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Página iii

Onde se lê:

Tese apresentada ao Programa de Pós-Graduação em Arquitetura, Tecnologia e Cidade da Universidade Estadual de Campinas, como parte dos requisitos para obtenção do título de doutor em Arquitetura, Tecnologia e Cidade.

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Sem mais.

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UNIVERSIDADE ESTADUAL DE CAMPINAS
FACULDADE DE ENGENHARIA CIVIL,
ARQUITETURA E URBANISMO

LOYDE VIEIRA DE ABREU

CONTRIBUIÇÕES DAS ÁRVORES PARA O BIOCLIMA TÉRMICO NO DESENHO URBANO EM CIDADES TROPICAIS: O CASO DE CAMPINAS, SP

CONTRIBUTIONS OF TREES FOR THERMAL BIOCLIMATE IN THE URBAN DESIGN IN TROPICAL CITIES: THE CASE OF CAMPINAS, SP

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Contribuições das árvores para o bioclima térmico no desenho urbano em cidades tropicais: o caso de Campinas, SP

Orientadora: Porfª . Drª. Lucila Chebel Labaki

Contributions of trees for thermal bioclimate in the urban design in tropical cities: the case of Campinas, SP

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CONTRIBUIÇÕES DAS ÁRVORES PARA O BIOCLIMA TÉRMICO NO DESENHO URBANO EM CIDADES TROPICAIS: O CASO DE CAMPINAS, SP

LOYDE VIEIRA DE ABREU

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"É melhor tentar e falhar,
que preocupar-se e ver a vida passar;
é melhor tentar, ainda que em vão,
que sentar-se fazendo nada até o final.
Eu prefiro na chuva caminhar,
que em dias tristes em casa me esconder.
Prefiro ser feliz, embora louco,
que em conformidade viver !"
Martin Luther King

SUMARIO

RESUMO

ABREU, Loyde Vieira. **Contribuições das árvores para o bioclima térmico no desenho urbano em cidades tropicais: o caso de Campinas, SP.** Campinas, 2012, 135 f**.** Tese (Doutorado em Arquitetura Tecnologia e Cidade) - Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Universidade Estadual de Campinas.

O sombreamento por árvores pode melhorar o bioclima térmico em cidades tropicais como Campinas, SP. As árvores se comportam de maneiras distintas no microclima urbano porém existem poucos estudos sobre a quantificação dos benefícios trazidos pelas diferentes espécies arboreas e sua disposição no ambiente construído. O objetivo desta pesquisa é quantificar a contribuição de indivíduos arbóreos e agrupamentos para a melhoria dos microclimas urbanos e do ambiente construído a partir da caracterização do bioclima térmico local, estudos dos efeitos dos cânios urbanos e avaliação da escala de influência da vegetação, bem como diretrizes de projeto urbano e arquitetônico para clima tropical de altitude. Foram analisadas as espécies Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.), Jacarandá mimoso (*Jacaranda mimosaefolia* D. Don.), Jambolão (*Syzygium cumini* L.), Mangueira (*Mangifera indica* L.), Pinheiro (*Pinus palustris* L.) e Pinheiro (*Pinus coulteri* L.) – isoladas, Mirindiba Bagre (*Lafoensia glyptocarpa* L.), Sibipiruna (*Caesalpinia pluviosa F.*), Espatódea (*Spathodea campanulata* P.Beauv.), Tipuana (*Tipuana tipu* F.) – isoladas e agrupadas –, Flamboyant (*Delonix indica* F.) e também, Chuva de Ouro (*Senna siamea L.*) – agrupadas. Foram utilizados dados meteorológicos - temperatura do ar, umidade relativa, velocidade do vento e radiação solar - da estação meteorologica urbana do Instituto Agronomico de Campinas (IAC) no período de 2003 a 2010 e dados coletados "in loco" no período de 2007 a 2010. Para as análises climáticas para a cidade de Campinas e simulação da variação de sombra, aproveitamento do vento e canions urbanos, foram calculados Temperatura Fisiologicamente Equivalente (PET) e Temperatura Média Radiante (T_{mrt}). Para quantificar a escala de influência da vegetação no microclima, análises da atenuação da Radiação Solar, Taxa de Cobertura Verde, Índice da Área da Planta (PAI), PET e T_{mrt} foram realizadas. Concluiu-se que a promoção de sombra e aproveitamento do vento bem como o manejo de árvores para o sombreamento de calçadas e edifícios, são estratégias a serem consideradas no projeto urbano e arquitetônico que visa melhorar o conforto térmico das cidades. Observou-se que a espécie Sibipiruna (*Caesalpinia pluviosa* F.) possui o melhor comportamento no microclima devido às características relacionadas à espécie, tais como Cobertura Verde e PAI e também àquelas relacionadas ao ambiente como disposição no espaço. Um clima confortável leva ao ambiente interno confortável particularmente em edifícios e, conseqüentemente, a eficiência energética. Proporcionar condições adequadas de conforto térmico ao ar livre é um passo importante para alcançar a sustentabilidade em espaços urbanos. A consciência destas questões é importante para arquitetos, planejadores e urbanistas, não apenas por orientar as possíveis soluções, mas também para enriquecer as possibilidades de projeto.

Palavras chave: conforto térmico; arborização urbana; vegetação e clima; trópicos-clima, planejamento urbano

ABSTRACT

ABREU, Loyde Vieira. **Contributions of trees for thermal bioclimate in the Urban Design in tropical cities: the case of Campinas, SP.** Campinas, 2008, 135 p. Thesis (PhD in Architecture, Technology and Cities) - School of Civil Engineering, Architecture and Urban Design, University of Campinas.

Shade trees can improve the thermal bioclimate in tropical cities such as Campinas, SP. Trees behave in different ways in urban microclimate, but there is a lack of research in terms of benefits brought by different species and disposition in building environment. The aim of this research is quantify the contribution by different species and their disposition to improve urban microclimate and urban environment, based on characterization of thermal bioclimate of Campinas, quantification of the urban climate changes causes by street canyons and evaluation of influence scale of vegetation on microclimate, as well as definition of urban guidelines for urban and architectural planning focused in Tropical climates. Twelve species and clusters were analyzed: Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.), Jacarandá (*Jacaranda mimosaefolia* D. Don.), Jambolão *(Syzygium cumini* L.), Mangueira (*Mangifera indica* L.), Pinheiro(*Pinus palustris* L.) and Pinheiro (*Pinus coulteri* L.) – isolated; Mirindiba bagre (*Lafoensia glyptocarpa* L.), Sibipiruna (*Caesalpinia pluviosa F.*) , Espatódea *(Spathodea campanulata* P.Beauv.), Tipuana (*Tipuana tipu* F.) – isolated and clusters –, Flamboyant (*Delonix indica* F.) and Chuva de Ouro (*Senna siamea L.*) – clusters. The meteorological data: air temperature, relative humidity, wind speed and solar radiation for the period 2003 to 2010 and environmental parameters collected "in loco": solar radiation, air and globe temperatures, relative humidity and wind speed, at different distances from the tree trunk (2.5 m, 10m, 25m, 50m) were required. To describe the background climate of Campinas and simulations climate modifications and street canyons, Physiologically Equivalent Temperature (PET) and Mean Radiant Temperature (T_{mrt}) was done by using Rayman Pro model. To quantify the scale of vegetation influence on urban microclimate, the indexes as Green Coverage Ratio (GCR), Plant Area Index (PAI) and Solar Radiation Attenuated Index (SRAI) was calculated, as well as PET and T_{mrt}. The results show not only that solar radiation and wind speed can influence air temperature, but also thermal comfort and heat stress as well. The street orientation east-west can improve the thermal climate, and for the others cases it is recommend urban forestry for shading sidewalk and buildings. The species Sibipiruna (*Caesalpinia pluviosa F.*) presents the best behavior in both seasons, winter and summer, in terms of thermal comfort due to tree features and disposition. The improvement of outdoor thermal comfort is an important step in order to achieve sustainability of urban spaces and configurations. The results can be valuable for architects, planners and urban designers, not only by indicating possible solutions, but mainly by enriching the design possibilities.

Keywords: thermal comfort; urban forestry, vegetation and climate, tropics-climate, urban planning

INTRODUÇÃO

A vegetação nas cidades é capaz de melhorar o conforto térmico, psicológico e fisiológico dos indivíduos (OKE, 1982; HÖPPE, 1993; SANTAMOURIS, 2001; LIN et al., 2010; STREILING; MATZARAKIS, 2003). Entretanto, o desenvolvimento acelerado das cidades brasileiras promove alterações no solo urbano, tais como a construção de edifícios, aumento das áreas pavimentadas, e também redução das áreas vegetadas, o que, consequentemente, modifica as condições do clima urbano (LOMBARDO, 1985; SANTAMOURIS, 2001).

Estudos mostram que o sombreamento das árvores reduz não só as temperaturas do ar (OKE, 1989; AKBARI, 2002; AKBARI; TAHA, 1992), mas também proporcionam melhorias no conforto térmico urbano (NICOLOPOULOU et al., 2001; GULYÁS et al., 2006; STREILING; MATZARAKIS, 2003; SPANGENBERG et al., 2008; DACANAL; LABAKI, 2011). A silvicultura urbana inserida regularmente na estrutura das cidades é uma boa pratica não somente pelo seu potencial de arrefecimento nas áreas de pedestre, mas também por controlar a radiação de onda longa e curta no solo (ASSIS; FROTA, 1999). Porém, existem poucas pesquisas que quantificam as contribuições das árvores para bioclima térmico de cidades tropicais, como Campinas, São Paulo.

Em uma pesquisa anterior (ABREU, 2008), foram avaliados cinco indivíduos arbóreos - Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.)*,* Jacarandá mimoso *(Jacaranda mimosaefolia* D. Don.), Jambolão (*Syzygium cumini* L.), Mangueira *(Mangifera indica* L.) – , e um agrupamento - Chuva de Ouro (*Senna siamea* L.)*.* Concluiu-se que as espécies com maior taxa de evapotranspiração e maior percentagem de atenuação da radiação solar são aquelas com maior capacidade de redução da temperatura do ar. Esta pesquisa, realizada em Campinas, São Paulo, é continuação do estudo sobre a escala de influência da vegetação no conforto térmico tanto no ambiente construído.

Visto que as árvores se comportam de maneiras distintas no microclima urbano, a quantificação dos benefícios para o bioclima térmico das diferentes espécies arbóreas comumente encontradas e suas disposições no ambiente construído é uma importante informação para o planejamento urbano que visa requalificar o microclima urbano. Esta proposta é capaz de introduzir uma transformação pequena e mudar a imagem da cidade com poucos gastos e grandes benefícios.

Primeiramente, foi necessário caracterizar o bioclima térmico para Campinas e simular as modificações no microclima urbano devido às configurações urbanas, com base nos dados dos últimos anos (2003 a 2010). Posteriormente, avaliou-se a escala de influencia de árvores isoladas e agrupadas no microclima urbano segundo a metodologia desenvolvida por Abreu (2008). Nesta etapa, foram avaliadas doze espécies: Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.)*,* Jacarandá mimoso (*Jacaranda mimosaefolia* D. Don.), Jambolão *(Syzygium cumini* L.), Mangueira *(Mangifera indica* L.), Pinheiro (*Pinus palustris* L.) e Pinheiro (*Pinus coulteri* L.) – isoladas; Mirindiba Bagre (*Lafoensia glyptocarpa* L.)*,* Sibipiruna (*Caesalpinia pluviosa F.*)*,* Espatódea (*Spathodea campanulata* P.Beauv.), Tipuana (*Tipuana tipu* F.) – isoladas e agrupadas –, Flamboyant (*Delonix indica* F.) and Chuva de ouro (*Senna siamea L.*) – agrupadas. Por último, foram feitas simulações com modelos tridimensionais baseando-se nas características das árvores analisadas e também na sua disposição no ambiente natural. Assim, também, foram realizadas simulações de cânions urbanos vegetados com algumas árvores.

Os resultados mostraram que o aproveitamento dos ventos nas cidades e a promoção de sombra são importantes estratégias para melhoria do bioclima térmico de Campinas. O manejo adequado das árvores nas cidades para a promoção do sombreamento das superfícies urbanas e das fachadas dos edifícios é capaz de mitigar os efeitos térmicos da radiação solar. As árvores que mais contribuem para melhoria do microclima são aquelas que possuem tronco plagiotrópico e folhas pequenas, como a Sibipiruna (*Caesalpinia pluviosa F.*). Assim também, sugere-se que o desenvolvimento de projetos urbanos observe as recomendações da razão altura-largura (W/H), bem como oriente as ruas e avenidas para que haja o melhor aproveitamento dos ventos e da insolação.

1.2 Hipóteses

As diferentes espécies arbóreas apresentam comportamentos distintos no microclima urbano. É possível estabelecer uma relação entre a melhoria do conforto térmico e as características ligadas às espécies arbóreas – copa, estrutura do tronco e folhas - e à sua disposição no ambiente construído.

1.3 Objetivo

O objetivo geral deste trabalho é quantificar a contribuição de indivíduos arbóreos e agrupamentos de maior presença nas cidades para a melhoria dos microclimas urbanos e do ambiente construído.

Os objetivos específicos são:

- Caracterizar, através de simulações, o bioclima térmico da cidade de Campinas e quantificar as principais modificações no clima urbano devido às configurações urbanas;
- Quantificar, por meio de medições em campo, as condições de conforto térmico proporcionado pelas árvores;
- Simular a contribuição das árvores no ambiente construído a partir do desenvolvimento de modelos tridimensionais baseados nas características morfológicas das árvores analisadas;
- Desenvolver recomendações para arborização urbana do ponto de vista de melhoria do conforto térmico.

1.4 Estrutura da Tese

A tese está organizada em cinco partes. A primeira parte (Capítulo 2) apresenta uma breve revisão bibliográfica sobre o tema desta pesquisa. A segunda parte (Capitulo 3) descreve os locais de medição, bem como os indivíduos arbóreos analisados. A terceira parte (Capitulo 4) descreve a metodologia da pesquisa, que subdivide-se em três partes: modificações do bioclima de Campinas, diferentes distancias de influência da vegetação no microclima urbano e simulação da contribuição das árvores nos microclimas. A quarta parte (Capítulo 5) apresenta os resultados da pesquisa, os quais são discutidos na quinta parte (Capitulo 6). A sexta parte (Capitulo 7) traz a conclusão da pesquisa, onde são apresentadas as diretrizes urbanas baseadas nos resultados, as considerações finais e os trabalhos futuros.

Chapter 2 - THERMAL BIOCLIMATE AS A FACTOR IN URBAN AND ARCHITECTURAL PLANNING IN TROPICAL CLIMATES

2.1 Importance of Thermal Bioclimate

Weather and climate are not only important factors in daily life but also in the creation and development of new commercial, residential and recreation areas for city dwellers. Also, weather is an important determinant of mood and behavior. With sufficient exposure time, pleasant weather can improve mood and enhance cognition (KELLER et al., 2005; PERSINGER, 1980; WATSON, 2000). Due to the need for urban planning, people are often directly exposed to weather in outdoor conditions. Therefore, a comfortable thermal environment is extremely important (GIVONI, 1997) to the success of urban public squares and parks (HWANG; LIN, 2007; NAKANO; TANABE, 2004; NIKOLOPOULOU et al., 2001; NIKOLOPOULOU; STEEMERS, 2003; SPAGNOLO; DE DEAR, 2003, MAYER et al., 2008, HWANG et al., 2010).

Thermal comfort can be described based on the human energy exchange and derived thermal indices, which include the effects of air temperature, air humidity, wind speed and short and long wave radiation fluxes. The effect of the short and long wave radiation can be described by the synthetical value of the mean radiant temperature. In addition thermo-physiological factors - which influence the energy exchange of the human body, i.e. clothing and human working activity - have to be implemented in the approaches in order to derive objective results.

2.4.1 Outdoor Thermal Comfort index

Thermal comfort is defined as that condition of mind that expresses satisfaction with the thermal environment (ASHRAE, 1966; FANGER, 1972; ISO 7730, 1994; 2005), and no preference to be warmer or cooler (FANGER, 1972). While indoor comfort sensation is well documented (e.g. FANGER, 1972; GIVONI, 1976; BRAGER; DE DEAR 1998, ASHRAE, 2001), there are a lot of indexes of how to assess comfort. The thermal indexes are based on the same idea: to combine several factors (e.g. Ta, RH, v, radiation fluxes, etc.) into a single variable, which sums up their simultaneous effects on the sensory and physiological responses of the body (GIVONI, 1976; ASHRAE 2001). They can be classified in two groups: empirical or rational. These indexes are well documented (e.g. GIVONI, 1976; HOUGHTON, 1985; ASHRAE, 2001) and some of them are exemplarily listed in Table 1.

In the past, thermal indices were frequently used to estimate the thermal environment. These indices, however, were based on single or composite meteorological parameters, such as wet-bulb or equivalent temperature (THOM, 1959; STEADMAN, 1971; ISO 7730, 1989). In the 1970s, several scientists began to use physiologically relevant indices that were derived from the human energy balance for the assessment of the thermal component (HÖPPE, 1984; 1993).

Table 1 - Selected thermal comfort indices for indoors and outdoors (Adapted of ALI-TOURDET; MAYER, 2005; BŁAŻEJCZYK, 2010)

Index	Definition
Empirical indices	
ET Effective Temp.	set in Monograms and represent the instantaneous thermal sensation estimated experimentally as a combination of Ta, RH and v
RT Resultant Temp.	comparable to ET but tested for a longer time to meet assumed thermal equilibrium
HOP Humid Operative Temp.	temperature of a uniform environment at a relative humidity RH = 100% in which a person looses the same total amount of heat from skin as the actual environment (comparable to ET* but RH equals 50% for HOP)
OP Operative Temp.	arithmetic average of Ta and Tmrt, that is including solar and infrared radiant fluxes weighted by exchange coefficients
WCI Wind Chill Index	based on the rate of heat loss from exposed skin caused by wind and cold and is function of Ta and v, suitable for winter conditions
Rational indices	
ITS Index of Thermal Stress	assumes that within the range of conditions where it is possible to maintain thermal equilibrium, sweat is secreted at sufficient rate to achieve evaporative cooling.
HSI Heat Stress Index	ratio of the total evaporative heat loss Esk required to thermal equilibrium to the maximum of evaporative heat loss Emax possible for the environment, for steady-state conditions (Sskin=Score=0) and Tsk = 35°C constant
ET* new Effective Temp.	temperature of a standard environment (RH = 50%, Ta = Tmrt, v < 0.15 m/s^{-1}) in which the subject would experience the same sweating SW and Tsk as in the actual environment. It is calculated for light activity and light clothing.
SET* Stand. Effective Temp.	similar to ET* but with clothing variable. Clothing is standardized for activity concerned.
OUT_SET* Out. Stand. Eff. Temp.	similar to SET* but adapted to outdoors by taking into account the solar radiation fluxes. Reference indoor conditions are: Tmrt = Ta ; RH = 50% ; v = 0.15 ms^{-1}.
PMV and PT Predicted mean vote Perceived Temp.	PMV expresses the variance on a scale from -3 to+3 from a balanced human heat budget and PT the temperature of a standardized environment which achieves the same PMV as the real environment. Clothing and activity are variables.
PET Physiol. Equiv. Temp.	temperature at which in a typical indoor setting: Tmrt = Ta ; VP = 12h Pa ; v = 0.1 ms-1, the heat balance of the human body (light activity, 0.9clo) is maintained with core and skin temperature equal to those under actual conditions, unity °C.
UTCI Universal Thermal Climate Index	temperature at which in a typical indoor setting: Tmrt = Ta ; RH = 50%; v= 0.5 m/s at 10 m height (approximately 0.3 m/s in 1.1 m); at high air temperatures (>29ºC) the reference humidity was taken constant at 20 hPa; a representative activity to be that of a person walking with a speed of 4 km/h (1.1 m/s). This provides a metabolic rate of 2.3 MET (135 $W.m^{-2}$).

A common model for the human energy balance is MEMI (Munich energy balance for individuals), and the derived thermal assessment index PET (physiologically equivalent temperature). Other models are the predicted mean vote (PMV) (FANGER, 1972) and standard effective temperature (GAGGE et al., 1986). The three thermal indices PET, SET* and PMV are part of the RayMan model, as are energy fluxes and body parameters by MEMI. They all require mean radiant temperature T_{mrt} as input. The following meteorological parameters were taken into account in these thermal indices:

- air temperature
- vapor pressure
- wind velocity
- mean radiant temperature

Body parameters used in MEMI are:

- human activity and body heat production
- heat transfer resistance of clothing.

To facilitate the thermo-physiological acquisition of indoor thermal conditions and surrounding outdoor air as point layers, PMV, PET indices should be calculated (VDI, 1998). Moreover, the use of PET for quantifying thermal comfort in micro scale has many advantages:

- It is a universal index and irrespective of clothing (clo values) and metabolic activity (met values);
- There are possibilities of using meteorological data to built a thermophysiological background and its real effect of climate sensation on human beings;
- Its measurement is in °C for which common experience can easily be reported.
- It does not rely on subjective measures;

- It is useful in both hot and colder climates (CHIRAG DEB; RAMACHANDRAIAH, 2010).

In order to compare the results of the Predicted Mean Vote (PMV) with the Physiological Equivalent Temperature (PET), Matzarakis, Izionmon and Mayer (1999) developed the framework stipulating two different levels of human sensations and heat stress in humans (internal heat production: 80 W, the thermal resistance of clothing: 0.9 clo). Table 02 was based on the European reality.

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

Thermal Sensarion	PMV (FANGER, 1972)	PET range for Western/Middle European (ºC PET)	PET ranger for Taiwan (ºC PET) (LIN et al, 1996)	PET ranger for São Paulo (MONTEIRO; ALLUCCI, 2009)
Very cold	- 3,5	<4	<14	
Cold	- 2,5	4-8	14-18	< 4
Cool	- 1,5	8-13	18-22	4-12
Slightly cool	- 0,5	13-18	22-26	12-18
Comfortable	0	18-23	26-30	18-26
Slightly warm	0,5	23-29	30-34	26-31
Warm	1,5	29-35	34-38	31-43
Hot	2,5	35-41	38-42	>43
Very hot	3,5	>41	>42	

2.1.2 Mean Radiant Temperature

To estimate thermal indices, common meteorological data such as air temperature, air humidity and wind speed are required. The mean radiant temperature T_{mrt} is the most important meteorological input parameter for obtaining the human energy balance during summer conditions (WINSLOW et al., 1936; CLARK; EDHOLM, 1985). Therefore, T_{mrt} has the strongest influence on thermo-physiological significant indices like PET or PMV.

T_{mrt} can be obtained through different measurement procedures and models. The procedure for determining T_{mrt} experimentally is very complex, time-intensive and expensive. This is due to the combination of pyranometer and pyrgeometer, which have to be orientated in six directions (4 cardinal directions, upwards, downwards) to measure the complete short- and long-wave radiation fluxes which are significant for a person in the 3D environment (FANGER, 1972; HÖPPE, 1992). Mean radiation flux densities of the human body can be calculated from the measured short- and long-wave radiation fluxes (HÖPPE 1992):

$$S_{str} = a_k \sum_{i=1}^{6} k_i F_i + a_i \sum_{i=1}^{6} L_i F_i \qquad \text{(Eq. 01)}$$

where K_i is the short-wave (solar) and L_i the long-wave (terrestrial) radiation fluxes, and a_k and a_i are the absorption coefficients for short-wave and long-wave radiation. F_i is the angle factors of the solid surfaces. Following the calculation of T_{mrt}, it can be calculated through the use of the Stefan–Boltzmann radiation law (in °C), where σ is the Stefan–Boltzmann constant ($5.67*10^{-8}$ W/m−2K^{-1}):

$$T_{mrt} = \sqrt[4]{\left(\frac{S_{str}}{a_l \sigma}\right)} - 273.2 \qquad \text{(Eq. 02)}$$

The measured radiation fluxes have to be multiplied with weighting factors for the human body. For a standing man, the incoming radiation fluxes have to be known in the four horizons (vertical position of the instruments), which are more important than the radiation fluxes in the vertical direction. The advantage of this method is that it is integral for measuring the short- and long-wave radiation fluxes. The disadvantage of this method is that it cannot be applied for long-term experimental investigations and studies.

For the estimation of long-term studies without directly measured radiation fluxes, T_{mrt} can be calculated through models such as RayMan. In the literature, recommended methods for estimating radiation fluxes are based on parameters including air temperature, air humidity, degree of cloud cover, atmospheric turbidity, and time of the day and the year. The albedo of the surrounding surfaces and their solid angle proportions, however, must be specified. Additionally, other factors like the geometrical properties of buildings, vegetation etc. must be taken into consideration. For such models to be applied in simple situations, the following atmospheric parameters are required:

- direct solar radiation
- diffuse solar radiation
- reflected short-wave radiation
- atmospheric radiation (long-wave)
- long-wave radiation from the solid surfaces

The following parameters describing the surroundings of the human body also must be known:

- sky view factor
- view factor of the different solid surfaces
- albedo of the different solid surfaces
- emissivity of the different solid surfaces

Many methods already exist for the calculation of short-wave radiation fluxes that apply simple and complex models with different time resolutions on the basis of different methods, and these are well-tested (e.g. VALKO, 1966; ZDUNKOWSKI; BRÜHL; 1983; JESSEL, 1983; OLSETH; SKARTVEIT, 1993; VDI 1998; BADESCU, 1997; CEBALLOS; DE MOURA 1997; SANTAMOURIS et al., 1999; CRAGGS et al., 2000;). Models using sunshine duration for the calculation of short-wave radiation fluxes are used (VALKO, 1966; GOPINATHAN, 1992; REVFEIM, 1997; SEN, 1998), as well as simple parameterizations for turbidity (KASTEN, 1980; POWER, 2001). Methods for the calculation of long-wave radiation fluxes also exist (CZEPLAK; KASTEN, 1987; SALISBURY; D'ARIA, 1992; NUNEZ et al., 2000). For complex situations in urban settings, several models and analytic methods are documented in the literature (KAEMPFERT, 1949, 1951; TERJUNG; LOUIE, 1974; MOHSEN, 1979; FRANK et al., 1981; ZDUNKOWSKI; BRÜHL 1983; LITTLEFAIR, 2001; KANDA et al., 2004).

The way in which radiation fluxes are modified in and around urban structures can be described by the sky view factor, which is also an important parameter for urban climate studies. There are many existing methods for its calculation (JOHNSON; WATSON, 1987, 1988; BECKER et al. 1989; CHEN; BLACK, 1991;HOLMER, 1992; RICH et al. 1993; CHAPMAN et al. 2001; FRAZER et al. 2001; PEREIRA et al. 2001; HOLMER et al. 2001). Also important on the local scale is the knowledge of shadowing (NIEWIENDA; HEIDT, 1996; MATZARAKIS et al. 2000; MATZARAKIS, 2001). Finally, radiative properties such as emissivity and albedo for the human body are also needed (UNDERWOOD; WARD, 1966).

To calculate the mean radiant temperature T_{mrt}, the relevant properties and dimensions of the radiating surfaces and of the visible section of the sky must be known. The posture of the human body (e.g. seated or standing) is also required. The entire surroundings of the human body are divided into n isothermal surfaces with the temperatures T_i (i=1 to n) and emissivities εi to which the solid angle portions ("angle factors") F_i are to be allocated as weighting factors. Long-wave radiation ($E_i=\varepsilon_i*\sigma*T_i$ 4) and diffuse short-wave radiation Di are emitted from each of the n surfaces of the surroundings. This results in a value for Tmrt as (FANGER, 1972; JENDRITZKY;NÜBLER, 1981):

$$T_{mrt} = \left[\frac{1}{\sigma} \sum_{i=1}^{n} \left(E_i + a_{k} \frac{D_i}{\varepsilon_p}\right)^{0.25}\right] \quad \text{(Eq. 03)}$$

where σ is the Stefan–Boltzmann constant (5.67*10−8 W/(m2K4)), and ε_p is the emission coefficient of the human body (standard value 0.97). D_i comprises the diffuse solar radiation and the diffusely reflected global radiation. a_k is the absorption coefficient of the irradiated body surface area of short-wave radiation (standard value 0.7). T_{mrt} is incremented to T_{mrt}*, if there is also direct solar radiation:

$$T_{mrt}^{*} = \left[T_{mrt}^{4} + \frac{f_p a_k l^{*}}{\varepsilon_p \sigma}\right]^{0.25} \quad \text{(Eq. 04)}$$

In this case, I* is the radiation intensity of the sun on a surface perpendicular to the incident radiation direction, and the surface projection factor fp is a function of the incident radiation direction and the body posture (VDI, 1998). For applications in human-biometeorology, it is generally sufficient to determine fp for a rotationally symmetrical person standing up or walking (JENDRITZKY et al. 1990).

2.4.1 Applied Model: RayMan Pro

Many climatic parameters and conditions are affected by natural and artificial morphology at a meso and micro scale, with influences the temporal and spatial behaviour of the parameters. These effects are significant at different levels of regional and urban planning i.e. urban parks, and they are also of importance for the planning and design of new buildings, recreational facilities and a variety of other applications. With some modification, existing methods for assessing climate in human biometeorology and applied climatology can be applied to tourism climatology (MATZARAKIS, 2001; MATZARAKIS et al., 2004).

For example, thermal indices that are derived from the energy balance of the human body can be of great advantage for regional and urban planning. Standard climate data, such as air temperature, air humidity and wind speed are required in order to calculate and quantify the thermal bioclimatic conditions.

The most important environmental parameters for deriving modern thermal indices, however, are the short and long wave radiation (and the derived mean radiant temperature). These can be determined using special techniques. For these purpose, several models and possibilities exist, i.e. the RayMan model, which has been developed for urban climate studies, has a broader use in applied climatology (MATZARAKIS, 2001; MATZARAKIS et al., 2004). Further outputs, such as sunshine duration and shadow, can be helpful in the design and structure of recreational areas and design of urban structures (Matzarakis, 2006).

2.2 Thermal Bioclimate in Urban and architectural planning

Urban sprawl without consideration of relevant climate issues can progressively decline sustainability in outdoor and indoor environments and is closely related with quality of life in tropical cities. Moreover, the energy consumption that has unintentionally increased at building level is a consequence of climatic modifications. This leads to a remarkable demand on the urban energy resources (OKE, 1984; JAUREGUI, 1997; AKBARI; TAHA, 1992; MCPHERSON; SACAMANO, 1992; MCPHERSON et al., 1989; MATZARAKIS, 2001). The motivation for developing a thermally desirable or neutral outdoor environment has implications that go beyond the requirements of urban design and also in the design of climate adjusted buildings. To re-establish indoor and outdoor thermal acceptable or neutral conditions, it is important to specify standards, how urban spaces can be structured and arranged according to the existing climate conditions in a region (GIVONI, 1989; GIVONI, 1991; ALCOFORADO; MATZARAKIS, 2010).

