University of São Paulo
"Luiz de Queiroz" College of Agriculture

# Use of different street trees species and their effect on human thermal comfort

Mariana Dias Baptista

Dissertation presented to obtain the degree of Master in Science, Area: Forest Resources. Option in: Conservation of Forest Ecosystems

Piracicaba
2014

**Mariana Dias Baptista**
**Forest Engineer**

# Use of different street trees species and their effect on human thermal comfort

versão revisada de acordo com a resolução CoPGr 6018 de 2011

Advisor:
Prof. Dr. **DEMÓSTENES FERREIRA DA SILVA FILHO**

Dissertation presented to obtain the degree of Master in Science, Area: Forest Resources. Option in: Conservation of Forest Ecosystems

**Piracicaba**
**2014**

**Dados Internacionais de Catalogação na Publicação**
**DIVISÃO DE BIBLIOTECA - DIBD/ESALQ/USP**

Baptista, Mariana Dias
Use of different street trees species and their effect on human thermal comfort / Mariana Dias Baptista. - - versão revisada de acordo com a resolução CoPGr 6018 de 2011. - - Piracicaba, 2014.
95 p: il.

Dissertação (Mestrado) - - Escola Superior de Agricultura "Luiz de Queiroz", 2014.

1. Planejamento urbano 2. Arborização de ruas 3. Clima urbano 3. Imagens termais I. Título

CDD 715.2
B222u

# DEDICATION

I dedicate my dissertation work to my family.
To my parents, Emanuel and Maria Luiza,
who have always loved me unconditionally and
whose good examples have taught me to work hard
for the things that I aspire to achieve.
To my brother Lucas,
who has never left my side and is very special.

## ACKNOWLEDGEMENTS

First and foremost, I would like to thank God. I could never have done this without the faith I have in you, my Lord.

I would like to thank my advisor Prof. Demóstenes, for his trust in my research and willingness to share the fruits of his experience.

I also want to thank to the CNPq Foundation for their financial support for my research.

Furthermore, I am thankful to the Canadian Bureau of International Education, for having graciously supported me and for allowing me to pursue my research in Canada.

I would like to thank Professor James Voogt for his contributions to this research and warm hospitality during my stay in Canada.

I would like to thank Jefferson for his readiness to help during all stages of this work

I thank all my fellow labmates in the Center of Quantitative Methods, especially to those who helped me during the stages of fieldwork and analysis: Léa, Helena, Camila, Diorny, Dalton, Cella and Déa.

I would also like to thank Vulevu, Lãparina, Flamboiã, Xaulim and Farofa. The friendship born during the period of our undergraduate studies sustained me during the academic battlefield of graduate studies.

A special thank you to my second family in Piracicaba: Jãgada, Pag´, Aufred, Matusa e Borça. This project would not have been entirely possible without their friendship and support.

Thanks to my friends, Marcela, Renata, Matheus and Paulinho, for their friendship that has withstood the test of time and distance.

Thanks to my fellow brothers and sisters in Christ from TLC, for their prayers and encouragement throughout these years.

I also want to thank my friends, Giulia, Juliana, Jéssica, Caroline, Letícia and Natália, with whom I navigated the trials and tribulations of my First Canadian Winter.

Last but not least, I would like to thank my entire family, especially my parents Maria Luiza and Emanuel for their ongoing love, dedication and support and my brother Lucas, for being my first best friend.

**EPIGRAPH**


 6966

- That’s great! Are you planting a new tree, Frank? What kind of tree are you planting? Guava? Jackfruit? Mango?
- No, it’s a tree of hope!

**CONTENTS**

## RESUMO


### O uso de diferentes espécies na arborização de ruas e seu efeito para o conforto térmico humano

As contínuas transformações nas áreas urbanas têm trazido muitos problemas relacionados à perda da qualidade ambiental, como por exemplo, a falta de árvores nas ruas. Podemos dizer que a arborização urbana influencia diretamente no conforto térmico das cidades, e as pessoas podem realmente sentir na pele a diferença nas condições ambientais entre uma rua arborizada e outra sem árvores. Por isso, um melhor manejo destas árvores pode beneficiar a qualidade do ambiente local, e consequentemente, a qualidade de vida da população. Um dos primeiros passos nesse manejo é a escolha de espécies, porém poucos estudos abordam o real efeito desta escolha para as condições ambientais futuras do local. O presente trabalho tem como objetivo investigar o efeito do uso de diferentes espécies na arborização urbana para o conforto térmico na cidade de Piracicaba-SP. Para isso, foi medida a temperatura do ar, umidade relativa, velocidade do vento, e temperatura de globo. Os equipamentos foram distribuídos ao longo de três ruas diferentes onde uma das espécies escolhida prevalecia. Sibipiruna, Ipê-de-El-Salvador e Tipuana foram as espécies escolhidas dentre as árvores mais utilizadas nas ruas de Piracicaba. Imagens termais dos pontos de medição e questionários voltados à população local foram utilizados para auxiliar na interpretação. Todos os dados coletados foram aplicados no cálculo do Índice de Conforto Térmico Universal (UTCI). A presença de árvores influenciou diretamente nas variáveis climáticas estudadas. As três áreas apresentaram diferença significativa entre os pontos arborizados e não arborizados, tanto no período seco quanto no chuvoso. As ruas arborizadas apresentaram menor temperatura, maior umidade relativa e menor velocidade do vento (exceto na área 3). Os resultados podem ajudar na tomada de decisões baseando-se no papel das árvores dentro do ambiente urbano, como a melhoria do conforto térmico para a população.


Palavras-chave: Planejamento urbano; Arborização de ruas; Clima urbano; Imagens termais

## ABSTRACT


### Use of different street trees species and their effect on human thermal comfort

The continuous transformation in urban areas has brought many problems related to the loss of environmental quality, such as the lack of trees in the streets. It is commonly understood that urban forestry influences directly on thermal comfort in urban areas, and people can actually feel the different environmental conditions between a street with and without trees in a city. That is why better management of the trees can benefit local environmental quality, and, consequently, the quality of life of its population. One of the first steps of this management is the choice of species, but few studies approach the real effect of this choice for future local environmental conditions. The present work aims at investigating the effect of using different species in urban forestry for thermal comfort in Piracicaba - Sao Paulo. In order to do so, instruments were used to measure the air temperature, relative humidity, wind speed, and globe temperature. These equipments were distributed along three different streets where a single species is planted. *Sibipiruna*, *Ipê-de-El-Salvador* and *Tipuana* were the chosen species of trees commonly used in the streets of Piracicaba. Thermal images of the measuring points and questionnaires aimed at the local people will be used to help interpreter different arrangements. All this data was applied for calculate the Universal Thermal Comfort Index (UTCI). The presence of trees influenced the climatic variables. The three areas showed significant differences between streets with and without trees, both in the dry and rainy period. The streets with trees presented lower temperature, higher humidity and lower wind speed (except in Area 3). In all cases, the trees species had positive effects on human thermal comfort index.The results can help to take choices based on the role that trees should play in a city, such as improve thermal comfort for the population.


Keywords: Urban planning; Street trees; Urban climate; Thermal images

-=

## LIST OF FIGURES

## LIST OF TABLES

# 1 INTRODUCTION

Due to rural exodus that occurred largely between sixties and eighties, over 80% of the Brazilian population lives in urban areas (IBGE, 2010). People migrated from rural areas to cities looking for a better quality of life, however in many cases this long awaited quality has not been found.

In developing countries like Brazil, the urbanization process happens at a fast pace and an inefficient urban planning worsens the consequences of the high rate of population growth. The high density of buildings and impervious areas, intensive use of motor vehicles, lack of suitable land use criteria, and neglect of urban trees have led to the increase in urban temperatures, causing thermal discomfort of the population living there (PAULA, 2004; BUENO, 1998; SETTLER, 1992).

Many studies have evaluated the contribution of urban vegetation to mitigate problems related to thermal comfort, and it is known that besides reducing the variation of air temperature at a microclimate level, it also increases the relative humidity of the air and slows wind speed (GEORGI; ZAFIRIADIS, 2006).

Therefore, planting of trees in urban areas is recommended in environmental projects with the objective of minimizing energy consumption, easing conditions of urban climate and helping maintain thermal comfort for human beings (GEORGI; ZAFIRIADIS, 2006; LIMA; NUNES; SOARES, 2009). According Schuch (2006), street trees are essential in the composition of urban green and play an important role in cities' environmental quality, influencing positively the microclimatic conditions.

As thermal comfort is directly influenced by the characteristics of the immediate surroundings, each tree species' features, such as its size, age, how it is affected by seasonal changes and its location in urban space can also influence the urban microclimate (ABREU; LABAKI, 2010). In their study, Spangenberg et al. (2008) found that leaf area index and density of leaf area of the canopy of a tree has a significant influence on the level of thermal comfort in regions of hot and humid weather. This may be evident especially during the hottest times of the day, where shadowing effect reduces incidence of solar radiation. In the same study, it was shown that the layout of each individual tree may also influence the sensation of thermal comfort, as isolated trees have less impact on the decrease of air temperature compared to alignments.

Vegetation has become an indispensable element in an urban environment, and therefore, the impact of trees must be studied and better understood (SPANGENBERG et al., 2008).

Hence, the aim of this research was to study the effects of using different tree species in the streets of Piracicaba for thermal comfort of the population, based on the following question:

- How does the choice of tree species affect human thermal comfort in streets in Piracicaba?

## 1.1 Background

It is proven that urban forestry has a positive influence on local environmental conditions, which is an important factor for quality of life. Therefore, knowing the consequences of the choice of species and management used for street trees in Piracicaba will bring a better understanding of the actual effect of these variables to microclimate, and thus for the environmental comfort of the local population and may encourage better management of urban trees.

## 2 OBJECTIVES

This project aims to study the effects of using three different street tree species planted in Piracicaba to urban microclimate and consequently human thermal comfort. Meteorological variables, such as wind speed, air temperature and relative humidity, were measured to help understand how it is influenced by the choice of species. Thermal images of the measuring points and questionnaires aimed at the local people were used to help interpret different arrangements

# 3 LITERATURE REVIEW

## 3.1 Climate

Firstly, it is important to explain the difference between “weather” and “climate”. We can consider weather as the state of atmosphere at a given time and point in space, whereas, climate is the “mean” state of an atmosphere-hydrosphere-land surface system over given time and space scales.

In climate studies it is important to identify the scale that will be analyzed. According to Oke (2006), three horizontal scales can be defined:

Microscale: It extends from less than one meter to hundreds of meters, where surface temperature and air temperature can be influenced in very short distances by the dimensions of individual buildings, trees, roads, streets, courtyards, gardens, etc.

Local scale: It can extend from one to several kilometers. It excludes microscale effects, and includes landscape features such as topography. On this scale, it can relate the climate of neighborhoods with similar types of urban design (surface cover, size and spacing of buildings, activity).

Mesoscale: a city influences weather and climate at the scale of the whole city, typically tens of kilometres in extent. A single station is not able to represent this scale.

Oke (2006) also found that the air currents arriving from the rural areas to the city find a different and stratified atmosphere with its own characteristics. Thus, he proposed to divide the urban atmosphere in two layers, which is widely accepted as vertical scales:

Urban canopy layer (UCL): represents the air layer below the level of the roofs. It is produced by microscale processes at street level, between buildings, etc. The active nature of this surface produces considerable complexity of factors acting on the atmosphere.

Urban boundary layer (UBL): it extends above the level of the roofs. It is more representative of the entire city, with features produced by the nature of the urban surface, whose roughness provided by the presence of relatively tall buildings, causes a particular aerodynamics. The wind speed is reduced, but there is an increased turbulence and drag produced by air friction.

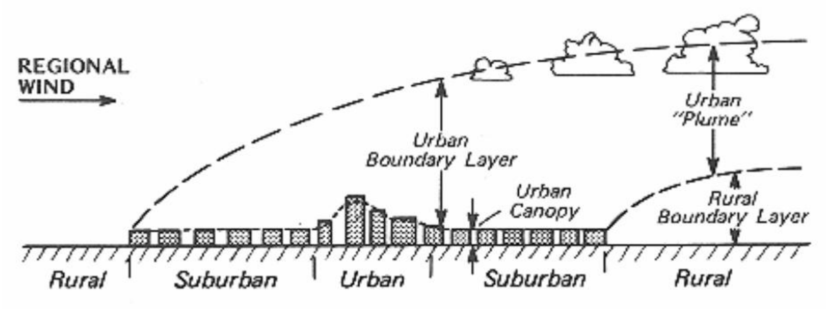



Figure 1 - The urban atmosphere showing the urban boundary layer and urban canopy layer
Source: Oke (1981)

### 3.1.1 Urban climate

The cities and their populations play a fundamental role in the dynamics of global climate change. The large and continuously growing fraction of the world population living in cities uses a disproportionate share of available resources and produces the great part of air pollutants that alter the climate (GRIMMOND et al., 2010) .

All natural climatic variables are influenced by the diverse composition of cities. In general, the temperature of the urban environment tends to be 1 to 3 degrees Celsius higher than in the surrounding areas degrees. The degree of warmth varies according to the type of structure and the nature of materials used in urban areas. Materials such as asphalt, brick and concrete provide a high thermal capacity compared to natural elements. A large amount of energy is stored during the day and released at night when conditions are more stable (ENVIRONMENTAL PROTECTION AGENCY - EPA, 2008; LOMBARDO, 1985).

According to Assis (2005), descriptive studies of urban climate have shown, in both tropical areas as in temperate ones, that climate changes are associated with effects of energy transformation in urban areas due to their morphology, thermal properties of superficial materials and anthropogenic heat production. This leads to a reduction of evaporative and convective cooling, because of soil impermeability, decrease of vegetation cover, and reduction of wind speed due to increase of superficial roughness.

### 3.1.2 Urban Forestry and climate

The expression “urban forest” was used for the first time in 1965, in North America, to emphasize the concept of including an integrative perspective, due to the participation of professionals with different backgrounds, such as foresters, landscape architects, agronomists (KONIJNENDIJK, 2003).

Today, the most accepted and commonly used term “urban forestry” was defined by Miller (1997) as: "‘the art, science and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic and aesthetic benefits trees provide society".

According to Oke (1989) urban trees can be present in a large variety of habitats, from a single tree competing in the urban environment to extensive remnant or planted forest stands. The urban climate mosaic can be influenced in a micro to local scale by every kind of composition. These influences have a direct relation to the “radiative, aerodynamic, thermal, and moisture properties of trees that so clearly set them apart from other urban materials and surfaces in terms of their exchanges of heat, mass and momentum with the atmosphere”. These characteristics result in capacity to promote “shade, coolness, shelter, moisture, and air filtration”, which makes them flexible tools for environmental design.

> Heat gain by the tree is particularly large because of three processes. First, the tree may receive large amounts of reflected short-wave radiation from the canyon walls and floor. Albedo values of urban material are larger than many anticipate (brick 0.20-0.40, stone 020-0.35, concrete 0.10-0.35, asphalt 0.05-0.20 (Oke, 1987)). Second, the long-wave radiant energy input is greatly boosted. This is because of the screening out of part of the cold sky and its replacement by the considerably warmer surfaces of the buildings, plus the fact that all built surfaces are very much hotter than the tree. This more than compensates for the slightly lower emissivity of built materials. Third, although not always the case, it is possible for the air temperature in a street canyon to exceed the leaf temperature of the tree, subjecting it to the advection of sensible heat. This is micro-oasis-type advection and is likely to be most prevalent when the tree is well watered and able to keep leaf temperature moderate via transpiration (OKE, 1989).

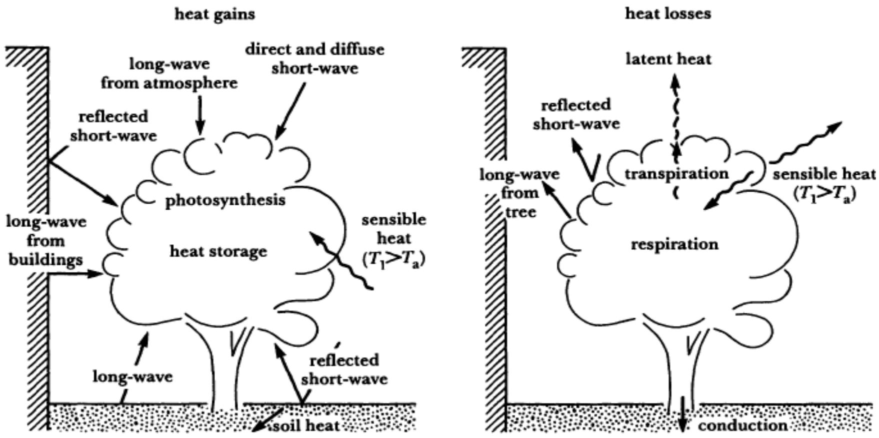



Figure 2 - Scheme of the daytime energy exchanges between an isolated tree and its street canyon environment (Tl: Leaf temperature and Ta: Air temperature)
Source: Oke (1989)

Also according to Oke (1989), the benefits provided by the trees at the microscale are important for the comfort and safety of pedestrians, dispersion of air pollution and energy conservation. However, the site and species selection may cause problems, if it is not done properly.

Therefore, Oke (1989) also emphasized the importance of carefully considering each application. For tropical climates, large trees with open canopies above the trunk provide conditions of comfort, while trees with a denser canopy and lower branches can protect against blowing sand. We can reduce heat loss by cold winds planting shrub clusters around a building, but to protect against strong winds larger trees are needed. Nevertheless, a solution can cause other problems, such as planting an avenue to bring in shade may cause a worsening in the quality of the air circulation is hindered by trees. For this reason, the selection of trees to urban purposes should be very carefully planned.

### 3.2 Selection of trees

Trees in the urban environment are exposed to a number of stresses which are very different from those suffered by trees in typical rural conditions. Therefore, a successful urban forestry depends on the plants functioning as planned, even under stressful environments. Thereby, the first important step to success is the selection and use of appropriate tree species and genotypes, because it improves quality and decreases costs in the establishment and management of urban green areas (SÆBØ; BENEDIKZ; RANDRUP, 2003).

Thus, planning is indispensable to ensure the establishment of an urban forest and street trees. The technical manual of urban forestry, realized by the city of São Paulo (2005), considers that an urban forestry project should respect cultural, environmental and historical aspects of the city. Moreover, planning must consider the urban forest potential to provide comfort for houses, "shading", shelter and food to fauna, biodiversity, decrease pollution, soil permeability conditions and landscape, which all contribute to improve urban conditions.

The selection of tree species is the first step in urban forestry planning, and consequently, some recommendations should be followed. The key features to consider by the City of São Paulo (2005) are: development, size, canopy (shape, density and habit), flowering, fruiting, roots, resistance to pests, diseases and pollution, no toxic principles, adaptability, survival and development at the planting site (due to soil characteristics, for example), as well as maintenance requirement. Furthermore, the restrictions of use should be evaluated by the three-dimensional physical space available at the planting site. It is also important to know about regional vegetation, within and around the city, looking for select species that are recommended for urban forestry and show satisfactory growth and vigor in the area.

According to the manual produced by *Comitê de Trabalho Interinstitucional para Análise dos Planos Municipais de Arborização Urbana no Estado do Paraná* (Interagency Working Committee for Analysis of Municipal Plans for Urban Forestry in the State of Paraná) (2012), a series of recommendations concerning the composition of species should be used for urban planting:

a) A single species for each street must be chosen for the composition, or one to each side of the street or a certain number of blocks, according to its extension. Thus, the monitoring of its development and maintenance of these trees will be facilitated, like pruning when necessary, to maximize the aesthetic benefits.

b) A single species should not exceed the limit of 10 to 15% of the total amount of existing trees in the same neighborhood or region. In general, it is recommended that a minimum number between 10 and 20 species is used in an urban forestry plan.

c) The species’ composition should seek the balance between native and exotic species. Preference should be given to seedlings of native species occurring in the bioclimatic region where the municipality is located, as they are adapted to the local ecosystem, thereby promoting their conservation, as well as the recovery and reintroduction of native fauna.

d) For native species with potential use in streets planting, but for which there is no information of its behavior in the urban environment, it is suggested experimental plantings (a block or part of a street) for monitoring these species to future widespread use.

e) Depending on the location to be wooded (cities with cold climates) , the choice of deciduous species (lose their leaves in a season) is extremely important for the utilization of solar heat on cold days, while in other cities with warm weather, evergreen species are more appropriate.

f) The shape and size of the canopy must be compatible with the three-dimensional physical space available, allowing free transit of vehicles and pedestrians, avoiding damage to facades and conflict with lighting and signposts.

g) In sidewalks, planting should be restricted to species with pivoting roots system, roots must have a deep habit to prevent the destruction and removal of sidewalks, asphalt, walls of deep foundations. It is noteworthy that in urban areas, even trees with pivoting roots, may have shallow roots due to soil conditions or area free of insufficient growth.

h) Prefer species that do not have very large flowers or fruits.

i) Select species that are rustic and resistant to pests and diseases species, since the use of fungicides and insecticides in urban areas is not allowed.

j) Species with resistant ramification must be selected to prevent the fall of branches.

## 3.3 Thermal comfort and index

The American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 55-2013 (2013), defined thermal comfort for a person as 'that condition of mind which expresses satisfaction with the thermal environment'.

Thermal comfort is closely related to the thermal balance of human body. The human being is a homoeothermic animal that maintains, within certain limits, the body core temperature relatively constant independent of ambient temperature (RUAS, 1999). Therefore, it is required to maintain the heat balance between body and environment, when the heat lost to the environment is equal to the heat produced by the body. Humans possess the most effective physiological mechanisms for keeping a heat balance: “the sensible heat loss can be altered by a variation of the cutaneous blood flow and thus of the skin temperature, latent heat loss can be increased by sweat secretion, and internal heat production can be increased by shivering or muscle tension” (FANGER, 1973).

Also according to Fanger (1973), the comfort conditions are expressed in controllable factors, namely the following four main physical parameters which constitute the thermal environment: air temperature; mean radiant temperature; wind speed and vapor pressure in ambient air. Besides the environmental factors, human comfort is also influenced by the activity level (internal heat production in the body) and thermal resistance of clothing.

