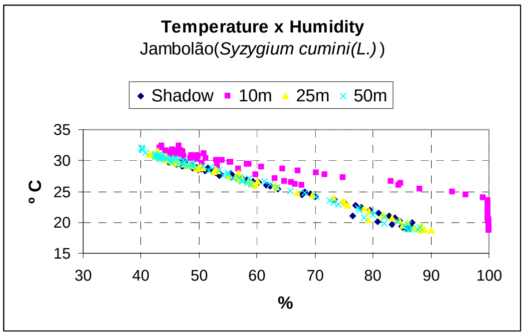

Fig 20. Temperature X relative humidity for Jambolão (Syzygium cumini(L.))

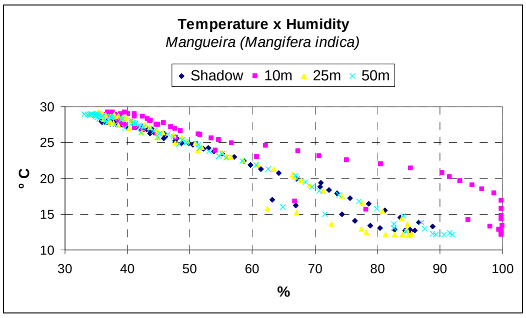

Fig 21. Temperature X relative humidity for Mangueira (Manguifera indica)

4. Conclusion

The species with dense and low canopy and leaves large, such as Jambolão *(Syzygium cumini)* and mangueira *(Manguifera indica)* presented the highest data for solar radiation atenuation and evapotranspiration rate. This phenomenon is possible due to the fact that the structure of the crown hinders the ventilation according to the ascending movement of hot air. Tree species, with the highest solar radiation mitigation and evapotranspiration rate, are those with greater capacity to reduce the temperature of the urban microclimate and energy spent in cooling indoor spaces.

Also, the capacity of air temperature mitigation depends on quantities of individuals and groups, as well as on the characteristics of the sample individual, like structure and density of the treetop, size, shape and color of leaves, tree age and growth.

It is worth noting the peculiar behaviour of these parameters at 10m distance. The relative humidity curves show a different inclination, and air saturation is observed at minimum temperature (early in the morning). The only exception is the leafless Ipê-Amarelo *(Tabebuia chrysotricha),* for which the maxim humidity if 85%. Further studies will be realized to understand this peculiar behavior and the influence of tree characteristics in the provided microclimate.

The benefits of evaluation of the behavior of different arboreal species at different distances is important to the best practices for using vegetation in urban areas aiming energy saving. The trees could be used to shade buildings, besides bringing thermal comfort in outdoor and indoor places. The solar radiation intercepted by crown provides natural protection of outdoor spaces, mitigation of temperatures and reduction of energy spent on cooling indoor spaces. These characteristics of vegetation should be taken into account by professionals of the urban built environment to improve the thermal comfort outdoors, reducing the effect of heat island so ensuring better quality of life for people.

As future research, it is important to evaluate the significance of trees for the built environment. From transpiration estimative, it is possible to quantify energy savings if a building will be shaded by trees so contributing to develop sustainable spaces.

5. Acknowledgements

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