Several studies on thermal bioclimate in urban areas reported that urban streets in particular consist of the shared active facets between their building envelope and the open urban canopy, bringing together the relation between urban configuration and physical properties of urban obstacles (buildings and vegetation primarly) and knowing that this affects outdoor and indoor environments (ALI-TOUDERT; MAYE, 2007; EMMANUEL ET AL., 2008). Due to urban morphology, the behavior and pattern of wind and solar radiation are the factors that have the highest variability and impacts on humans (HERRMANN; MATZARAKIS, 2012; LIN et al. ,2010). Shading and wind can play an important role in cities and can substantially modify urban climate and consequently thermal bioclimate (ALI-TOUDERT; MAYER, 2007; LINDBERG; GRIMMOND, 2011; HERRMANN; MATZARAKIS, 2012).

The reduction of evaporation caused by lack of vegetation and water supply on one hand, and on other hand, the increase of rough surfaces due to the presence of buildings in urban areas are typical modifications in urban design promoting heat island formation and intensity (LOMBARDO, 1985; OKE, 1984). Controlling radiation by vegetation can build a possibility of regulation of an urban micro climate modification. In addition, this builds a possibility for climate change adaptation (GREEN, 1993; ABREU; LABAKI, 2010; MATZARAKIS; ENDLER, 2010). During the day, the modification of the short and long wave radiation fluxes by vegetation in combination with wind speed can cause a reduction of heat stress (MATZARAKIS; ENDLER, 2010). On the contrary, during the night in a vegetative environment, the emission of long wave radiation is lower and so thermal bioclimate can be more pronounced in comparison to open spaces (MATZARAKIS, 2001). In urban configurations the absorption of radiation and heat storage can be factors with negative effects on thermal bioclimate especially during the night (ALCOFORADO; MATZARAKIS, 2010).

The objective of this chapter is to provide a solid foundation of pertinent and valid findings of the urban climate and bioclimate conditions, which can then be used in further studies, as well as bioclimatic design to improve and adapt to the urban design. This is important knowledge that urban planners, designers, micro climatologists and forestry engineers must apply in their modeling and designs.

2.2.1 Architectural design and urban planning in Brazil

Usually cities and buildings tend to be planned and designed according to particular climatic and cultural environments (for example, BUTTI; PERLIN, 1979; ACHARYA, 1996; KENNEDY; KATOSHEVSKI, 2009). In Brazil, many not sensitive to climate buildings have been designed in the recent past and require large energy consumption in order to provide thermal comfortable indoor environment during the winter and summer seasons. The combination effect between the design of these buildings and the reduction of green areas accelerate the formation of heat islands (OKE, 1984; LOMBARDO, 1985; MONTEIRO; ALLUCCI 2010). The consequences of these fast transformations are various, heterogeneous and complex. The urban territory adds new functions, uses and spaces through a dynamic and unexpected way because of the new development impulses and pressures. Luxurious residential areas emerge in midst of depreciated peripheries along with a strong concern to reduce sustainability. Paradoxically, there are poor housing clusters in areas of risk or otherwise climatically important such as green areas, mountain slopes and riverbanks or in urban voids without considering thermal comfort issues and approaches (SOBRAL,2005).

Urban planning and design influence the formation of heat islands because of the urban geometry and thermal properties of built-up surfaces (OKE, 1982; MATZARAKIS, 2001). The phenomenon is also observed in São Paulo, Brazil, based on air temperature in urban spaces (LOMBARDO, 1985; SOBRAL, 2005). From the relationship between air temperature and thermal comfort a conclusion was drawn that São Paulo is more comfortable in summer than in winter because of precipitations and the higher amount of clouds (SOBRAL, 2005). Another research showed the importance of the consideration from a local topography, solar and wind orientations and patterns in urban design, as well as the localization and distribution of green areas (ASSIS; FROTA, 1999). Subsequently, forestry and green areas are suggested in order to mitigate the negative effects of heat islands and to modify and restructure environment so to reach thermal comfort levels (BUENO-BARTHOLOMEI; LABAKI, 2003; ABREU; LABAKI, 2010; DACANAL; LABAKI, 2011).

2.2.2 The microclimate of an urban street canyon

The lack of inclusion of the climate issues in the architectural and urban planning causes implications in thermal bioclimate, especially in tropical cities (OKE, 1982; GIVONI, 1989; MILLS, 1999). In general, the open spaces are shared active facets between the building envelope and the open urban canopy. Urban obstacles and their orientation can influence the radiation fluxes expressed by mean radiant temperature, wind speed and consequently, have interferences both in outdoor and indoor environments. Representative urban canyons are difficult to find if all modifying parameters have to be considered: aspect ratio, orientation, construction materials, presence of vegetation, etc. (OKE, 1987).

Studies on thermal comfort and urban heat islands often refer only to case studies and measurement campaigns, and are limited to decline long-term information about special conditions in urban areas, particularly thermal comfort issues. The radiations exchanges in canyon geometry affected strongly the timing and magnitude of the energy regime of the individual canyon surfaces and were very different from each other (NUNEZ; OKE, 1977; YOSHIDA ET AL. 1990; MILLS, 1993; SANTAMOURIS ET AL, 1999; ALI-TOUDERT; MAYER, 2005).

Research on urban canyon based on "in loco" measurement shows the modification in urban climate, where the air temperature was systematically cooler during the day and warmer at night (NAKAMURA; OKE, 1988; YOSHIDA et al., 1990). This result can be explained by the orientation of the street canyons. In the Kyoto's canyon, the south facing wall and floor were the primary sites of solar absorption during the day, and their role as a source of sensible heat for the canyon continued at night-time (NAKAMURA; OKE, 1988). In hot weather conditions, Santamouris et al. (1999) confirmed these findings.

Others urban canyon studies based on radiation fluxes estimation and simulation present similar results as those found in cities. The existing long-term data of an urban climate station was used for a microscale (ALI-TOUDERT; MAYER, 2005). To quantify the influence of the height-width ratio and the effect or orientation in radiation fluxes in a typical urban canyon of a medium-size western European city, simulation based on data from the urban station of Freiburg, Germany, was done (HERRMANN; MATZARAKIS, 2012). The results show that day hours are cooler and nights are warmer than urban station temperatures. The building heights being close to 40 m, thermal stress still occurs at noon for north-south orientated streets. Thermal stress at noon is mitigated significantly at building height above 10m. The street rotation reveals the daytime periods and height-width ratios for which T_{mrt} is most affected by global radiation at each specific location and geographical latitude.

2.2.3 Effects of Vegetations on Microclimate

An important characteristic of tropical cities is urban greenery that creates the comfortable shades along the streets and within individual house lots and also plays the role of carbon sink, which is proportional to the green coverage. The climatic changes due to thermal characteristics of different kinds of surfaces present in urban spaces and by their behavior with respect to the incident solar radiation represent serious impacts on the equilibrium of the environment (OKE, 2004; BAUMÜLLER et al.. 1999; GUDERIAN, 2000). By observing the importance of vegetation in the control of the incident solar radiation and regulator of the urban climatic changes, it becomes meaningful to qualify and quantify the influence of trees on thermal comfort.

Several works focusing on trees and theirs benefits in urban environment have been published (HEISLER, 1977; HERRINGTON, 1977; BERNATZKY, 1979; MEYER; BAUERMEL, 1982; OKE, 1989; MCPHERSON ET AL., 1994; CARDELINO; CHAMEIDES, 1990; CANTUARIA, 2000; DIMOUDI; NIKOLOPOULOU, 2003; BUENO-BARTHOLOMEI; LABAKI, 2003; ABREU; LABAKI, 2008; DACANAL; LABAKI, 2011). Different methodologies are used in various researches confirming that the vegetation can influence in urban microclimate, improve thermal comfort and increase the potential of health impairment of urban populations (SANTAMOURIS, 2001; AKBARI, 2002; DIMOUDI; NIKOLOPOULOU, 2003; AKBARI et al., 1996). In fact, the arboreal species behave in different ways in outdoor spaces, especially because of the differences in shade trees, nevertheless, there are a few studies that quantify these benefits (BUENO-BARTHOLOMEI; LABAKI, 2003; KATOSHEVSKI; KENNEDY, 2007; SHAHIDAN et al., 2010).

The urban trees can reduce air temperature, increase air humidity, reduce wind speed, as well as air pollutants (STREILING; MATZARAKIS, 2003). It was confirmed that the positive effect of single and cluster of trees on the bioclimate of the city, the mean radiation temperature T_{mrt} and the human biometeorological thermal index known as the physiological equivalent temperature (PET) are distinct due to differences between areas with trees and without trees. Local air temperature can be influenced not only by the green coverage, but also leaf area, that is, important arboreal characteristics (TSUTSUMI et al., 2003). Some studies confirm that specific features of the species, like structure and density of the treetop, size, shape and color of leaves, tree age and growth, can influence in performance of solar radiation attenuated by canopy, air temperature and air humidity (SCUDO, 2002; BUENO-BARTHOLOMEI; LABAKI, 2003; ABREU; LABAKI, 2010). The tree canopy is a major component able to contribute to microclimatic environments because it can attenuate solar radiation and control the wind speed (STEVEN et al., 1986). In tropical climates, the possibility to change wind conditions and shade modify the microclimate and improve thermal comfort (LIN et al.,2010).

After evaluating thermal comfort by index PET (Physiologically Equivalent Temperature) PMV and SET in outdoor spaces in Freiburg, Germany, authors verified that the trees could modify the microclimate (GULYÁS et al., 2006). In Brazil, recent researches concluded that outdoor thermal comfort is closely related with urban forestry (SPANGENBERG et al. , 2007; MORENO; LABAKI, 2008). Various Brazilian researches used PET, but these indexes need to be adopted by local climate (MONTEIRO; ALUCCI, 2010). However, climate and microclimate of outdoor spaces in different latitudes suggest distinct thermal comfort index, because these are not associated just with characteristics of the ambient but with the population (MORENO; LABAKI, 2008).

Benefits Associated with Trees in subtropical climate

Additionally to their aesthetic value, urban trees can modify the climate of a city and improve urban thermal comfort in hot climates, like subtropical climate in Brazil. The urban trees, individually can also act as shading and wind-shielding elements modifying the ambient conditions around individual buildings. Also collectively, forestry can moderate the intensity of urban heat islands by altering the heat balance of the entire city (AKBARI, 2002; AKBARI; ROSE, 2008). Studies show that shade and wind speed promotion can improve the thermal comfort in tropical climates (BUENO-BARTHOLOMEI; LABAKI, 2003; LIN et al. 2010). Therefore, planting trees is a good solution for improving thermal comfort in tropical cities.

The canopy characteristics of trees can directly influence thermal comfort results, Fig 1., therefore, the behavior of individual arboreal in microclimate can be modified according to the type, hight, age, season, and disposition in urban outdoor spaces (PEIXOTO et al., 1995; BROWN; GILLESPIE, 1995). The tree leaves can absorb, reflect and transmit the solar radiation and by the evapotranspiration influence indirectly thermal comfort (SANTAMOURIS, 2001; SCUDO, 2002; ABREU; LABAKI, 2011).

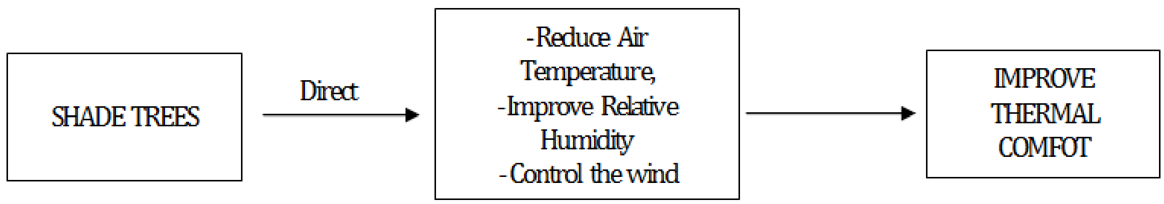


Fig 1. *Shade influence in thermal comfort*

Trees cast their own distinctive shadow, both in shape and density, and these behaviors depend on the shadow and the radiation filtered influenced by the form and density of the canopy (ROBINETTE, 1972). The amount of radiation intercepted depends on the density of the twigs and branches and leaf cover, where these elements influence the overall character of tree shape and density (BROWN; GILLESPIE, 1995; SCUDO, 2002; ABREU; LABAKI, 2011). Not only can the form and density of canopy influence in shade tree qualities, but also the individuality of trunks, Fig. 2, and that of the leafs need to be considered, Fig 3., (ABREU;LABAKI, 2011).

For example, tree species in Brazil can attenuate solar radiation between 76.3 – 92.8 % in summer (ABREU; LABAKI, 2010; BUENO-BARTHOLOMEI; LABAKI, 2003) and tree species in Malaysia have different density value when the average heat infiltration under canopy is compared (SHAHIDAN et al., 2010). These results confirm that the structure of crown, dimension, shape and color of vegetation leaves influence the reduction level of solar radiation.

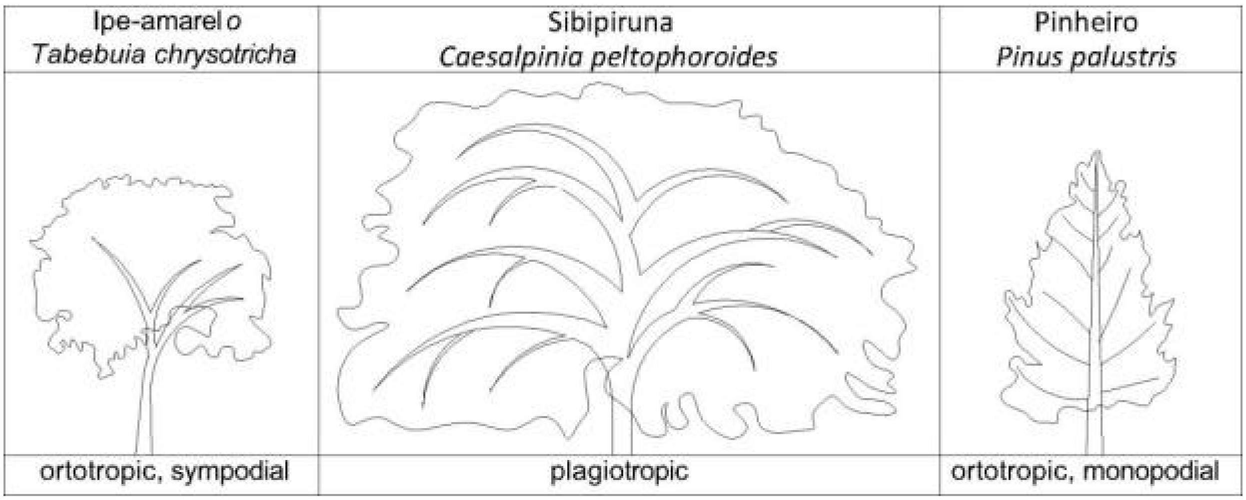


Fig 2. *Trunks characteristics*

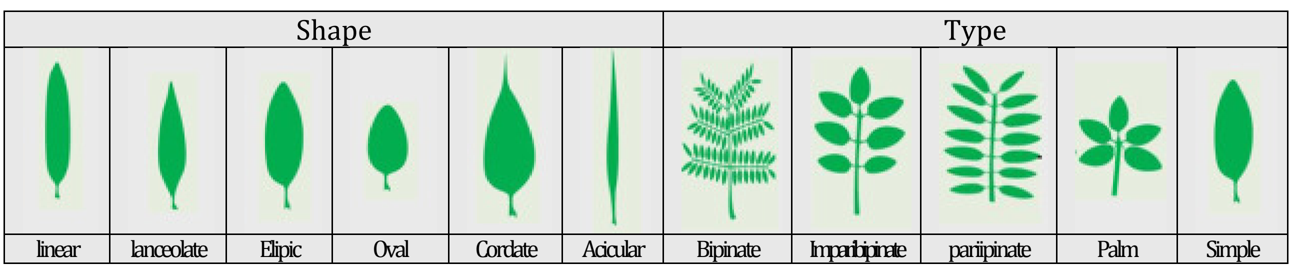


Fig 3. *Leaf characteristic*

Other studies show that individual trees can reduce the air temperature in different distances and consequently improve thermal comfort (ABREU; LABAKI, 2010). By computer simulation of the air temperature distribution of an around 10m high single tree, it was observed that the maximum range of air temperature is approximately 25 m from the tree (HIRAOKA, 2002). The air temperature distribution as well humidity still depends on wind velocity and direction (VOGT et al., 2003).

It is known that vegetation has a great potential to control air movement but this effect cannot be determined with certainty. Studies show that the vegetation can influence the pattern of air movement through guidance, filtration, obstruction and deflection and it depends on vegetation characteristics, such as geometry, height, permeability and crown of the vegetation are the structural vegetal characteristics that influence the controlling air movement (SCUDO, 2002; VOGT et al., 2003).

Trees' arrangement and their contributions in street canyons

Design strategies for sustainable urban planning need to consider the trees' contribution for the mitigation of urban heat island intensity and heat stress. One of the strategies for urban heat island mitigation is the tree shading of urban parks and sidewalks (GRIMMOND, 2007).

Several recent studies have shown that vegetation is beneficial in lowering air temperatures, in providing shade and in improving thermal comfort. Field measurements by Shashua-Bar and Hoffman (2005) showed that some tree-aligned streets and boulevards in the Tel-Aviv area, Israel, had 1–2.5°C lower air temperatures than non-vegetated streets at the hottest part of the day (15:00 h). In Colombo, Sri Lanka, it was observed a maximum difference of 7 °C, while temperature differences between sunlit and shaded urban surfaces reached up to 20 °C. In this research, the shading is proposed as the main strategy for reducing air and radiant temperatures, especially achieved by deep canyons, covered walkways and shade trees (EMMANUEL et al., 2007). In Campinas, Brazil, recent studies demonstrated the importance of tree shading in controlling the thermal comfort (BUENO-BARTHOLOMEI;LABAKI, 2003; ABREU; LABAKI, 2008; ABREU; LABAKI, 2010; DACANAL; LABAKI, 2011).

Applying the simulation software ENVI-met (BRUSE, 2010) to the climate of Thessaloniki, Greece, Chatzidimitriou et al. (2005) found small temperature decrease for tree-aligned streets (less than 1°C), but up to 20°C lower surface temperatures and more than 40°C lower mean radiant temperatures. The cooling effect was found to increase with a rising number of trees. In the hot dry climate of Ghardaia, Algeria, Ali-Toudert and Mayer (2005) found that shading trees could considerably improve the thermal comfort in streets. In another simulation study of different greening scenarios using ENVImet in Rio de Janeiro, Brazil, Spangenberg (2008) found that an increased amount of urban green (tree cover of 30% of the ground and 100% green roofs) could almost re-create the comfortable conditions of a natural forest.

The integrative thermal effects of different tree species and the site's built-up elements, and the interaction between them in an urban open space was observed in Tel-Aviv, Israel (SHASHUA-BAR et al., 2010). Three arboreal species analyzed - Ficus retusa, Tipuana tipu, Date Palm - presented different behavior due to their canopy coverage level and planting density. The cooling effect of these trees in summer in a hot dry climate is significant and can reach up to 3–4 degrees cooling, which is about 50% of the air temperature rise from sunrise to noon hours.

Chapter 3 - SITES AND OBSERVATIONS

3.1 Campinas Climate

Fig 4. *Campinas localization*

The research was carried out in the city of Campinas, in the coastal interior of the state of São Paulo, Brazil, and it is the third largest city in the state, after São Paulo and Guarulhos, with 1,080,113 inhabitants and 1358,63 population density (inhab/Km2) (BRASIL, 2010). Campinas, Brazil, is located at 22 ° 48'57 "S, 47 ° 03'33" W and altitude of 640 m (Fig. 4.). The city's climate is classified as tropical of altitude, Cwa (KOTTEK et al., 2006). The average annual air temperature is 22.3 º C, annual rainfall of 1411 mm, with the predominance of rain in the months from November to March and dry periods of 30 to 60 days during July and August.

3.2 Scale

The scales adopted in field measurement of this research were instantaneous and microclimate which allowed to assess the weather conditions and not the climate. However, the "*in loco*" climate, mainly 1 km, is influenced not only by local environmental parameters (solar radiation, air temperature, relative humidity and wind speed), but also by macroclimatic and mesoclimatic conditions (MONTEIRO, 1976; CAUDRAT; PITA, 1997).

In studies concerned in qualifying and quantifying trees and theirs benefits micro scale, they should consider the same surrounding conditions - no shade of buildings or other trees; topography of the land not very rugged; uniformity of conditions around trees related to the lack of pavement and buildings nearby; standardization of the surface at the measuring points - and time - in the open, with no or few clouds.

3.3 Sites and Arboreal Species Selected

Fig 5. *Isolated Trees Analyzed*

The criteria for the choice of species were those most used in tree planting programs by the city government in Campinas, Brazil. The trees should fulfill such conditions such 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.

Twelve species were selected: Ipê Amarelo *(Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.)*,* Jacarandá mimoso (*Jacaranda mimosaefolia* D. Don.), Jambolão (*Syzygium cumini* L.), Mangueira (*Mangifera indica* L.), Pinheiro (*Pinus palustris* L.) and Pinheiro (*Pinus coulteri* L.) – isolated; Mirindiba bagre (*Lafoensia glyptocarpa* L.)*,* Sibipiruna (*Caesalpinia pluviosa F.*), Espatódea *(Spathodea campanulata* P.Beauv.)*,* Tipuana (*Tipuana tipu* F.) – isolated and clusters –*,* Flamboyant (*Delonix indica* F.) and Chuva de ouro (*Senna siamea* L.) – clusters. Fig 5. and 6. show the isolated and cluster of trees analyzed, respectively. The characteristics of single and clusters of tree analyzed as crown, trunk and leaf are related at Table 3 and 4, respectively.

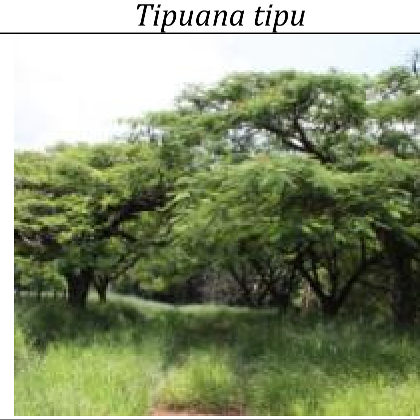
		
Caesalpinia pluviosa	*Spathodea campanulata*	*Tipuana tipu*
		
Senna siamea	*Lafoensia glyptocarpa*	*Delonix indica*

Fig 6. *Clusters of Trees analyzed*

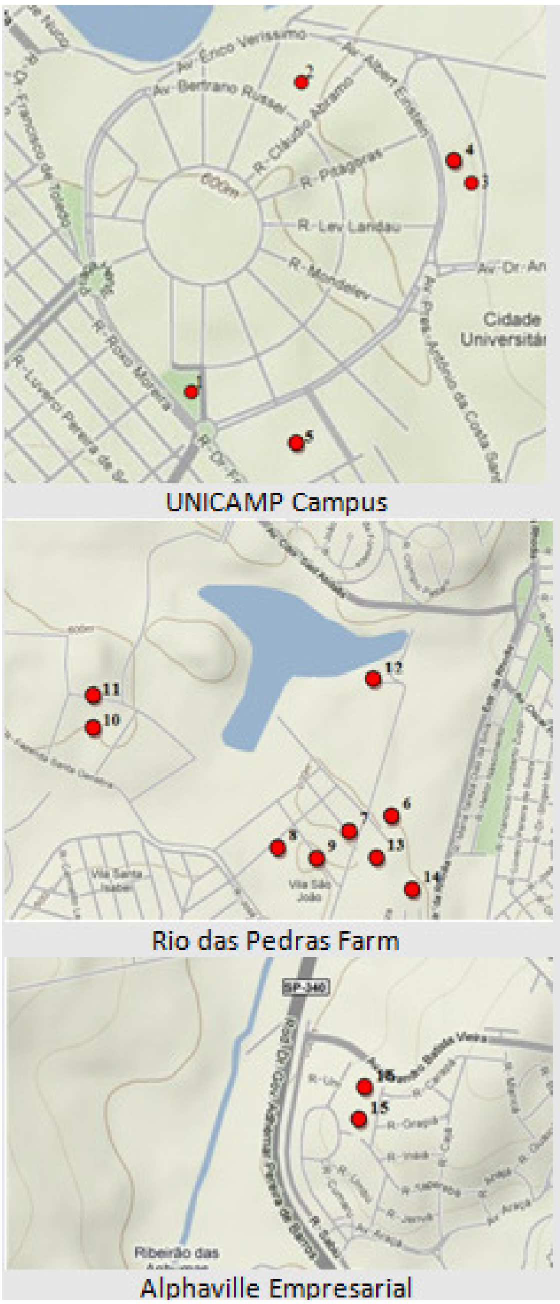
Table 3 - Features for Single Trees analyzed

ARBOREAL CHARACTERISTICS			ARBOREAL SPECIES									
			Tabebuia chrysotricha	*Caesalpinia pluviosa*	*Jacarandá mimosaefolia*	*Pinus palustris*	*Pinus coulteri*	*Spathodea campanulata*	*Tipuana tipu*	*Lafoensia glyptocarpa*	*Syzygium cumini*	*Mangifera indica*
CROWN	Profile	Height (m)	8.31	11.2	7.77	9.15	6.5	8.85	13.45	6.45	8.01	8.49
		permeability	Medium	Medium	Maximum	Maximum	Maximum	Medium	Medium	Medium	Small	Small
	Density		Medium	Maximum	Small	Medium	Medium	Medium	Medium	Medium	Maximum	Maximum
	Shape		Globe	Elliptic	Asymmetric	Triangular	Triangular	Globe	Globe	Globe	Semi-Eliptic	Semi-Eliptic
	Texture		Rough Homogeneous	Rough Homogeneous	Harshly Heterogeneous	Harshly slightly-Homogeneous	Harshly Heterogeneous	Harshly Heterogeneous	Rough slightly-Homogeneous	Rough slightly-Homogeneous	Semi rough Homogeneous	Semi rough Homogeneous
	Floor plan	Diameter	7.12	16.15	6.2	4.85	4.95	7.3	14.9	7.3	9.27	8.52
		PAI	0.48	0.92	0.27	0.47	0.34	0.78	0.72	0.75	0.88	0.85
	Phenology		Deciduous	Semi-deciduous	Semi-deciduous	Semi-deciduous	Semi-deciduous	Semi-deciduous	Semi-deciduous	Semi-deciduous	Perennial	Perennial
TRUNK	Roughness		High	Medium	Slightly	High	Medium	Medium	High	Medium	Medium	Slightly
	Color		Gray	Gray	Gray	Dark Brown	Dark Brown	Dark Brown	Brown	Gray	Brown	Brown
	Diameter		0.34	0.578	0.54	0.43	0.38	0.55	0.63	0.32	0.43	0.48
	Type		Ortotropic simpodial	Plagiotropic	ortotropic simpodial	Ortotropic monopodial	Ortotropic monopodial	Ortotropic simpodial	Plagiotropic	Plagiotropic	Plagiotropic	Plagiotropic
	Bran-ching	Height bole	3.11	2.93	2.9	1.54	1.35	2.2	2.87	1.3	1.75	1.7
		Insertion	switches	Switches	Switches	Verticillata	decussata	Decussate	Switches	Switches	Switches	switches
		arrangment	acute axis	Horizontal axis	acute axis	vertical axix	vertical axix	acute axis	Horizontal axis	acute axis	Horizontal axis	Falling axis
LEAVES	Blade		Verticillate	Opposite	Opposite	Alternate	Alternate	Opposite	Opposite	Opposite	Opposite	verticillate
	Type		Palm	Bipinate	Impabipinate	Simple	Palm	Impabipinate	Impabipinate	Paripinate	Simple	Palm
	Shape		Ovate	Linear	Lanceolate	Acicular	Acicular	Cordate	Elliptic	Cordate	Elliptic	Lanceolate
	Height (m)		0.058	0.008	0.004	0,07	0,09	0.06	0.03	0,064	0.06	0.05
	Width (m)		0.07	0.0015	0.0014	0,001	0,002	0.13	0.015	0,045	0.15	0.3
	Color		Light green	green	Light green			Dark Green	Dark Green	Dark Green	Dark Green	Dark Green

Table 4 - Features for Clusters of Trees analyzed

ARBOREAL CHARACTERISTICS			ARBOREAL SPECIES					
			Caesalpinia pluviosa	*Spathodea campanulata*	*Tipuana tipu*	*Lafoensia glyptocarpa*	*Delonix indica*	*Senna siamea*
CROWN	Profile	Height (m)	11.2	8.85	13.45	6.45	8.01	8.85
		permeability	Medium	Medium	Medium	Medium	Small	Medium
	Density		Medium	Maximum	Medium	Medium	Medium	Maximum
	Shape		Globe	Elliptic	Globe	Globe	Globe	Semi-Eliptic
	Texture		Rough Homogeneous	Rough Homogeneous	Harshly Heterogeneous	Rough slightly-Homogen.	Rough slightly-Homogen.	Semi rough Homogeneous
	Floor plan	Diameter	16.15	7.3	14.9	7.3	9.27	7.3
		PLAI	0,89	0,775	0,775		0,73	0,52
	Density		Medium	Maximum	Small	Medium	Medium	Maximum
	Phenology		Deciduous	Semi-deciduous	Semi-deciduous	Semi-deciduous	Semi-deciduous	Perennial
TRUNK	Roughness		High	Medium	Medium	High	Medium	Medium
	Color		Gray	Gray	Dark Brown	Brown	Gray	Brown
	Diameter		0.34	0.55	0.85	0.63	0.32	0.43
	Type		Ortotropic simpodial	Plagiotropic	Ortotropic simpodial	Plagiotropic	Plagiotropic	Plagiotropic
	Branching	Height bole	2.93	2.2	2.87	1.3	1.75	2.2
		Insertion	Switches	Decussate	Switches	Switches	Switches	Decussate
		arrangment	Horizontal axis	acute axis	Horizontal axis	acute axis	Horizontal axis	acute axis
LEAVES	Blade		Verticillate	Opposite	Opposite	Opposite	Opposite	Opposite
	Type		Palm	Bipinate	Impabipinate	Impabipinate	Paripinate	Simple
	Shape		Ovate	Linear	Cordate	Elliptic	Cordate	Elliptic
	Height (m)		0.058	0.008	0.06	0.03	0,064	0.06
	Width (m)		0.07	0.0015	0.13	0.015	0,045	0.15
	Color		Light green	Green	Dark Green	Dark Green	Dark Green	Dark Green
CLUSTER	Composition		homogeneous	homogeneous	homogeneous	l homogeneous	homogeneous	homogeneous
	Density		high	low	high	medium	low	medium
	Disposition		cluster	cluster	cluster	cluster	cluster	cluster
	Form		Linear (2 lines)	Linear (2 lines)	Linear (2 lines)	Linear (1 lines)	Linear (2 lines)	aleatory
	Number of trees		10	5	5	3	5	5
	Distance among trees		10.0m	9.52m	9.60m	12.47m	12	7.4

The trees studied were localized at the Unicamp Campus, Rio das Pedras Farm and Alphaville Campinas Empresarial, Fig 7. Those measurement fields are situated on urban area of Campinas, city.