The assessment of the thermal environment is one of the main issues in bioclimatic research, and more than 100 simple bioclimatic indices have thus far been developed to facilitate it. (BŁAŻEJCZYK et al., 2013)

One of these indices is the Universal Thermal Comfort Index (UTCI). The aim of the UTCI has been to make available a method to measure the outdoor thermal environment combining the interaction of air temperature, wind speed, humidity and radiation fluxes on the human thermo-physiological state in terms of equivalent temperature (BRÖDE; KRÜGER; FIALA, 2013). The reference environmental features are 50% relative humidity (RH), with a vapor pressure not exceeding 2 kPa (kilopascals); air temperature (Ta) equal to the mean radiant temperature (Trm) and; speed wind of 0.5 m/s, measured at 10m high (BRÖDE et al., 2010).

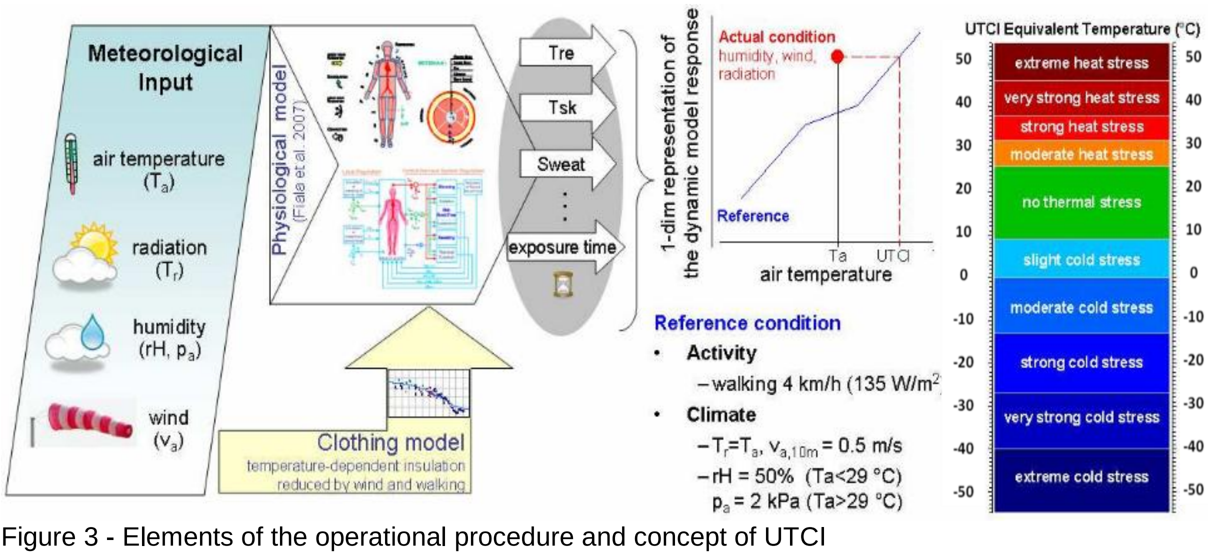



Figure 3 - Elements of the operational procedure and concept of UTCI
Source: Bröde (2013)

## 3.4 Thermal images

According to Voogt and Oke (1997), surface temperature data are important in studies of urban atmospheric conditions. It directly influences the air temperature in the lower layers of the urban environment. It is also an important factor in energy balance of the surfaces, and helps determine the climate indoors. Finally, it promotes exchanges of energy that affect the comfort of the urban population (VOOGT; OKE, 2003).

However, it is a difficult measurement since urban structures present a complex interaction with atmosphere. Furthermore, there is a great variation in microscale due to changes in incoming radiant load depending on steepness, shading and properties of each material. Directional variation of thermal emittance may cause another problem in the interpretation of aerial or satellite thermal images. This effect is called effective anisotropy (VOOGT; OKE, 1997).

Thermal images that provide information on surface temperature can be taken from three different levels. Satellite images can cover an extensive area. However, resolution may be limited, as well as the temporal coverage. The images are impacted by weather and atmosphere conditions. On the other hand, airborne images have a high resolution and can show more details of urban features. However, it is more expensive and the coverage is irregular. Ground-based measurements are another method used when we want to provide a unique perspective of some urban features. It provides a higher temporal resolution and it can avoid corrections due to atmospheric influence (VOOGT, 2003).

In the case of plants, many aspects can influence the surface temperature of leaves. It may be anatomical characteristics, like leaf mass, size, shape, angle, reflectance properties; physical aspects, as incoming radiative energy, air temperature, wind; and biological phenomena, like transpiration, which is regulated by stomatal conductance (MONTEITH; UNSWORTH, 2013). According to Leuzinger, Vogt and Körner (2010) all these variations can occur in an interval of weeks as well as in seconds. The foliage temperature has important consequences for the plant itself, but also for the environment surrounding the plant. It is particularly important for the local to global climate, because the foliage temperature has a significant connection with atmospheric conditions.

Meier and Scherer (2012) found in their results that “canopy temperature of urban trees depends on species-specific properties and the location of the tree”. In their study it was observed that mature trees stay relatively cool in contrast to impervious surfaces, even in a hot and dry situation. For this reason, the knowledge of species-specific canopy temperature and the impacts of urban structures on the energy and water balance of trees is essential to optimise urban climates. However, any recommendation for urban planning objectives should be based on climatological impacts that are desired or that are to be avoided.. The full range of climatological effects should be take into account in an evaluation and optimisation of benefits from urban trees. These include the alteration of “surface temperature underneath trees, air quality, human thermal comfort, the ventilation of street canyons and the energy consumption of buildings” (MEIER; SCHERER, 2012).

## 3.5 ENVI-met

According Bruse and Fleer (1998), ENVI-met is a three-dimensional microclimate model designed to simulate interactions between urban surfaces, vegetation and atmosphere. It allows analysis of the effects of small scale changes in urban design. For example, it can be applied in urban climatology, architecture, building design or environmental planning.

ENVI-met is a freeware program based on different scientific research projects and is therefore under constant development. The model is based on the fundamental laws of fluid dynamics and thermo- dynamics (Bruse, 2004). It includes the simulation of:

- Flow around and between buildings
- Exchange processes of heat and vapour at the ground surface and at walls
- Turbulence
- Exchange at vegetation and vegetation parameters
- Bioclimatology
- Pollutant dispersion

According to Assis et al (2013), firstly, the model must be calibrated to local conditions considering that it is a three-dimensional model in its main module, with a one-dimensional "environment" composed, in the horizontal plane, by the area of nesting and a vertical profile of mesoscale, which goes to the altitude of 2500m above sea level. The model does not assimilate data, there is just a single input information which describe the initial conditions in their various layers: soil (three sub-layers to a depth of 1.75 m), surface (including profiles paving, building and vegetation) and atmosphere;

Initialization' model assumes neutral atmosphere conditions (in terms of static stability), where the potential temperature can be considered constant over the height of the mixing air layer (STULL, 1988 Apud ASSIS et al, 2013). Therefore, it is recommended to start the simulation in the evening, after sunset or before sunrise.

The typical spatial resolution goes from 0.5m to 10m, and temporal resolution is 10 seconds. Thus, the appropriate urban scale application of the model is the design or urban design, in other words, fractions of districts or neighborhoods (ASSIS et al, 2013).

## 4 MATERIALS AND METHODS

### 4.1 Area of study

Piracicaba is a city sited in southeastern of Brazil at an altitude of 546 m and located approximately 160 km from São Paulo city, the capital of the State (Figure 4). It has 364,571 inhabitants, mostly living in the urban area (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA - IBGE, 2010).


Figure 4 - Location of Piracicaba. Source: http://noticias.uol.com.br

According to Souza (2004), the region of Piracicaba is placed at a critical point of transition from currents of general circulation, which causes two distinct periods: one hotter and rainy, and another less hot and drier. Although having this particularity, Piracicaba can be classified according to Koeppen-Geiger's Climate Classification System as "Cwa", which corresponds to a humid sub-tropical climate with dry winters and hot summers, with average temperatures of 24.7°C in the hotter months and 17.7°C in the coldest one. The average precipitation is 1253 mm/year, and it has a monthly average insolation of 201.5 hours.

The field measurements were carried out at 3 different sites, where there is a prevalence of at least 50m continuous of a single tree species planted on the street. In each site, two points of measurement was select: one under the canopy (point A) and another outside (point B).

The selected streets have the same orientation (NW-SE) but different configurations. The first one is located in a high density residential area, with a height/width equal to 0.85, while the second and third ones are in less dense suburban residential areas and their ratios (h/w) are 0.5 and 0.75, respectively. This ratio height/width is an important urban design element that helps create the experience of being in a city and in a place that is comfortable for pedestrians.

The site 1 is located at Caetano Romano Lane, between the geographical coordinates of 22.73° S (latitude) and 47.64° W (longitude), and 544m of altitude. The width of the street is 5m and the distance between measurement points is approximately 25 m (Figure 5).


Figure 5 - a) Street view of area 1; b) Satellite view

The site 2 is located at Armando Cesare Dedini Street, between the geographical coordinates 22.72° S (lat) and 47.66° N (long), and 508m of altitude. The width of the street is 8m and the distance between measurement points is approximately 50m (Figure 6).


Figure 6 - a) Street view of area 2; b) Satellite view

Finally, the third site is located at Beija-flores Street, between the geographical coordinates 22.71° S and 47.67° W, and 477m of altitude. The width of the street is 6m and the distance between measurement points is approximately 75m (Figure 7).


Figure 7 - a) Street view of area 3; b) Satellite view

**4.2 Climate measurements**

The weather stations consist of a register of air temperature and relative humidity (Therma Data, Figure 8) that was properly sheltered from direct radiation. On the outside, a thermo-anemometer (Testo Hot Bulb, Figure 8) and a globe thermometer (Testo 175 T2, Figure 8) were mounted (Conformity and Accuracy tests in Annexe A and B). The equipment was set to record and store data every 15 minutes over a three day period between 9:00 AM and 4:00 PM, during rainy (March/April) and dry (July) seasons. These are seasons when the population suffers more discomfort.

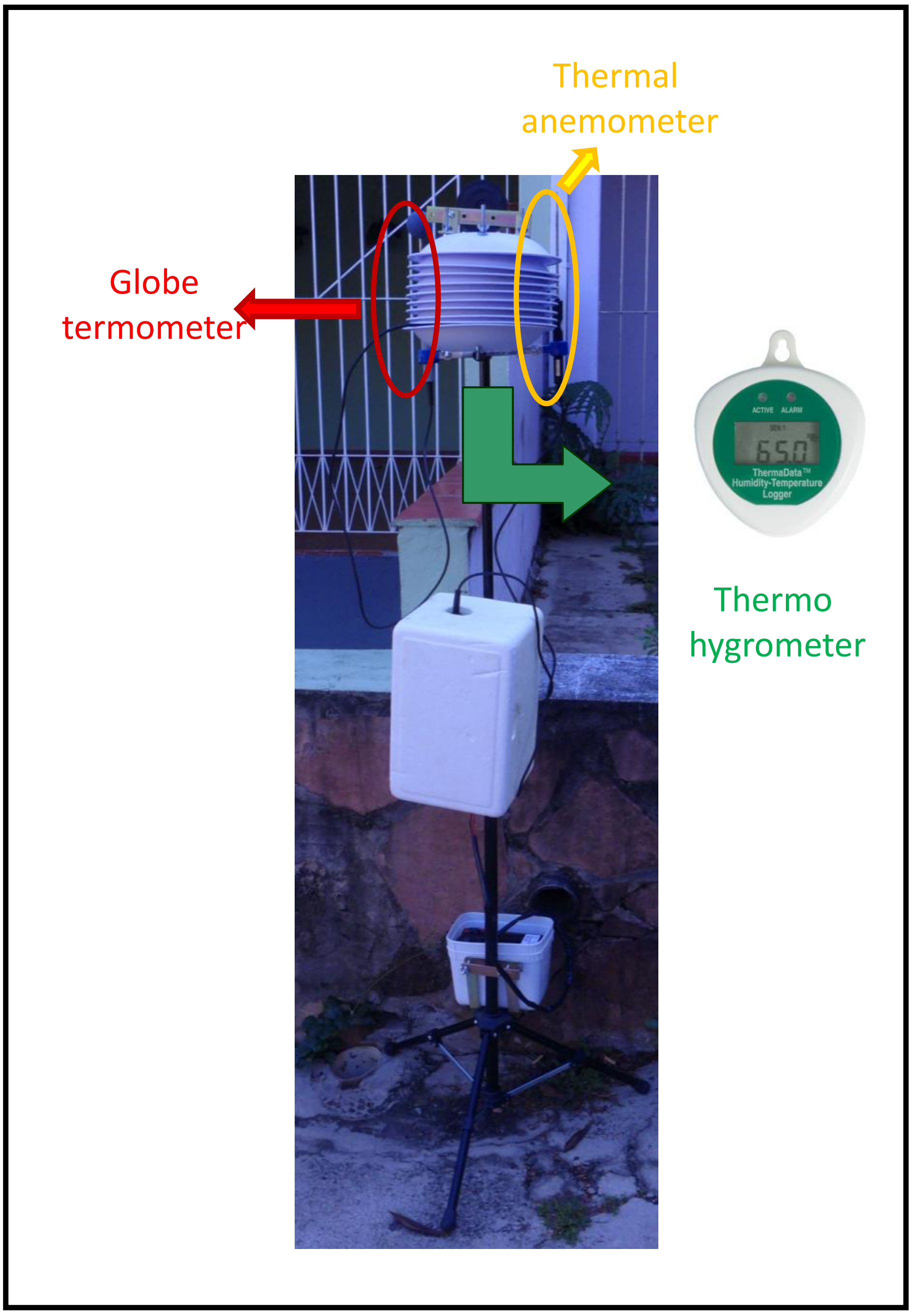



Figure 8 - Weather station

Thermal images were taken from a ground-based view aiming to analyze the surfaces temperatures. An infrared camera, model Flir SC660, was used to capture the pictures, which were taken at three different hours, 09:00 AM, 12:00 PM and 03:00 PM. The images were processed in FLIR Quick Report software, version 1.2. Asphalt's surface temperature was used as a parameter to contrast areas outside and beneath trees canopies.

### 4.2.1 Statistics

Statistical analyzes were performed using SAS program. To match the data processing was required. Thus, the results were raised to the power of 1.5. Subsequently, we applied the f test to verify if the variances were homogeneous, and finally, the Tukey-Kramer method as a significance test at 5% of probability. This is a single-step multiple comparison procedure and statistical test. It is used in conjunction with an ANOVA to find means that are significantly different from each other.

## 4.3 UTCI Index

The software BioKlima (version 2.6) was used to calculate the UTCI index. It employed the weather station's data, such as air temperature, relative humidity, and wind speed.

For the analyses, the calculated values for UTCI were compared in the same level of the Predicted Mean Vote (PMV) proposed by (Fanger, 1973). The extremes levels for cold (Extremely cold; Very cold; and Cold) were considered Very cold, as well as high levels of warmth (Extremely hot; and Very hot) were considered Very hot. The values were not calibrated for Piracicaba condition.

| UTCI | |
|---|---|
| <-40 | Extremely cold |
| -40 a -27 | Very cold |
| -27 a -13 | Cold |
| -13 a 0 | Cool |
| 0 a 9 | Slightly Cool |
| 9 a 26 | Comfortable |
| 26 a 32 | Warm |
| 32 a 38 | Hot |
| 30 a 46 | Very hot |
| >46 | Extremely hot |

| Fanger | |
|---|---|
| -3 | Very cold |
| -2 | Cold |
| -1 | Slightly cold |
| 0 | Comfortable |
| 1 | Slightly hot |
| 2 | Hot |
| 3 | Very hot |

Figure 9 - Comparison between comfort indexes

## 4.4 ENVI-met

Because of logistical problems and safety, the instruments were not exposed during the night and for a very long period of days. For this reason, the model ENVI-met was used in order to simulate some data.

The input data for the simulations in each area are shown in Table 1. The for specific humidity at 2500m was obtained from local airport soundings at Campo de Marte, available from the homepage of University of Wyoming (UWYO, 2013). A scenario was made for each area, including trees, streets and buildings. Input area files are shown in Appendix A, B and C.

Table 1 - Input configuration data applied in the ENVI-met simulations for every area.

| | *Format/ Unit* | *Area 1* | *Area 2* | *Area 3* |
|---|---|---|---|---|
| Start Simulation at Day | DD.MM.YYYY | 01.04.2013 | 12.03.2013 | 15.03.2013 |
| Start Simulation at Time | HH:MM:SS | 6:00:00 | 6:00:00 | 6:00:00 |
| Total Simulation Time | hours | 48 | 48 | 48 |
| Save Model State each | min | 30 min | 30 min | 30 min |
| Wind Speed in 10 m ab. Ground | [m/s] | 1.3 | 1.3 | 1.3 |
| Wind Direction | (0:N..90:E..180:S..270:W) | 73 | 58 | 58 |
| Roughness Length $z_0$ at Reference Point | [m] | 0.1 | 0.1 | 0.1 |
| Initial Temperature Atmosphere | [K] | 293 | 295 | 295 |
| Specific Humidity in 2500 m | [g Water/kg air] | 3* | 3* | 3* |
| Relative Humidity in 2m | [%] | 75 | 100 | 100 |

*Source: http://weather.uwyo.edu/upperair/sounding.html

## 4.5 Species characterizations

Species were chosen based on their size, similar ages, and the frequency with which they are employed at streets on Piracicaba that was verified from data gathered by the Department of Forest Science at ESALQ.

The three chosen species were: *Handroanthus pentaphyllus* (Ipê-de-El-Salvador); *Tipuana tipu* (Tipuana); and *Poincianella pluviosa* var. *peltophoroides* *(*Sibipiruna). These species descriptions were available in Lorenzi (2002).

### 4.5.1 *Poincianella pluviosa var. peltophoroides (*Sibipiruna*)*

This species is a native of the Brazilian Atlantic Forest, which at maturity can have a height ranging from 8 to 25 m, and a Diameter at Breast Height (DBH) ranging from 30 to 40 cm. It has bipinnate leaves with 20 to 25 cm of length (Figure 10).

It flowers from the end of August until mid-November. The inflorescence is conic and the yellow flowers open gradually from the base to apex. Their fruits ripen from late July until mid-September.

It is one of the most employed trees in urban forestry in South-central Brazil, and despite the large and fast development, it does not produce aggressive roots and it should be a good option for urban forestry, in the ornamentation of public roads, squares and even on sidewalks. By having a medium to fast growth, it is also recommended for mixed plantations in degraded land

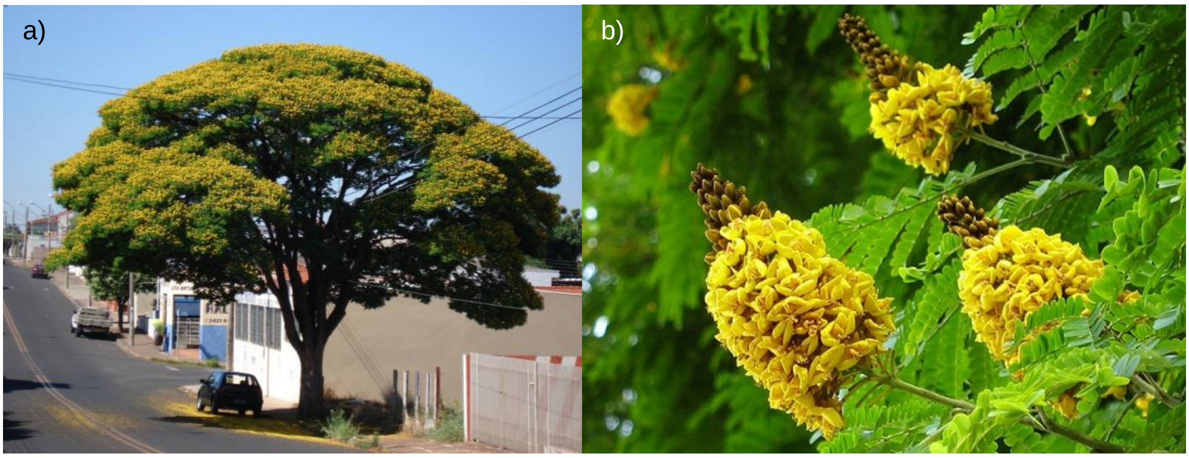


Figure 10 – (a) Sibipiruna tree on the street; and (b) Flower' details.

### 4.5.2 *Tipuana tipu* (Tipuana)

This species is originally from Bolivia and northern Argentina; it is a semi-deciduous to deciduous tree that can reach 15m in height. It presents vigorous ascending dense branches, forming a rounded leafy canopy (Figure 11).

It has odds pinnate leaves with 8-10 leaflets and one at the tip, and small axillary inflorescences, yellow colored, that appear between September and December.

It is frequently employed in parks and used as an urban street tree in the south and southeast of the country. It has a remarkable ornamental effect during flowering. This tree provides great shade and can be included in the landscape composition of large gardens and planting in large avenues. It has a fast growth and good tolerance to adverse conditions.

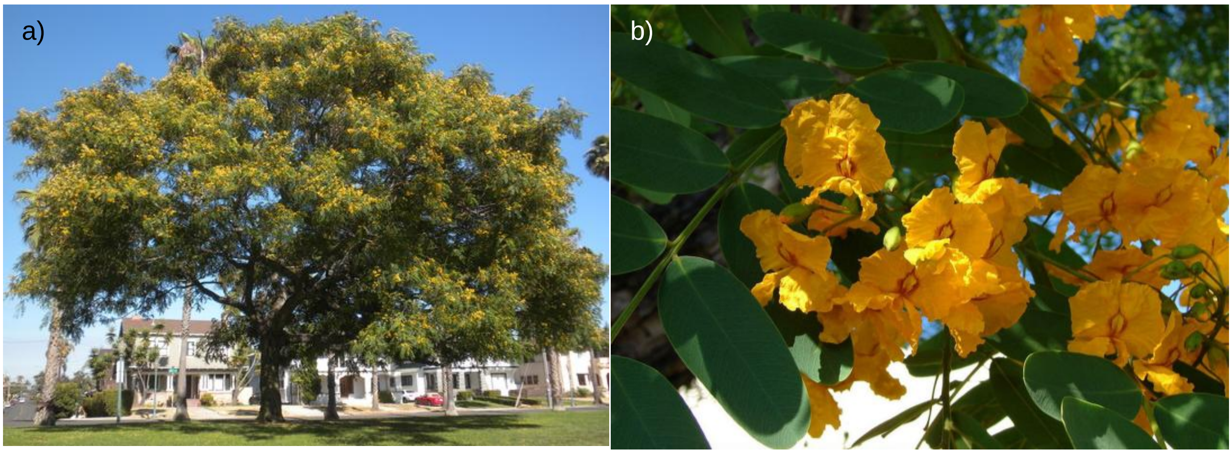


Figure 11 – (a) Tipuana tree on the street; and (b) Flower' details.

### 4.5.3 *Handroanthus pentaphyllus* (Ipê-de-El-Salvador)

This species is originally from Central America; trees can reach 35m in height and a trunk diameter of 150 cm, and the canopy often reaches 30m in diameter. They present pinkish flowers between the end of winter and beginning of spring (September-October). Their canopies have a high leaf density, with semi-deciduous to deciduous foliage (Figure 12).

Largely employed in Brazilian urban forestry, they should preferably be planted in large squares and parks because of their large size.

Figure 12 – (a) Ipê tree on the street; and (b) Flower' details.

## 4.6 Surveys

The pedestrians' perception of thermal comfort was assessed by a questionnaire, which was applied at the same time as quantitative measurements were gathered, trying to find a relationship between the values obtained in the data analyses and responses in the survey.

Data for characterization of the interviewed population, such as gender, age, weight, height, type of clothing and performed activity were collected, as well as data for validation of comfort indices, such as the thermal sensation at the time of the interview and thermal preference, and these questions were based on the Predicted Mean Vote (PMV) suggested in Fanger (1994).

Moreover, some additional questions about pedestrians' perception of urban trees were asked. They were divided in dichotomous questions (yes or no), multiple choice, and open-ended questions. (Appendix D)

# 5 RESULTS

## 5.1 Microclimate data

As expected, there are differences in microclimatic conditions between streets with and without trees. If we observe all three areas, generally, we can note that temperature and wind speed values were lower for streets with trees, and the relative humidity had higher values for these locations.

### 5.1.1 Air temperature

Air temperature is the easiest weather parameter to relate with human comfort. It is directly influenced by radiation and consequently, by the kind of surface in surrounding areas.

In table 2, it is shown the results of mean and standard deviation for each area in different seasons (dry/rainy) and conditions (sun/shadow).

Table 2 – Results of statistical analysis

| Area | Species | Season | Condition | N | Mean | Std Dev |
|---|---|---|---|---|---|---|
| 1 | Sibipiruna | Rainy | shadow | 87 | 27.7 | 11.4 |
| 1 | Sibipiruna | Rainy | sun | 87 | 28.9 | 16.1 |
| 1 | Sibipiruna | dry | shadow | 87 | 21.7 | 20.1 |
| 1 | Sibipiruna | dry | sun | 87 | 24 | 25.8 |
| 2 | Tipuana | Rainy | shadow | 86 | 27 | 20.8 |
| 2 | Tipuana | Rainy | sun | 86 | 29.2 | 26.7 |
| 2 | Tipuana | dry | shadow | 87 | 23.9 | 25.4 |
| 2 | Tipuana | dry | sun | 87 | 25.4 | 27.5 |
| 3 | Ipê | Rainy | shadow | 87 | 27.6 | 16.4 |
| 3 | Ipê | Rainy | sun | 87 | 29.7 | 18.5 |
| 3 | Ipê | dry | shadow | 77 | 21.1 | 22.9 |
| 3 | Ipê | dry | sun | 77 | 22.4 | 25.8 |

In Area 1, we can observe the difference between air temperature in street without trees and with *Sibipiruna*, both in the dry and rainy periods (Figures 13 and 14). The average air temperature was 21.7°C at point A (shade), while at point B (sun) it was 24.0°C during the dry season, with a significant difference of 3.3°C, in a level of 5% of significance (p value < 0.0001). For the rainy period, the average air temperature at point A was 27.7°C, and 28.9°C at point B, presenting a significant difference of 1.2 °C (p value < 0.0001).

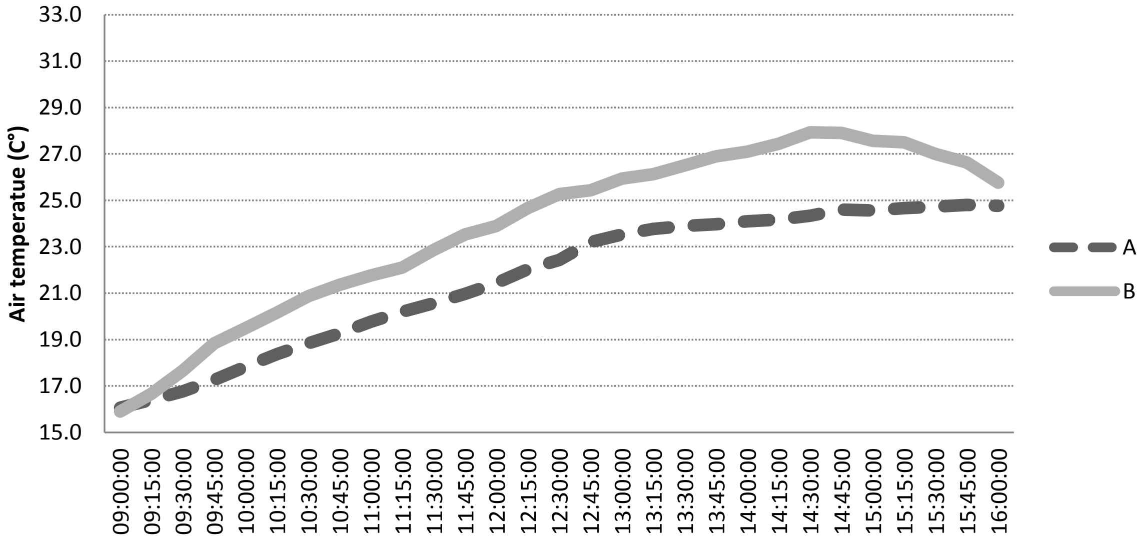



Figure 13 - Hourly average of air temperature in area 1 during the dry season

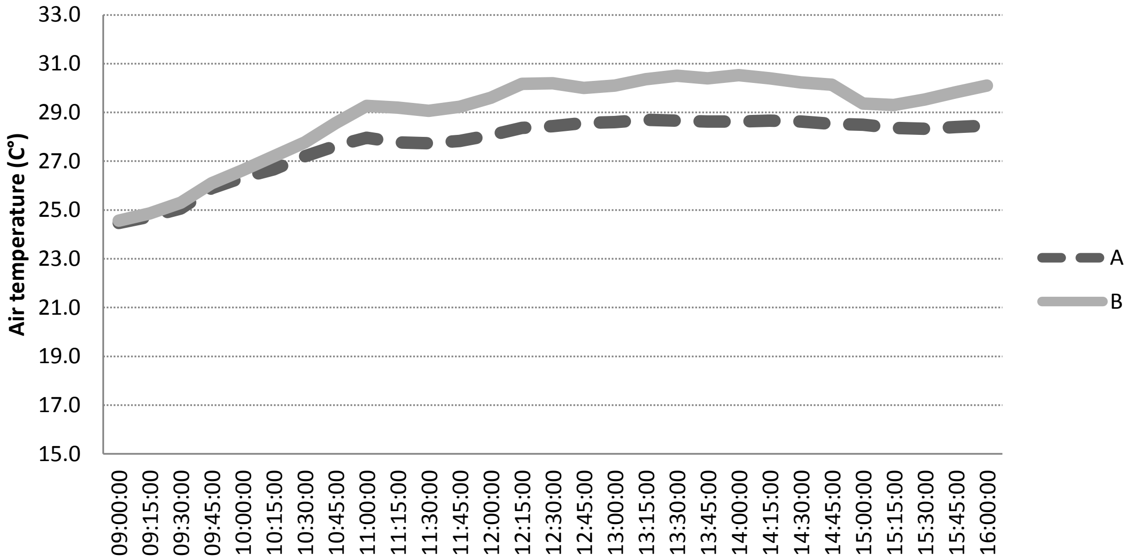



Figure 14 - Hourly average of air temperature in area 1 during the rainy season

During the dry season the temperature range reached 12.2°C in a period of 5 hours and 30 minutes (elapsed time between the recording of minimum and maximum temperature) in the street without trees, while in the street with trees the difference between the maximum and the minimum temperature was 8.7 °C, which happened after 6 hours and 30 min. In the rainy season, the temperature range reached 6.6°C in the street without tree, and 4.5°C in the path with trees, in a period of 4h30min and 4h50min, respectively.

These data illustrate the effect of trees in urban environment, as they protect from solar radiation, the temperature range in the shaded area is not so large and the increase of air temperature is more gradual, in other words, it occurs over a longer period of time.

In Area 2, we can also observe the difference between air temperature in street without and with *Tipuana* trees, in both periods (Figure 15 and 16). The average air temperature at point A was 23.9°C and it was 25.4°C at point B in the dry season, with a significant difference of 1.5°C (p value< 0.0001). For rainy season, the average temperature was 27.0°C at point A and 29.2°C at point B, with a difference of 2.2°C (p value< 0.0001).

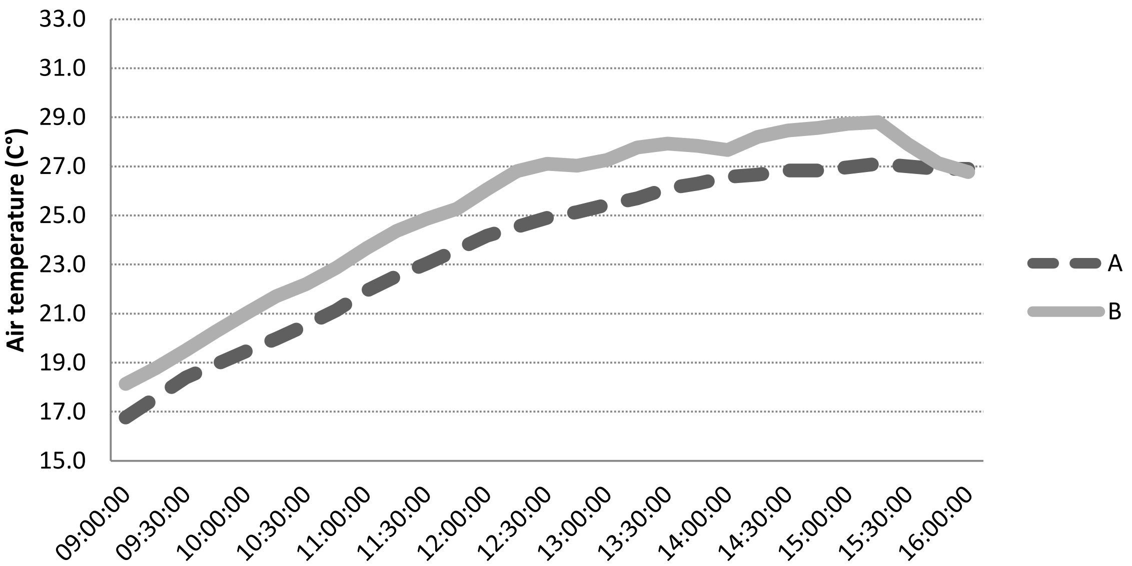



Figure 15 - Hourly average of air temperature in area 2 during the dry season

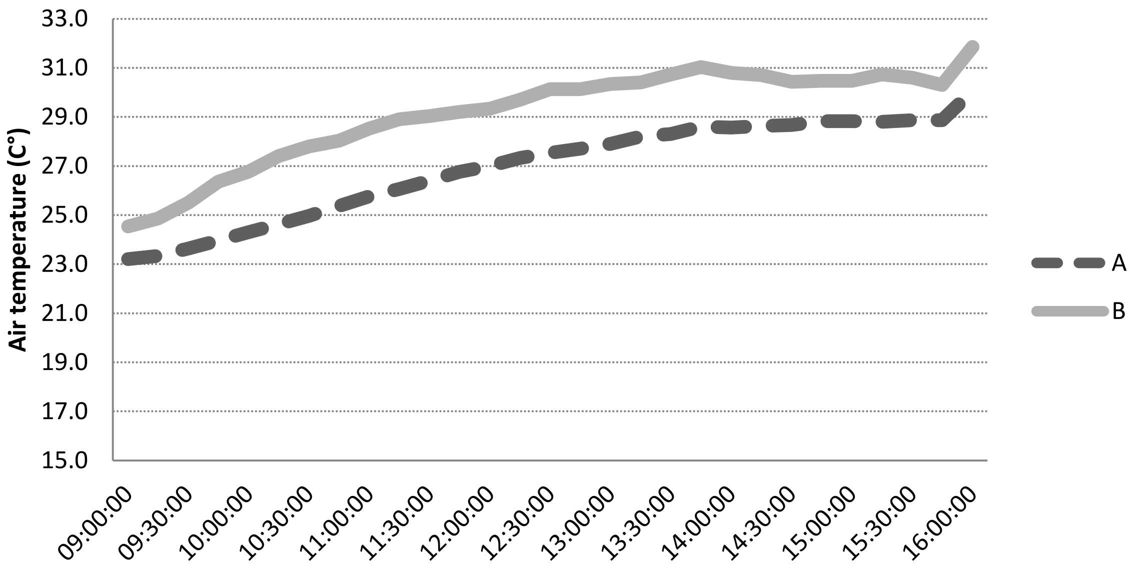



Figure 16 - Hourly average of air temperature in area 2 during the rainy season

During the dry season the temperature range reached 10.7°C in the street without tree, while in the path with trees the difference between the maximum and the minimum temperature was 10.3 °C. While in the rainy season, the temperature range reached 6.9°C in the street without tree, and 6.0 °C in the path with trees.

Finally, in Area 3, the difference between air temperature in street without trees and with *Ipês* is shown in Figure 17 and 18, in the dry and rainy periods respectively. The average temperature 21.1°C at point A and 22.4°C at point B during the dry season, with a difference of 1.3°C. In rainy season, the temperature was 27.6°C at point A and 29.7 at point B, with a difference of 2.1°C between these sites.

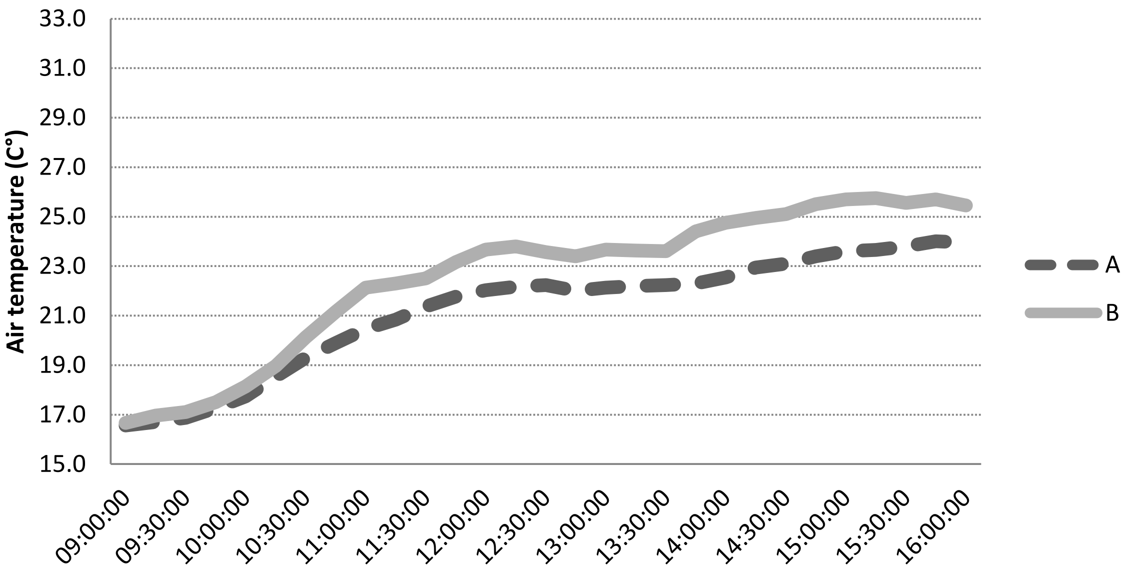



Figure 17 - Hourly average of air temperature in area 3 during the dry season

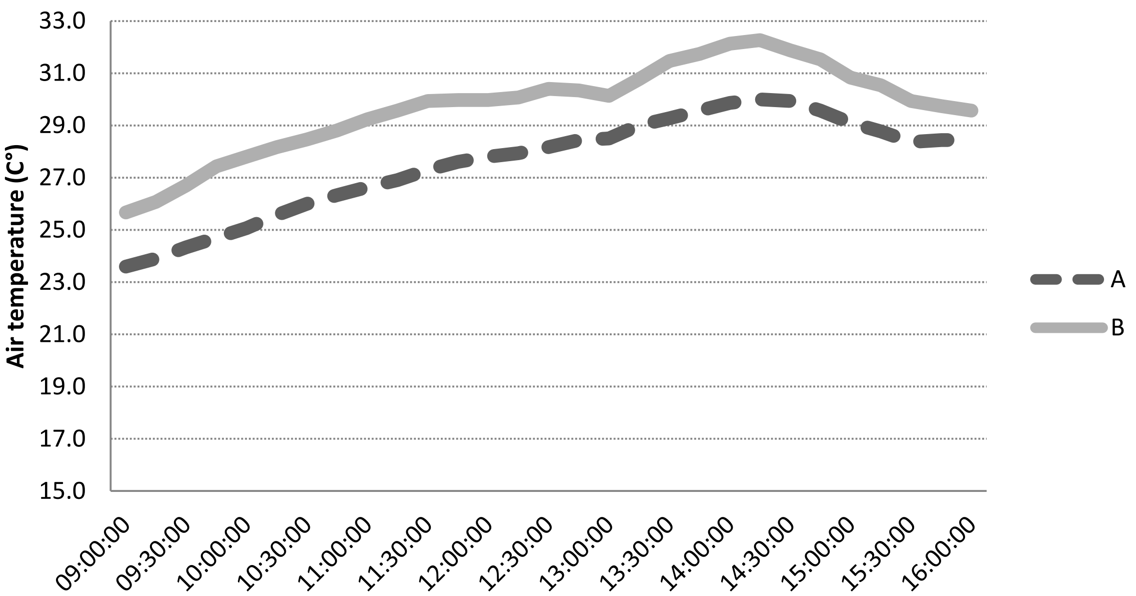



Figure 18 - Hourly average of air temperature in area 3 during the rainy season

During the dry season the temperature range reached 10.1°C in the street without tree, while in the path with trees the difference between the maximum and the minimum temperature was 8.7 °C. In the rainy season, the temperature range reached 6.7°C in the street without tree, and 6.5 °C in the path with trees.

When each area is compared, it can be noticed the influence that trees has on this variable (Figure 19). Observing the results for the dry period, the area planted with Tipuana presented a higher average temperature equal to 23.7 °C, which could be explained by the loss of some leafs during this period, because it is a semi deciduous species. The Sibipiruna's area showed 21.6°C and the street with Ipês 21.2°C, but the differences between averages temperatures were not significant for any area.

For rainy season, a significant difference between average temperatures of Tipuana's area and the other areas was found. In area 1 (Sibipiruna) the temperature reached 27.7°C. In area 2 (Tipuana), it was 26.8°C, and 27.5 in area 3 (Ipês).

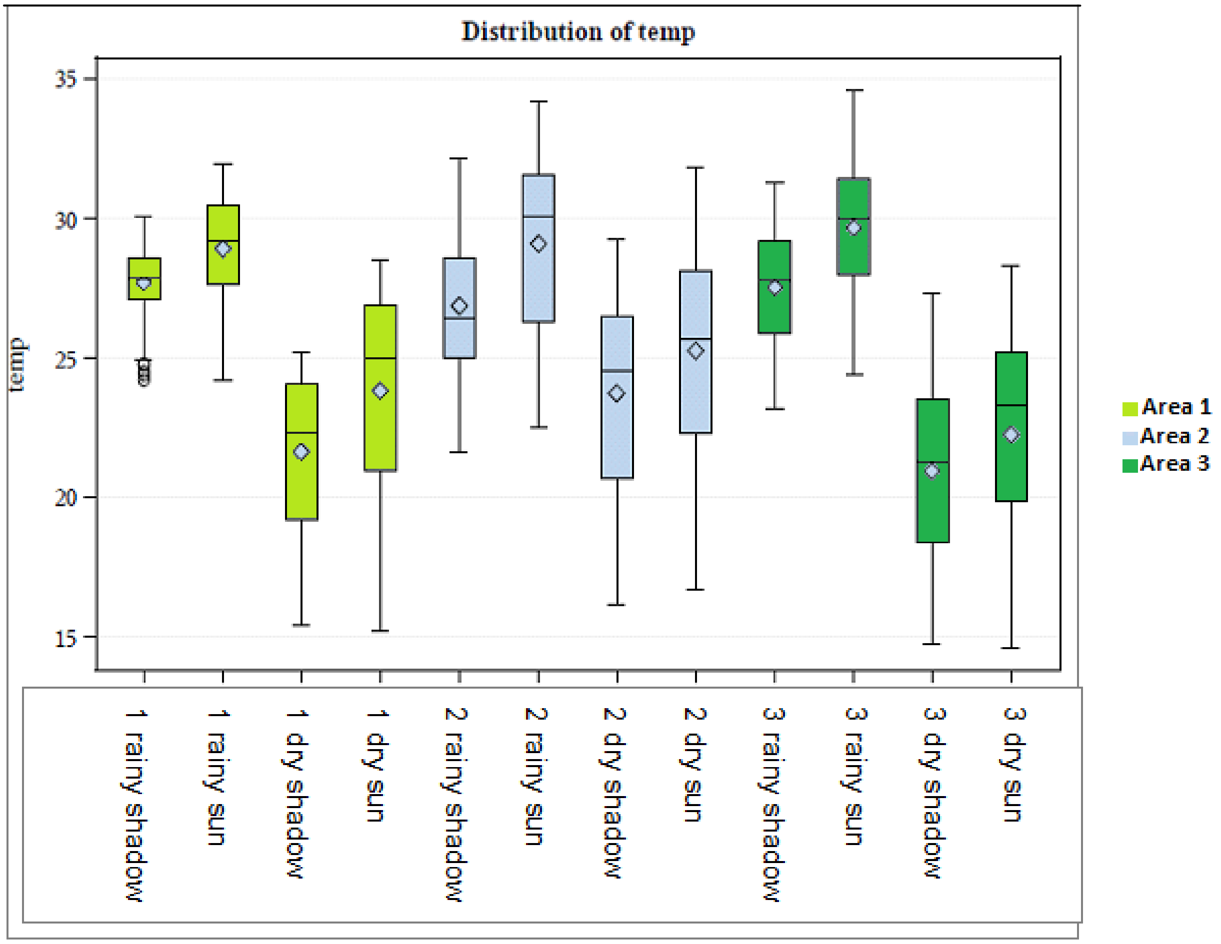



Figure 19 – Distribution of air temperature within each area

Despite the statistical results show significant between certain points, areas can not be compared to each other, since the data were collected on different days. The figure 20 shows the behavior of the curves of the measurements taken by the university meteorological station and the data collected in the experiment station. We can notice the similarity in behavior which evidence that the behavior it was not influenced by species, but by the day of collection.