1 - *Syzygium cumini* L. - individual tree

2 - *Mangifera indica* L. - individual tree

3 - *Tabebuia chrysotricha* (Mart. ex DC.) Standl. - individual tree

4 - *Jacarandá mimosaefolia* D.Don. - individual tree

5 - *Senna siamea* L. - clusters of trees

6 - *Caesalpinia peltophoroides L.* - individual tree

7 - *Caesalpinia peltophoroides L.* - clusters of trees

8- *Spathodea campanulata* P.Beauv. - individual tree

9- *Spathodea campanulata* P.Beauv.- clusters of trees

10- *Tipuana tipu* (Benth.) K. - individual tree

11- *Tipuana tipu* L. - clusters of trees

12- *Delonix indica* L. – clusters of trees

13- *Lafoensia glyptocarpa* K. - individual tree

14 - *Lafoensia glyptocarpa* K.- clusters of trees

15- *Pinus palustris* L. - individual tree

16- *Pinus coulteri* L. - individual tree

Fig 7*. Individuals and Clusters of Trees Studies Fields*

Chapter 4 - METHODOLOGY

This chapter details the methods, materials and instrumentation for the development of the field work. The methodology used consist in three parts: background analysis of urban climate and bioclimate conditions of Campinas, assessment of the influence on microclimate and simulation of the tree's contribution on microclimates, Fig. 8.

The first part evaluates the background of the urban climate and bioclimate conditions of Campinas, Brazil. To show the effects of urban morphology modification in terms of shading and wind speed changes and investigate the typical urban configuration with typical dimensions that influence on radiation flux and wind speed can be described. The analyzes thermal bioclimate conditions not only based on air temperature, but also on Mean Radiant Temperature (T_{mrt}) and Physiologically Equivalent Temperature (PET) conditions. In the second part, assessment of the influence on microclimate, the methodology of field measurement developed in master research was used (ABREU, 2008). These results show that certain trees, single and clusters, changes the microclimate in different distances and which trees' features can more influence on thermal comfort sensations than others. The third part, simulation of tree's contributions on microclimate, integrates the urban climate changes and the strategies of planting trees. Based on assessment of the influence on microclimate and the multi criteria analysis (MCA), trees were classified and those who have the best performances were selected. From these selected trees, theirs features can be extracted for developing tridimensional models. The simulations of street canyons with trees models based on real trees was done. The results can quantify the contributions of trees shading on built-up environment.

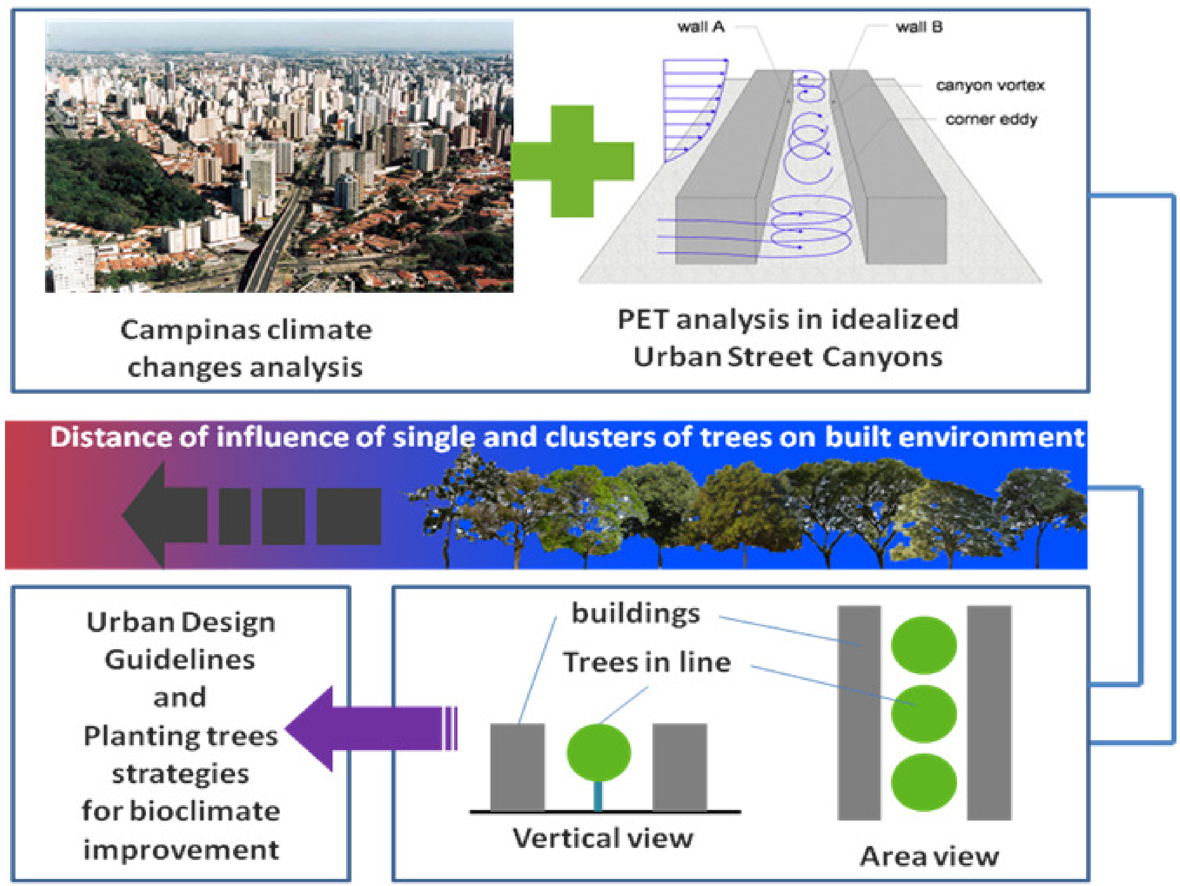


Fig 8. Study methodology schemes

The methodological approach in this study is focused on generalization. The generalization procedure for quantifying the thermal comfort of different studied situation is possible by control variables: urban street geometry and trees features. Figure 9 shows the modeling procedure followed in this study in quantifying the effects of the system's control variables.

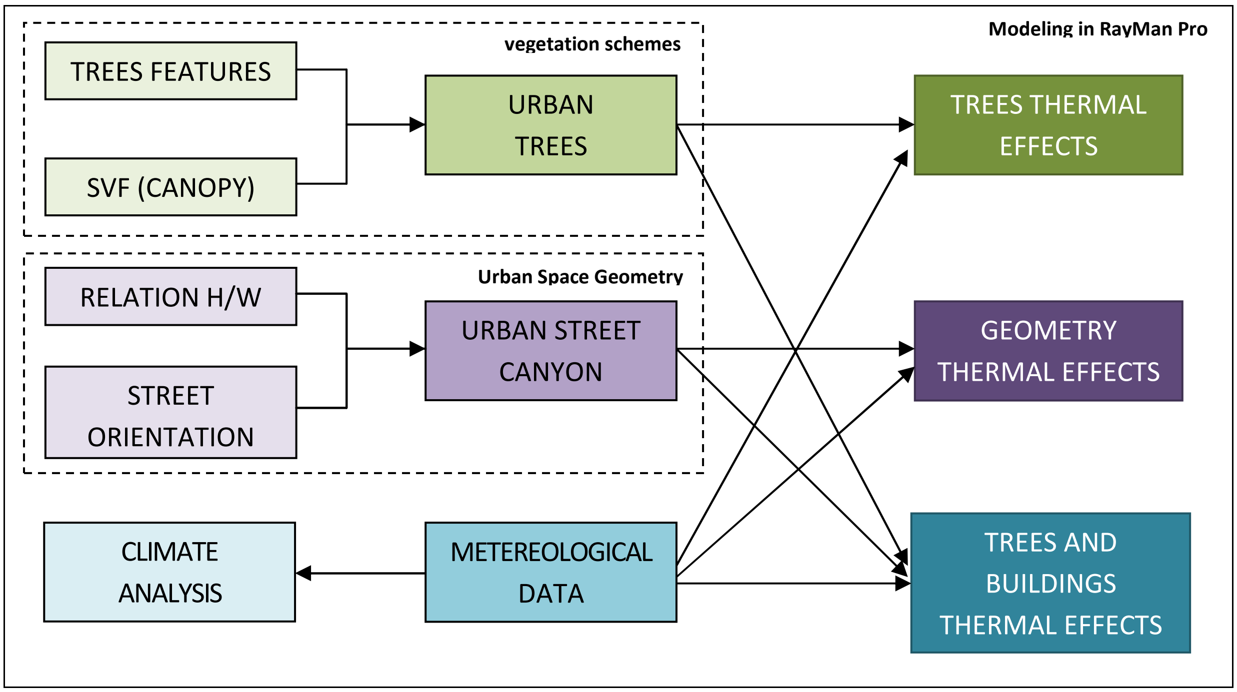


Fig 9. *Flowchart of the input data for simulation on RayMan Pro*

4.1 First Part: Background analysis of urban climate and bioclimate conditions of Campinas

Data

The data used in this part was collected at a meteorological urban station of Campinas Agronomic Institute (IAC). The meteorological data: air temperature, relative humidity, wind speed and solar radiation of an over seven year period (25.6.2003 to 14.12.2010) were used. The data was in time resolution of 1 h.

Methods

The energy balance of human body (HÖPPE, 1993) is a modern human biometeorological method, based on the human energy balance and derived thermal indices, which are able to describe and quantify the effects of the thermal environment on humans (MAYER, 1993; VDI, 1998). Hourly meteorological data of air temperature, air humidity, wind speed and global radiation were used to calculate the Mean Radiant Temperature (T_{mrt}) and the Physiologically Equivalent Temperature (PET). Thus, simulations were done in the RayMan model (MATZARAKIS et al., 2007, 2010) which is able to transfer the global radiation from an area with free horizontal urban structures and estimate the mean radiant temperature due to atmospheric influences firstly by clouds and other meteorological compounds such as vapor pressure or particles.

Examples of Rayman Pro use

The RayMan model can be applied for diverse applications. Results of radiation fluxes, sunshine duration and shadow, was produced with meteorological data. The calculation of hourly, averages of sunshine duration, short wave and long wave radiation fluxes without topography, and with and without obstacles in urban structures was carried out with RayMan. Data could be entered through the import of pre-existing files (Fig. 10). The output is given in form of text data (Fig. 11).

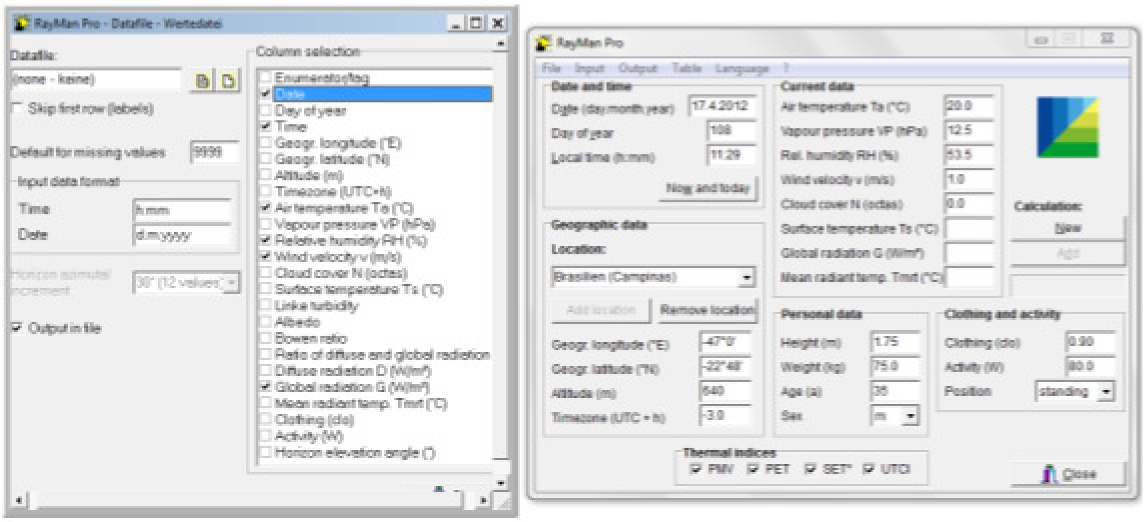
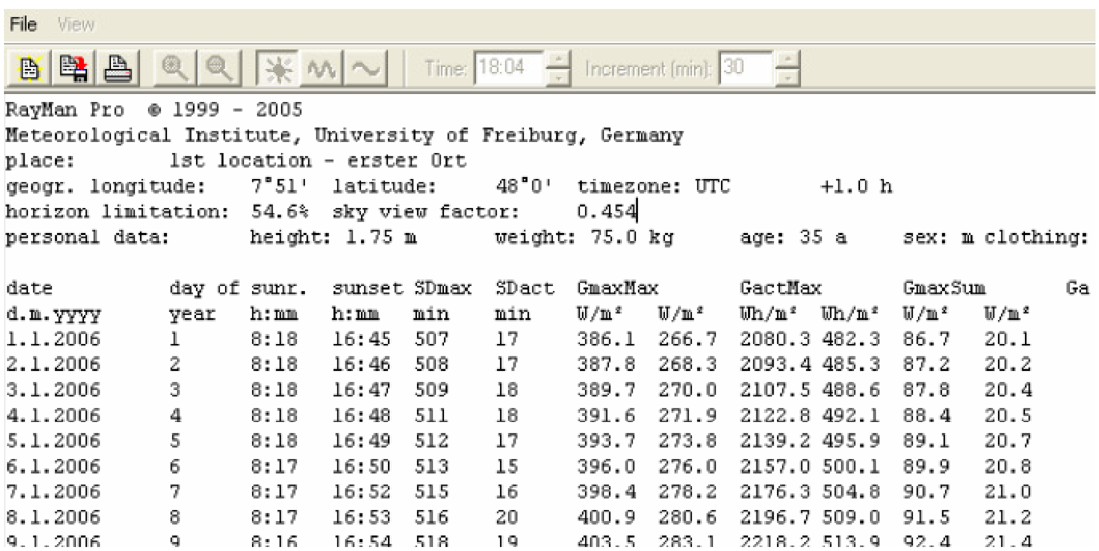


Fig 10. *Input data imported from pre existent file*



File View
Time: 18:04 Increment (min): 30

RayMan Pro © 1999 - 2005
Meteorological Institute, University of Freiburg, Germany
place: 1st location - erster Ort
geogr. longitude: 7°51' latitude: 48°0' timezone: UTC +1.0 h
horizon limitation: 54.6% sky view factor: 0.454
personal data: height: 1.75 m weight: 75.0 kg age: 35 a sex: m clothing:

date	day of year	sunr.	sunset	SDmax	SDact	GmaxMax		GactMax		GmaxSum		Ga
d.m.yyyy		h:mm	h:mm	min	min	W/m²	W/m²	Wh/m²	Wh/m²	W/m²	W/m²	
1.1.2006	1	8:18	16:45	507	17	386.1	266.7	2080.3	482.3	86.7	20.1	
2.1.2006	2	8:18	16:46	508	17	387.8	268.3	2093.4	485.3	87.2	20.2	
3.1.2006	3	8:18	16:47	509	18	389.7	270.0	2107.5	488.6	87.8	20.4	
4.1.2006	4	8:18	16:48	511	18	391.6	271.9	2122.8	492.1	88.4	20.5	
5.1.2006	5	8:18	16:49	512	17	393.7	273.8	2139.2	495.9	89.1	20.7	
6.1.2006	6	8:17	16:50	513	15	396.0	276.0	2157.0	500.1	89.9	20.8	
7.1.2006	7	8:17	16:52	515	16	398.4	278.2	2176.3	504.8	90.7	21.0	
8.1.2006	8	8:17	16:53	516	20	400.9	280.6	2196.7	509.0	91.5	21.2	
9.1.2006	9	8:16	16:54	518	19	403.5	283.1	2218.2	513.9	92.4	21.4	

Fig 11. *Table output of daily information about maximum and actual sunshine duration and global radiation*

RayMan provides the shadow for every day and minute of the year for any given simple or complex urban morphology as an additional output. Figure 12 shows the shadow for the morphology of Freiburg, latitude (48° N). Information on shadow in simple and complex environments is of particular importance for the quantification of intensity and duration of thermal stress in summer. It is also important for recreational and environmental issues regarding urban green space and the effects of trees in urban areas.

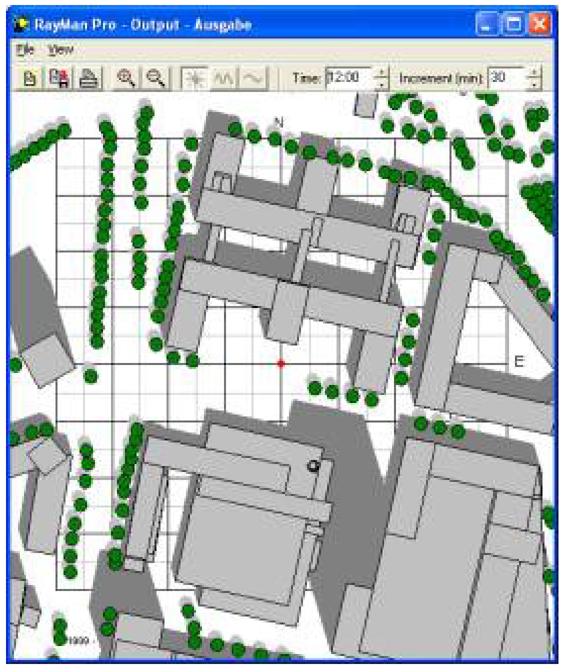


Fig 12. *Shadow output (MATZARAKIS et al., 2006)*

Figure 13 and 14 illustrates results of Freiburg for 2003 as examples. Figure 13 explains the PET conditions in classes, in which 38.3 % of the studied hours are very cold, followed by the cold (11.2 %) and cool (14.8%) and slightly cool (12.6 %). Only 9.6 % are in the range of thermal comfort; 5.6% and 3.2 % in slightly and warm class respectively. 3.3 and 1.4 % of the hours of 2003 were lying in the hot and very hot class. Based on PET a bioclimate diagram, which includes ten days frequencies of the daily PET values for the year 2003 was calculated for the analysis of the general bioclimate conditions (Fig. 14). The thermal human-bioclimate conditions are expressed in percentages of the occurrence of classes for ten day intervals. The data are hourly data. Good description of the general thermal bioclimatic regime is possible using this kind of bioclimate diagrams, including relevant information in terms of frequencies and extremes.

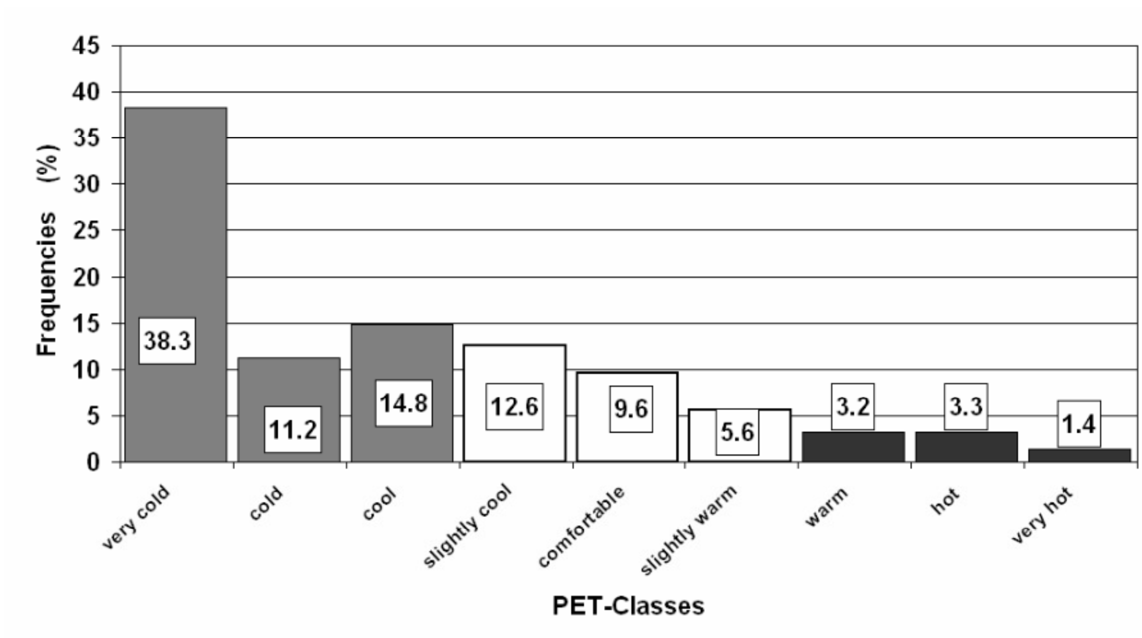


Fig 13. *PET classes for Freiburg in 2003 (MATZARAKIS et al., 2005)*

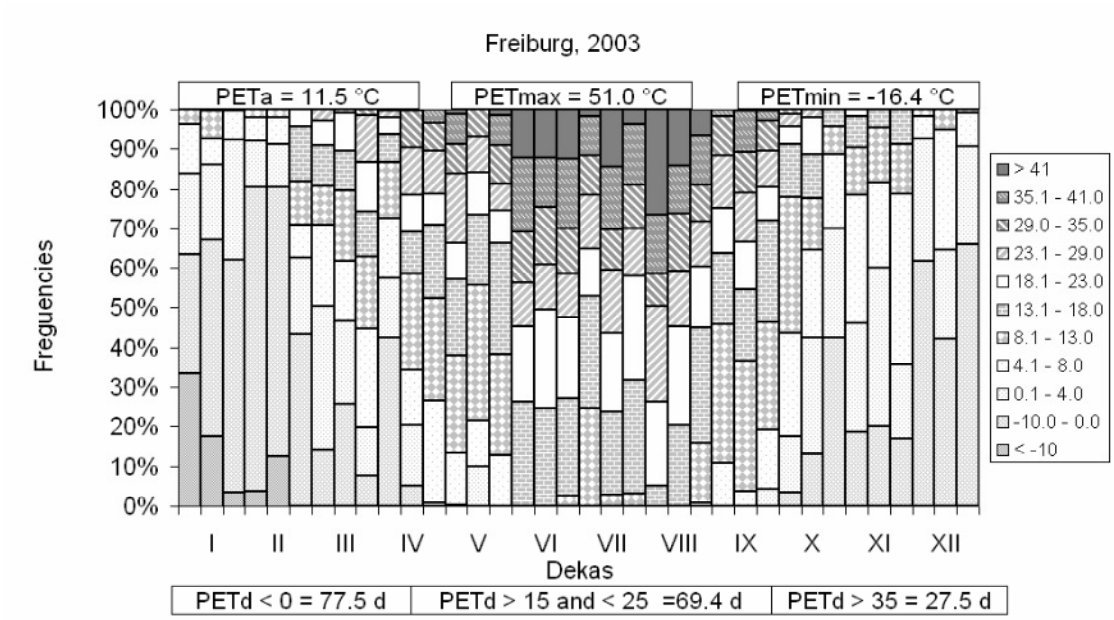


Fig 14. *Frequency analysis of the PET classes for Freiburg in 2003 (with modified mean radiant temperature) based on the urban morphology (MATZARAKIS et al, 2005)*

4.1.1 Campinas bioclimate changes

For the description of real situations in urban areas, different urban configurations are required. The PET results from Campinas during the study period were applied for simulations of wind speed and shade modifications in order to get information about the background situation of thermal bioclimate for typical conditions in Campinas.

The following setups were used:

- wind speed reduction of 1.0 m/s,
- wind speed increase of 1.0 m/s and
- Setup of T_{mrt} equal to T_a, representing the shade situation.

4.1.2 Urban Street Canyons

From observing the typical urban structure of Campinas, São Paulo, the relation between height and widht (H/W) vary between 0.3 and 2.2 (Fig. 15.). Studies of climatic zones of Campinas (PEZZUTO, 2007) show. The predominance of buildings' height is 1 to 3 pavements - around 9m -, until 6 pavements - around 21m - and maximum found in Campinas, 14 pavements - around 44m -(PEZZUTO, 2007).

Fig 15. *Razão H/W de certas ruas de Campinas, São Paulo*

The following configurations and setups used were: the model canyon was 500 m in length, its width varied in three times – 9 m, 21 m and 44 m - and its height in steps of 2,5 m between 5 to 40. In addition, the canyon can be rotated in steps of 15° (Fig. 16). The results are presented using CTIS (Climate-Tourism/Transfer-Information-Scheme)-software (MATZARAKIS et al., 2010a). CTIS was developed for the transfer of climate information for tourism purposes and can be applied here.

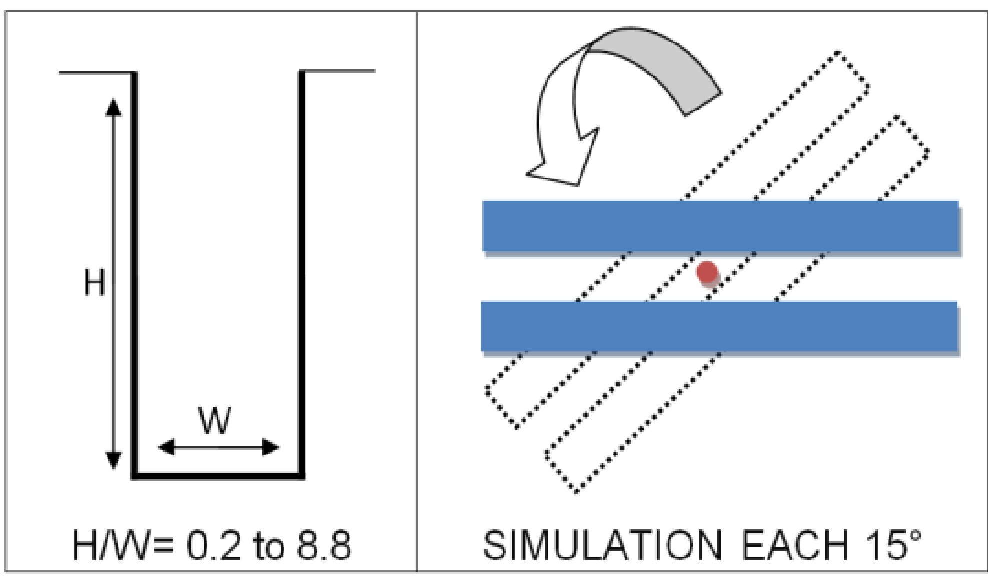


Fig 16. *Street Canyon configurations and setups*

4.2 Second Part: Assessment of the trees' influence on microclimate

4.2.1 Data

Tube solarimeters, Delta-T TSL   Delta DL2 Datalogger

Fig 17. *Solarimeters and Datalogger*

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, figure 17. One set of equipment was installed at the middle of the tree's shadow, while the second one was installed in the sun. Data are collected beneath the crowns of the studied trees and in the open simultaneously. Measurements started at about 6:00 a.m. and finished at about 6:00 p.m. and were recorded each ten minutes. This equipment measures average irradiance (W/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).

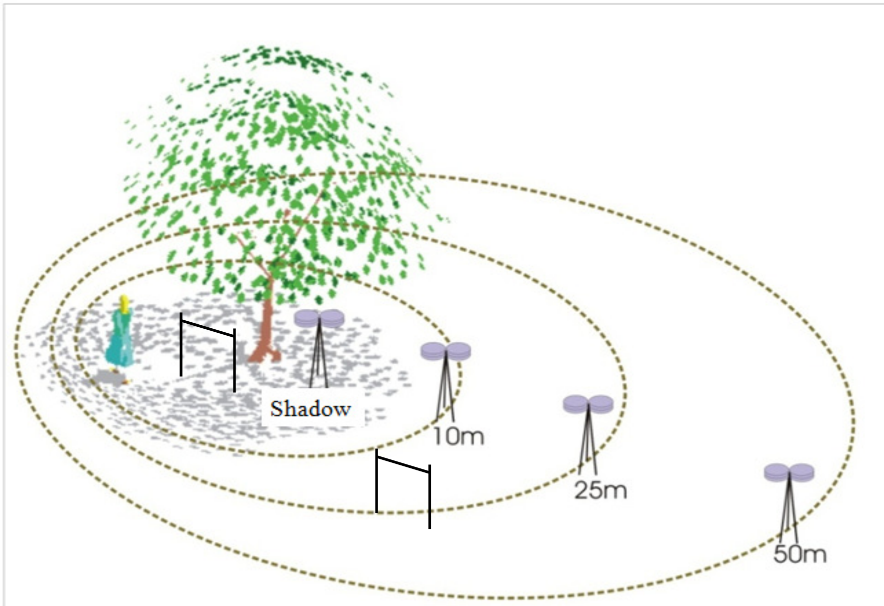
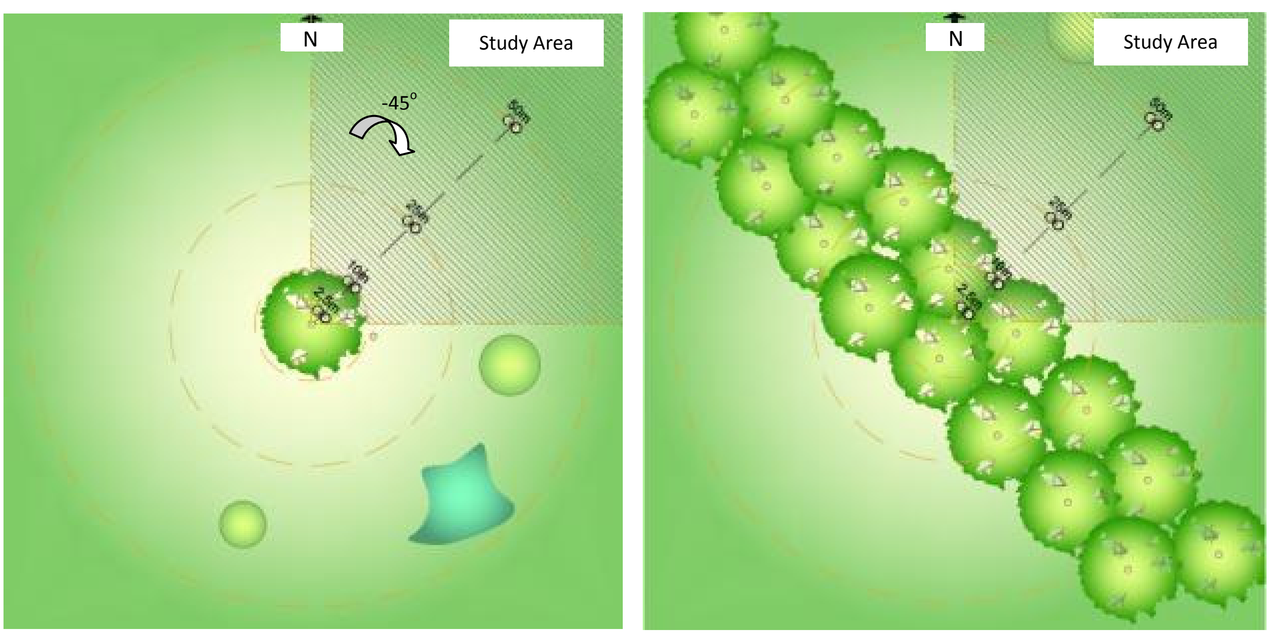


Fig 18. *The measurement points from the tree trunk in individual tree analyses*



Single trees analysed: *Caesalpinia pluviosa*   Clusters of trees analysed: *Caesalpinia pluviosa*

Fig 19. *Scheme of the disposition of tripod on field site*

According to the objectives of this study, measuring points were selected in four locations - in the shadow, at 10m, 25m and 50m of each isolated or clusters of trees studied (Fig 18) - with various orientation, where the sensors were fixed to a tripod for the data of environmental parameters (air temperature, relative humidity, globe temperature). Figure 19 show the scheme of the disposition of the tripod in isolated and clusters of trees and table 5 presents the orientation of measuring points and other details of fields sites.