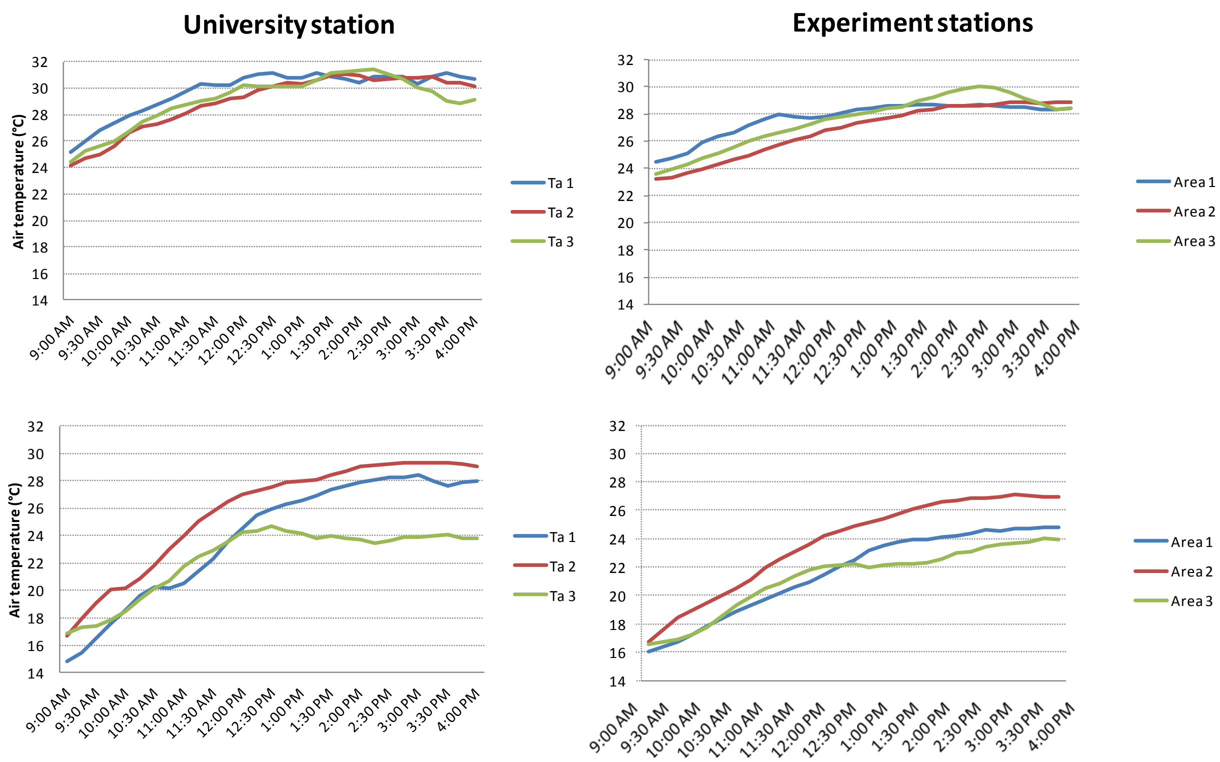



Figure 20 - Air temperature in University station and experiment station in the same day.

### 5.1.2 Relative humidity

The relative humidity has an important influence on human thermal comfort. It is also affected by the presence of plants, and generally, areas with trees present higher values of relative humidity. The difference is showed in the following graphics.

For area 1 during the rainy period (Figure 21), the average of relative humidity for the measurement point under the trees (A) was 67.9%, while for the point that received direct radiation (B) the result was 63.8%. For dry season (Figure 22), the values presented were 63.9% and 56.2%, for point A and B, respectively.

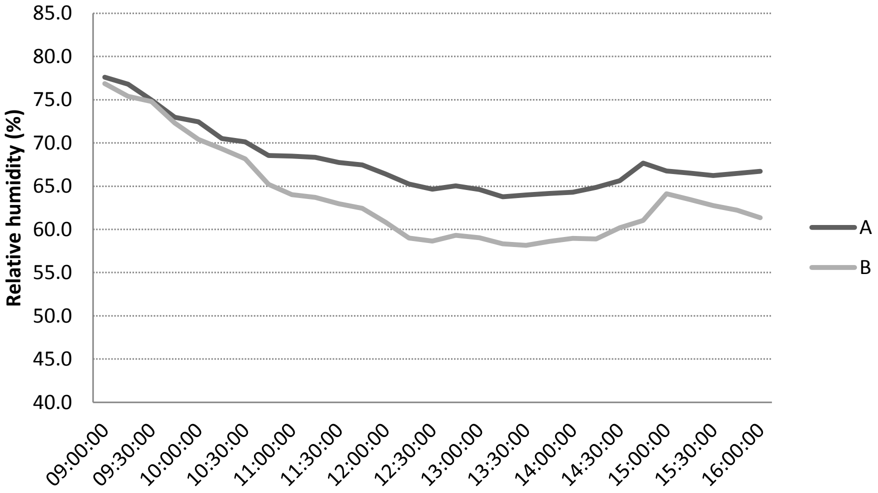



Figure 21 - Hourly average of relative humidity in area 1 during rainy season

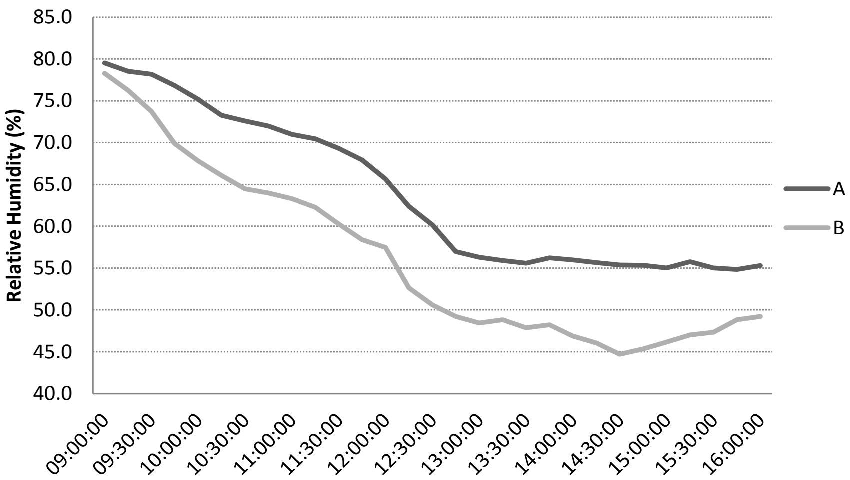



Figure 22 - Hourly average of relative humidity in area 1 during dry season

During the rainy period in area 2 (Figure 23), the average of relative humidity for the measurement point under the trees (A) was 69.4%, while for the point that received direct radiation (B) the result was 62.3 %. For dry season (Figure 24), the values presented were 60.7% and 54.5%, for point A and B, respectively.

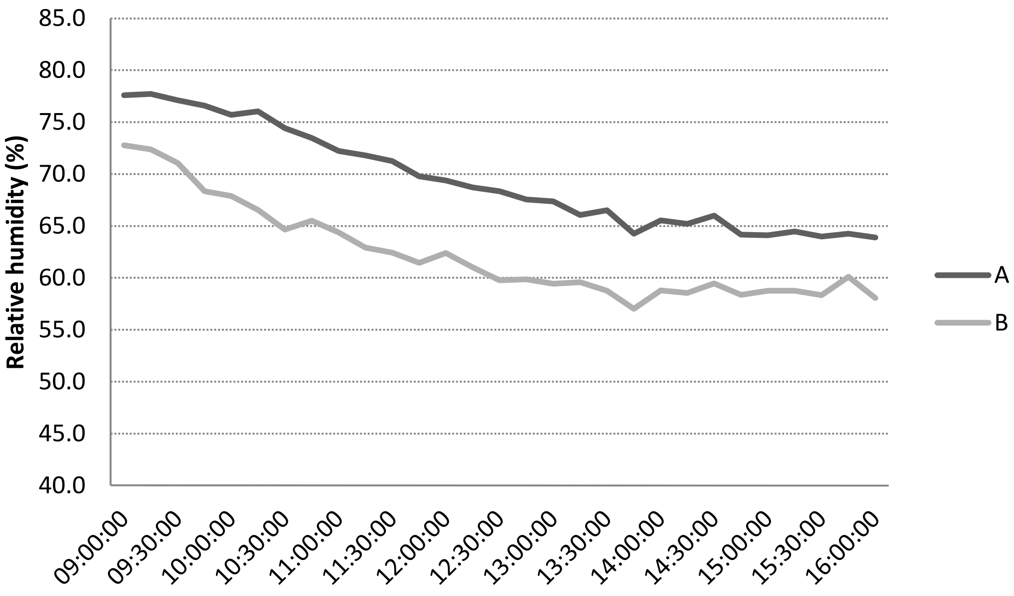



Figure 23 - Hourly average of relative humidity in area 2 during the rainy season

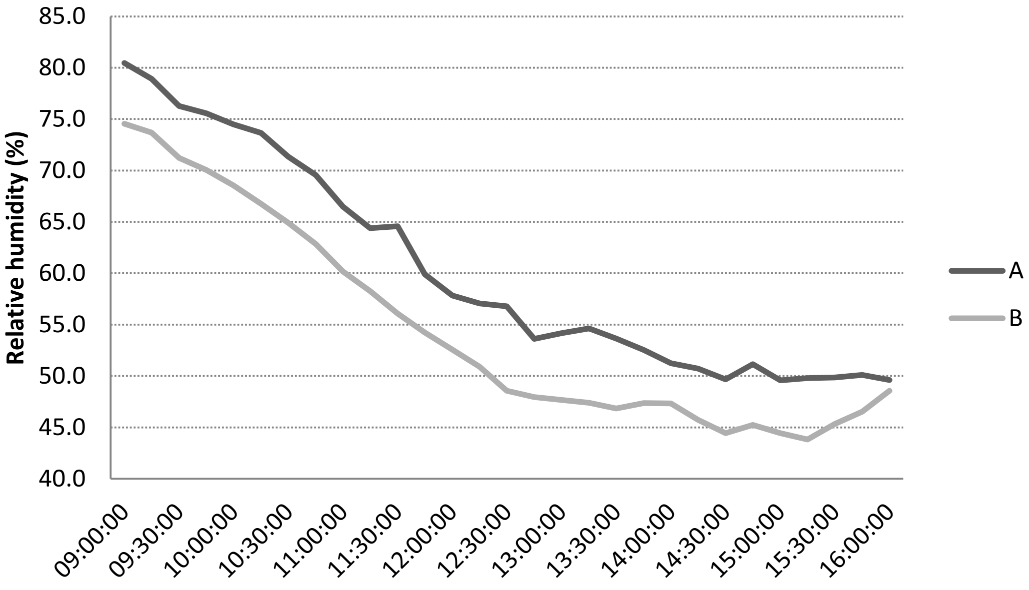



Figure 24 - Hourly average of relative humidity in area 2 during the dry season

Finally, during the rainy period in area 3 (Figure 25), the average of relative humidity for the measurement point under the trees (A) was 69.7%, while for the point that received direct radiation (B) the result was 63.6 %. For dry season (Figure 26), the presented values were 67.1% and 60.2%, for point A and B, respectively.

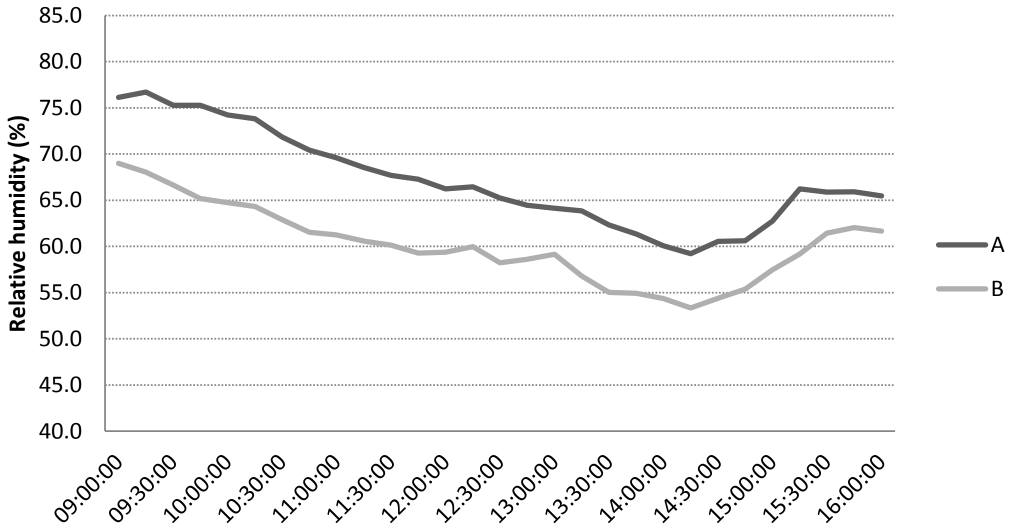



Figure 25 - Hourly average of relative humidity in area 3 during the rainy season

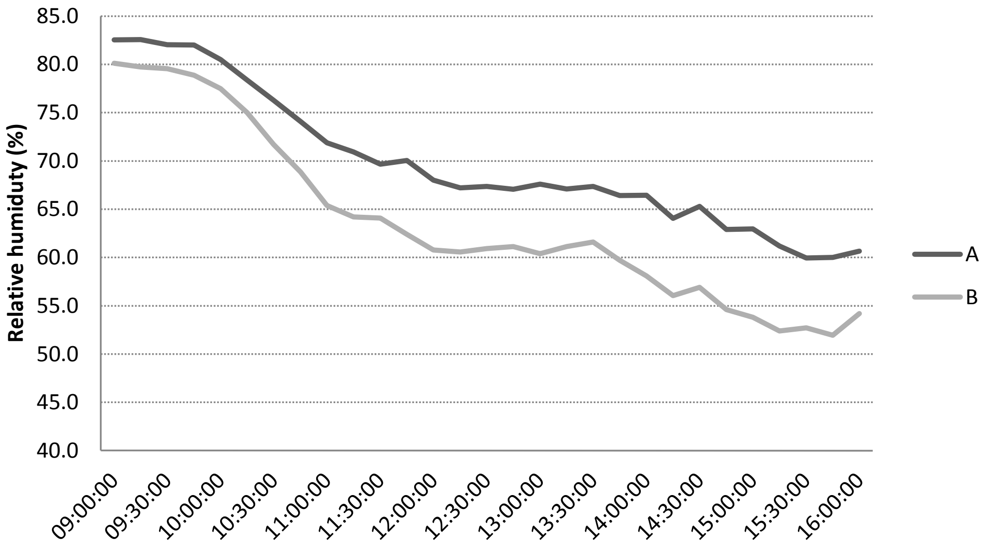



Figure 26 - Hourly average of relative humidity in area 3 during the dry season

### 5.1.3 Wind speed

The wind speed is a complex component of weather parameters and it is influenced by many environmental characteristics. Therefore, it is difficult to interpret. However, it is commonly agreed that trees can reduce wind speed, depending on their size, shape and positioning.

In Figure 27, we observe lower wind speed values for most of the time in areas with trees (A). The average wind speed in area 1 was 0.45 m/s at point A and 0.71 m/s at point B during rainy period. In the dry season, the mean values were 0.47m/s at point A and 0.62m/s at point B.

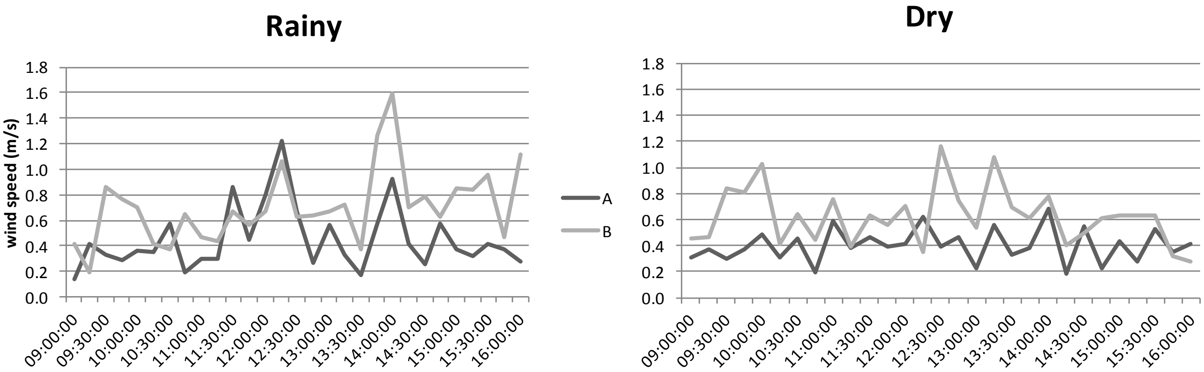



Figure 27 - Hourly average of wind speed in area 1

During the rainy period in area 2, the average wind speed was 0.45 m/s at point A and 0.57m/s at point B. While in the dry season, it was 0.46 m/s at point A and 0.65m/s at point B. These observations confirm the statement that trees have a positive influence in relation to wind speed (Figure 28).

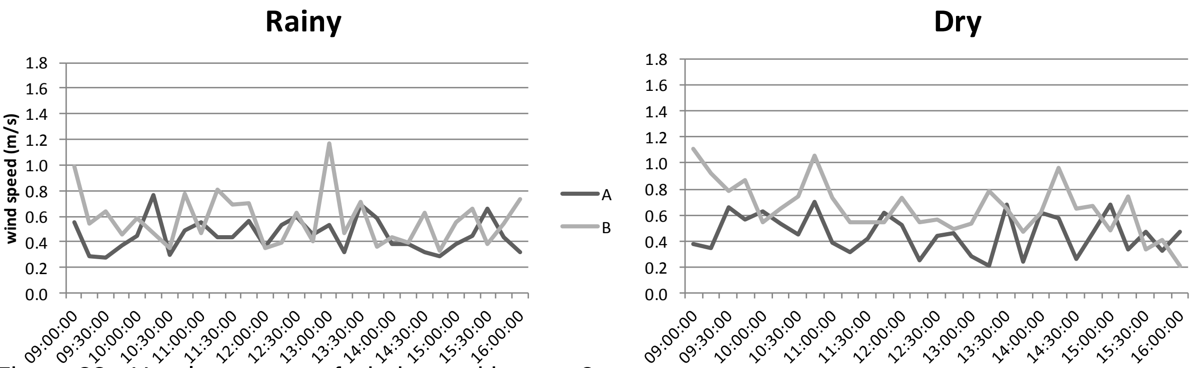



Figure 28 - Hourly average of wind speed in area 2

Nevertheless, the wind speed in the area 3 showed a difference of behavior despite having the presence of trees (Figure 29), point A was located in an area with lots of land not built, which favored the passage of air currents. Therefore, the average values for wind speed were 0.85 m/s at point A and 0.64 at point B, during the dry period; and for rainy season, 0.76m/s at point A and 0.67 at point B.

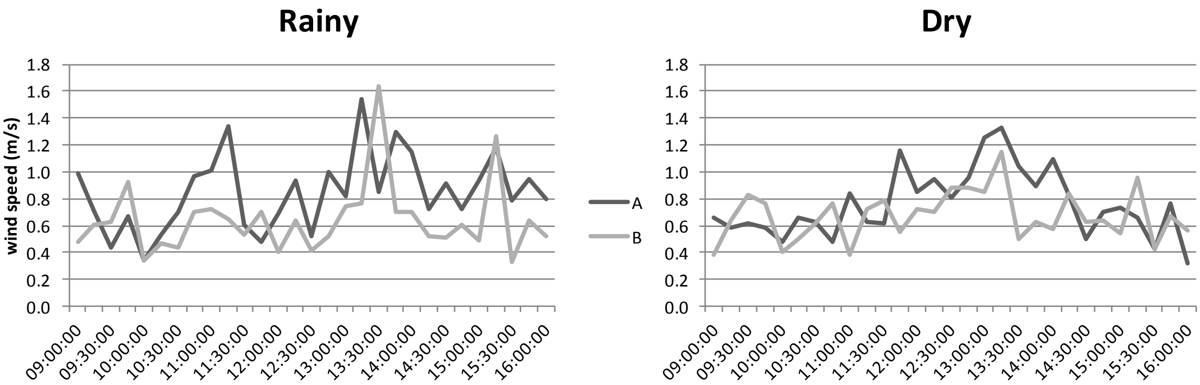



Figure 29 - Hourly average of wind speed in area 3

## 5.2 Surface temperature using thermal images

The surface temperature is an important factor that influences directly the microclimate characteristics, and consequently human thermal comfort. The asphalt surface temperature was analyzed for both periods at three different times.

The images processed in FLIR Quick Report software showed the difference between the asphalt surface temperature outside and beneath trees canopies.

During the dry season, it can be noted that the highest difference between the surface temperatures of asphalt occurs at 12:00PM, due to the high level of radiation incident to that surface. The Figure 30 illustrates this effect, where we can see more red and white in the image (b) than in the image (a). The mean difference in surface temperature between measurements at point A (shadow) and point B (sun) was 15.2°C (Figure 31).

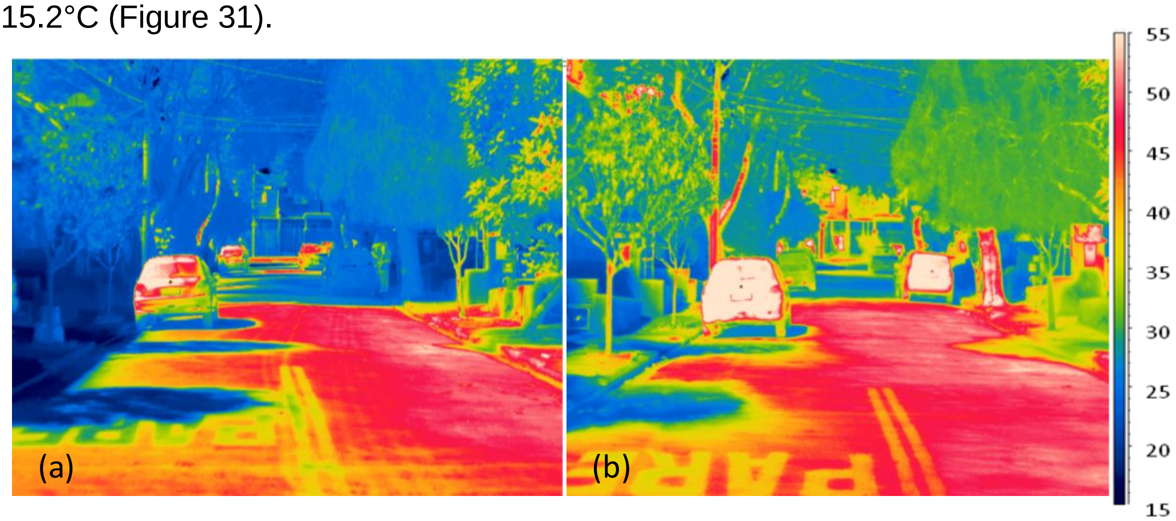



Figure 30 - Thermal images in the dry season: Area 1. (a) 9:00 AM; (b) 12:00 PM. Date: 17/07/2013. Direction: Southeast

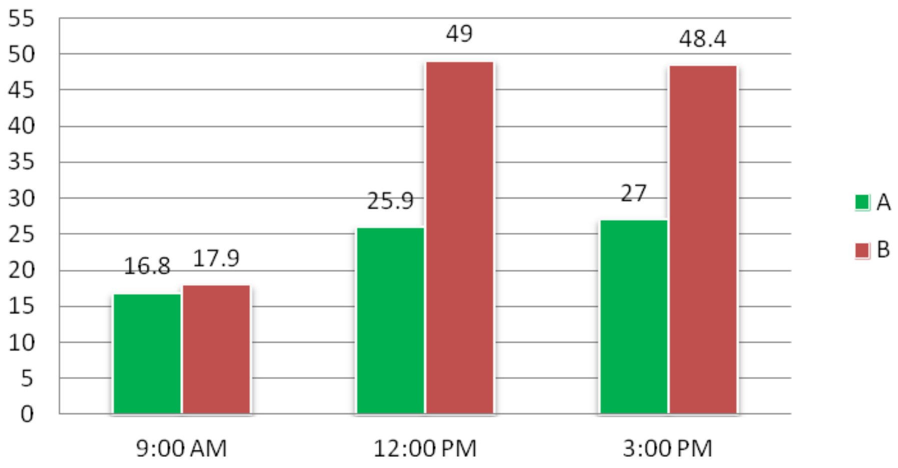



Figure 31 - Average of asphalt's surface temperature in area 1 during dry season

The same fact can be noted in data collected in area 2 during the dry season and observed in Figure 32.

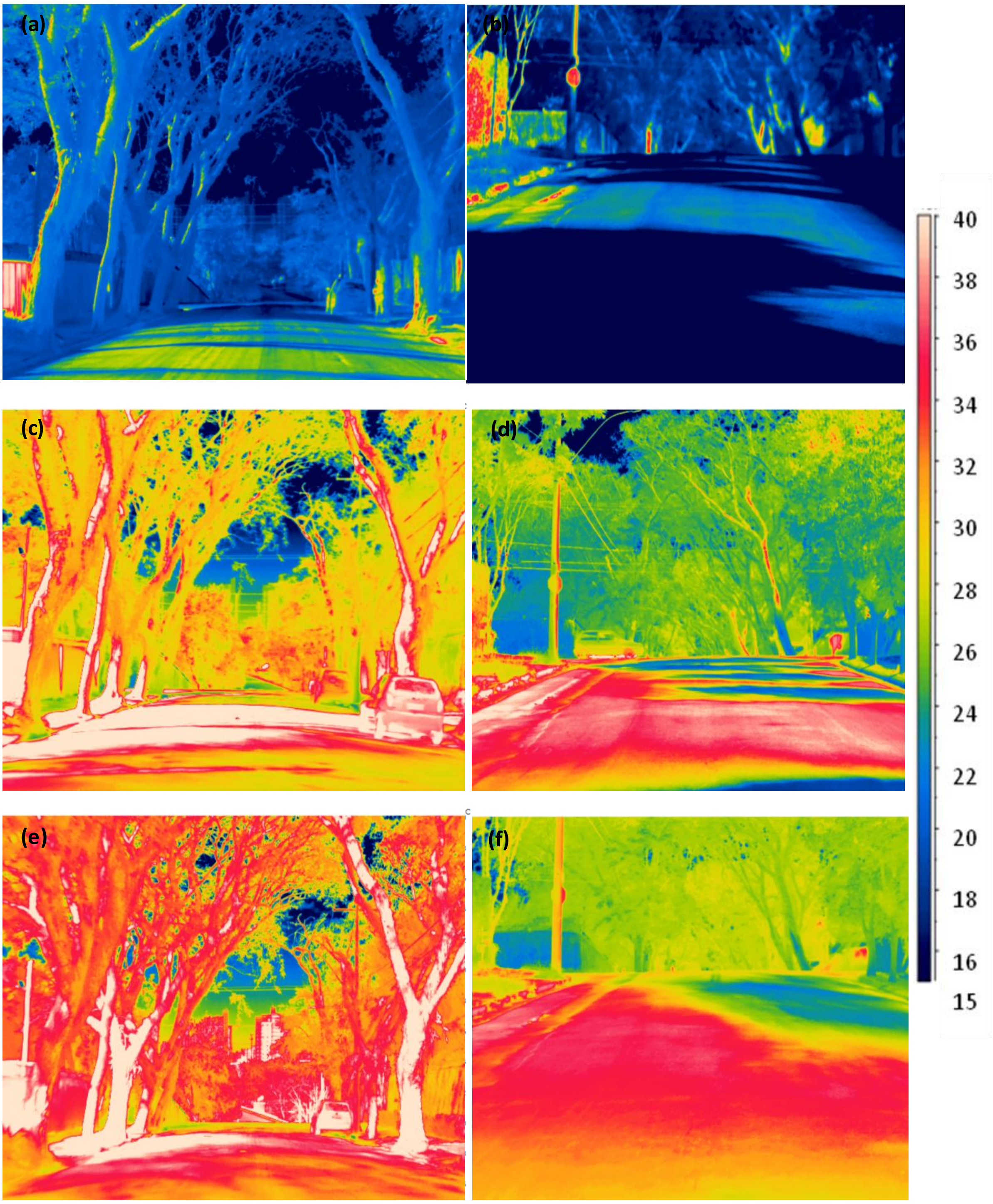



Figure 32 - Thermal images in the dry season: Area 2. (a), (c) and (e) beneath canopies at 9:00 AM, 12:00 PM, and 03:00 PM, respectively (Direction: Southeast). (b), (d) and (f) outside canopies at 9:00 AM, 12:00 PM, and 03:00 PM (Direction: Northwest), respectively. Date: 18/07/2013

The highest value for surface temperature was detected at 12:00PM (44.5°C), and the average difference between point A and B was 10.8°C (Figure 33).

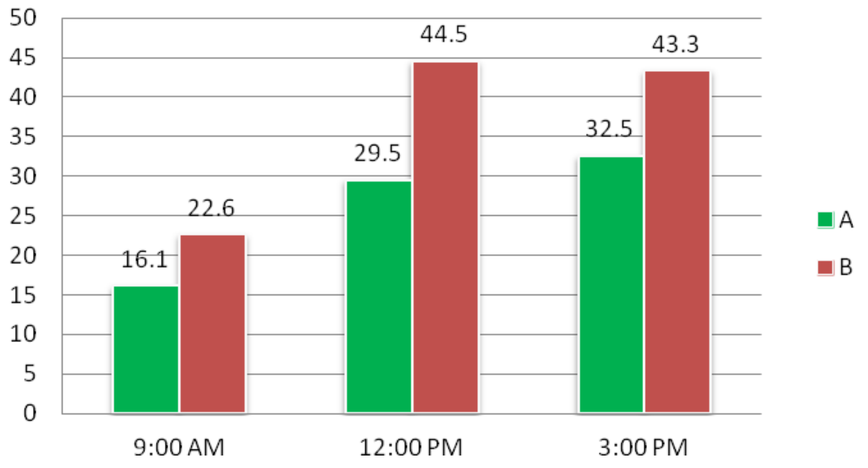



Figure 33 - Average of asphalt's surface temperature in area 2 during dry season

The thermal images in area 3 show the differences between surface temperatures at 09:00 AM and 12:00 PM in each measuring points (Figure 34).

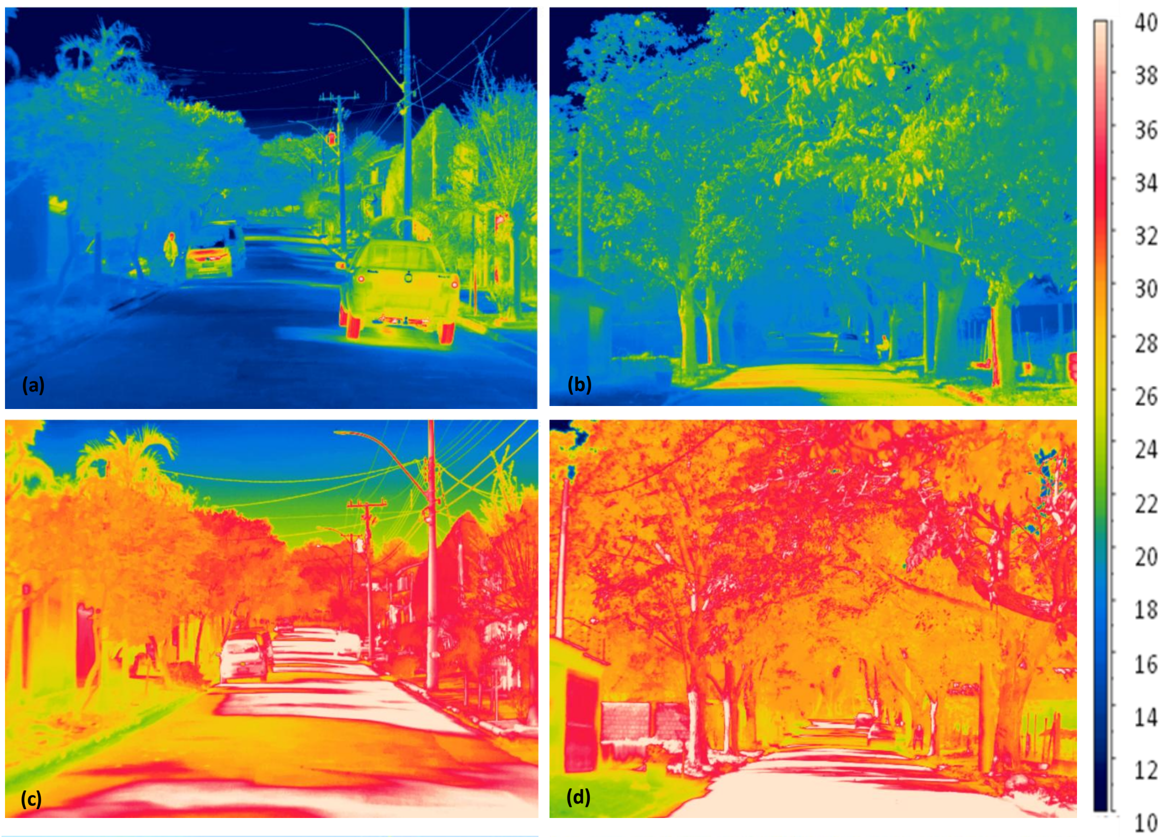



Figure 34 - Thermal images in the dry season: Area 3. (a) and (c) outside canopies at 9:00 AM and 12:00 PM, respectively. (b) and (d) beneath canopies at 9:00 AM and 12:00 PM, respectively. Directions: Southeast. Date: 19/07/2013

In area 3, the highest temperature was also reached at 12:00PM, it was 39.7°C (Figure 35). At 2:00 PM, it started to rain and that was the explanation for the low values of the surface asphalt temperature at this time

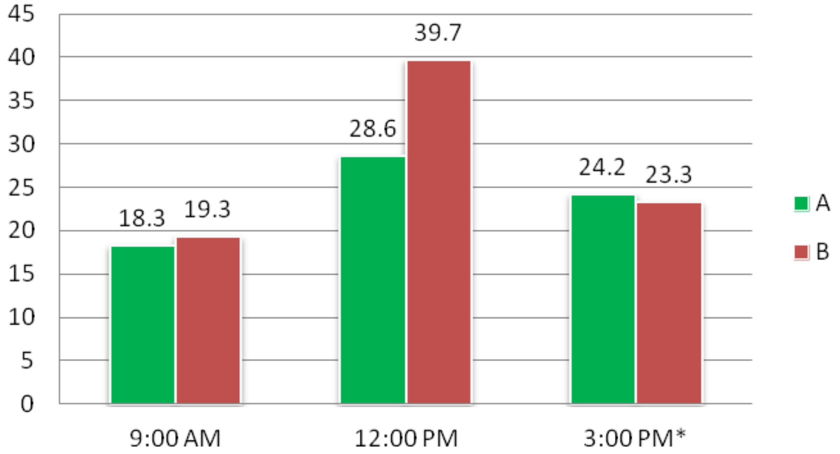



Figure 35 - Average of asphalt's surface temperature in area 3 during dry season

When we observe the Figure 36, it can be noted that the highest difference between the surface temperatures of asphalt occurs at 12:00PM, due to the high level of radiation incident to that surface, where we can see the different color between (b) and (d).

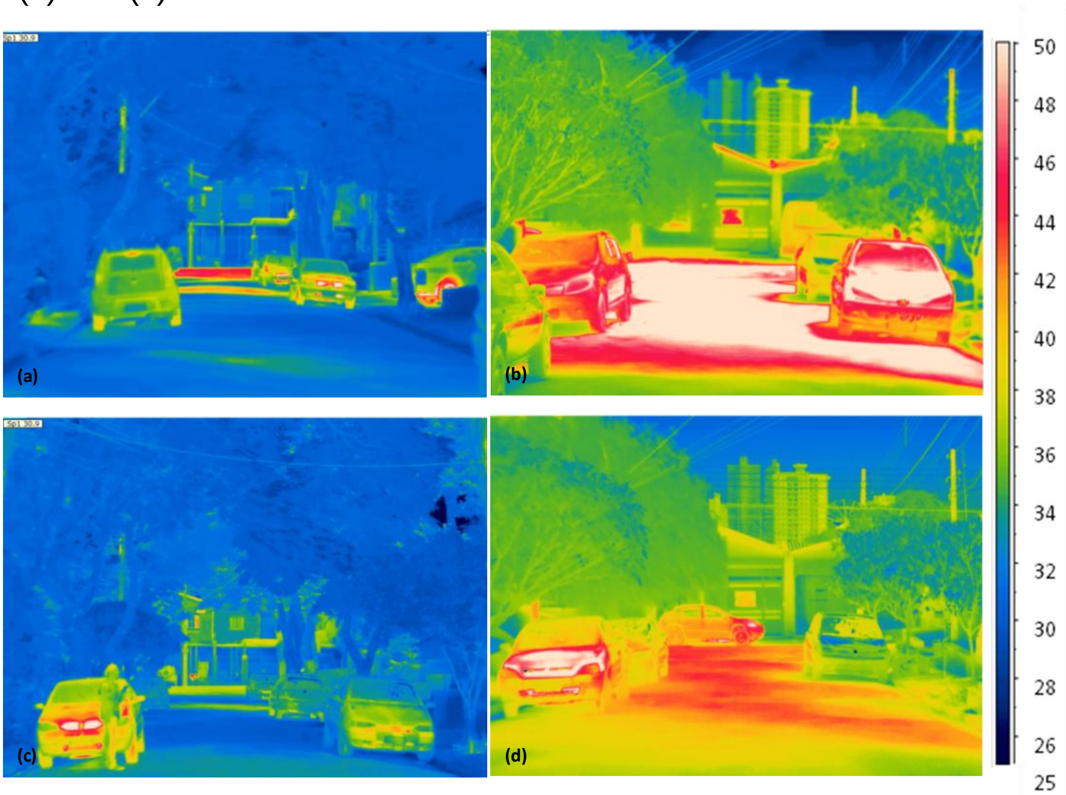



Figure 36 - Thermal images in the rainy season: Area 1. (a) and (c) beneath canopies at 12:00 PM, and 03:00 PM, respectively. Directions: Southeast. (b) and (d) outside canopies at 12:00 PM, and 03:00 PM, respectively. Directions: Northwest. Date: 01/04/2013

This effect is confirmed in Figure 37. The mean difference in surface temperature between measurements at point A (shadow) and point B (sun) was 13.0°C.

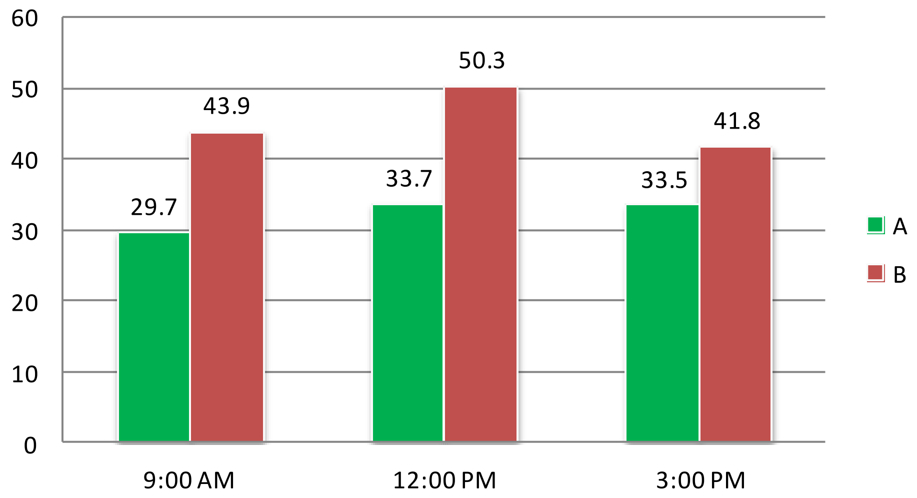



Figure 37 - Average of asphalt's surface temperature in area 1 during rainy season

The same fact can be observed in area 2 (Figure 38).

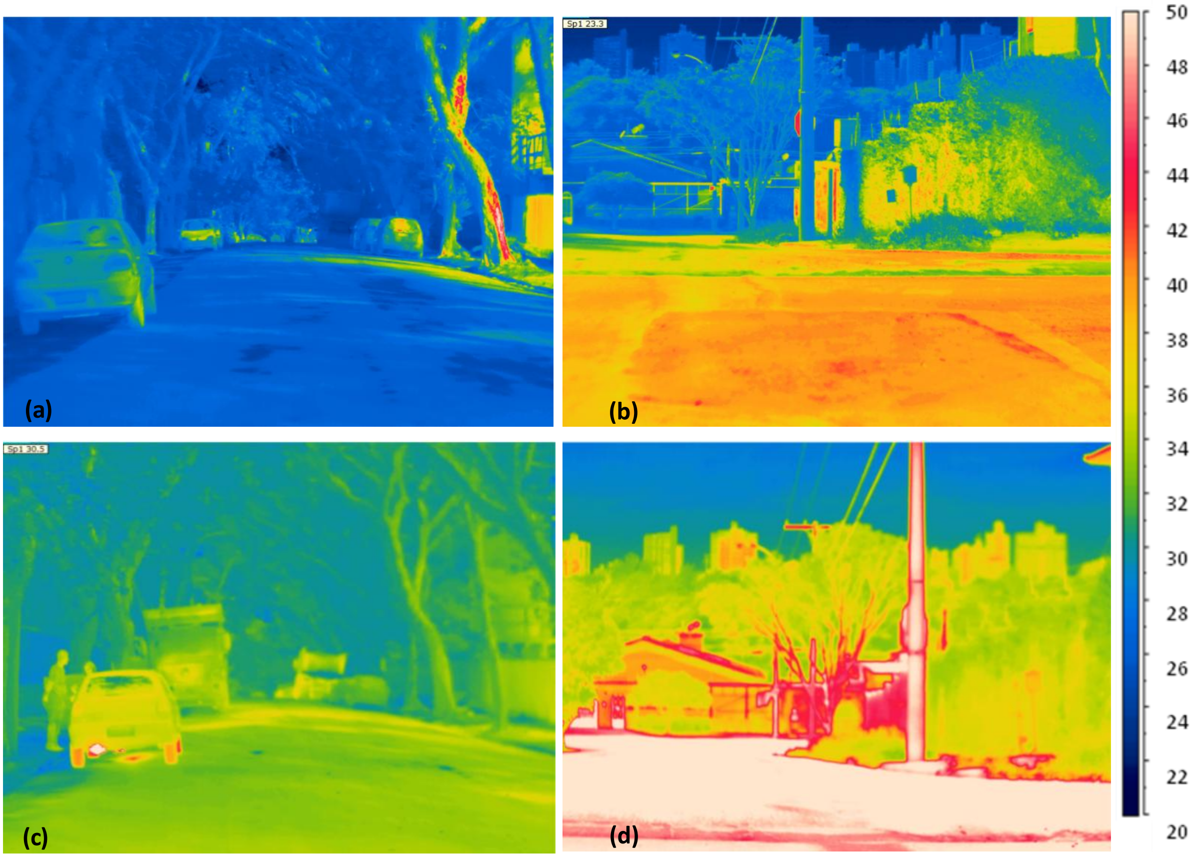



Figure 38 - Thermal images in the rainy season: Area 2. (a) and (c) beneath canopies at 09:00 PM, and 03:00 PM, respectively. Direction: Northwest. (b) and (d) outside canopies at 09:00 PM, and 03:00 PM, respectively. Direction: Southeast. Date: 25/03/2013

The highest value for surface temperature was detected at 12:00PM (51.4°C), and the average difference between point A and point B was 13.3°C (Figure 39).