In each set there was a 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. And, wind speed data was collected from a single in one fixed site with a Testo anemometer, model 0635-1549, connected to a multifunction recorder, model 445, fig 20. All recording sets were protected from solar radiation through especially prepared shelters and data were collected each 10 minutes, during 12 hours throughout the day. Data were collected between 2007 and 2010.

Fig 20. *Measurement Equipments.*

Table 5- Orientation and data of field measurement

TREES: ISOLATED AND CLUSTER	ORIENTATION OF DATA LOGGER	DAYS OF MEASUREMENT	SEASON	RESEARCH
Tabebuia chrysotricha	-45º	27-29.03.2007 15-17.03.2007 21-23.03.2007	Summer Winter Winter	Master
Jacaranda mimosaefolia	-45º	25-27.05.2008	Winter	Master
Syzygium cumini	75º	19-21.03.2010 18-20.08.2007	Summer Winter	PhD Master
Mangifera indica	-45º	22-24.03.2010 5;6;10.07.2007	Summer Winter	PhD Master
Pinus palustris	30º	21-23.03.2010 20-22.08.2010	Summer Winter	PhD
Pinus coulteri	0º	21-23.03.2010 20-22.08.2010	Summer Winter	PhD
Spathodea campanulata	45º	17;21;22.07.2009	Winter	PhD
Spathodea campanulata (cluster)	45º	17;21;22.07.2009	Winter	PhD
Caesalpinia pluviosa	-45º	28-30.04.2008 13-15.07.2009	Summer Winter	PhD
Caesalpinia pluviosa (cluster)	-45º	28-30.04.2008 13-15.07.2009	Summer Winter	PhD
Lafoensia glyptocarpa	-45º	31.01;1-2.08.2010	Winter	PhD
Lafoensia glyptocarpa (cluster)	45º	31.07; 1-2.08.2010	Winter	PhD
Tipuana tipu	0º	21-23.10.2009	Summer	PhD
Tipuana tipu (cluster)	45º	21-23.10.2009	Summer	PhD
Delonix Regia (cluster)	75º	30-31.10;01.01.2009 24-27.08.2010	Summer Winter	PhD
Senna Siamea (cluster)	0º	17;21;22.3.2010	Summer	Master

4.2.2 Methods and analyses

Physiologically Equivalent Temperature (PET)

The minutely meteorological data of air temperature, air humidity, wind speed and global radiation by field measurements for a period of 2007 to 2010 were required to calculate the Physiologically Equivalent Temperature (PET) and Mean Radiant Temperature (Tmrt) by each individual and cluster of trees analyzed in different distances (shade, 10m, 25m and 50m) using software RayMan Pro.

Solar Radiation Attenuated

The attenuation of solar radiation depends on the trees features such as the density of the twigs and branches and leaf cover of tree species that influence solar radiation attenuated by trees. The percentage of radiation attenuated by each tree or clusters of trees is obtain by the methodology of Bueno-Bartholomei (2003), that it consists in simultaneously making measurements of solar radiation in the shade and another in the sunlight, in accordance with the expression:

$$AT = \frac{S_{sun} - S_{sh}}{S_{sun}} \times 100 \qquad \text{(Eq. 05)}$$

Where AT is solar radiation attenuation (%); S_{sun} is the area that gives the total incident energy (kWh/m^2), collected by the solarimeter in the sunlight, in the time interval considered; and S_{sh} is the area that gives the total incident energy (kWh/m^2), collected by the solarimeter in the shade, in the time interval considered.

Green Coverage Ratio

An important characteristic of tropical cities is urban greenery that creates the comfortable shades along the streets and within individual house lots and also plays the role of carbon sink, which is proportional to the green coverage. To count up the trees (species and size) through field surveys is possible, but to find the canopy area is complex.

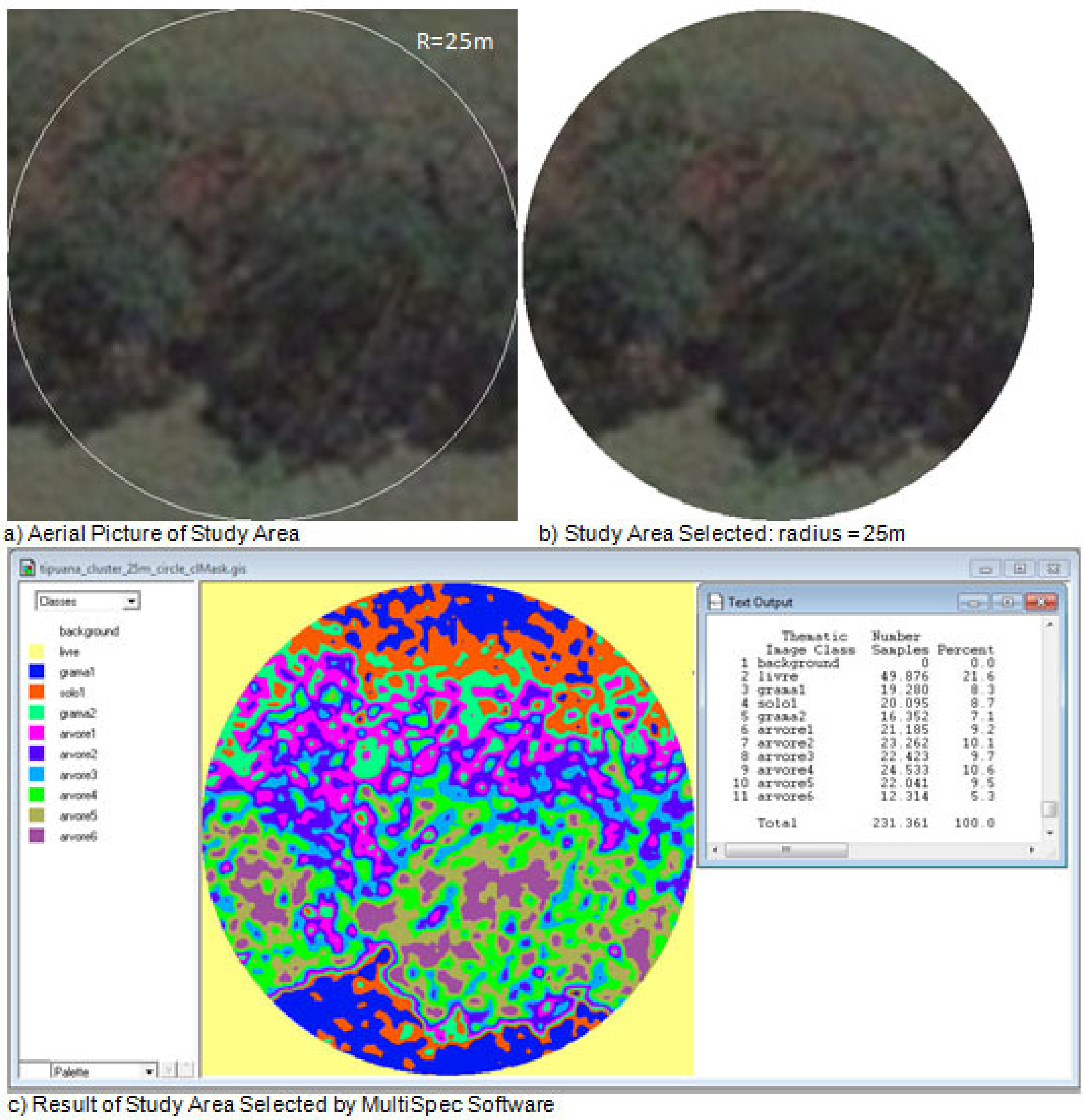


***Fig 21.** Crown trees area's estimation by study area with 25 m radius*

The satellite image can define the green coverage ratio, however there still is a difficulty to identify the canopy of high trees from other greenery such as bush, agricultural fields or open space covered with grass. In this study, the aerial pictures of field measurement were selected and treated by MultiSped© which is made it possible to identify the trees clusters due their textures and to calculate the percentage of canopy.

The study areas was defined in three circles sizes - 10m, 25m and 50m - based on measurement points were sketched over aerial pictures where the circumferences center is the exact measurement point called "shade" on tree clusters studies and the tree stem on isolated arboreal studies. Figure 21 illustrates the process of aerial photo analyses. The green canopy ratio is defined by the summation of trees' crown to the circle area shown in figure 09 and in accordance with expression:

$$GC = \frac{\sum_{\text{PLA}}}{(\pi * R^2)} \times 100 \qquad \text{(Eq. 06)}$$

where GC is Green Canopy Ratio (%); Σ_{PLA} is the summation of Plant Area, R is the Study Radius defined area.

Plant Area Factor

A widely used method to describe the amount of foliage is the plant area index (PAI) when referring to all light blocking elements (stems, twigs, leaves), or the leaf area index (LAI) when accounting for leaves only (NEUMANN et al., 1989; LEVY; JARVIS, 1999; ROSS et al., 2000; MEIR et al., 2000; NACKAERTS et al., 2000; HOLST et al., 2004).

There are direct and indirect techniques for determination of stand's PAI or LAI, while harvesting of the whole canopy or some samples of the vegetation is destructive and laborious, taking samples from litter is non-destructive but also very time-consuming. It is very common to use the radiation regime below the canopy itself for the description of the crown layer among modeling approaches (LAW et al., 2001; ROSS et al., 2000) including statistical and three-dimensional radioactive transfer models.

Some researchers analyzed the structure of the foliage via hemispherical photography ("fish-eye") for specific points below the canopy, looking for gaps in the canopy layer, where direct or diffuse radiation can reach the ground (TSUTSUMI et al., 2003). A representative PAI for the stand can be calculated by taking photographs at different points (LEVY; JARVIS, 1999; GARDINGEN et al., 1999; MEIR et al., 2000; FRAZER et al., 2001).

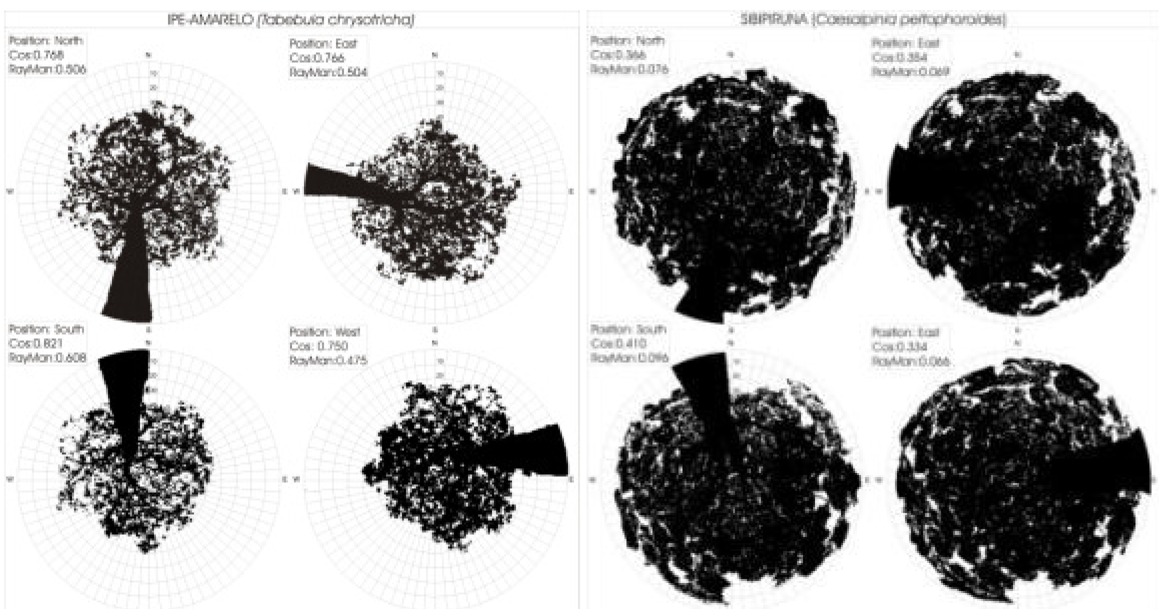


Fig 22. *Samples of individual trees treatment*

In this study, the Plant Area Index (PAI) of selected individual and clusters of trees was obtained by taking four "fish-eye" photographs in orthogonal projection and in different orientation - north, south, east and west - below canopy of each measurement site, figure 22. The Sky View Factor (SVF) was calculated by RayMan Pro where the sky is replaced by branches and green leaves, and the results represents the PAI.

4.3. Third Part : simulation of the tree's contribution on microclimates

Data

The meteorological data: air temperature, relative humidity, wind speed and solar radiation of an over seven year period (25.6.2003 to 14.12.2010) from an urban station in Campinas were required.

Simulation of trees' features

The simulations were conducted using the RayMan model (MATZARAKIS et al., 2007; MATZARAKIS et al., 2010) where the influence of trees' features on thermal bioclimate could be observed. The input data were: meteorological data, plant area Index (HOLST et al., 2004) and 3D-models of studied trees. Based on trees' characteristics such as tree height, crown radius, trunk length and trunk diameter (Fig. 23) and disposition of clusters (Fig. 24), tri-dimensional models were built. The arboreal species studied were: Ipê Amarelo *(Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.)*,* Jacarandá mimoso (*Jacaranda mimosaefolia* D. Don.), Jambolão (*Syzygium cumini* L.), Mangueira (*Mangifera indica* L.), Pinheiro (*Pinus palustris* L.) and Pinheiro (*Pinus coulteri* L.) – isolated; Mirindiba bagre (*Lafoensia glyptocarpa* L.)*,* Sibipiruna (*Caesalpinia pluviosa F.*), Espatódea *(Spathodea campanulata*

P.Beauv.), Tipuana (*Tipuana tipu* F.) – isolated and clusters –, Flamboyant (*Delonix indica* F.) and Chuva de ouro (*Senna siamea* L.) – clusters. This results were be compared with empirical results.

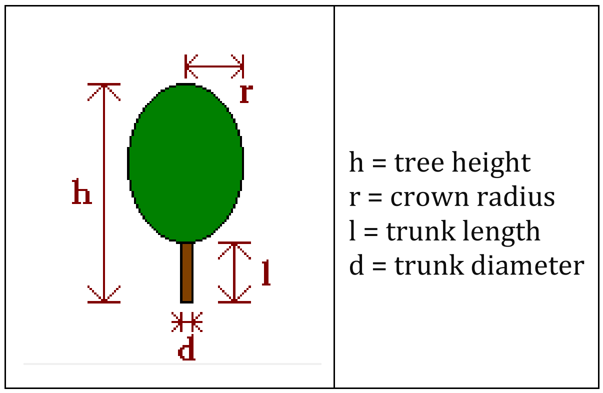


Fig 23. *Trees configuration*

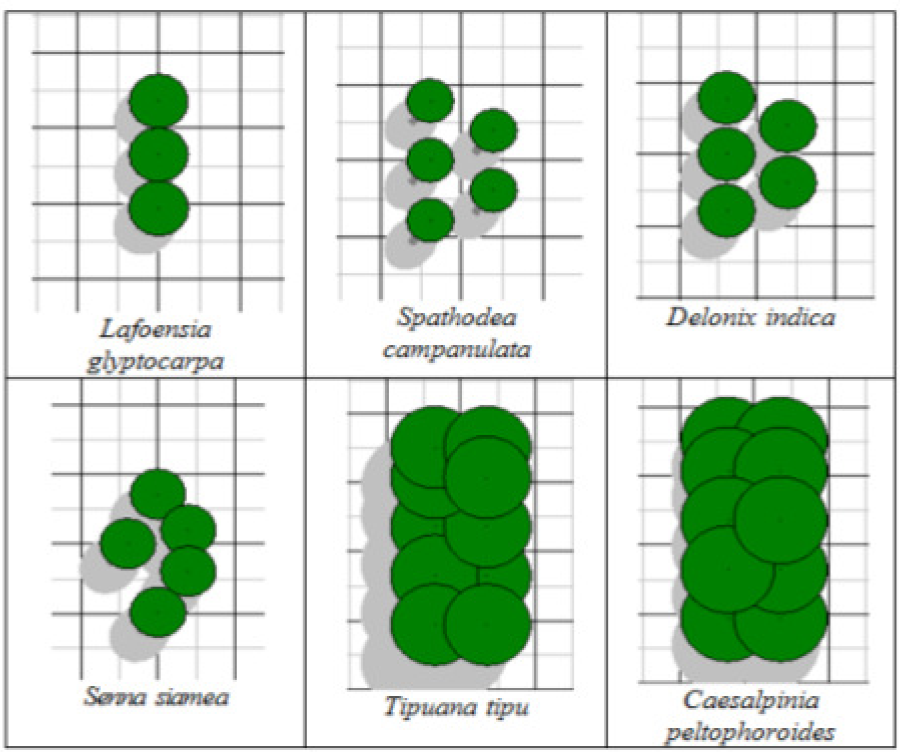


Fig 24. *Tri-dimensional models of trees' clusters*

Simulation of vegetated street canyons

The thermal bioclimate conditions can be mitigated by shading trees in urban canyons in Tropical cities. To investigate the thermal effect of vegetation on typical urban configuration, the influence on radiation flux and wind speed can be described. The vegetated street canyons based on over seven years of measurements at the urban climate station in Campinas, Brazil was analyzed with the application of the RayMan model (Matzarakis et al., 2007; Matzarakis et al., 2010)**.** The RayMan model is able to calculate thermal indices (i.e. PET) with less data availability. The main primary input parameters for RayMan in the present study were air temperature, relative humidity, wind speed and global radiation.

The thermal bioclimate conditions can be mitigated by shading trees in urban canyons in Tropical cities. To investigate the thermal effect of vegetation on typical urban configuration, the influence on radiation flux and wind speed can be quantified with the application of the RayMan model (MATZARAKIS et al., 2007; MATZARAKIS et al., 2010). The RayMan model is able to calculate thermal indices (i.e. PET) with less data availability. The main primary input parameters for RayMan in the present study were air temperature, relative humidity, wind speed and global radiation.

To select the arboreal specie with the best capacity the mitigate heat stress used to simulation, the quantitative analysis (through scoring, ranking and weighting) of trees' characteristics was required. The Multi-Criteria Analysis (MCA) can provide techniques for comparing and ranking different outcomes as thermal effects and trees features, even though a variety of indicators. Table 6 classified the tree species in four classes: Excellent performance when its punctuation is above 65, very good performance, between 55 and 65, good performance, between 45 to 55, and regular is below 45.

Table 6 - Multi-Criteria Analysis of Arboreal characteristics

ARBOREAL CHARACTERISTICS			ARBOREAL SPECIES									
			Tabebuia chrysotricha	*Caesalpinia pluviosa*	*Jacarandá mimosaefolia*	*Pinus palustris*	*Pinus coulteri*	*Spathodea campanulata*	*Tipuana tipu*	*Lafoensia glyptocarpa*	*Syzygium cumini*	*Mangifera indica*
CROWN	Profile	Height (m)	8.31	11.20	7.77	9.15	6.50	8.85	13.45	6.45	8.01	8.49
		permeability	2.00	2.00	1.00	1.00	1.00	1.00	2.00	2.00	3.00	3.00
	Density		2.00	3.00	1.00	2.00	2.00	2.00	2.00	2.00	3.00	3.00
	Shape		3.00	5.00	2.00	1.00	1.00	3.00	3.00	3.00	4.00	4.00
	Texture		2.00	2.00	2.00	1.00	1.00	1.00	2.00	2.00	3.00	3.00
	Floor plan	Diameter	7.12	16.15	6.20	4.85	4.95	7.30	14.90	7.30	9.27	8.52
		PAI	0.48	0.92	0.27	0.47	0.34	0.78	0.72	0.75	0.88	0.85
	Phenology		1.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	3.00	3.00
TRUNK	Roughness		1.00	2.00	3.00	1.00	2.00	2.00	1.00	3.00	2.00	3.00
	Color		1.00	1.00	1.00	2.00	2.00	2.00	2.00	2.00	3.00	3.00
	Diameter		0.34	0.58	0.54	0.43	0.38	0.55	0.63	0.32	0.43	0.48
	Type		2.00	3.00	2.00	1.00	1.00	2.00	3.00	3.00	3.00	3.00
	Bran-ching	Height bole	3.11	2.93	2.90	1.54	1.35	2.20	2.87	1.30	1.75	1.70
		Insertion	3.00	3.00	3.00	1.00	2.00	2.00	3.00	3.00	3.00	3.00
		Arrangement	2.00	3.00	2.00	1.00	1.00	2.00	3.00	2.00	3.00	4.00
LEAVES	Blade		2.00	3.00	3.00	1.00	1.00	3.00	3.00	3.00	3.00	2.00
	Type		2.00	5.00	4.00	1.00	2.00	4.00	4.00	3.00	1.00	2.00
	Shape		3.00	6.00	5.00	1.00	1.00	2.00	4.00	2.00	4.00	5.00
	Height (m)		0.058	0.008	0.004	0,07	0,09	0.06	0.03	0,064	0.06	0.05
	Width (m)		0.07	0.0015	0.0014	0,001	0,002	0.13	0.015	0,045	0.15	0.30
	Color		3.00	2.00	2.00	1.00	1.00	1.00	2.00	3.00	1.00	1.00
TOTAL			**48.49**	**73.79**	**50.69**	**33.44**	**33.52**	**48.87**	**68.62**	**51.12**	**59.55**	**62.39**

Criteria:

Crown permeability: small (3); medium (2); maximum (1) / Crown Density: Small (1); Medium (2); Maximum (3)/Crown Shape: triangular (1); Asymmetric (2); Globe (3); Semi-Elliptic (4); Elliptic (5) /Crown Texture: Harshly (1); Rough (2); Semi-Rough (3)/Crown Phenology: Deciduous (1); Semi-deciduous (2); Perennial (3) /Trunk Roughness: High (1); Medium (2); Slightly (3)/Trunk Color: Gray (1); Dark Brown (2); Brown (3) /Trunk Type : Orthotropic monopodium (1); Orthotropic simpodial (2); Plagiotropic (3) /Branching Insertion: Verticillata (1); Decussata (2); Switches (3) /Branching Arrangment: Vertical Axis (1); Acute Axis (2); Horizontal Axis (3); Falling Axis (4) /Leaves Blade: Alternate (1); Verticillate (2); Opposite (3) /Leaves Type: Simples (1); Palm (2); Paripinate (3); Impabipinate (4); Bipinate (5) /Leaves Shape: Acicular (1); Cordate (2); Ovate (3); Elliptic (4); Lanceolate (5); Linear(6) / Leaves Color: dark Green (1); green (2); Light green (3)

The results shows that Sibipiruna (*Caesalpinia pluviosa F.*) and Tipuana (*Tipuana tipu* L.) have excellent performance, Jambolão (*Syzygium cumini* L.) and Mangueira *(Mangifera indica* L.), very good performance, Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.)*,* Jacarandá mimoso *(Jacaranda mimosaefolia* D. Don.), Espatódea (*Spathodea campanulata*), Mirindiba Bagre (*Lafoensia glyptocarpa* L.), good performance, and Pinheiro (*Pinus palustris* L.) and Pinheiro (*Pinus coulteri* L.) regular performance. By comparing both results we can concluded that the Sibipiruna (*Caesalpinia pluviosa F.*) - single - behavior are the best, as well as Tipuana (*Tipuana Tipu*)*.* Mirindiba Bagre (*Lafoensia glyptocarpa* L.) are very representative as very good performance, and Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.)*,* as good performance.

To simulate the interrelation between tree and urban geometry, it was done by following configurations and setups: the model canyon was 500 m in length, its height varied in three times – 9 m, 21 m and 44 m - and its width in steps between 15 to 40 (Fig 25.). In addition, the canyon can be rotated in steps of 15°. The tree models are aligned and the features of tree different arboreal species - Mirindiba Bagre (*Lafoensia glyptocarpa* L.), Sibipiruna (*Caesalpinia pluviosa F.*), Tipuana (*Tipuana tipu*) - were used. Table 7 shows the trees features used in the simulation. The meteorological data was required.

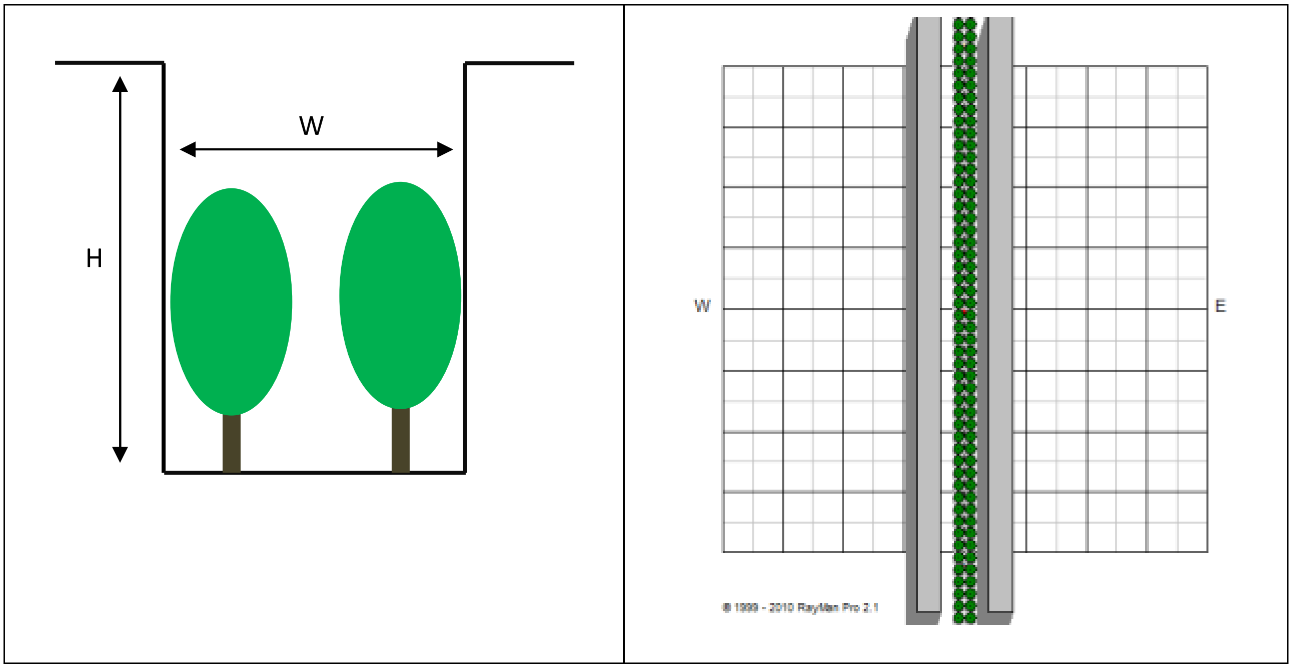


Fig 25. *Street Canyon configurations and setups*

Table 7 - Tree Species features used in simulation

ARBOREAL CHARACTERISTICS			ARBOREAL SPECIES		
			Caesalpinia pluviosa	*Tipuana tipu*	*Lafoensia glyptocarpa*
CROWN	Profile	Height (m)	11.2	13.45	6.45
		permeability	Medium	Medium	Medium
	Floor plan	Diameter	16.15	14.9	7.3
		PAI	0.92	0.72	0.75
	Phenology		Semi-deciduous	Semi-deciduous	Semi-deciduous
TRUNK	Roughness		Medium	High	Medium
	Diameter		0.578	0.63	0.32
	Type		Plagiotropic	Plagiotropic	Plagiotropic
	Height bole		2.93	2.87	1.3

The results are presented using CTIS (Climate-Tourism/Transfer-Information-Scheme)-software (MATZARAKIS et al., 2010a). CTIS was developed for the transfer of climate information for tourism purposes and can be applied here.

Chapter 5 - RESULTS

5.1 First Part: Background analysis of urban climate and bioclimate conditions of Campinas

5.1.1 Campinas bioclimate changes

To quantify the background conditions at the urban climate station, the data were analyzed in terms of PET classes (MATZARAKIS; MAYER, 1996). Fig. 33 shows the PET classes for the period of 25 June 2003 to 14 December 2010. Also the frequency distribution on a 10 day basis in each month for air temperature (T_a), PET-Classes and mean radiant temperature (T_{mrt}) for the studied period are presented in Figures 2, 3 and 4, respectively. In general, Campinas belongs to a comfortable and warm climate region according to PET classification and temperature above 29°C means a discomfort sensation. Around 18.4% of the hours in the original dataset from the urban climate station in

Campinas can be found as warm (PET>29°), slightly hot (PET>35°), hot (PET>41°), very hot (PET>45°), and extremely hot (PET>50.1°).

From the frequency diagram (Fig. 26 - 29), different thermal stress levels can be extracted, with heat stress level occurring during the year where months as from January to March, November and December can be found above 35% in the warm (PET>29°). It was observed in Figure 2 that air temperature above 29°C was around 10% in two periods, January to April and September to December within the study period. Fig 26. shows that temperatures above 29°C occurring during the study period are around 20% throughout the year. Fig 4. shows that temperatures above 29°C founded during the study period is around 30%. The air temperature is different from the Physiologically Equivalent Temperature (PET) within the study period and it need to be considered in the analysis of urban climate.

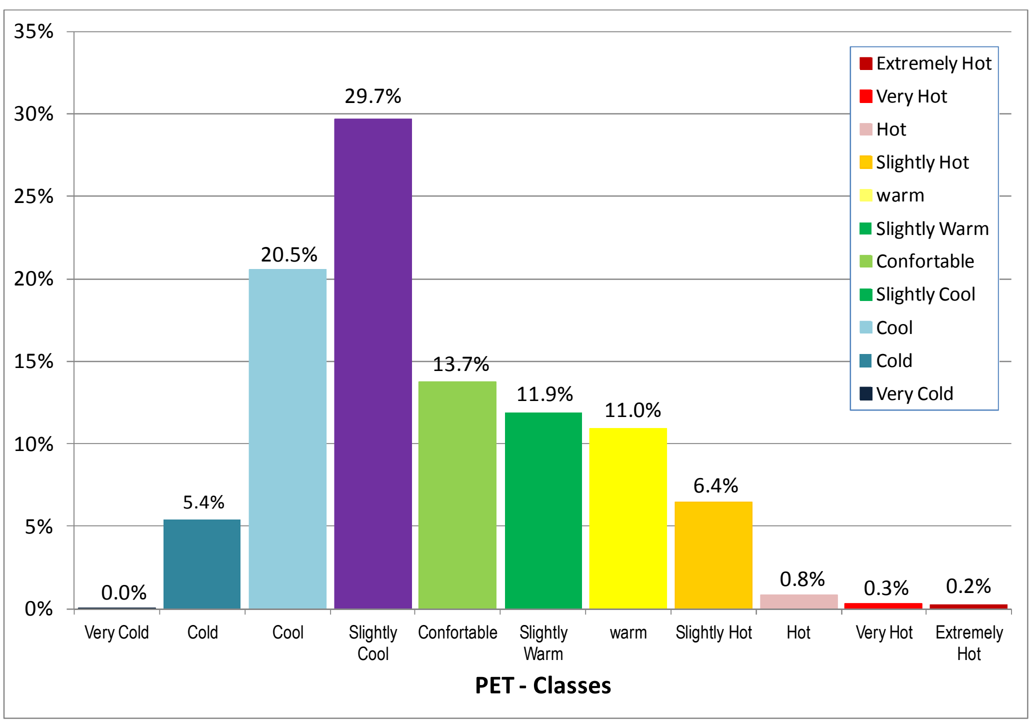


Fig 26. *Physiologically Equivalent Temperature (PET) classes at the urban station Campinas for the period June 25th, 2003 to December 31st, 2010.*

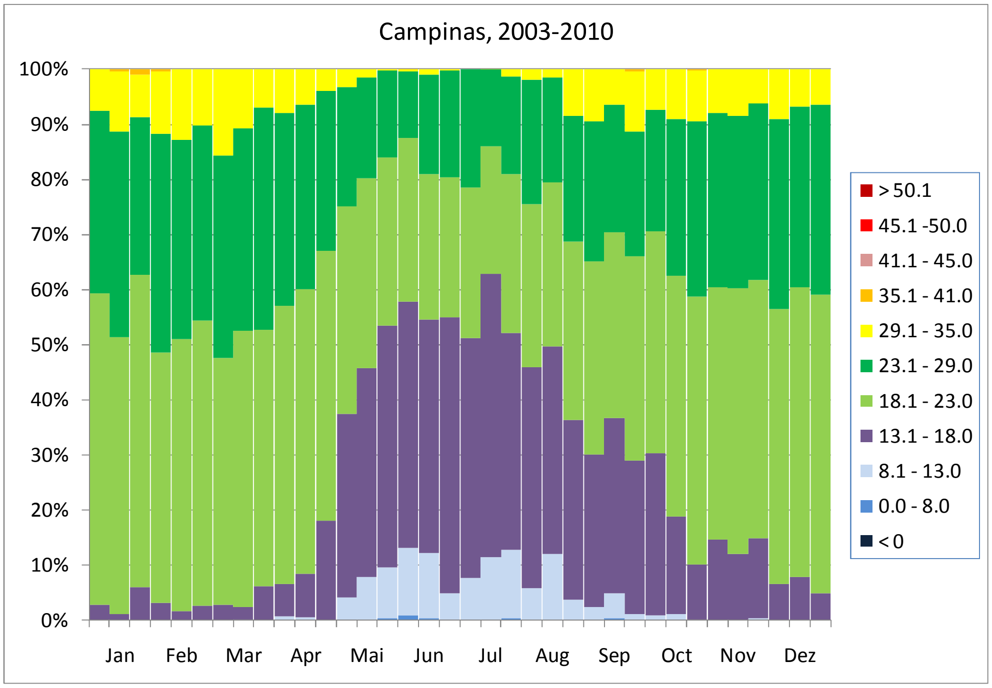


Fig 27*. The frequency distribution of Ta at the urban climate station Campinas for the period June 25th, 2003 to December 31st, 2010.*

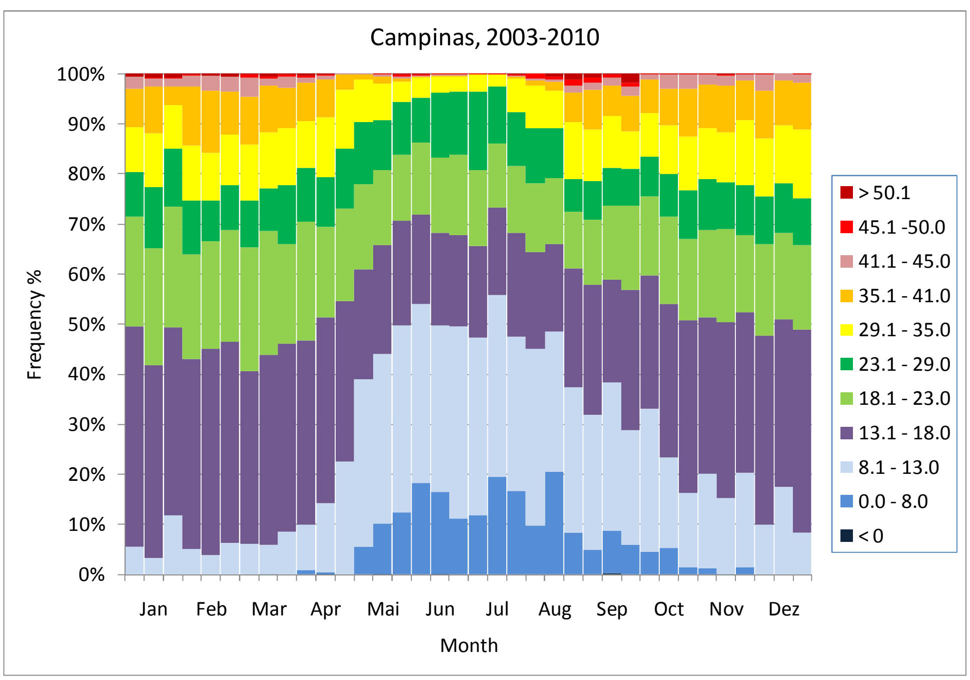


Fig 28*. The frequency distribution of PET at the urban climate station Campinas for the period June 25th, 2003 to December 31st, 2010.*

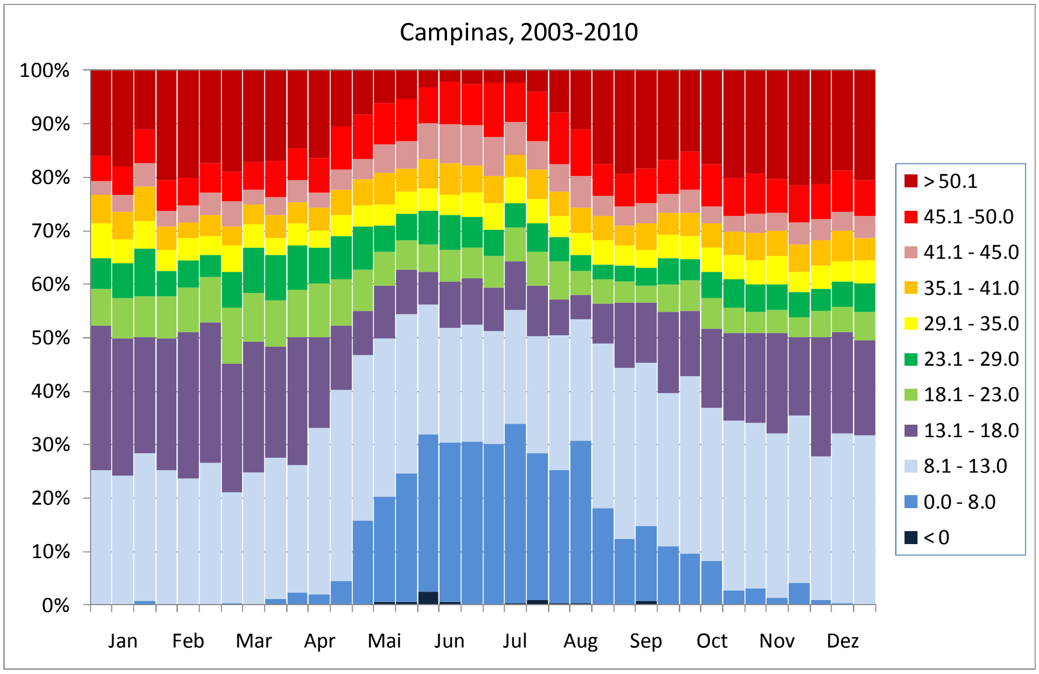


***Fig 29**. The frequency distribution of T_{mrt} at the urban climate station Campinas for the period June 25th, 2003 to December 31st, 2010.*

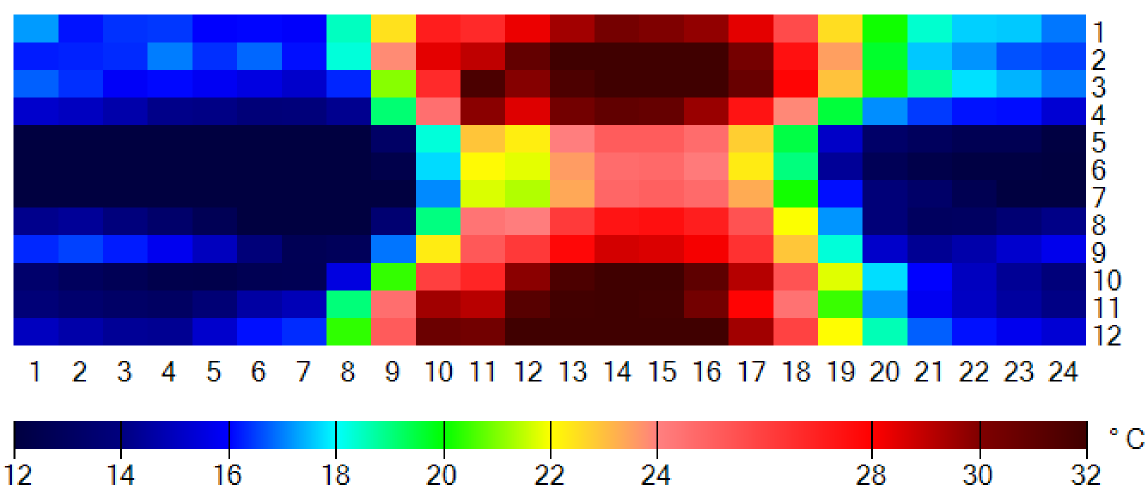


***Fig 30.** The mean monthly diurnal course of PET (°C) based on the data of the urban climate station and for the period June 25th, 2003 to December 31st, 2010.*

Fig 30. shows the mean monthly diurnal course of the PET based on the data of the urban climate station in terms of thermal comfort and for the period June 25th, 2003 to

December 31st, 2010. It was observed that day hours are above 29°C during months between September and April, summer period, within the study period.

Our purpose is to verify the urban climate changes in Campinas due to urban modifications. The mean monthly diurnal course of PET of the simulation of shade where T_{mrt} had equalled Ta within the study period (Fig 31.) and the simulation of wind speed increase in 1.0 m/s (Fig 32.) and wind speed decrease in 1.0 m/s (Fig 33.) were presented.

From Fig 31., it can be seen that the different thermal comfort levels at night hours during winter periods are different from summer period. Also, there was no record of air temperature above 30°C during the day hours. This result shows clearly the influence of the solar radiation on air temperatures in comparison with diurnal course of the PET within study period.

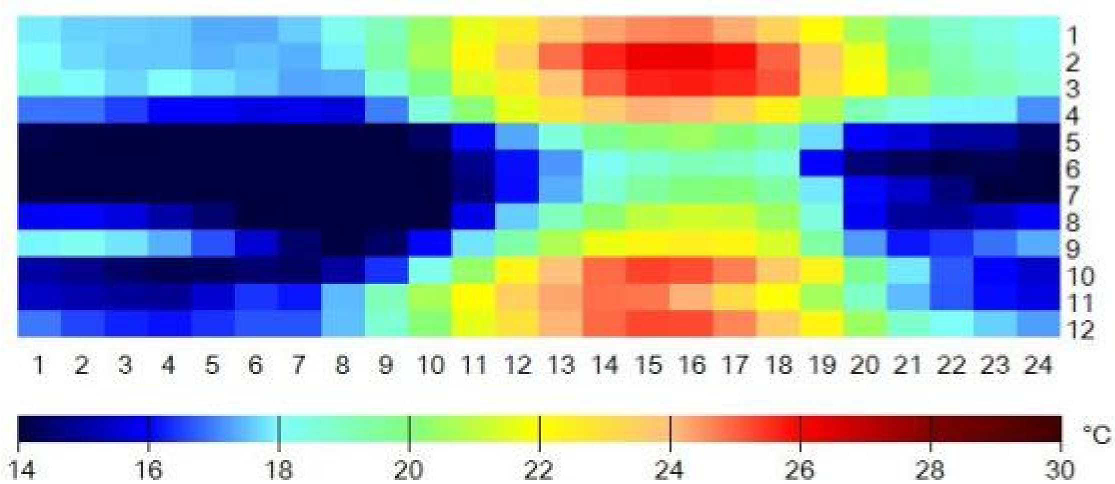


Fig 31. *The mean monthly diurnal course of PET (°C) if wind T_{mrt} equals Ta based on the data of the urban climate station and for the period June 25th, 2003 to December 31st, 2010.*

In the both Fig 32. and 33., there are similar thermal comfort levels conditions during night hours, due to absent of global radiation. However during the day, the improvement of thermal comfort levels can be observed because of wind speed increase**.** In another words, if the wind speed increases, the thermal bioclimate conditions can be better, but if the wind speed decreases, the day hours in summer will be PET (°C) higher than 30 °C. The simulations results confirm that the wind speeds have influence on mitigation of air temperature and adding on thermal comfort.

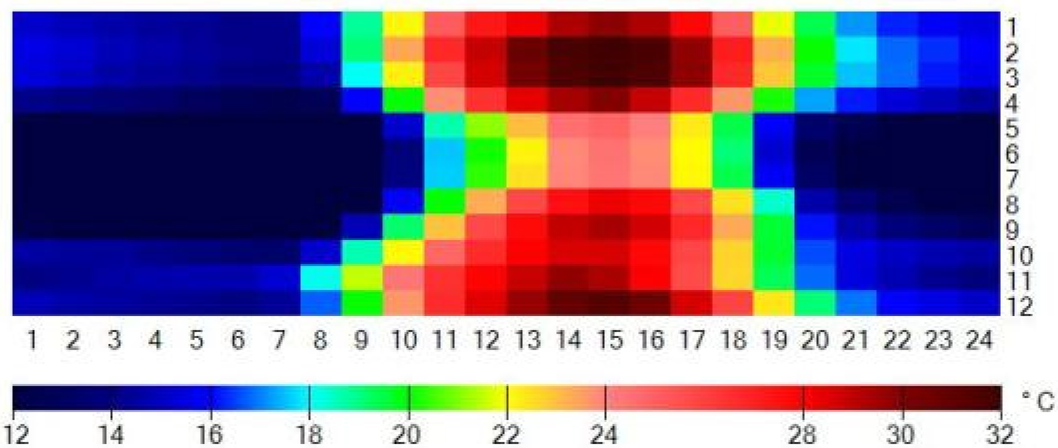


Fig 32. *The mean monthly diurnal course of PET (°C) if wind speed increase in 1.0 m/s based on the data of the urban climate station and for the period June 25th, 2003 to December 31st, 2010.*

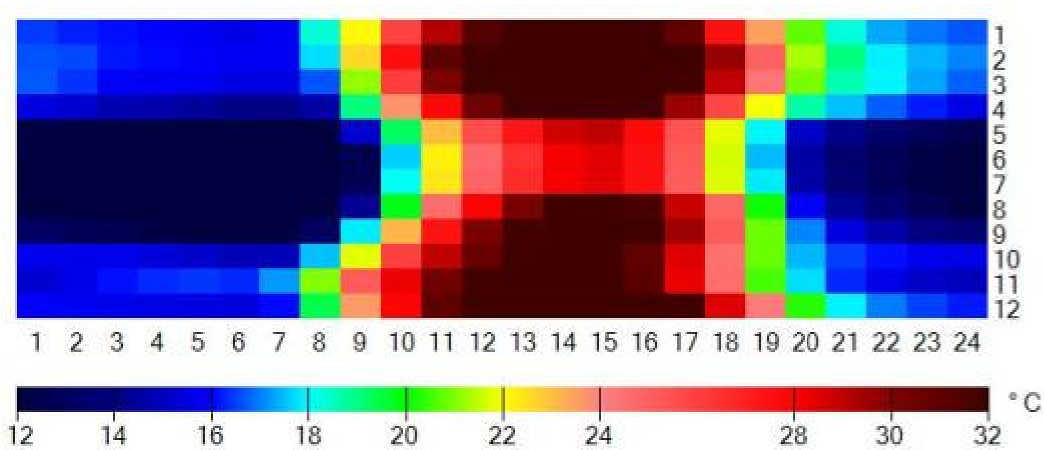


Fig 33. *The mean monthly diurnal course of PET (°C) if wind speed decrease in 1.0 m/s based on the data of the urban climate station and for the period June 25th, 2003 to December 31st, 2010.*

Table 8 shows comparison among results for these different situations: wind speed below 1.0 m/s, wind speed above in 1.0 m/s, T_{mrt} equal T_a and PET obtained from the Annual data of the urban climate station and for the period June 25th, 2003 to December 31st, 2010.

Table 8 - The annual percentages of thresholds based on PET for the period June 25th, 2003 to December 31st, 2010.

	PET>25°	**PET>30°**	**PET>35°**	**PET>40°**
v-1 m/s	49.3%	29.0%	19.1%	10.2%
v+1 m/s	40.6%	21.9%	11.4%	3.1%
T_{mrt} = T_{ar}	75.7%	34.1%	6.3%	0.1%
PET	44.4%	26.8%	16.7%	7.8%

It was observed in table 9 that 44.4% of PET values were found when PET is above 25 °C, the highest percentage observed was 75.5% of PET if T_{mrt} is equal to T_{ar}, and the lowest percentage observed was 40.6% of PET if wind speed is above 1m/s. From 26.8% of PET above 30 °C found from 2003 to 2010, the highest percentage observed was 34.1% of PET if T_{mrt} is equal to T_{ar}, and the lowest percentage observed was 21.9% of PET if wind speed is above 1m/s. From 16.7% of PET above 35 °C found from 2003 to 2010, the highest percentage observed was 19.1% of PET if wind speed is below 1m/s, and the lowest percentage observed was 6.3% of T_{mrt} is equal T_{ar}. From 7.8% of PET above 35 °C found from 2003 to 2010, the highest percentage observed was 10.2% of PET if wind speed is below 1m/s, and the lowest percentage observed was 0.1% of T_{mrt} is equal T_{ar}.

The simulations performed in this study show that thermal bioclimate conditions can be affected by modifications of solar radiation and wind speed. It was observed that above 25°, 30°, 35° and 40°C thresholds, if the wind speed increases, the PET is reduced in the situations analyzed and if the wind speed decreases, the PET increases. In shade situation, if T_{mrt} is equal T_{ar}, the PET will increase in situations above 25 and 30°C, and it will be less than PET in situations above 35 and 40 °C.

5.1.2 Urban Street Canyons

By analyzing the influences of orientation on street canyon, the orientation and shadow study was made. Figure 34 shows the polar diagram of height-width ratio equal 0.45, 1.05 and 2.2 in different directions, North-South and East-West. From this figure can see the influence of height-width ratio on sky view factor (SVF), as well as the orientation influences on the shade of the buildings.

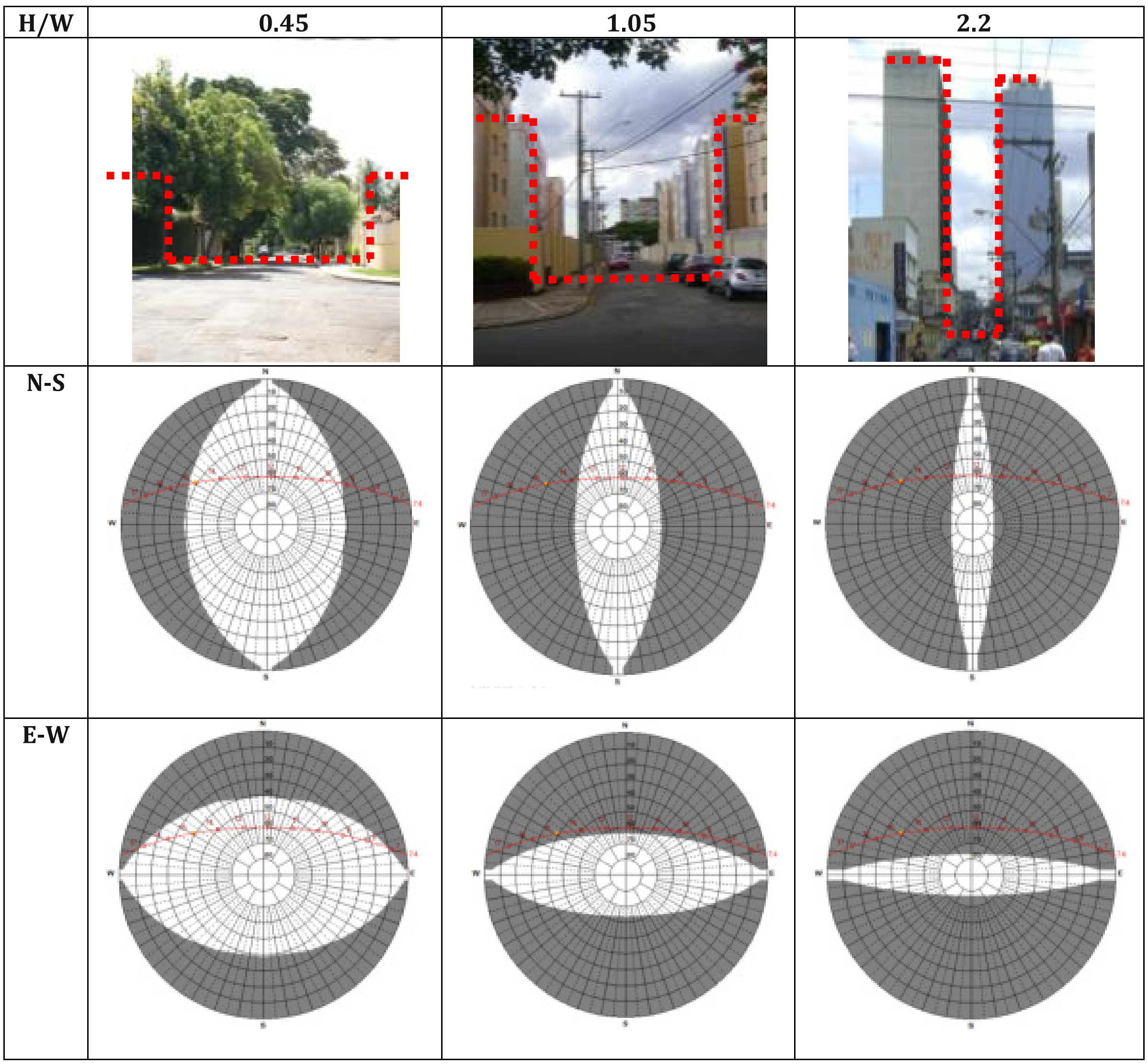


Fig 34. *Polar diagram of street canyon of Height-Width Ratio of 0.45, 1.05 and 2.2*

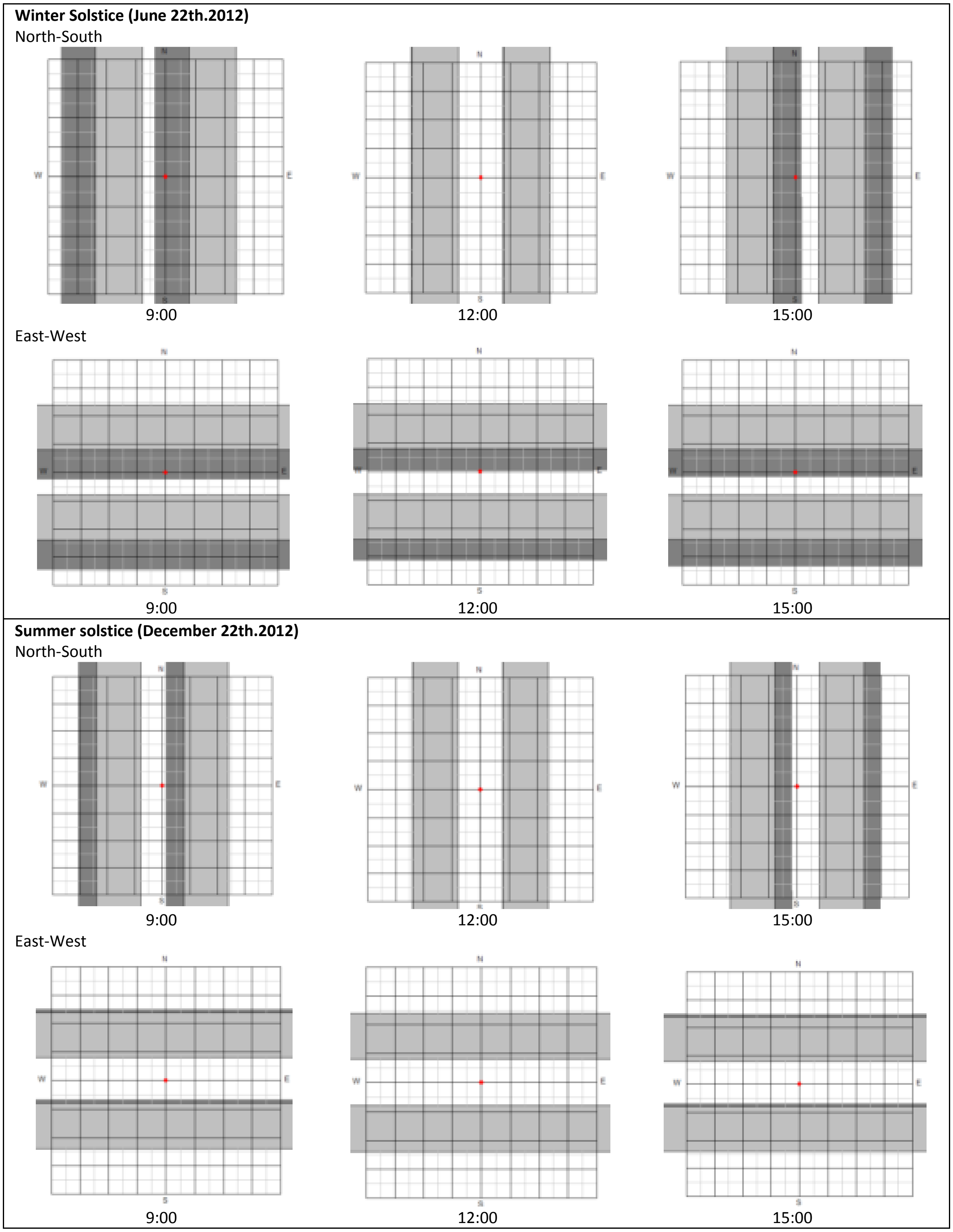


Fig 35. *Orientation study of street canyon, H/W = 0.45*

Figure 35 shows the shadow studies of height-width ratio equal 0.45 in different directions (North-South and East-West) during summer solstice and winter solstice. Three day periods, 9:00, 12:00 and 15:00, were done. During summer and winter solstice, the North-South orientation had facades' shaded during morning and afternoon. In East-West orientation, the south façades are shaded during winter solstice, and north façades are shaded during summer solstice during the morning and afternoon period.

Fig. 36 and 37 show the diurnal courses of the PET of idealized urban canyon in Campinas in north-south and east-west orientation, respectively. The height of the canyon in this case is 21 m and the width varies from 5 to 40 m. In addition, PET at urban climate station of Campinas is included. From both figures above, it can be seen that conditions are similar during the night because of the absence of global radiation. By comparing the results of Urban Station with different widths, the PET are above in 2º from 19 to 24h. During the day, the effect of solar radiation in north-south orientated canyon (Fig. 36), with widths above 12.5 m where the highest values are reached. For the east-west orientation (Fig. 37), the increase is lower, reaching high PET values when the width approaches 40 m. The same performance happened in terms of Mean Radiant Temperature.