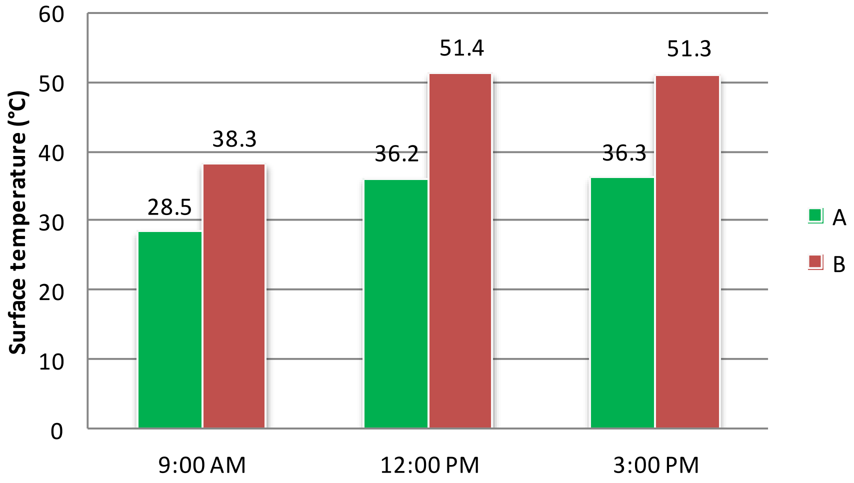



Figure 39 - Average of asphalt's surface temperature in area 2 during rainy season

For area 3, the surface temperature varied differently as the presence of empty lots increased the input radiation in the afternoon and caused a greater heating of the asphalt at 3:00 PM (Figure 40), which reached 49.3°C at this time. The average difference between point A and B was 11.4°C (Figure 41).

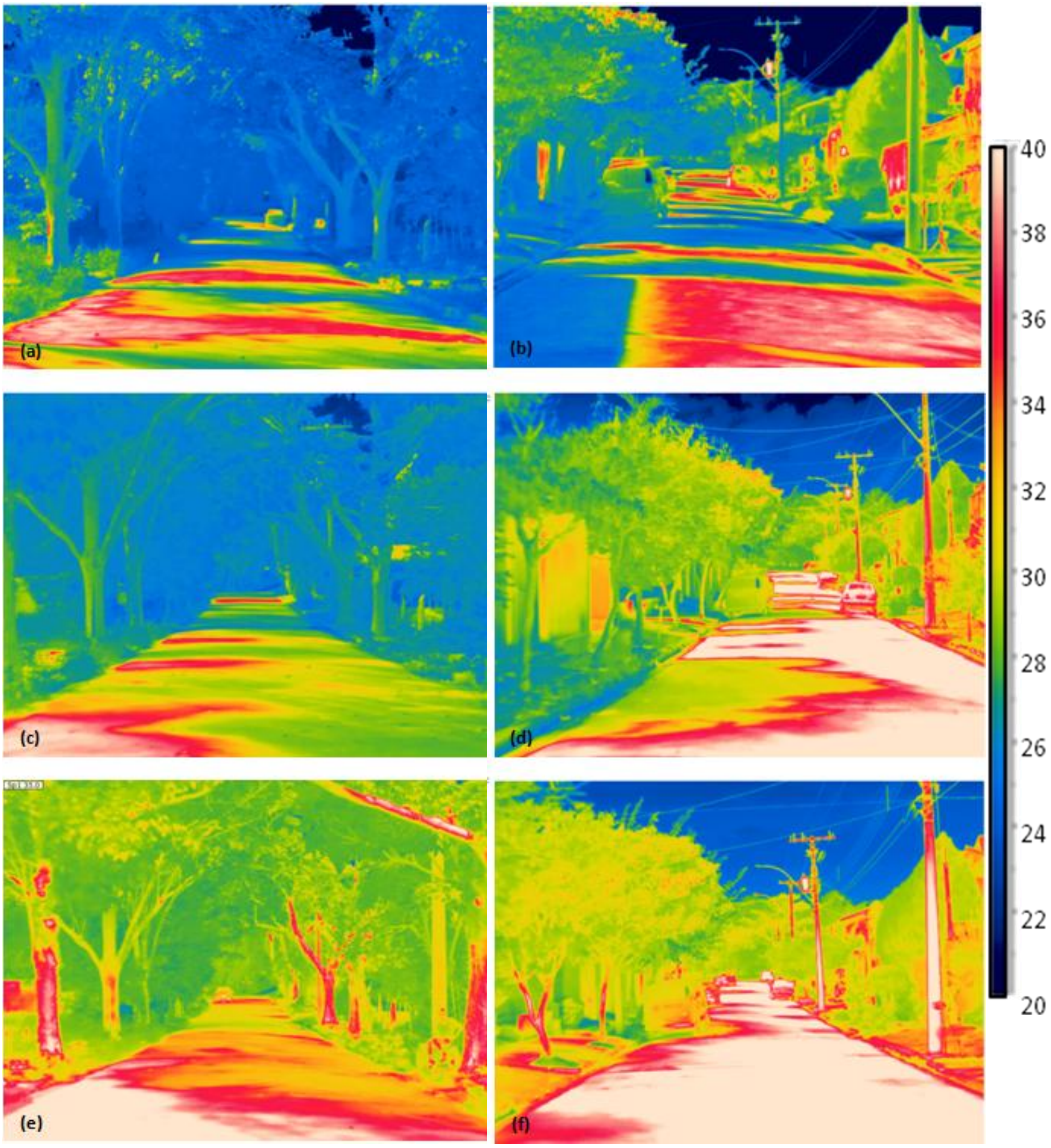



Figure 40 - Thermal images in the rainy season: Area 3. (a), (c) and (e) beneath canopies at 09:00 PM, 12:00 PM and 03:00 PM, respectively. (b), (d) and (f) outside canopies at 09:00 PM, 12:00 PM and 03:00 PM, respectively. Directions: Southeast. Date: 26/03/2013

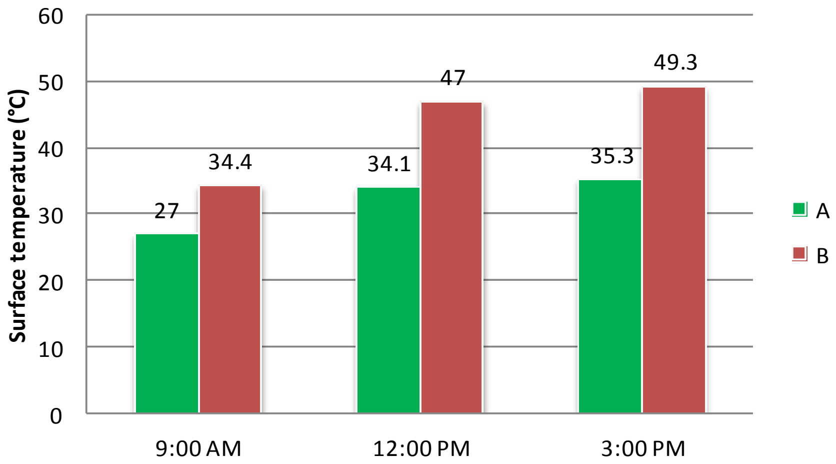



Figure 41 - Average of asphalt’s surface temperature in area 3 during rainy season.

## 5.3 Envi-met results

When predicted data is compared with gathered data in area 1, we notice similar behavior between temperature curves. However, the simulated temperature is underestimated in relation to collected data (Figure 42).

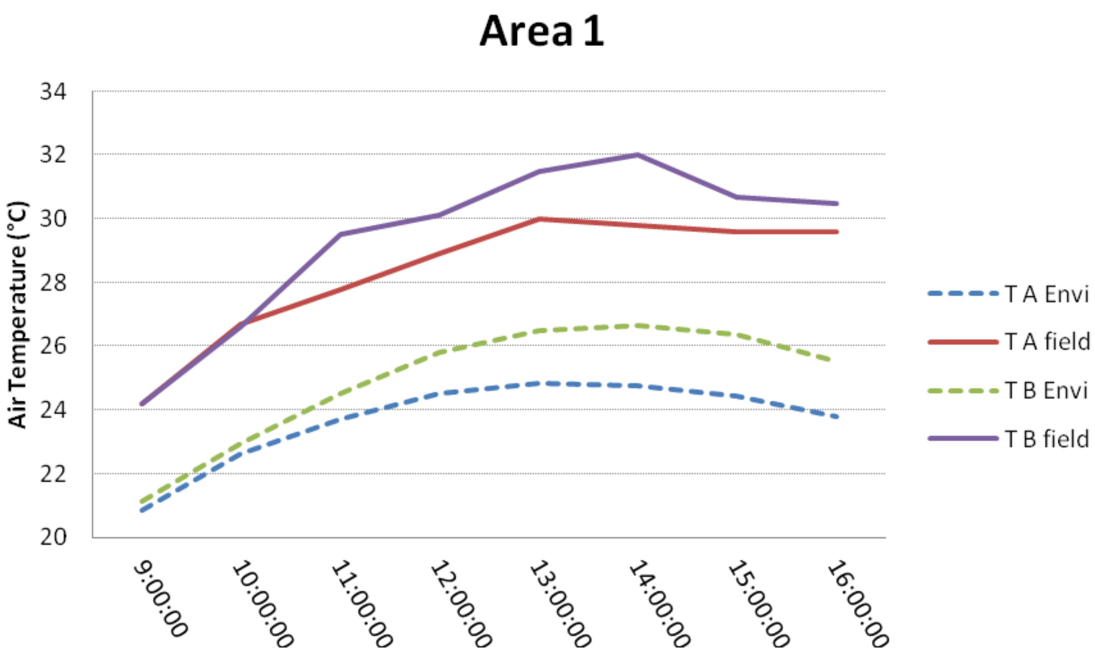



Figure 42 - Comparison of air temperature measured and predicted by Envi-met in area 1

This correlation is weaker in area 2 and 3 (figures 43 and 44), because there is a greater complexity in this scenario. Also, it can be noted a greater difference between the data of point B (sun).

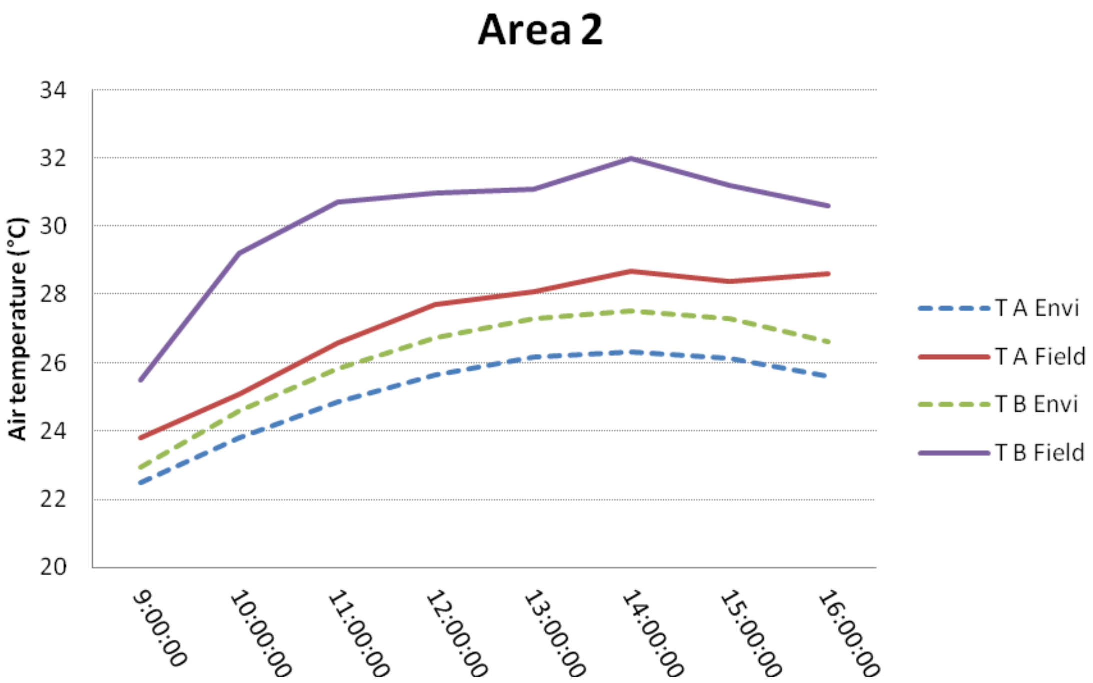



Figure 43 - Comparison of air temperature measured and predicted by Envi-met in area 2

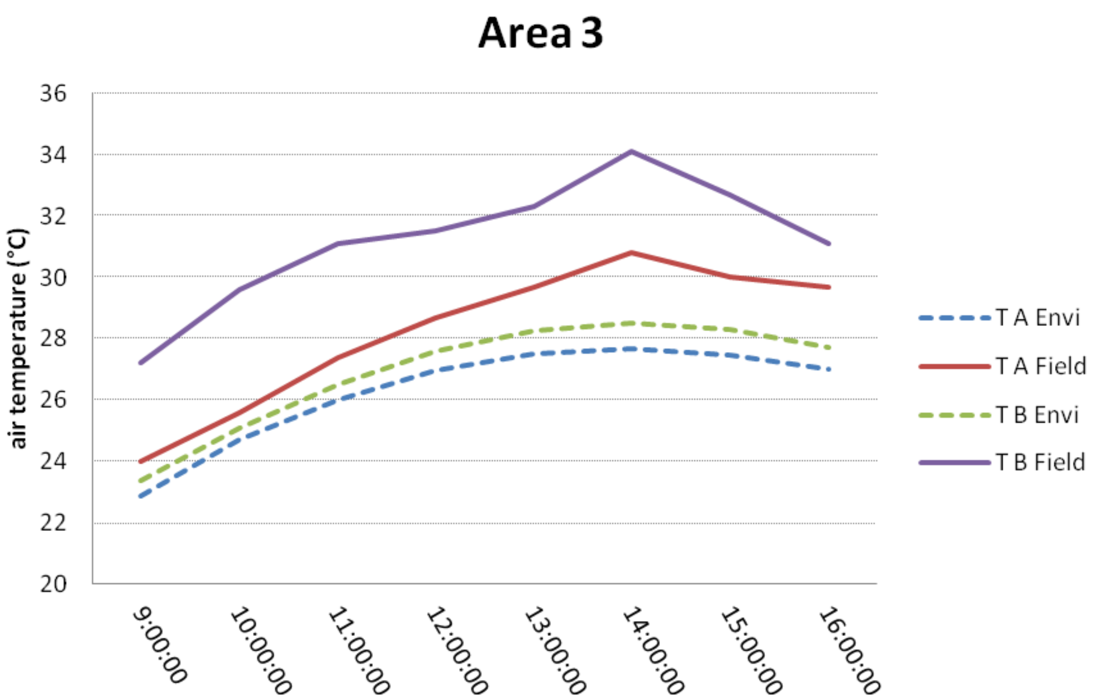



Figure 44 - Comparison of air temperature measured and predicted by Envi-met in area 3

The Envi-met software presented interesting results, but they were not suitable for a more complexe analysis at this moment. The next steps are improving the correlation between measured and predicted data, and recalculate the predictions for each scenario.

## 5.4 Survey analysis

The data collected by survey was used to characterize the people interviewed and it helped in the analyses of thermal comfort.

### 5.4.1 General characterization

Three hundred people were interviewed, among them 166 women and 134 men. In Figure 45, the percentage of each gender is shown.

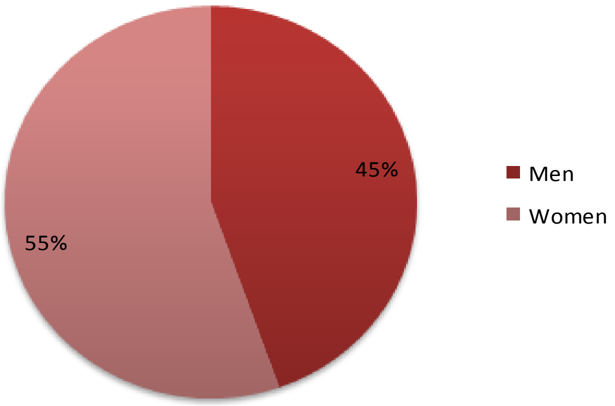



Figure 45 - Distribution of gender among respondents

We tried to select people of all ages, because this factor directly influences the level of thermal comfort. However, we avoided choosing people younger than 18 years and older than 70.  The classes of ages, height and weight are shown in Figure 46, 47 and 48.

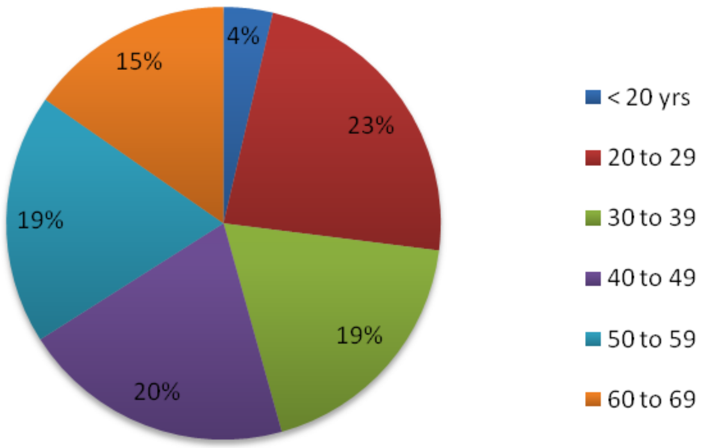



Figure 46 - Classes of age of respondents

It is important to emphasize that the selection of respondents was random, and height and weight was not used as a choice factor.

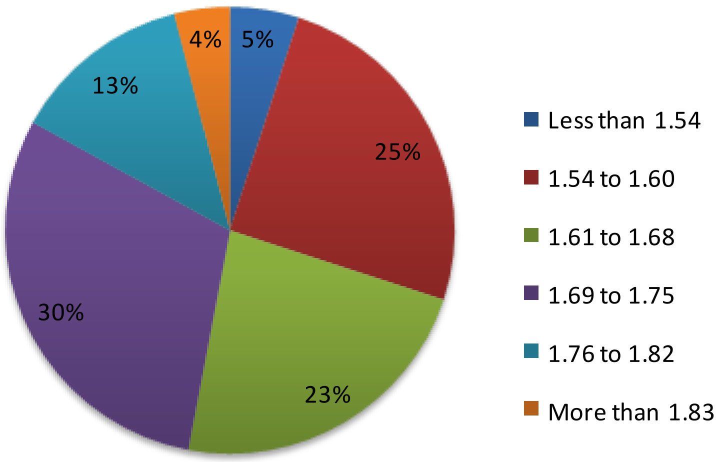



Figure 47 - Classes of height of respondents (in meters)

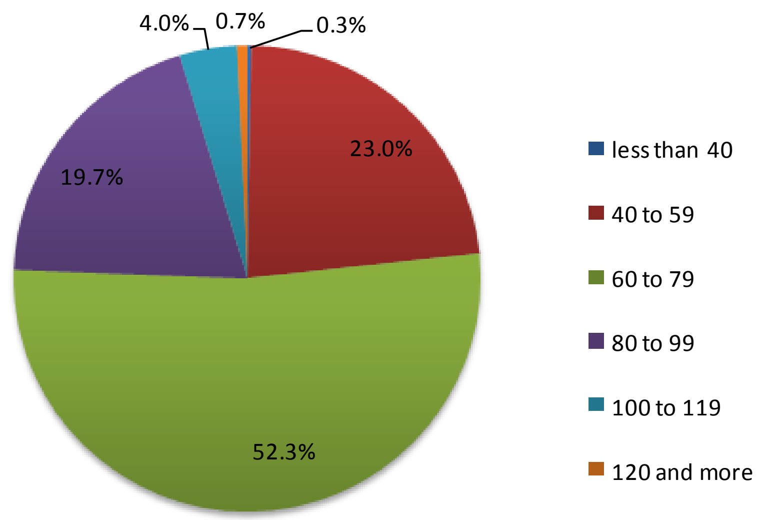



Figure 48 - Classes of weight of respondents in kilograms

### 5.4.2 Thermal sensation

The thermal sensation data was analyzed for each different time and area. The Figure 49 shows the thermal sensation reported by pedestrians during the rainy (R) and dry (D) seasons, in each area (1, 2 or 3), and under tree canopy (a) or outside (b).