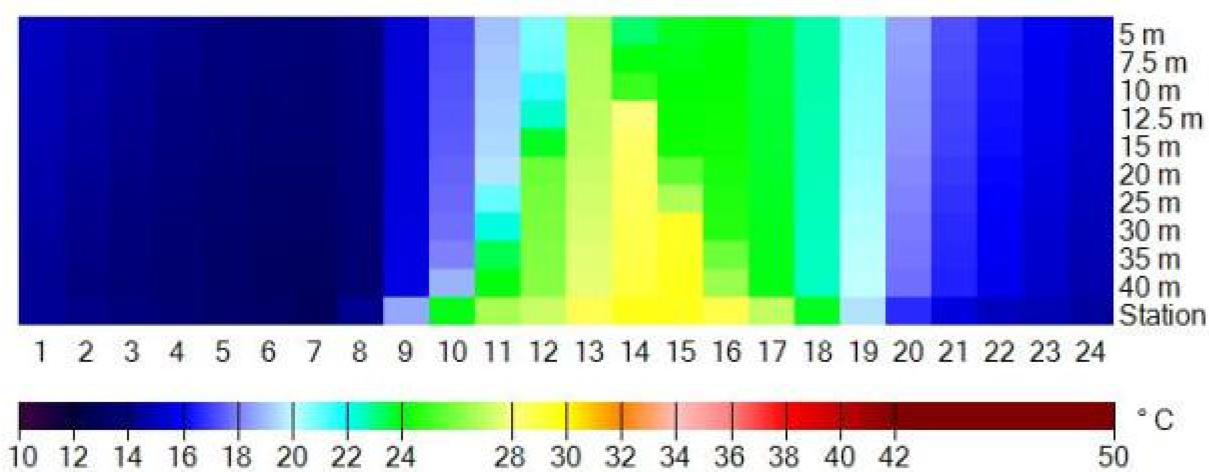


Fig 36. *Diurnal courses of Physiologically Equivalent Temperature (PET) (ºC) for an urban canyon with north-south orientation.*

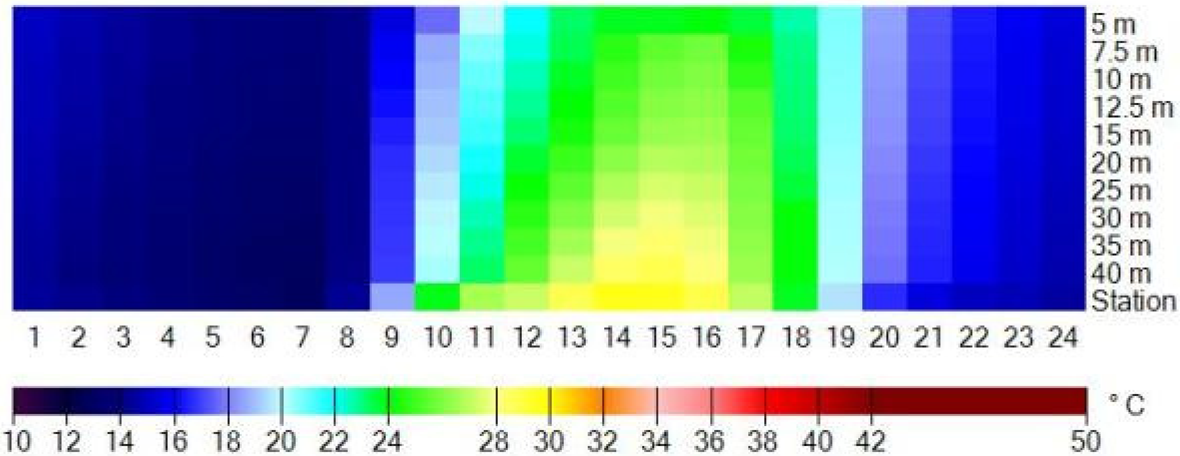


Fig 37. *Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for an urban canyon with east-west orientation.*

Figure 38 and 39 show the diurnal courses of the Mean Radiant Temperature (T_{mrt}) of idealized urban canyon in Campinas in north-south and east-west orientation, respectively. The height of the canyon in this case is 21 m and the width varies from 5 to 40m. In addition, T_{mrt} at urban climate station of Campinas is included.

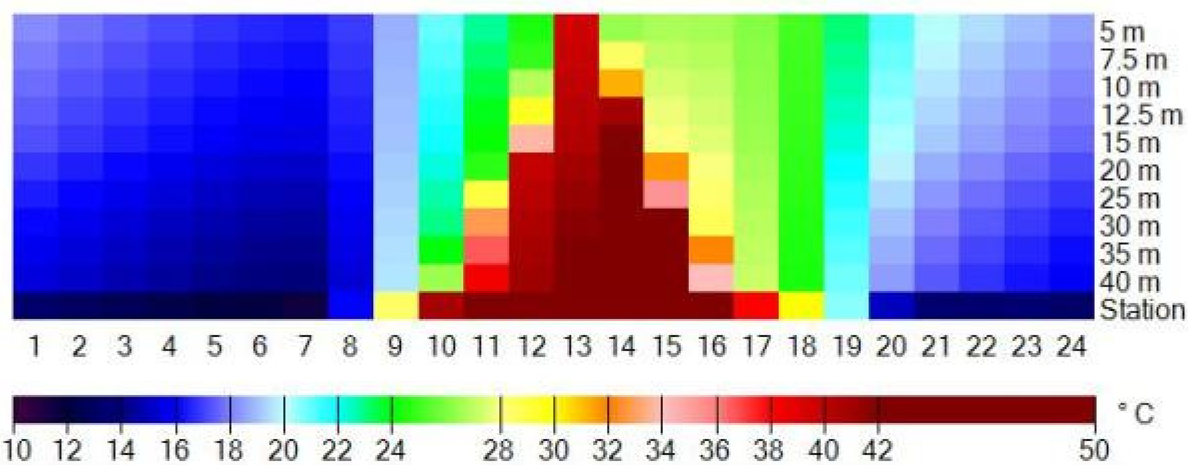


Fig 38. *Diurnal courses of Mean Radiant Temperature (T_{mrt}) (°C) for an urban canyon with north-south orientation.*

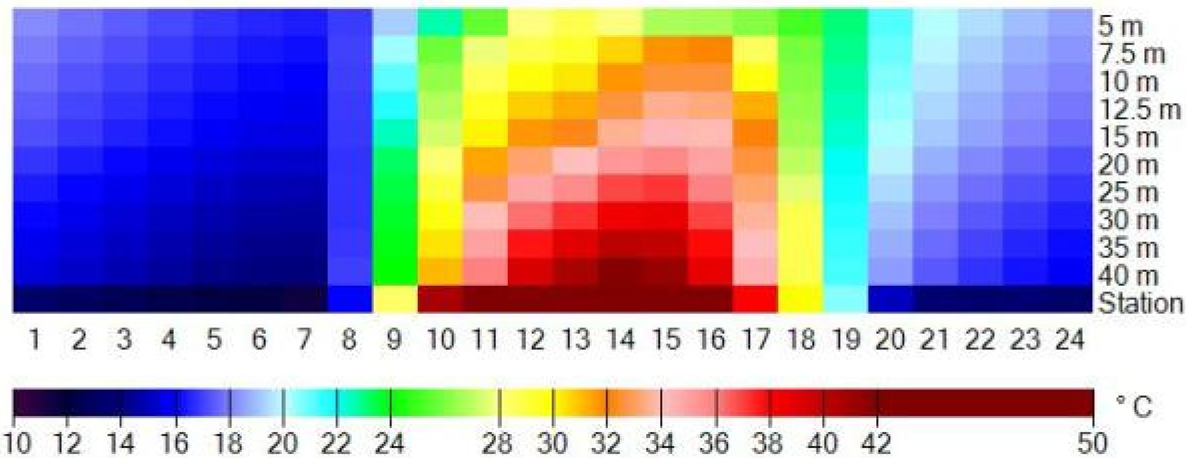


Fig 39 . *Diurnal courses of Mean Radiant Temperature (T_{mrt}) (°C) for an urban canyon with east-west orientation.*

From both figures above (Fig 38. and 39.), it can be seen that conditions are similar during the night because of the absence of global radiation. By comparing the results of Urban Station with different widths, T_{mrt} increase progressively when the width approaches 5 m. During the day, the effect of solar radiation in north-south orientated canyon (Fig 38.), with widths above 12.5 m where the highest values are reached as PET results of the same orientation. For the east-west orientation (Fig. 39), the increase is lower, reaching high PET values when the width approaches of 40m as PET results of the same orientation

Fig. 40 and 41 present the diurnal course of PET and T_{mrt} in idealized urban canyon in Campinas in north-south, east-west and northeast-southwest (predominant direction of wind in this region), respectively. The width of the canyon in both cases is 20 m and the height varies from 9, 21 and 44 m, the typical configurations of Campinas city. PET and T_{mrt} from urban station of Campinas are included.

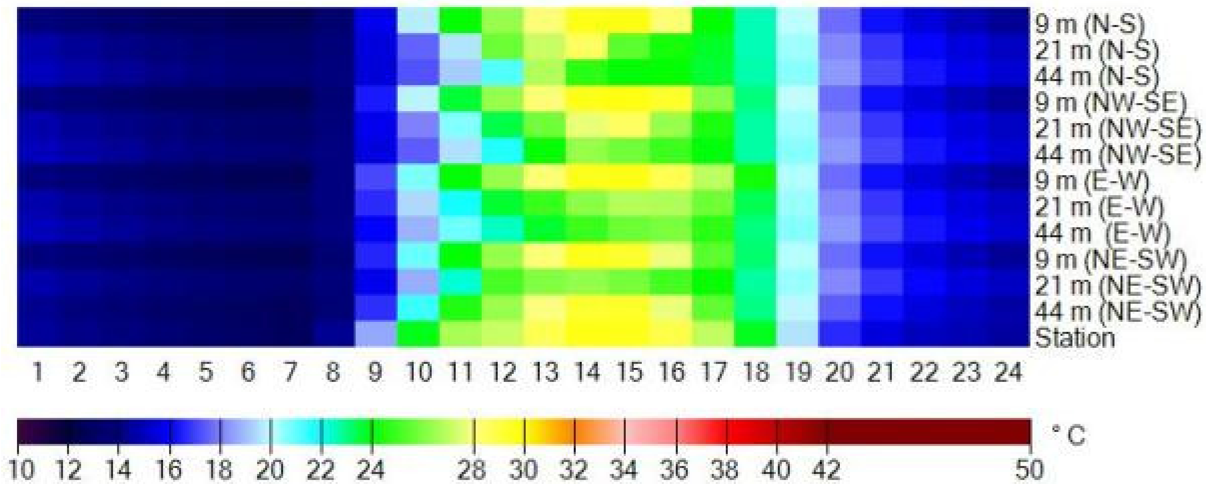


Fig 40. *Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for an urban canyon with north-south, northwest-southeast, east-west and northeast-southwest orientations, variable height (9 m, 21 m, 44 m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.*

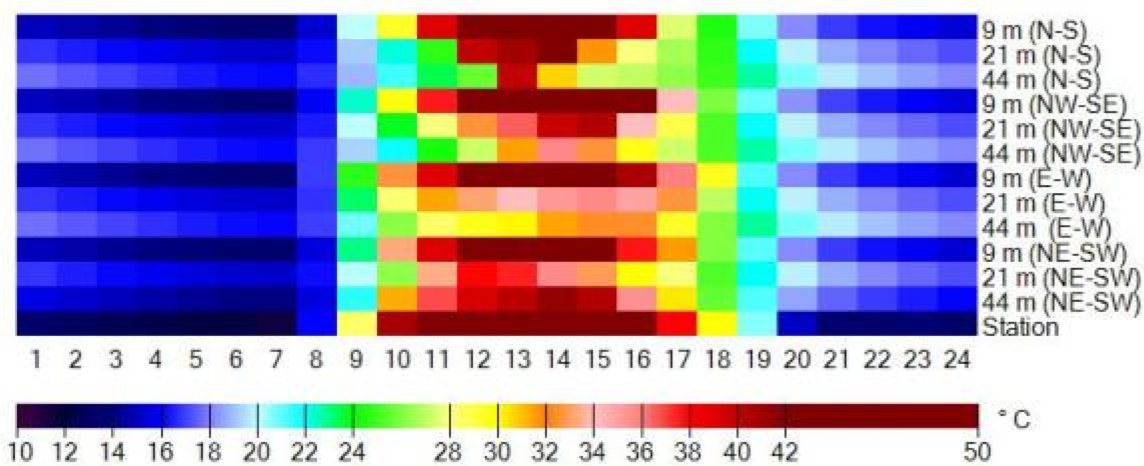


Fig 41. *Diurnal courses of Mean Radiant Temperature (T_{mrt}) (°C) for an urban canyon with north-south, northwest-southeast, east-west and northeast-southwest orientations, variable height (9 m, 21 m, 44 m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.*

From these figures above, the significant differences on temperatures during of night can be extracted. According to the different orientation, the conditions depends on the different heights of buildings. For height equal to 9 m (H/W = 0.45), the orientation of street canyon has a low influence in terms of PET and T_{mrt}. For height equal to 21 m (H/W = 1.05), the orientation of street canyon as the east-west and northeast-southwest orientations can improve thermal comfort. When the height is 44 m (H/W= 2.2), the orientation of street canyon as the northeast-southwest orientation present temperatures above 29 ° in terms of PET and T_{mrt}. In terms of T_{mrt}, figure 48 shows that all orientation have thermal stress, except the east-west orientation of height equal to 44 m (H/W= 2.2).

Fig 42. and 43. show the stepwise (15°) rotation of an urban canyon with a height of 21m and width of 20 m of diurnal courses of PET and T_{mrt}, respectively. The orientation 0 ° and 180° in these figures are identical and are marked as the north-south in preceding figures (fig. 11 - 13); likewise, east-west is marked as 90 ° in Fig 43. and 45. The results of these orientation can also be found in the other diurnal courses of PET and T_{mrt} (Fig. 43 to 48).

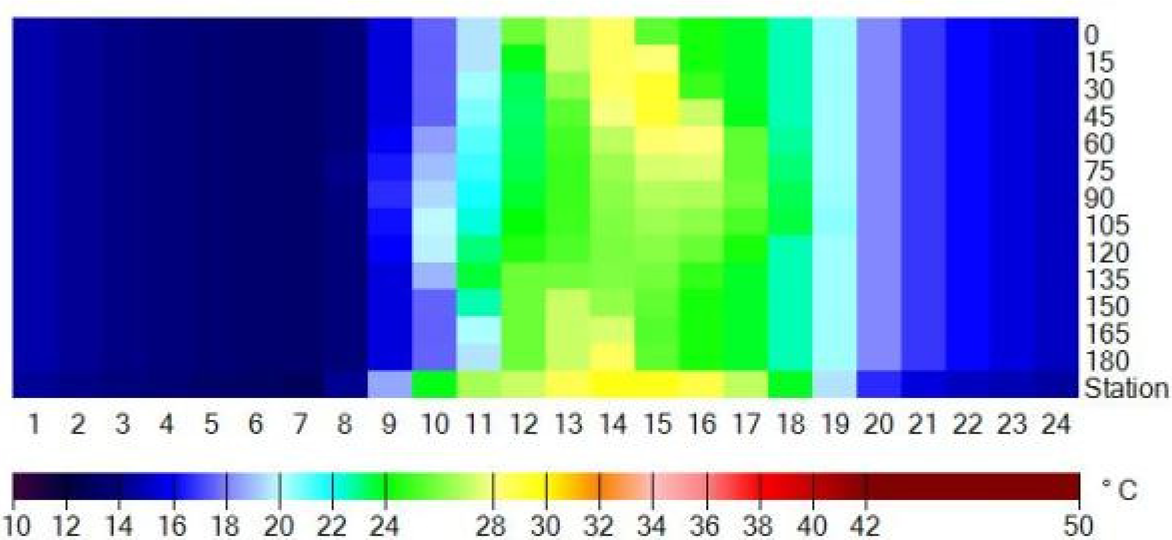


Fig 42. *Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for the stepwise (15°) rotation of an urban canyon with a height and width of 15m based on data from climate station for the period June 25th, 2003 to December 31st, 2010.*

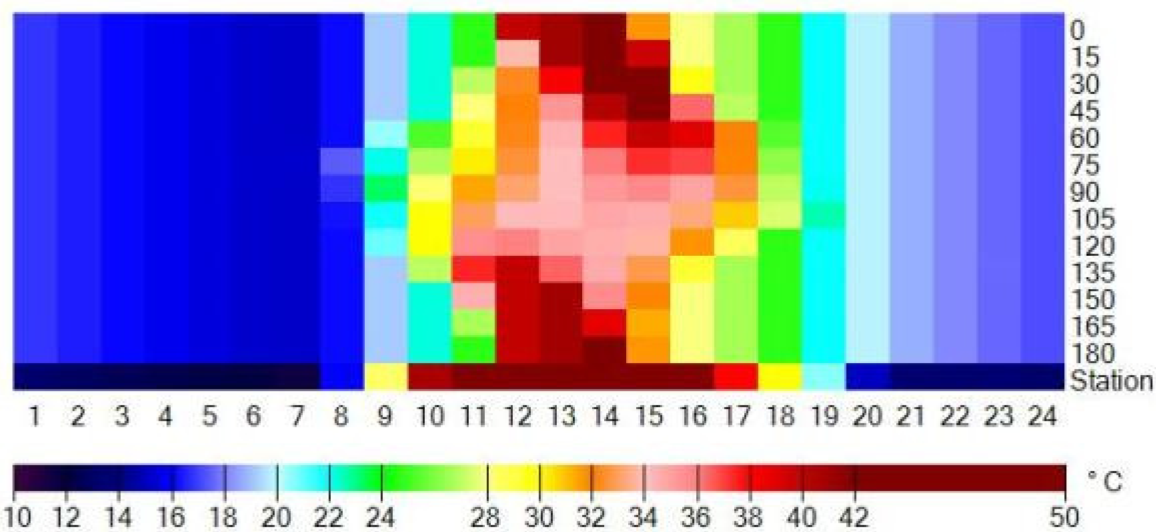
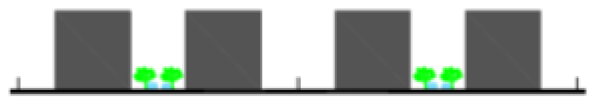
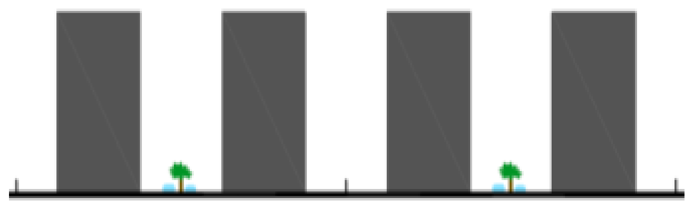


Fig 43. *Diurnal courses of Mean Radiant Temperature (T_{mrt}) (°C) for the stepwise (15°) rotation of an urban canyon with a height and width of 15m based on data from climate station for the period June 25th, 2003 to December 31st, 2010.*

These figures above show that north-south and east-west orientations are the two extremes, with highest values of PET and T_{mrt} north-south orientations and lowest values for east-west orientations at midday. The rotation in both directions starting at 0° reduces the values during midday and offsets the maximum value of T_{mrt} towards the morning or the evening while the overall daytime values are decreasing. This leads to the described situation for 105 °. The conditions during the night are very similar due to the lack of global radiation, but the orientation of the canyon also affects the timing of the first increase of PET and T_{mrt} in the morning.

Based on radiation fluxes estimations and simulations results, the urban guidelines for Campinas was reached in table 9. From this table, it was observed that there is low influence of street orientation in height-width ratio until 0.5. Therefore, it is recommended to manage the forestry and green areas by promoting shade on pedestrian paths and façades.

Table 9 - Urban climate guidelines for Campinas based on thermal bioclimate

H/W	URBAN GUIDELINES	SIDE VIEW
< 0.5	The management of forestry and green areas promotes shade on pedestrian ways and façades are recommended.	
0.5 to 1.0	The street can be orientated between 90º and 120º; for the others orientation, it is recommended the management of forestry and green areas.	
1.0 to 2.0	The street can be orientated between 45º and 135º; for the others orientation, it is recommended the management of forestry and green areas.	
>2.0	The north-south street orientation is not recommended.	

5.2 Second Part: Assessment of the trees' influence on microclimate

Attenuation of Solar Radiation by certain trees

To quantify the distance of influence on microclimate by certain trees, it is necessary to describe the study area. From the aerial photograph of field measurement, the Green Coverage Ratio (GCR) was defined by MultiSped© which is able to identify the trees clusters due to their textures and calculate the percentage of canopy.

Table 10 - Results for single trees

SPECIES	Surface Material (m2)				Green Converage ratio (%)			SRA(%)		PAI (%)	SVF (%)
		r = 10 m	r = 25 m	r = 50 m	r = 10 m	r = 25 m	r = 50 m	Sum	Win		
Tabebuia Chrysotricha	Tree Analised	80,2	108,8	279,6	25,5	5,5	3,5	82,85	46,42	0,79	0,21
	Asfalt	0,0	345,4	1044,7	0,0	17,6	13,3				
	Grass	233,8	1508,3	4275,7	74,4	76,8	54,5				
	other trees	0,0	0,00	924,6	0,0	0,0	11,8				
	Buildings	0,0	0,00	1325,3	0,0	0,0	16,9				
Syzygium cumini	Tree Analised	146,4	135,2	171,5	46,6	6,9	2,2	87,24	89,14	0,48	0,52
	Asfalt	0,0	347,9	1009,0	0,0	17,7	12,8				
	Grass	167,6	1259,1	4106,6	53,4	64,1	52,3				
	other trees	0,0	217,8	2007,9	0,0	11,1	25,6				
	Buildings	0,0	0,00	554,9	0,0	0,0	7,1				
Manguifera indica	Tree Analised	184,8	350,9	521,3	58,8	17,9	6,6	89,22	88,68	0,52	0,48
	Asfalt	0,0	0,0	852,2	0,0	0,0	10,8				
	Grass	129,2	1471,2	5463,9	41,1	74,9	69,6				
	other trees	0,00	140,4	631,6	0,0	7,1	8,0				
	Buildings	0,00	0,00	5463,9	0,0	0,0	69,6				
Jacaranda mimosifólia	Tree Analised	39,6	117,9	221,2	12,6	6,0	2,8	------	63,85	0,90	0,10
	Asfalt	0,0	0,0	2073,3	0,0	0,0	26,4				
	Grass	274,4	1636,2	3977,8	87,4	83,4	50,6				
	other trees	0,0	208,3	874,8	0,0	10,6	11,1				
	Buildings	0,0	0,0	702,8	0,0	0,0	8,9				
Caesalpinia pluviosa	Tree Analised	256,2	581,6	572,9	81,6	29,6	7,3	83,86	69,54	0,41	0,59
	Asfalt	0,0	0,0	0,0	0,0	0,0	0,0				
	Grass	59,4	968,6	5638,7	18,9	49,3	71,8				
	other trees	0,0	0,0	542,7	0,0	0,0	6,91				
	Buildings	0,0	0,0	1105,6	0,0	0,0	14,1				
Spathodea campanulata	Tree Analised	208,6	140,54	250,4	66,4	7,1	3,2	------	55,00	0,57	0,43
	Asfalt	0,0	0,00	0,0	0,0	0,0	0,0				
	Grass	105,7	1776,7	6563,9	33,6	90,5	83,6				
	other trees	0,0	0,0	540,9	0,0	0,0	6,9				
	Buildings	0,0	42,6	465,7	0,0	2,2	5,9				
Tipuana tipu	Tree Analised	1524,4	812,1	590,8	77,7	41,4	7,5	76,29	------	0,66	0,34
	Asfalt	0,0	0,0	0,0	0,0	0,0	0,0				
	Grass	440,5	1152,9	7259,2	22,4	58,7	92,5				
	other trees	0,0	0,0	0,0	0,0	0,0	0,0				
	Buildings	0,0	0,0	0,0	0,0	0,0	0,0				
Lafoensia glyptocarpa	Tree Analised	722,7	150,7	194,1	36,8	7,7	2,5	------	63,90	0,61	0,39
	Asfalt	0,0	0,0	0,0	0,0	0,0	0,0				
	Grass	1237,2	1261,2	6845,3	63,0	64,2	87,2				
	other trees	0,0	0,0	1005,6	0,0	0,0	12,8				
	Buildings	0,0	0,0	0,0	0,0	0,0	0,0				
Pinus palustris	Tree Analised	250,0	115,6	110,5	12,7	5,9	1,4	79,76	69,87	0,80	0,20
	Asfalt	0,0	0,0	1591,7	0,0	0,0	20,3				
	Grass	1712,5	1846,9	5916,6	87,2	94,1	75,4				
	other trees	0,0	0,0	0,0	0,0	0,0	0,0				
	Buildings	0,0	0,0	231,1	0,0	0,0	2,9				
Pinus coulteri	Tree Analised	145,5	85,4	225,4	7,4	4,3	2,9	83,83	78,32	0,86	0,14
	Asfalt	208,5	691,1	1813,9	10,6	35,2	23,1				
	Grass	1608,5	1043,	2131,6	81,9	53,2	27,1				
	other trees	0,0	142,4	2439,0	0,0	7,2	31,1				
	Buildings	0,0	0,0	1240,0	0,0	0,0	15,8				

Table 11 - Results for trees' clusters

SPECIES		Surface Material (m2)			Green Converage ratio (%)			SRA(%)		BLAI (%)	SVF (%)
		r = 10 m	r = 25 m	r = 50 m	r = 10 m	r = 25 m	r = 50 m	Sum	Win		
Caesalpinia pluviosa	Cluster	231,7	865,4	2216,2	73,8	44,1	28,2	94,8	92,5	0.99	0.01
	Asfalt	0,0	0,00	0,00	0,00	0,00	0,0				
	Grass	81,9	1095,0	5633,7	26,1	55,8	71,7				
	other trees	0,0	0,00	0,00	0,00	0,00	0,0				
	Buildings	0,0	0,00	0,00	0,00	0,00	0,0				
Spathodea campanulata	Cluster	233,6	485,0	781,0	74,4	24,7	9,9	------	55%	0,57	0,42
	Asfalt	0,0	0,00	0,0	0,0	0,0	0,0				
	Grass	80,4	1480,0	7069,0	25,6	75,4	90,0				
	other trees	0,0	0,00	0,0	0,0	0,0	0,0				
	Buildings	0,0	0,00	0,0	0,0	0,0	0,0				
Tipuana tipu	Cluster	243,3	1131,4	2197,5	77,5	57,6	27,9	76,3	-----	0,659	0,34
	Asfalt	0,0	0,0	0,0	0,0	0,0	0,0				
	Grass	70,6	833,5	5659,4	22,5	42,5	72,1				
	other trees	0,0	0,0	0,0	0,0	0,0	0,0				
	Buildings	0,0	0,00	0,00	0,0	0,0	0,0				
Lafoensia glyptocarpa	Cluster	185,1	1384,5	822,1	58,9	70,5	10,5	-----	63,9	0,60	0,39
	Asfalt	0,0	0,0	0,0	0,0	0,0	0,0				
	Grass	129,3	575,4	5764,7	41,2	29,3	73,4				
	other trees	0,0	0,0	350,9	0,0	0,0	4,4				
	Buildings	0,0	0,0	902,3	0,0	0,0	11,5				
Senna Siamea	Cluster	218,3	760,0	1643,4	69,5	38,7	20,9	79,7	69,8	0,79	0,20
	Asfalt	0,0	0,0	528,1	0,0	0,0	6,7				
	Grass	95,7	932,5	3097,8	30,5	47,5	39,4				
	other trees	0,0	267,5	2579,6	0,0	13,6	32,8				
	Buildings	0,0	0,0	0,0	0,0	0,0	0,0				
Delonix indica	Cluster	238,0	724,3	1261,6	75,8	36,9	16,1	83,8	78,3	0,86	0,13
	Asfalt	0,0	0,0	0,0	0,0	0,0	0,0				
	Grass	76,0	1233,1	6338,0	24,2	62,8	80,7				
	other trees	0,0	0,0	250,3	0,0	0,0	3,2				
	Buildings	0,0	0,0	0,0	0,0	0,0	0,0				

To define the study areas, three circles sizes - 10m, 25m and 50m - based on measurement points were sketched over aerial pictures where the circumferences' center is the exact measurement point called "shade" on tree clusters studies and the tree stem on isolated arboreal studies. The characteristics of the measurement points in terms of Green Coverage ratio (GC), Attenuation of Solar Radiation (SRA), Plant Area Index (PAI) and Sky View Factor (SVF) are shown for isolated and cluster of trees in Table 10 and 11, respectively.

Fig. 44 and 45 present the results of diurnal courses of Mean Solar Radiation for isolated trees and clusters of trees, respectively, based on data from field measurement for the study period.