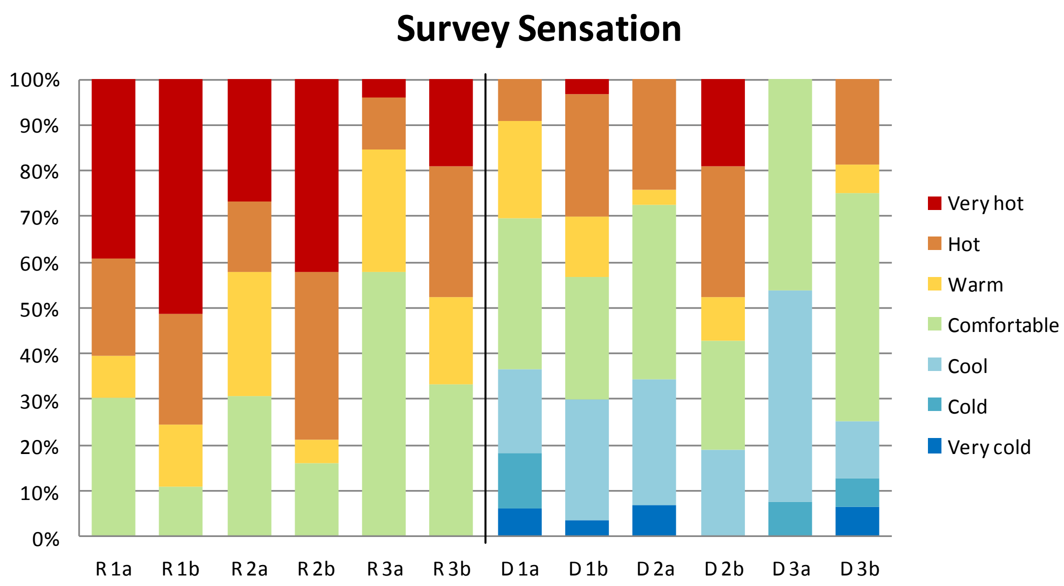



Figure 49 - Thermal sensation reported by pedestrians

At different seasons, the percentage of people unsatisfied is higher in areas without trees, regardless of planted species. In area 3 (planted with *Ipês*), we can observe a larger percentage of pedestrians declaring as “comfortable” (Figure 49). This can be explained by a smaller number of interviews conducted at the site, because the street is rarely used by pedestrians.

After asking about present thermal sensation, it was questioned about their preferences in relation to the weather at that time. The results are shown in Figure 50.

| | N | % |
|---|---|---|
| Much colder | **7** | **2.3%** |
| Colder | **34** | **11.3%** |
| Little cooler | **110** | **36.7%** |
| Like this | **112** | **37.3%** |
| Little warmer | **30** | **10.0%** |
| Warmer | **5** | **1.7%** |
| Much warmer | **2** | **0.7%** |
| **Total** | **300** | **100.0%** |

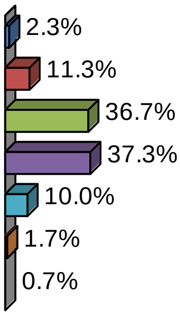



Figure 50 - Preference related to the current thermal sensation

The people interviewed were asked to grade the thermal sensations based on their preferences. The scores ranged from 0 to 10, and higher grades meant they were feeling more comfortable. About 75 percent of people rated the comfort with a grade from 6 to 10 (Figure 51).

Mean = **8.05** Standard deviation = **2.23**

| | N | % |
|---|---|---|
| 0 | **6** | **2.0%** |
| 1 | **4** | **1.3%** |
| 2 | **3** | **1.0%** |
| 3 | **7** | **2.3%** |
| 4 | **10** | **3.3%** |
| 5 | **43** | **14.3%** |
| 6 | **26** | **8.7%** |
| 7 | **50** | **16.7%** |
| 8 | **80** | **26.7%** |
| 9 | **28** | **9.3%** |
| 10 | **43** | **14.3%** |
| **Total** | **300** | **100.0%** |

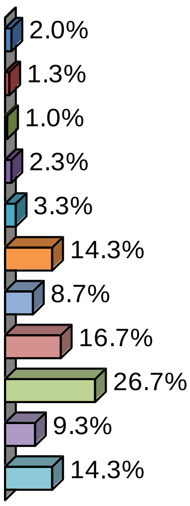



Figure 51 - Grades based on their preferences

The sensation described by pedestrian was transformed in the Predicted Mean Vote (PMV), and the values were compared with the results for UTCI index. In Figure 52, the correlation coefficient between them is shown ($R^2$= 0.4095), as well as the equation. In Martini (2013), the correlation coefficient was equal to 0.43, evidencing an underestimation of the comfort's data, and overestimated data for discomfort to the heat.

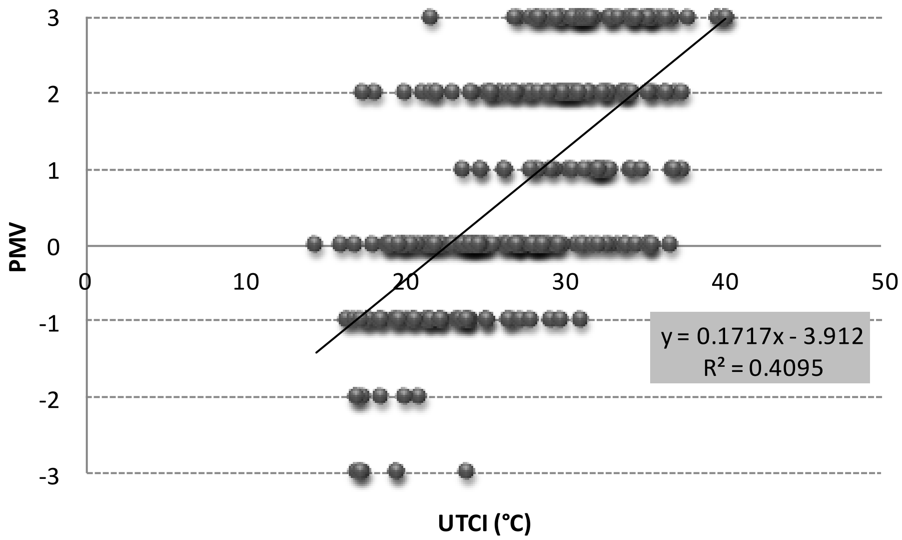



Figure 52 - Correlation Survey x UTCI

### 5.4.3 Perception questions

The survey presented a qualitative part, with dichotomous and opened questions. Firstly, it was asked: “Are trees important for cities?” and 98.7% answered “Yes”. The second question was open and asked them to mention the positive and negative aspects of having trees in the city. Air purification, shade, and thermal comfort were the most cited positive aspects, while, leaf fall (dirt), contact with power lines and lifting sidewalks by root, appeared as negative consequences.

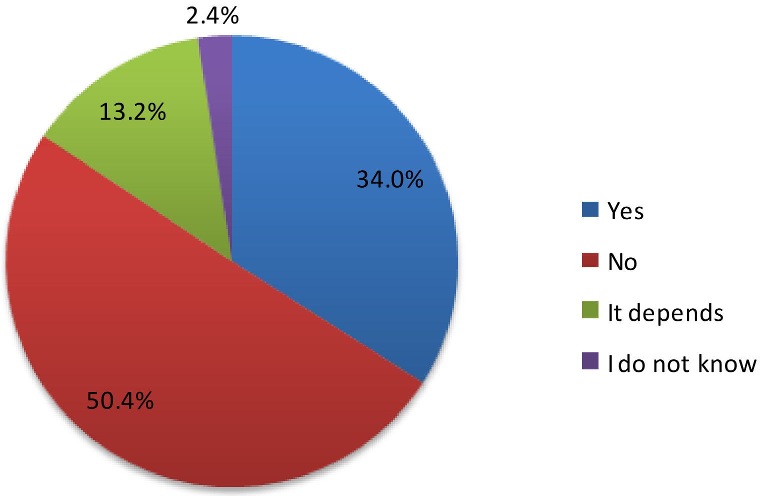



Figure 53 - Satisfaction with the urban trees in the city of Piracicaba

The survey also questioned their satisfaction concerning urban trees in the city of Piracicaba. 50.3 percent of respondents said they were not satisfied with the condition of trees, whereas 34.0 percent said they were satisfied. Moreover, 13.2 percent of them answered “it depends”, because they believe in a difference of management between neighborhoods. The remainder did not answer (Figure 53).

The next question asked about the size of tree that they thought it would be the best to plant in the streets, and 40.4 percent answered that small trees are the best, because they do not reach the electric wires or lift sidewalks due to their roots. On the other hand, 28.6 percent said it would be better to plant large trees, because they offer greater benefits than smaller ones (Figure 54).

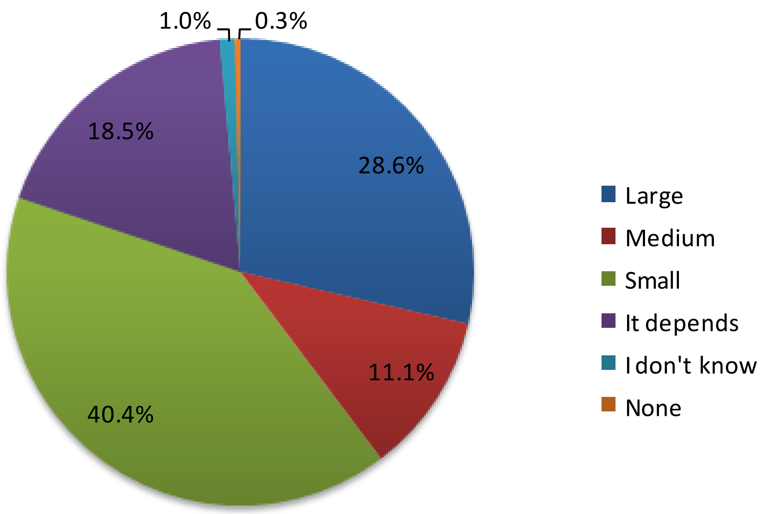



Figure 54 - The best size of tree

The last two questions inquired about the presence of any tree at the property of the respondents, and in case of an affirmative answer, they would say if they know what species it is. Within the 72.2 percent who said they have a tree at home, 55.1 percent said they knew the species planted.

After, we asked if they had a tree planted in their property: 72.2 percent answered “yes”. For these people, we also inquired if they knew which species are planted and 55.4 percent said they knew it. The majority of plants cited were fruit trees. These data are shown in Table 3.

Table 3 - Percentage of people with tree in their properties

| | **Do you have a tree in your property?** | **Do you know what species is planted?** |
|---|---|---|
| Yes | 72.2 | 55.1 |
| No | 27.4 | 44.9 |

## 6 CONCLUSIONS

The presence of street trees is an important factor when we are dealing with the human thermal comfort. This could be proved by the differences shown in the analysis of each microclimatic variable and responses in the survey.

The areas with trees presented lower air temperature average and higher values of relative humidity when compared with areas without trees. The influence in wind speed was noted in our analysis; however, this variable should be studied for each particular situation, since the recommendation will depend on the site’s use purpose.

For all these reasons, the choice of suitable species should be fundamental step in the planning of urban forestry.

Comparing the trees studied, we conclude that the three species presented satisfactory results for employment on the streets in order to minimize thermal discomfort in urban environments, because in all three cases the presence of trees showed a positive and significant response for human thermal comfort.

It is possible some changes in climate between sites might be due to differences in the canyon geometry, or materials or other factors but there is not enough information to assess this. That is the reason why we can not affirm that differences in microclimate variables are just due to species characteristics.

The thermal images helped in data interpretation and showed the role of trees in cooling the asphalt, which is very important to improve the conditions of thermal comfort.

The UTCI index showed some correlation with the respondents' answers, but despite the calibration based on Fanger scale, it has not produced satisfactory results. A new calibration and analysis should be made in order to implement Bioklima program in our region.

The Envi-met proved to be an interesting tool for urban planning in order to predict future scenarios. However, it should be further investigated, as it presents a complexity with respect to input data, which may be interfering in the correlation of simulated results and collected data.

## REFERENCES

ABREU, L.V.; LABAKI, L.C. Conforto térmico propiciado por algumas espécies arbóreas: avaliação do raio de influência através de diferentes índices de conforto. **Ambiente Construído**, Porto Alegre, v. 10, n. 4, p. 103-117, out./dez. 2010.

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS. **Thermal environmental conditions for human occupancy**: ASHRAE standard 55-2013. New York, 2013. 54 p.

ASSIS, E.S. A abordagem do clima urbano e aplicações no planejamento da cidade: reflexões sobre uma trajetória. In: ENCONTRO NACIONAL SOBRE CONFORTO NO AMBIENTE CONSTRUÍDO, 8.; ENCONTRO LATINO-AMERICANO SOBRE CONFORTO NO AMBIENTE CONSTRUÍDO, 4., 2005, Maceió. **Anais...** p. 92-101. Disponível em: <http://www.fau.usp.br/aut5823/Assis_2005_reflexoes_trajetoria.pdf>. Acesso em: 07 jan. 2014.

BRUSE, M.; FLEER, H. Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. **Environmental Modelling & Software,** Canberra, v.13, n.3/4, p. 373-384, 1998. Disponível em: <http://www.sciencedirect.com/science/article/pii/S1364815298000425>. Acesso em: 24 fev 2014

BRÖDE, P.; KRÜGER, E.L.; FIALA, D. UTCI: validation and practical application to the assessment of urban outdoor thermal comfort. **Geographia Polonica,** Warsaw v. 86, n. 1, p. 11-20, 2013. Disponível em: <http://www.scopus.com/inward/record.url?eid=2-s2.0-84879145133&partnerID=40&md5=db0367489a89a241fe9a9dadef335fc6>. Acesso em: 24 fev 2014.

BUENO, C.L. **Estudo da atenuação da radiação solar incidente por diferentes espécies arbóreas.** 1998. 177 p. Dissertação (Mestrado em Engenharia Civil) – Faculdade de Engenharia Civil, Universidade Estadual de Campinas, Campinas, 1998.

Comitê de Trabalho Interinstitucional para Análise dos Planos Municipais de Arborização Urbana No Estado Do Paraná. **Manual para elaboração do plano municipal de arborização urbana.** Paraná.18p. Mai. 2012

DWYER, J.F.; MCPHERSON, E.G.; SCHROEDER, H.W.; ROWNTREE, R.A. Assessing the benefits and costs of the urban forest. **Journal of Arboriculture**, Champaign, v.18, p. 227-234, Sept. 1992.

Environmental Protection Agency. **Reducing urban heat islands:** compendium of strategies. Washington, 2008. 19 p. Disponível em: <http://www.epa.gov/heatisland/resources/pdf/BasicsCompendium.pdf>. Acesso em: 06 maio 2014.

FANGER, P.O. Assessment of man's thermal comfort in practice. **British Journal of Industrial Medicine,** London, v. 30, n. 4, p. 313-324, 1973. Disponível em: <http://oem.bmj.com/content/30/4/313.abstract>. Acesso em: 10 fev. 2013.

GEORGI, N.J.; ZAFIRIADIS, K. The impact of park trees on microclimate in urban areas. **Urban Ecosystem**, Duluth, v. 9, n. 3, p.195–209, September 2006.

GONÇALVES, A; RIBEIRO, A.C.; RODRIGUES, E.; CORTEZ, P.; NUNES. L.; FELICIANO, M. Avaliação da influência dos espaços verdes no conforto térmico urbano In: CONFERÊNCIA NACIONAL DO AMBIENTE, 9., 2007, Aveiro. **Anais...** Aveiro: Universidade de Aveiro, 2007. p. 1357–1361. Disponível em: <http://bibliotecadigital.ipb.pt/bitstream/10198/5711/3/CNA4.pdf>. Acesso em: 01 ago. 2011.

GRIMMOND, C.S.B.; ROTH, M.; OKE, T.R.; AU, Y.C.; BEST, M.; BETTS, R.; CARMICHAEL, G.; CLEUGH, H.; DABBERDT, W.; EMMANUEL, R.; FREITAS, E.; FORTUNIAK, K.; HANNA, S.; KLEIN, P.; KALKSTEIN, L. S.; LIU, C. H.; NICKSON, A.; PEARLMUTTER, D.; SAILOR, D.;  VOOGT, J. Climate and more sustainable cities: climate information for improved planning and management of cities (producers/capabilities perspective). **Procedia Environmental Sciences,** Philadelphia,v. 1, p. 247-274, 2010. Disponível em: <http://www.sciencedirect.com/science/article/pii/S1878029610000174>. Acesso em: 10 fev. 2013.

IBGE. **Censo demográfico 2010**. Disponível em: <http://ibge.gov.br/en/vamos-conhecer-o-brasil/nosso-povo/caracteristicas-da-populacao>. Acesso em: 08 set 14

KONIJNENDIJK, C.C. A decade of urban forestry in Europe. **Forest Policy and Economics,** New Haven, v. 5, n. 2, p. 173-186, 2003. Disponível em: <http://www.sciencedirect.com/science/article/pii/S1389934103000236>. Acesso em: 14 nov. 2012.

LEUZINGER, S.; VOGT, R.; KÖRNER, C. Tree surface temperature in an urban environment. **Agricultural and Forest Meteorology,** New Haven, v. 150, n. 1, p. 56-62, 2010. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0168192309001993>. Acesso em: 14 nov. 2012.

LIMA, D.C.R.; NUNES, L.A.; SOARES, P.F. Avaliação da influência da vegetação no conforto térmico em espaços livres. In: SIMPÓSIO DE PÓS-GRADUAÇÃO EM ENGENHARIA URBANA, 2, 2009, Maringá. **Resumos…** Disponível em: <http://www.dec.uem.br/simpgeu/pdf/137.pdf>. Acesso em: 09 ago. 2011.

LOMBARDO, M.A. **Ilhas de calor nas metrópoles:** o exemplo de São Paulo. São Paulo: Hucitec,1985. 244 p.

LOMBARDO, M.A. **Atmosfera urbana.** São Paulo, 2011. 24 diapositivos: color. Disponível em:

<http://www.ambiente.sp.gov.br/cea/files/2011/12/Magda_Lombardo.pdf>. Acesso em: 06 maio 2014.

LORENZI, H. **Árvores brasileiras:** manual de identificação e cultivo de plantas arbóreas do Brasil. 4. ed. Nova Odessa: Instituto Plantarum, 2002. 2 v.

MEIER, F.; SCHERER, D. Spatial and temporal variability of urban tree canopy temperature during summer 2010 in Berlin, Germany. **Theoretical and Applied Climatology**, Vienna, v. 110, n. 3, p. 1-12, 2012. Disponível em: <http://dx.doi.org/10.1007/s00704-012-0631-0>. Acesso em: 14 fev. 2014.

MONTEIRO, L.M.; ALUCCI, M.P. Questões teóricas de conforto térmico em espaços abertos: consideração histórica, discussão do estado da arte e proposição de classificação de modelos. **Ambiente Construído**, Porto Alegre, v. 7, n. 3, p. 43-58, jul./set. 2007.

OKE, T.R. The micrometeorology of the urban forest. **Philosophical Transactions - Royal Society of London. Series B,** London, v. 324, n. 1223, p. 335-349, 1989. Disponível em: < http://www.scopus.com/inward/record.url?eid=2-s2.0-0024923709&partnerID=40&md5=efa1ca430b02b050691826bb780d8869>. Acesso em: 14 nov. 2012.

______. **Initial guidance to obtain representative meteorological observations at urban sites:** Instruments and Observing Methods (IOM). Geneva: World Meteorological Organization, 2006. 51 p. (Report, 81).

PAULA, R.Z.R. **Influência da vegetação no conforto térmico do ambiente construído.** 2004. 110 p. Dissertação (Mestrado em Engenharia Civil) - Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Universidade Estadual de Campinas, Campinas, 2004.

SÆBØ, A.; BENEDIKZ, T.; RANDRUP, T.B. Selection of trees for urban forestry in the Nordic countries. **Urban Forestry & Urban Greening,** Alnarp, v. 2, n. 2, p. 101-114, 2003. Disponível em: <http://www.sciencedirect.com/science/article/pii/S1618866704700278>. Acesso em: 14 nov. 2012.

SCHUCH, M.I.S. **Arborização urbana:** uma contribuição à qualidade de vida com uso de geotecnologias. 2006. 102 p. Dissertação (Mestrado em Geomática) - Universidade Federal de Santa Maria, Santa Maria, 2006.

SPANGENBERG, J.; SHINZATO, P.; JOHANSSON, E.; DUARTE, D. Simulation of the influence of vegetation on microclimate and thermal comfort in the city of São Paulo. **Revista da Sociedade Brasileira de Arborização Urbana**, Piracicaba, v. 3, n. 2, p. 1-19, jun. 2008.

VOOGT, J.A. **How researchers measure urban heat islands.** London, 2003. 34 diapositivos: color. Disponível em: <http://www.epa.gov/heatislands/resources/pdf/EPA_How_to_measure_a_UHI.pdf >. Acesso em: 06 maio 2014.

VOOGT, J.A.; OKE, T.R. Complete urban surface temperatures. **Journal of Applied Meteorology,** Washington, v. 36, n. 9, p. 1117-1132, 1997. Disponível em: <http://dx.doi.org/10.1175/1520-0450(1997)036<1117:CUST>2.0.CO>. Acesso em: 14 nov. 2012.

______. Thermal remote sensing of urban climates. **Remote Sensing of Environment,** Saint Paul, v. 86, n. 3, p. 370-384, 2003. Disponível em: <http://www.sciencedirect.com/science/article/pii/S0034425703000798>. Acesso em: 14 nov. 2012.

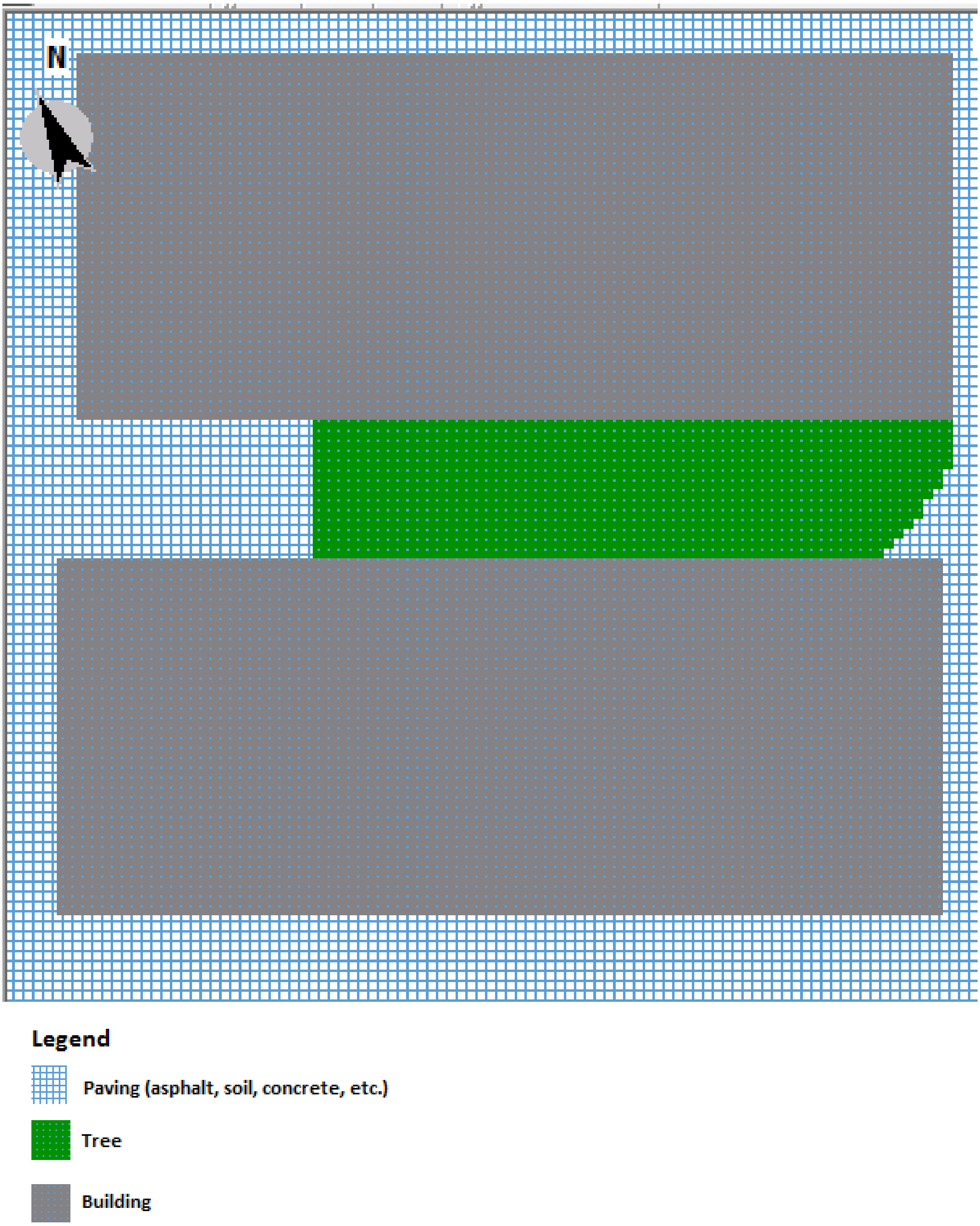
## BIBLIOGRAFIA CONSULTADA

MARTINI, A. **Microclima e conforto térmico proporcionado pelas árvores de rua na cidade de Curitiba, PR**. 2013. 129 p. Dissertação (Mestrado em Engenharia Florestal) - Universidade Federal do Paraná, Curitiba, 2013.

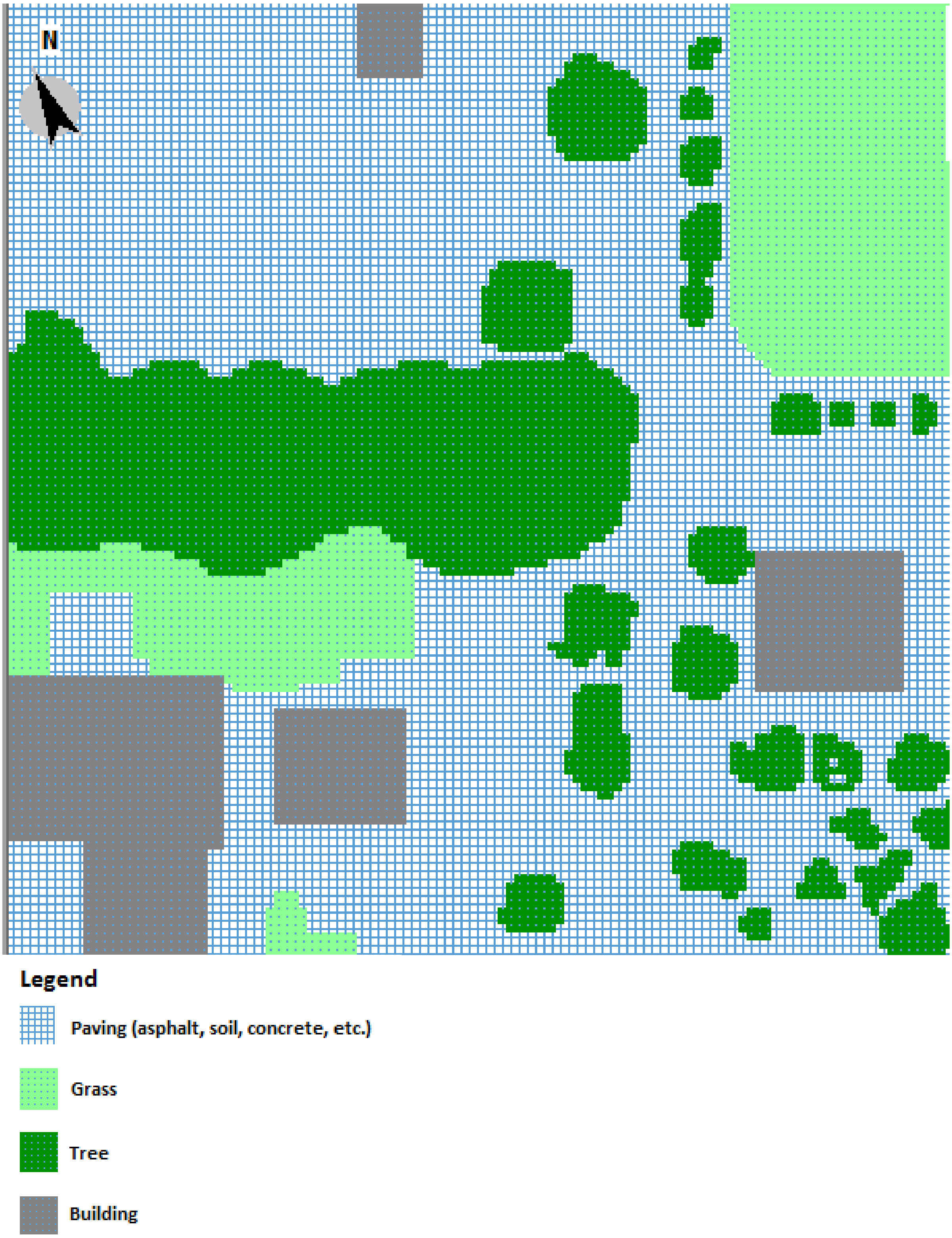
SILVA, I.M. **Efeito do uso do solo sobre o conforto higrotérmico.** 2012.170 p. Dissertação (Mestrado em Recursos Florestais) – Escola Superior de Agricultura “Luiz de Queiroz”, Universidade de São Paulo, Piracicaba, 2012.

# APPENDIX

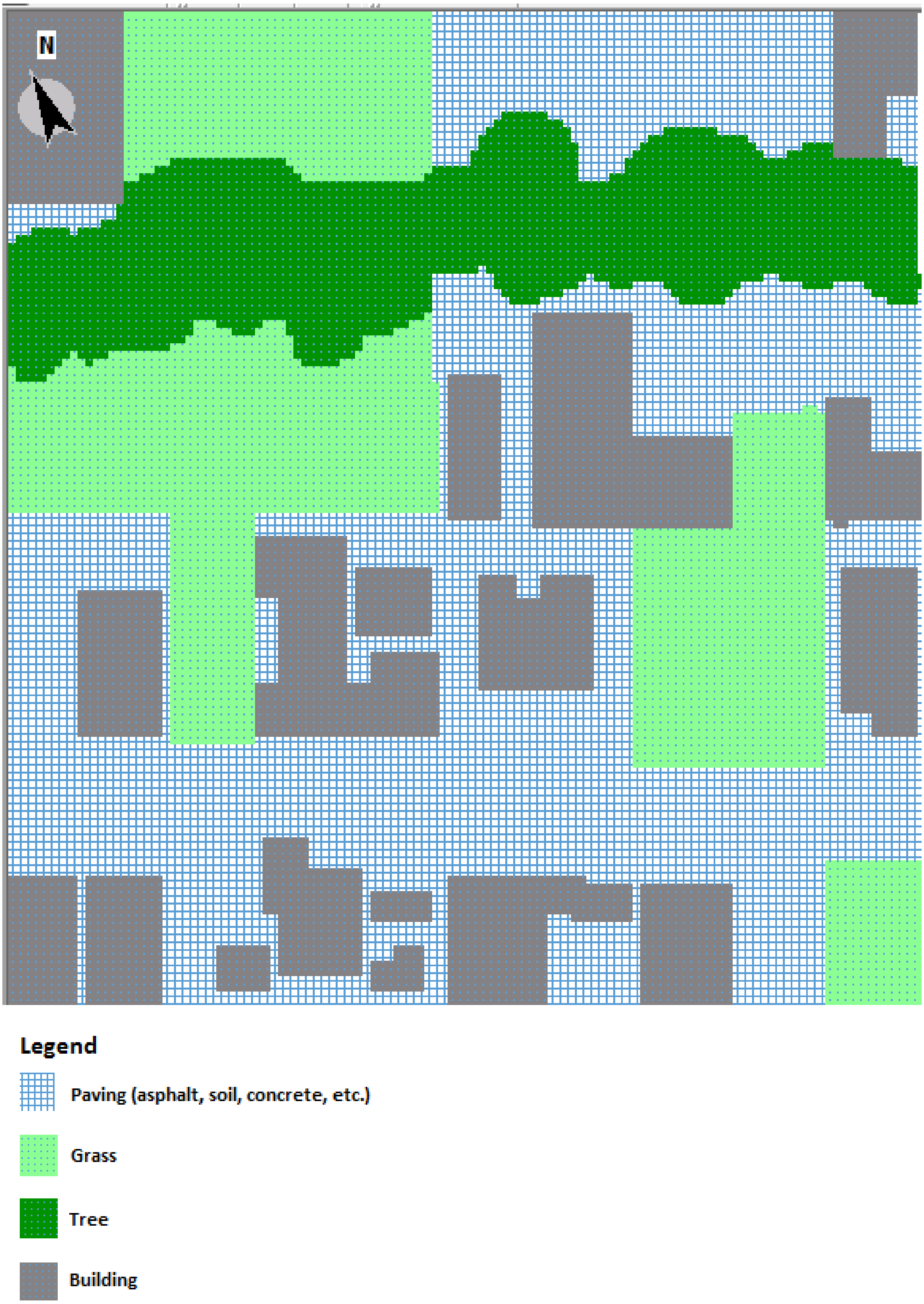
## APPENDIX A – Scenario A



**PPENDIX B – Scenario 2**



## APPENDIX C – Scenario 3



**APPENDIX D -** Questionnaire

| Local: | Data: | Hora: |
|---|---|---|

Local da entrevista: Sombra ☐ Sol ☐

Condição do céu: Limpo ☐ Parcialmente coberto ☐ Nublado ☐

No momento você está se sentindo com:

☐ Muito frio ☐ Frio ☐ Pouco de frio ☐ Neutro ☐ Pouco de calor ☐ Calor ☐ Muito calor

Em uma escala de 0 a 10, como você está se sentindo confortável em relação ao clima de hoje (0 = “nada confortável” e 10 = “muito confortável”).

☐ 0 ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10

Você se sentiria melhor se hoje estivesse:

☐ Muito + frio ☐ + Frio ☐ Pouco + frio ☐ Como está ☐ Pouco + calor ☐ +Calor ☐ Muito + calor

Você acha que é importante ter árvores na cidade?

( )Sim ( )Não ( )Não sei

Quais são os pontos positivos? E negativos?

☐ Ar ☐ Sombra ☐ Temperatura ☐ Estética ☐ Fauna Outro: ____________

☐ Sujeira ☐ Segurança ☐ Calçada Outro: ____________

Em sua opinião, é melhor plantar árvores maiores ou menores na calçada? Por quê?

Você está satisfeito com a quantidade de árvores na cidade de Piracicaba?

( )Sim ( )Não ( )Não sei

Você tem uma árvore plantada em sua residência?

( ) Sim ( )Não ( ) Não informou

Se sim, onde ela está plantada? Você sabe qual é a espécie?

( ) Calçada ( )Quintal ( )Sim ( )Não Se souber, nome da espécie:_______________

Mora há quanto tempo em Piracicaba? ___________ De onde veio?_____________

Idade: ____ Altura: _____ Peso:_____ Sexo: ( )M ( )F

Vestimenta: __________________________________

Atividade:____________________________

## APPENDIX E – Statistical analysis

| area | season | cond | temp_t LSMEAN | LSMEAN Number |
|---|---|---|---|---|
| 1 | summer | shadow | 146.091306 | 1 |
| 1 | summer | sun | 155.764881 | 2 |
| 1 | winter | shadow | 101.305458 | 3 |
| 1 | winter | sun | 117.281111 | 4 |
| 2 | summer | shadow | 140.113544 | 5 |
| 2 | summer | sun | 157.930014 | 6 |
| 2 | winter | shadow | 116.482752 | 7 |
| 2 | winter | sun | 127.994974 | 8 |
| 3 | summer | shadow | 144.947341 | 9 |
| 3 | summer | sun | 162.143326 | 10 |
| 3 | winter | shadow | 100.007201 | 11 |
| 3 | winter | sun | 109.104151 | 12 |

Least Squares Means for effect area*season*cond
Pr > |t| for H0: LSMean(i)=LSMean(j)

Dependent Variable: temp_t

| i/j | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | <.0001 | <.0001 | <.0001 | 0.0898 | <.0001 | <.0001 | <.0001 | 1.0000 | <.0001 | <.0001 | <.0001 |
| 2 | <.0001 | | <.0001 | <.0001 | <.0001 | 0.9941 | <.0001 | <.0001 | <.0001 | 0.0478 | <.0001 | <.0001 |
| 3 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | 1.0000 | 0.0061 |
| 4 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | 1.0000 | <.0001 | <.0001 | <.0001 | <.0001 | 0.0029 |
| 5 | 0.0898 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | 0.3496 | <.0001 | <.0001 | <.0001 |
| 6 | <.0001 | 0.9941 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | 0.5739 | <.0001 | <.0001 |
| 7 | <.0001 | <.0001 | <.0001 | 1.0000 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 | 0.0132 |
| 8 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 | <.0001 |
| 9 | 1.0000 | <.0001 | <.0001 | <.0001 | 0.3496 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 | <.0001 |
| 10 | <.0001 | 0.0478 | <.0001 | <.0001 | <.0001 | 0.5739 | <.0001 | <.0001 | <.0001 | | <.0001 | <.0001 |
| 11 | <.0001 | <.0001 | 1.0000 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | <.0001 | | 0.0007 |
| 12 | <.0001 | <.0001 | 0.0061 | 0.0029 | <.0001 | <.0001 | 0.0132 | <.0001 | <.0001 | <.0001 | 0.0007 | |

# ANNEX

**ANNEX A –** Certificate of conformity

testo

## Kalibrier-Protokoll

Certificate of conformity • Protocole d'étalonnage
Protocollo di collaudo • Informe de calibración

Gerät / Module type /
Modèle / Modelo: **testo 175 T2**

Messbereich / Measuring range /
Etendue de mesure / Rango de medición : **Temperature: -35...55°C(int.)**
**-40...120°C(ext.)**

Serien-Nr. / Serial no. /
N°. de série / Número de serie: **40105596**

Segmenttest / Display test /
Test d'affichage / Test del visualizador: ☑ **OK**

| Messwerte / Measured values / Valeurs mesurées / Valores medidos: | | |
|---|---|---|
| Sollwert / Reference / Référence / Referencia: | Zulässige Toleranz / Permissible tolerance / Tolérance admise / Tolerancia permitida : | Istwert / Actual Value / Valeur réelle / Valor medido : |
| Internal: | | |
| **25.0 °C** | **±0.4 °C** | **24.9 °C** |
| External: | | |
| **25.0 °C** | **±0.3 °C** | **25.0 °C** |

J. Yeung

Prüfer / Inspector /
Responsable / Verificador

**ANNEX B –** Accuracy hot bulb probe

## Genauigkeit Hitzkugelsonden
## Accuracy hot bulb probes
## Précision sondes à boules chaudes

**Hitzkugelsonden**, abgeglichen im Freistrahl Ø 350 mm
**Hot bulb probes**, adjusted in a free jet diam. 350 mm
**Sondes à boules chaudes**, ajustées en jet libre diàm. 350 mm

Bezugsdruck 1013 hPa, Bezugstemperatur 22 °C
Reference pressure 1013 hPa, reference temperature 22 °C
Pression de référence 1013 hPa, température de référence 22 °C

bezogen auf testo Referenz DKD-Labor-Strömung
referring to the testo reference DKD laboratory for velocity
Anémomètre de référence labo DKD pour les mesures de vitesse d´air

| *Best.-Nr.*<br>*Order no.*<br>*Réf.* | *Meßbereich*<br>*Measuring range*<br>*Etendue de mesure* | *Genauigkeit*<br>*Accuracy*<br>*Précision* |
|---|---|---|
| 0635.1549 | m/s: 0...10,00 m/s<br>°C: -20,0...70,0 °C | ± (0,03 m/s + 5% v. Mw./of mv/v.m.)<br>(0...10,00 m/s) |
| 0635.1049 | m/s: 0...10,00 m/s<br>C: -20,0...70,0 °C | |
| 0635.1045<br>für/for/pour<br>**testo 452**<br>0635.1540<br>für/for/pour<br>**testo 400** | m/s: 0...10,00 m/s<br>°C: -20,0...70,0 °C<br>%rF: 0...100 %<br>nicht betauen!<br>not to be dewed!<br>ne pas roser! | Temperaturkompensation besser als<br>Temperature compensation better than<br>Température de compensation mieux que<br>± 0,2 % v. Mw./°C / of mv/°C / v.m./°C<br>(-10...60 °C) |
| 0628.0035 | m/s: 0...10,00 m/s<br>C: -20,0...70,0 °C | |

0973.0403/02.02/T/wh/09.02.2004

Testo gleicht die thermischen Sonden auf einen Referenzdruck von 1013 hPa ab. Weicht in der praktischen Anwendung der Umgebungs- bzw. Prozeßdruck vom Referenzdruck (1013 hPa) ab, kann beim **testo 400** der Absolutdruck zur automatischen Druckkompensation direkt eingegeben werden. Bei anderen Geräten ergibt sich die wahre Geschwindigkeit aus der Formel:

$V_{wahr} = V_{Anzeige} * \text{Korrekturfaktor}$ bzw.

$$V_{wahr} = V_{Anzeige} * \frac{1013\ [hPa]}{\text{Umgebungsdruck}\ [hPa]}$$

The thermal sensors are calibrated by Testo with a reference pressure of 1013 hPa.
If the ambient or process pressure applied in practice deviates from the reference pressure (1013 hPa), the absorption pressure in the case of **testo 400** can be input directly for automatic pressure compensation. The real velocity in other instruments can be calculated from the following formula:

$V_{real} = V_{indicated} * \text{Correction factor}$ or

$$V_{real} = V_{indicated} * \frac{1013\ [hPa]}{\text{Ambient pressure}\ [hPa]}$$

Les capteurs thermiques sont étalonnés avec une pression de réference du 1013 hPa.
Si la pression ambiante ou la pression de processus se différencient de la pression de réference (1013 hPa), la compensation automatique de la pression absolue peut être modifiée directement sur le **testo 400**. Pour d'autres appareils, la vitesse réelle est déterminée par la formule suivante.

$V_{vraie} = V_{indiquée} * \text{Coefficient de correction}$ ou

$$V_{vraie} = V_{indiquée} * \frac{1013\ [hPa]}{\text{La pression ambiante (hPa)}}$$

| Ortshöhe (m) / Location height / L'hauteur de la position | mittlerer Luftdruck (hPa) / Average air pressure / Pression d'air moyenne | Korrekturfaktor / Correction factor / Coefficient de correction |
|---|---|---|
| 500 | 954 | 1,061 |
| 600 | 943 | 1,074 |
| 700 | 932 | 1,087 |
| 800 | 921 | 1,100 |
| 900 | 909 | 1,114 |
| 1000 | 898 | 1,127 |
| 1100 | 888 | 1,141 |
| 1150 | 882 | 1,148 |
| 1200 | 877 | 1,155 |
| 1250 | 872 | 1,162 |
| 1300 | 866 | 1,169 |
| 1350 | 861 | 1,177 |
| 1400 | 856 | 1,184 |
| 1450 | 850 | 1,191 |
| 1500 | 845 | 1,198 |
| 1550 | 840 | 1,206 |
| 1600 | 835 | 1,213 |
| 1650 | 830 | 1,221 |
| 1700 | 825 | 1,228 |
| 1750 | 820 | 1,236 |
| 1800 | 815 | 1,244 |
| 1850 | 810 | 1,251 |
| 1900 | 805 | 1,259 |
| 1950 | 800 | 1,257 |
| 2000 | 795 | 1,275 |
| 2050 | 790 | 1,283 |
| 2100 | 785 | 1,291 |
| 2150 | 780 | 1,299 |
| 2200 | 775 | 1,307 |
| 2250 | 770 | 1,315 |
| 2300 | 766 | 1,323 |
| 2350 | 761 | 1,332 |
| 2400 | 756 | 1,340 |
| 2450 | 751 | 1,348 |
| 2500 | 747 | 1,357 |
| 2550 | 742 | 1,365 |