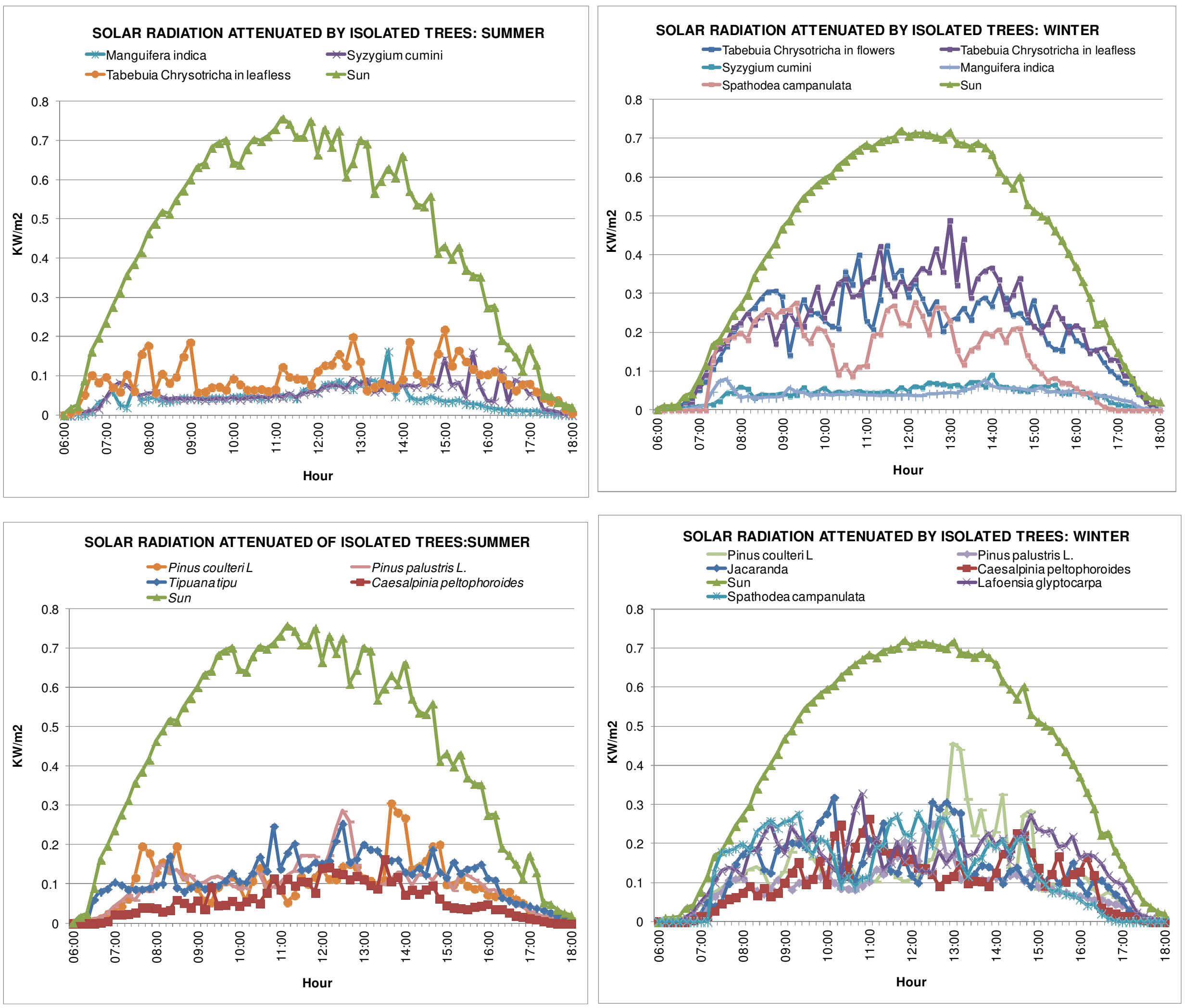


Fig 44. *Diurnal courses of Mean Solar Radiation for isolated trees based on data from field measurement for period of 2007 to 2010.*

From Fig 44., it can observed the variation of solar radiation attenuated by isolated trees due to specific features of each arboreal species mainly crown, trunk and leaf shape and size. The perennials trees such as Jambolão (*Syzygium cumini* L.) and Mangueira

(Mangifera indica L.) have a similar behavior during both seasons while the semi-deciduous and deciduous trees as Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.) and Sibipiruna (*Caesalpinia pluviosa F.*) present different results for the studied period. The trees capacity of solar radiation attenuation relate not only with the phenology, but also with the trunk type and the shape and size of leaves. For example, Jambolão (*Syzygium cumini* L.), Mangueira *(Mangifera indica* L.) and Sibipiruna (*Caesalpinia pluviosa F.*)have a plagiotropic trunk, but different shape leaves, whereas Jambolão (*Syzygium cumini* L.), Mangueira *(Mangifera indica* L.) provide the homogeneous shade during the day. By comparing Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.), with Sibipiruna (*Caesalpinia pluviosa F.*), the trunk structure differences as orthotropic simpodial and plagiotropic, respectively, and leaves' shape was observed. The orthotropic monopodial trunk structure found in trees as Pinheiro (*Pinus palustris* L.) and Pinheiro (*Pinus coulteri* L.) provide a lot of variations on solar radiation attenuation during the day and reduces the shade's quality.

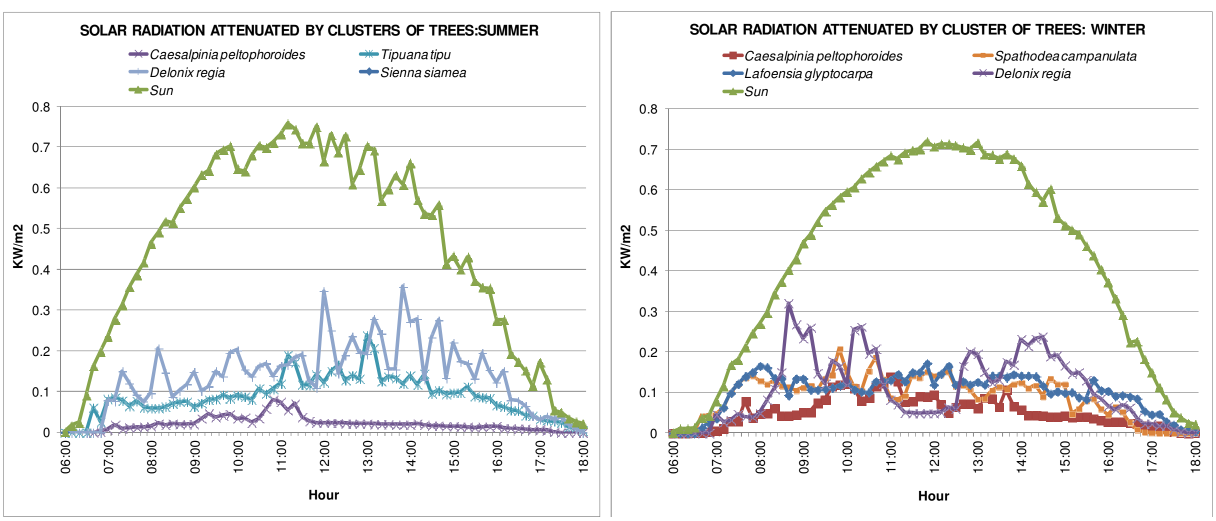


Fig 45. *Diurnal courses of Mean Solar Radiation for cluster of trees based on data from field measurement for period of 2007 to 2010.*

From Fig 45., some comparisons may be extracted. Despite the reduction in solar radiation attenuated by clusters of trees due seasons, the Sibipiruna (*Caesalpinia pluviosa F.*) cluster produced shade quality during the day on one hand, on the other hand the *Delonix regia* F. clusters didn't present uniform shade during the day in both seasons. These species have same species features as plagiotropic trunk structure and similar shape' leaves, but different crown shape.

Fig 46. and 47. present the results of plant area index (Cos and RayMan) and the summation of solar radiation attenuated of isolated trees and clusters of trees, respectively. The plant area index (PAI) can show the differences of trees dispositions (isolated or clusters) and species' features such as the crown and trunk structures and leaves dispositions.

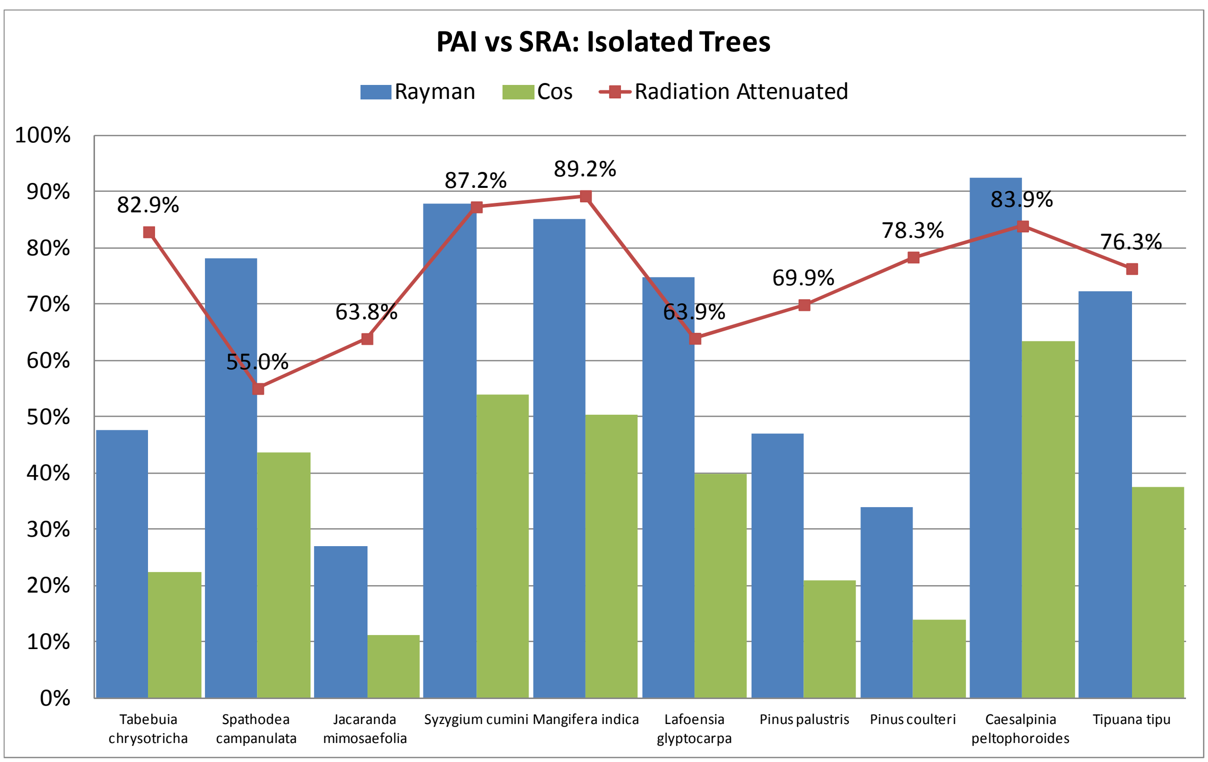


Fig 46. *Results of Solar Radiation Attenuated and Plant Area Index (PAI)for isolated trees*

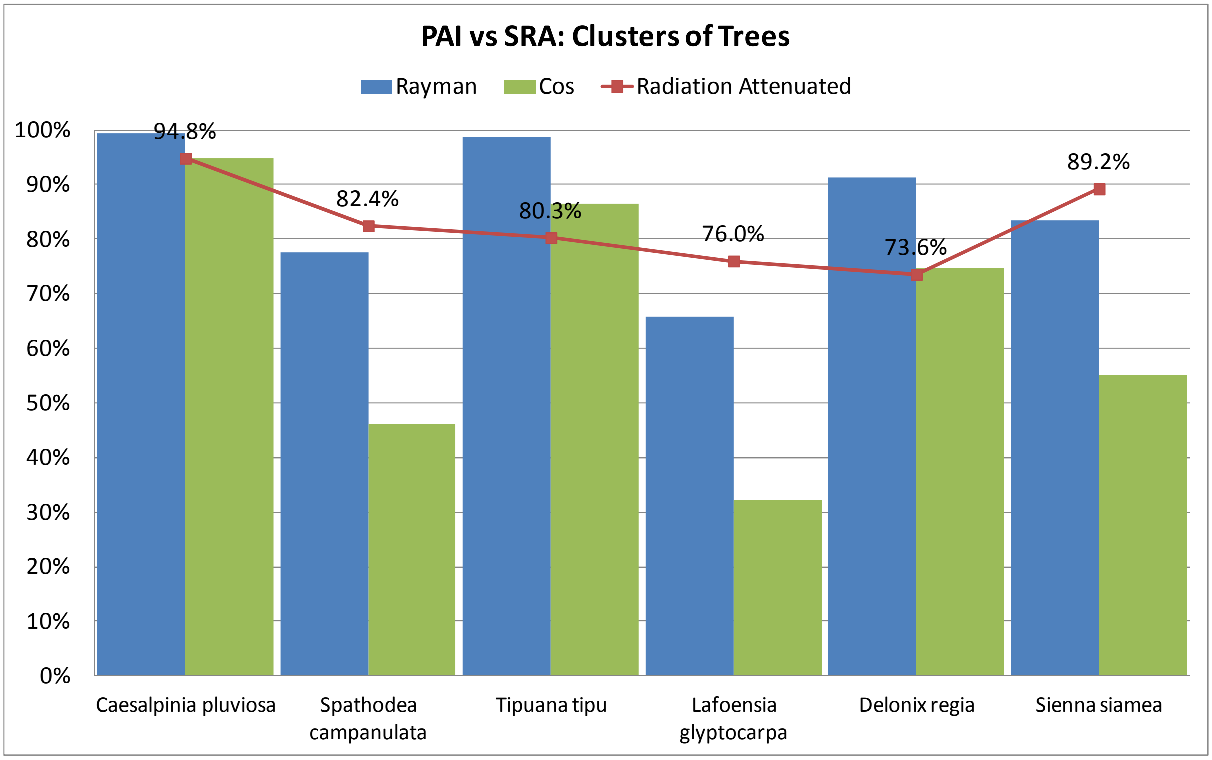


Fig 47. *Results of Solar Radiation Attenuated and Plant Area Index (PAI)for isolated trees*

From these figures (Fig 46. and 47.), it was observed that results of PAI was different from SRA by trees shade. The results of PAI relate with trees features and the results of Solar Radiation Attenuated with trees' capacity to improve thermal comfort. When the isolated or cluster of trees have uniform shade, the results of IAF are closer than SRA results.

Fig 48. shows the correlation among Green Coverage Ratio, PAI (cos and Rayman) and SRA for isolated tree, whereas PAI (cos and Rayman) have a moderate correlation and SRA have a weak correlation. Figures 49 to 52 present the results of correlation between green coverage and air temperature as well as green coverage and PET for isolated and cluster of trees, respectively.

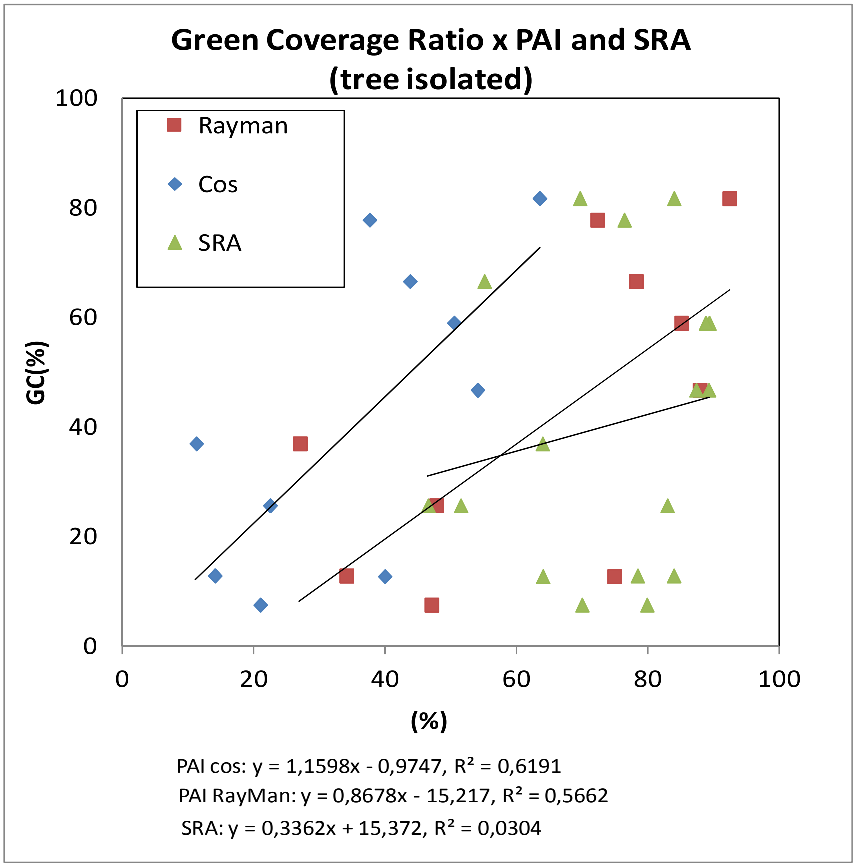


Fig 48. *Correlations between the green coverage ratios, Plant Area Index (PAI) and Solar radiation Attenuated (SRA)*

In Fig 49., the air temperature for shade during summer period presents more correlation than winter. The air temperatures of other situations (10 m, 25 m and 50 m) can modify the microclimate, especially for distance of 10 m during summer period. In Fig 50., the PET for shade presents the most correlation during both season, summer and winter. The correlations differences between Air Temperatures vs Green Coverage and PET vs Green Coverage show the thermoregulation capacity in microclimate in which the trees influences are important in terms of PET. In Fig 51., the correlation between green coverage and air temperature for distance of 50 m during both season are more than others. During winter season, the air temperature for shade, 10 m and 25 m radius present more correlation than summer period. Meanwhile, the correlation between Green coverage and PET present high values for 25 m and 50 m radius during the summer season and for 25 m radius during winter season (Fig 52.). The clusters of trees' green coverage have influenced the air temperature to distance of 50m on the one hand, on the other hand the thermal comfort in microclimate to distance of 25 m.

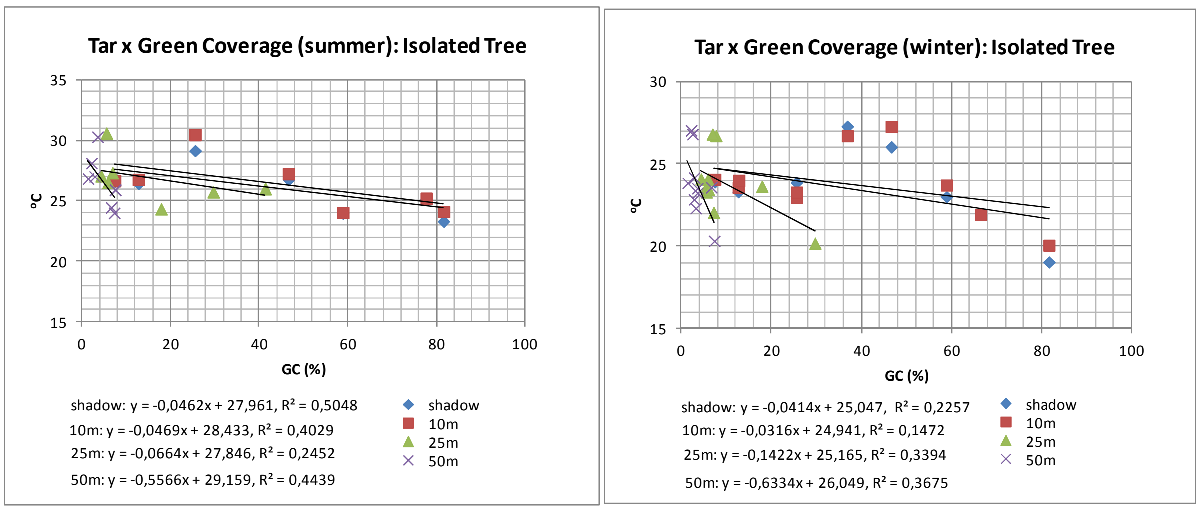


Fig 49. *Correlation between Green Coverage and Air Temperature in different distances for period of 2007 to 2010: isolated trees*

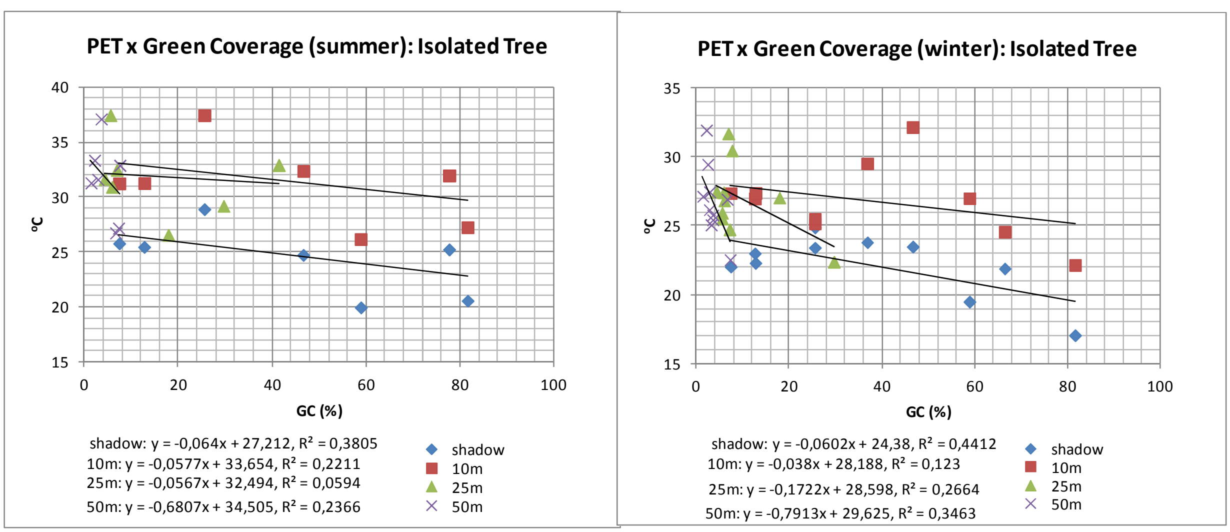


Fig 50. *Correlation between Green Coverage and Physiologically Equivalent Temperature (PET) in different distances for period of 2007 to 2010: isolated trees*

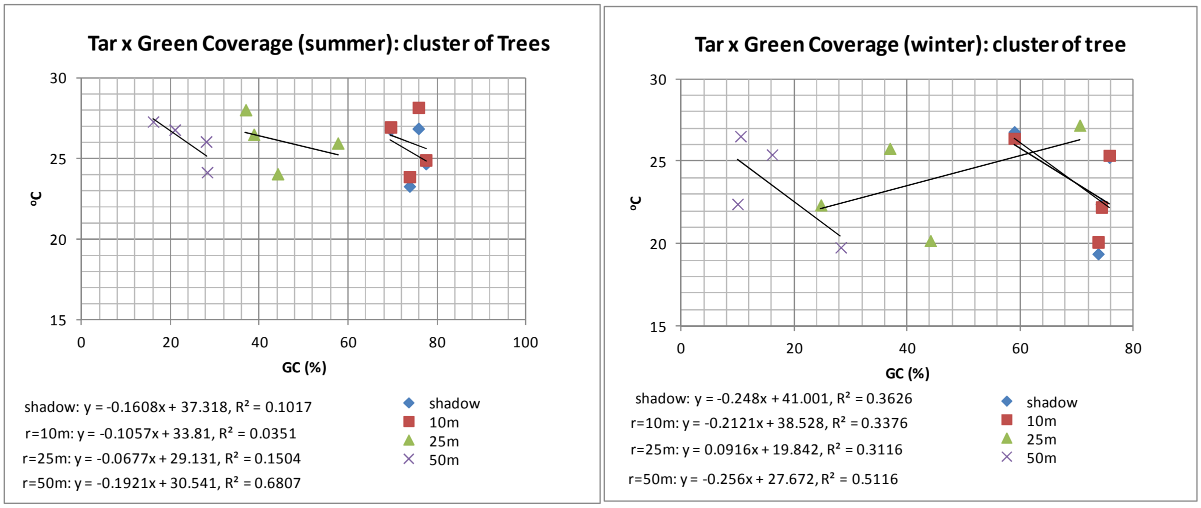


Fig 51. *Correlation between Green Coverage and Air Temperature in different distances for period of 2007 to 2010: isolated trees*

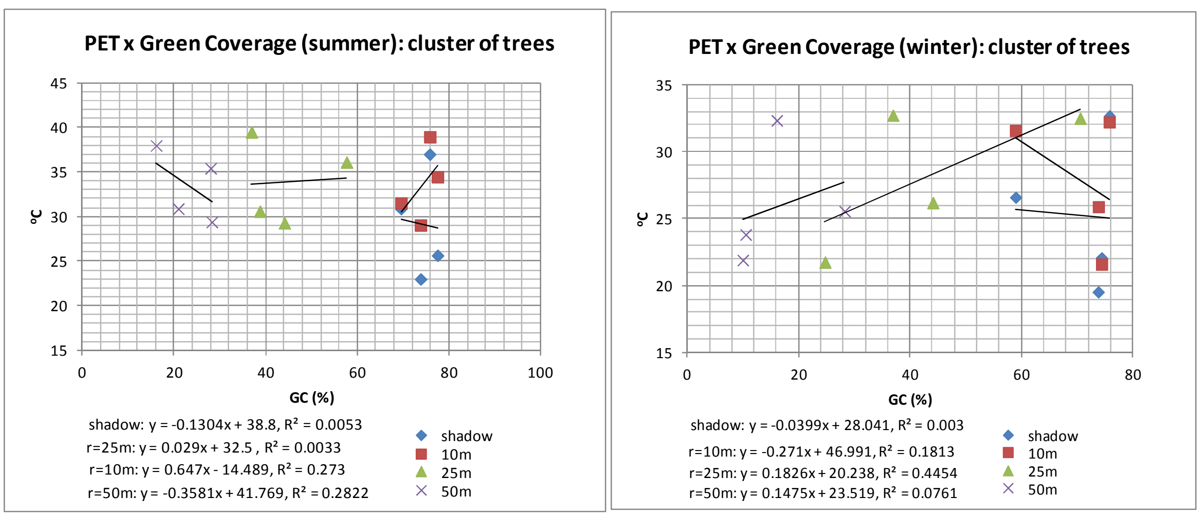


Fig 52. *Correlation between Green Coverage and Physiologically Equivalent Temperature (PET) in different distances for period of 2007 to 2010: Cluster of trees*

Distance of influence on microclimate by certain arboreal species

To describe the microclimate behaviour in different distances of one isolated trees, figures 53 and 54 present the frequencies results of Air Temperature in both seasons, winter and summer, respectively. Figures 55 and 56 present the frequencies results of PET in both seasons, winter and summer, respectively. Figures 57 and 58 present the frequencies results of Mean Radiant Temperature in both seasons, winter and summer, respectively.

These results show the differences between Air Temperature, PET and T_{mrt} in which the trees' shadow can influence more in therms of PET and T_{mrt} than Air Temperature during both seasons (Fig 53 - 58.). Jambolão (*Syzygium cumini* L.), Mangueira *(Mangifera indica* L.) and Sibipiruna (*Caesalpinia pluviosa F.*) were the best and similar results of shadow in the winter. Jambolão (*Syzygium cumini* L.) and Mangueira *(Mangifera indica*) had the most excellent results in summer. Sibipiruna (*Caesalpinia pluviosa F.*) provided the greatest influence in the radius of 10m, 25m and 50m in winter. In summer, the behaviour of all species analyzed were similar.

To describe the microclimate behaviour in different distances of clusters of trees, the results of PET and Mean Radiant Temperatures by Sibipiruna (*Caesalpinia pluviosa F.*) , Mirindiba Bagre (*Lafoensia glyptocarpa* L.), Tipuana (*Tipuana tipu*), Espatódea (*Spathodea campanulata*), Flamboyant (*Delonix indica*) and Chuva de ouro (*Senna siamea*) are present in both seasons, summer and winter. Figures 59 and 60 show the frequencies results of Air Temperature in both seasons, winter and summer, respectively. Figures 61 and 62 show the frequencies results of PET in both season, winter and summer, respectively. The figures 63 and 64 show the frequencies results of Mean Radiant Temperature in both seasons, winter and summer, respectively.

These results show that not only species characteristics as leaf size, crown size and plagiotropic trunk, but also disposition of cluster can influence thermal comfort within different distances (Fig. 59 to 64). The species Sibipiruna (*Caesalpinia pluviosa F.*) , Mirindiba Bagre (*Lafoensia glyptocarpa* L.) and Tipuana (*Tipuana tipu*) can improve more thermal comfort than the others. By comparing the results of Mean Radiant Temperature in the shade of clusters, Sibipiruna (*Caesalpinia pluviosa F.*) and Tipuana (*Tipuana tipu*)clusters can modify significantly the microclimate.

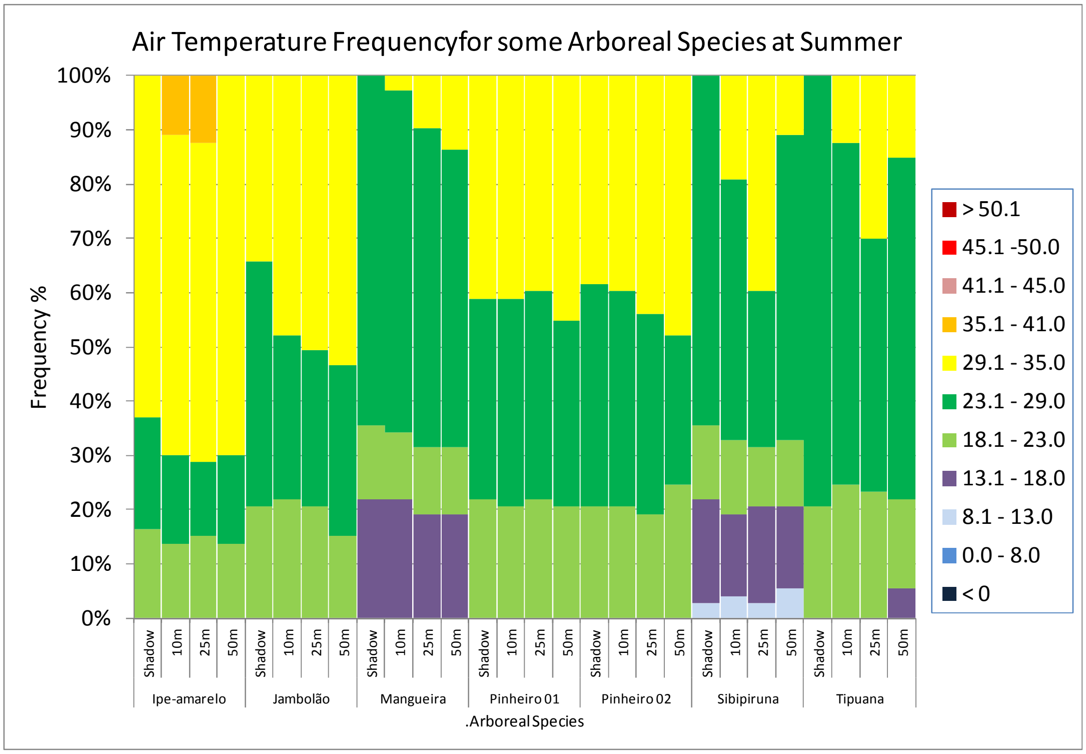


Fig 53. *Results of Air Temperature frequencies by different species in summer*

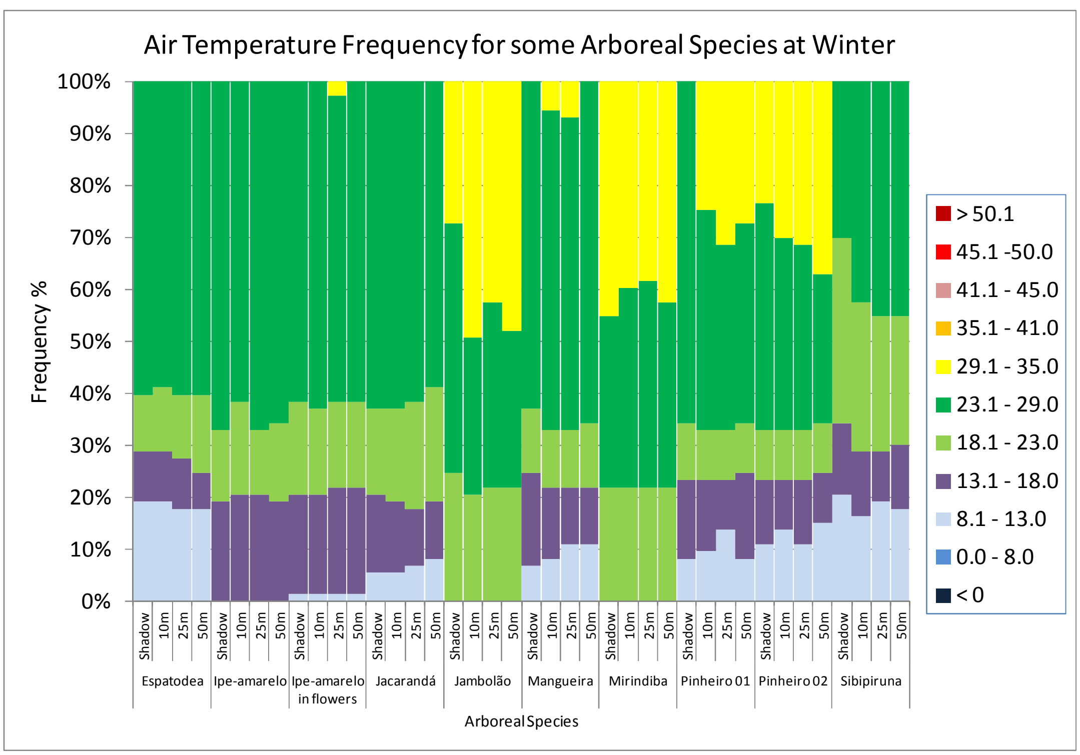


Fig 54. *Results of Air Temperature frequencies by different species in winter*

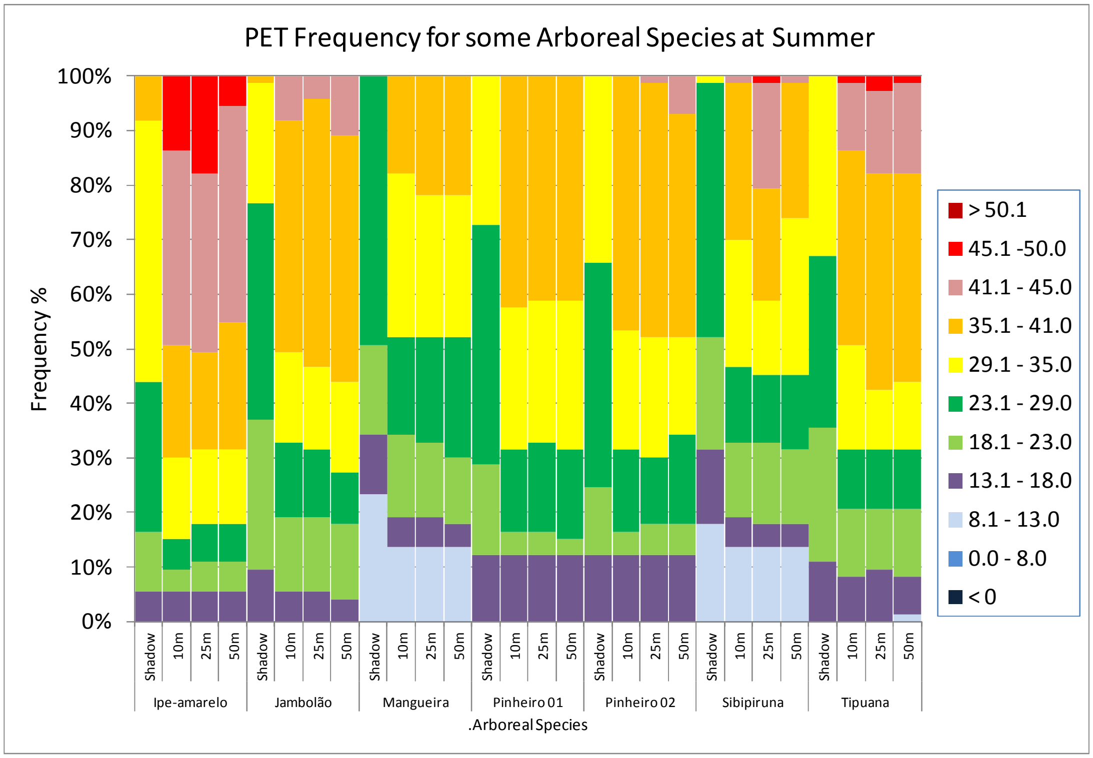


Fig 55. Results of PET frequencies by different species in summer

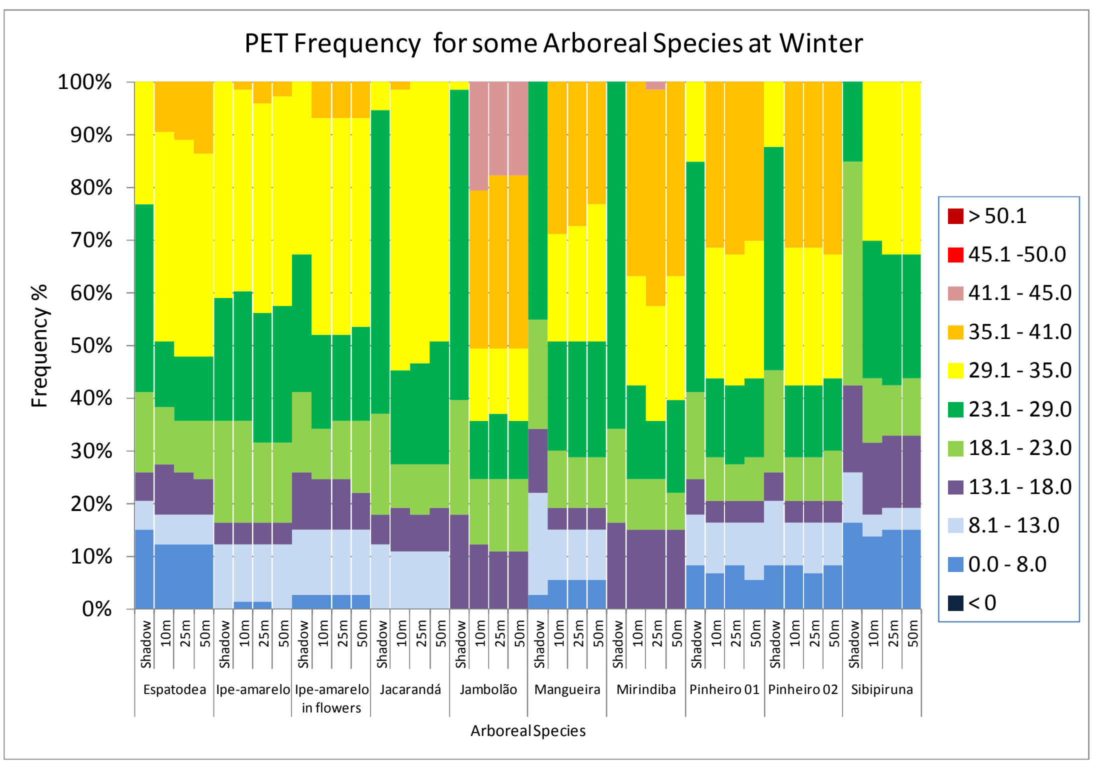


Fig 56. *Results of PET frequencies by different species in winter*

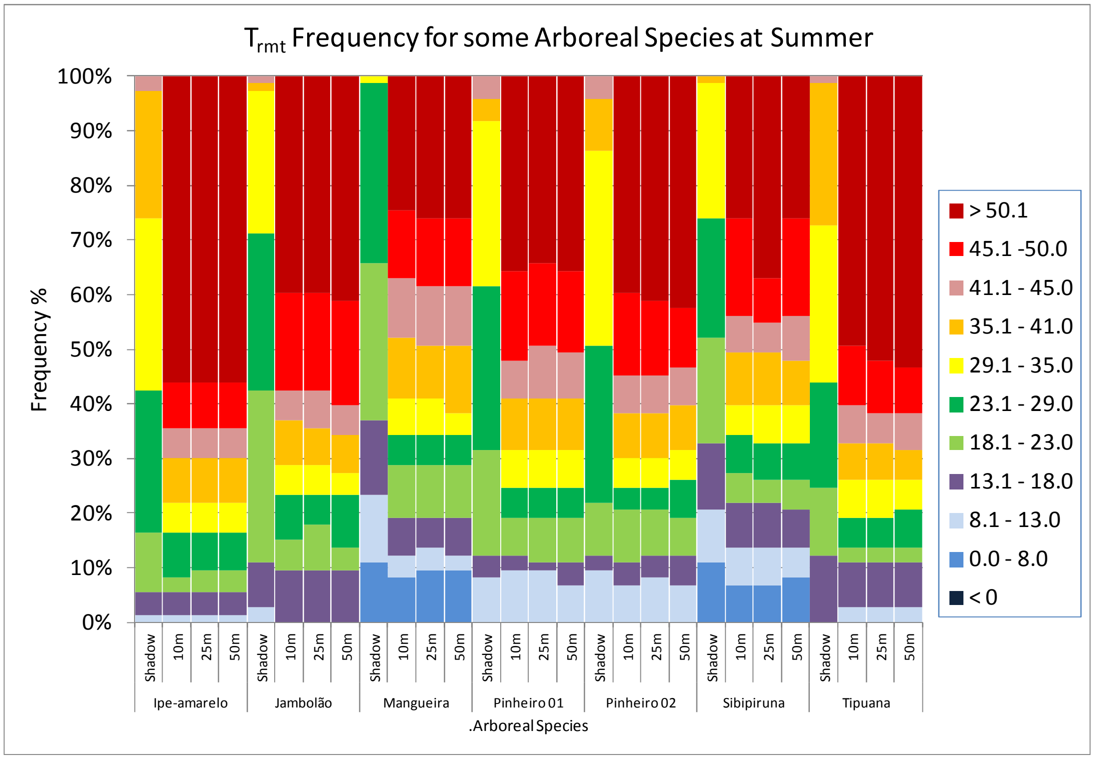


Fig 57. *Results of Mean Temperature Radiant frequencies by different species in summer*

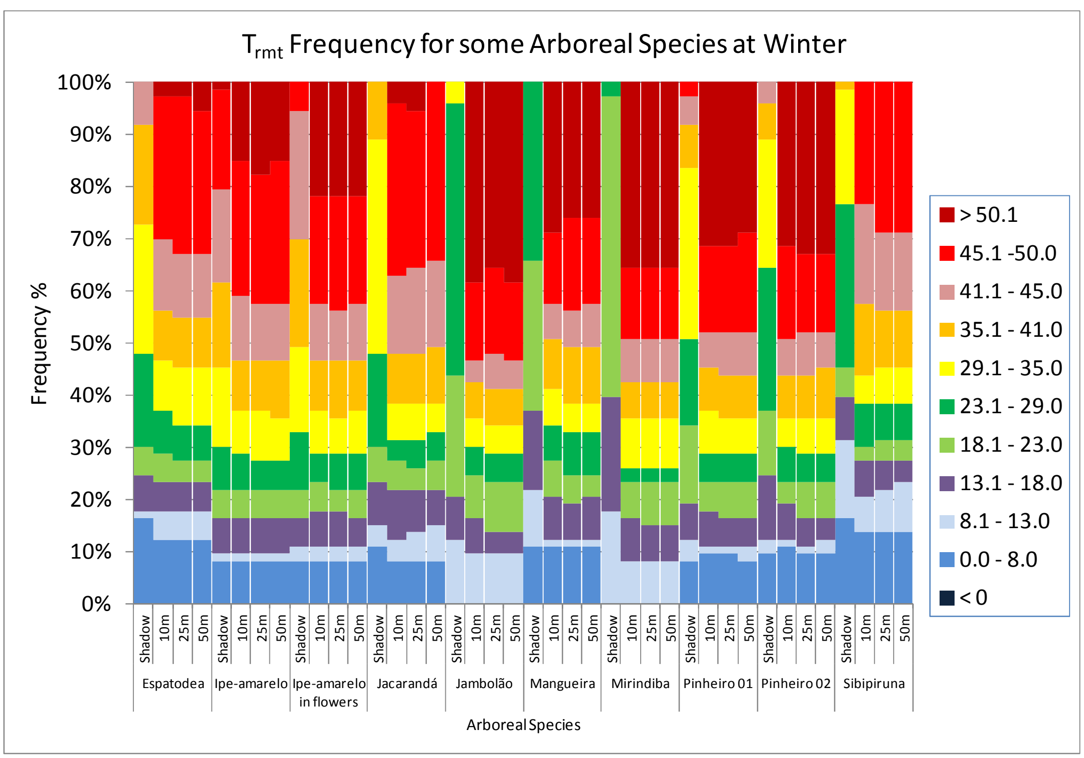


Fig 58. *Results of Mean Temperature Radiant frequencies by different species in winter*

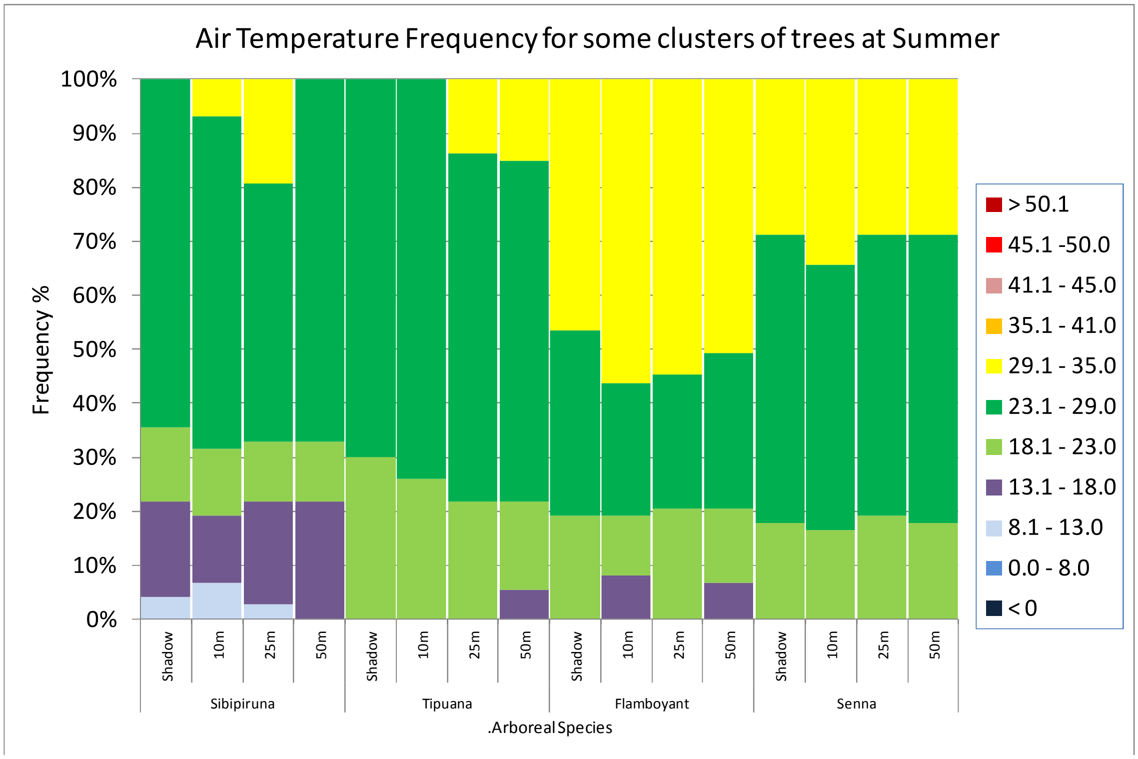


Fig 59. *Results of Air Temperature frequencies by different species in summer*

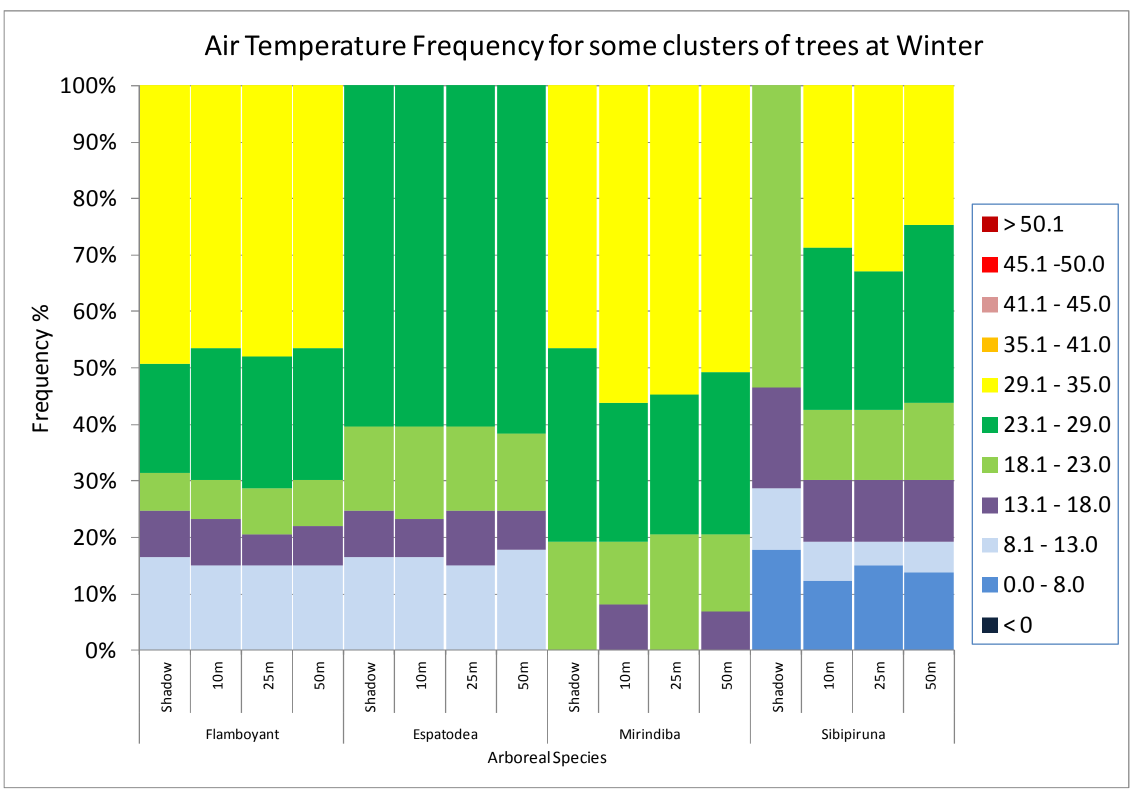


Fig 60. *Results of Air Temperature frequencies by different species in winter*

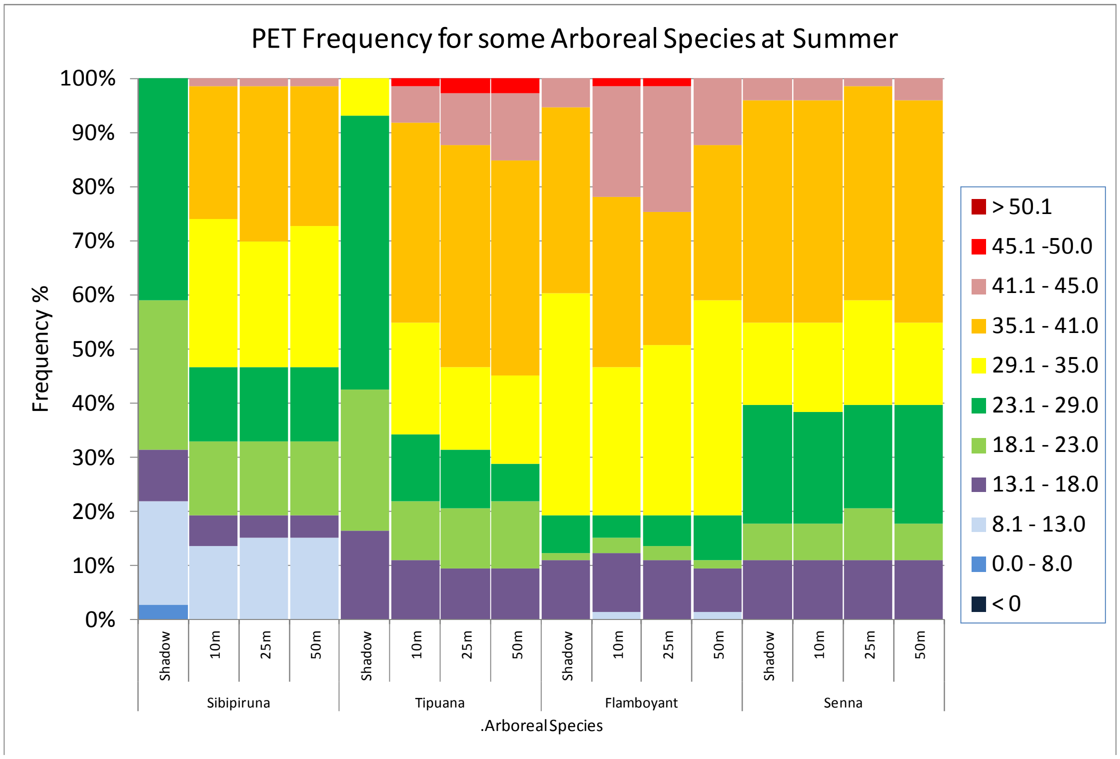


Fig 61. *Results of PET frequencies by different species in summer*

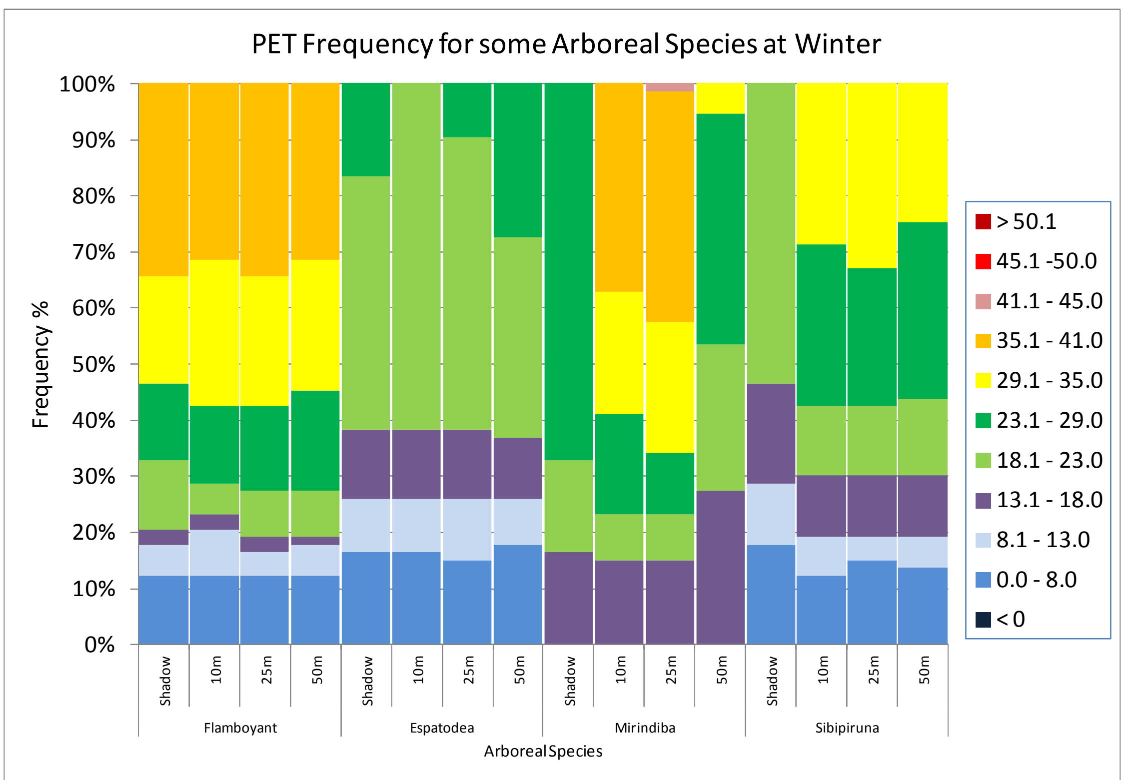


Fig 62. *Results of PET frequencies by different species in winter*

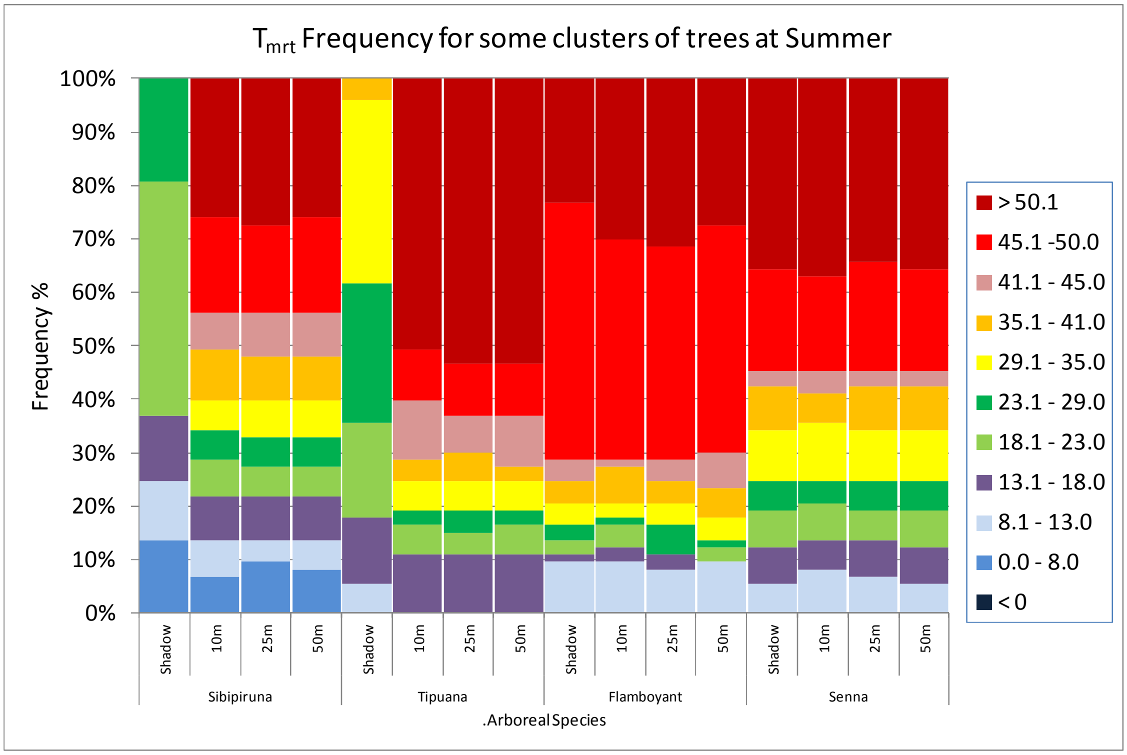


Fig 63. *Results of Mean Temperature Radiant frequencies by different species in summer*

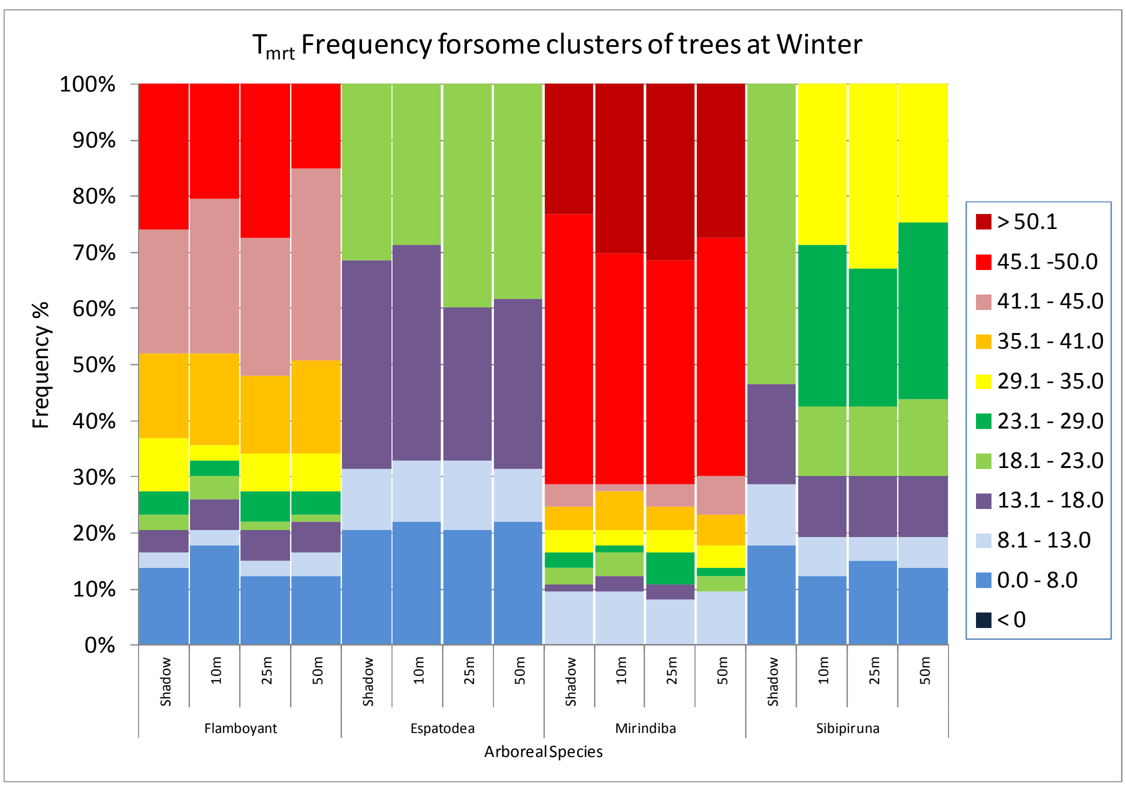


Fig 64. *Results of Mean Temperature Radiant frequencies by different species in winter*

Fig 65. and 66. summarize the PET results for shade from 6:00 to 18:00 in both seasons, summer and winter, respectively. In the summer, some species such as Jambolão (*Syzygium cumini* L.), Mangueira *(Mangifera indica* L.), Sibipiruna (*Caesalpinia pluviosa F.*) and Tipuana (*Tipuana tipu*) present temperatures up to 29ºC during the day and mitigate the temperatures in the early of morning and in the end of afternoon (Fig 65.). In winter, Jacarandá mimoso *(Jacaranda mimosaefolia* D. Don.), Jambolão (*Syzygium cumini* L.), Mangueira *(Mangifera indica* L.) – isolated trees - , Mirindiba Bagre (*Lafoensia glyptocarpa* L.), Sibipiruna (*Caesalpinia pluviosa F.*), Espatódea *(Spathodea campanulata)*, Tipuana (*Tipuana tipu)* – isolated and clusters of trees - present temperatures up to 29ºC during the day (Fig 66.).

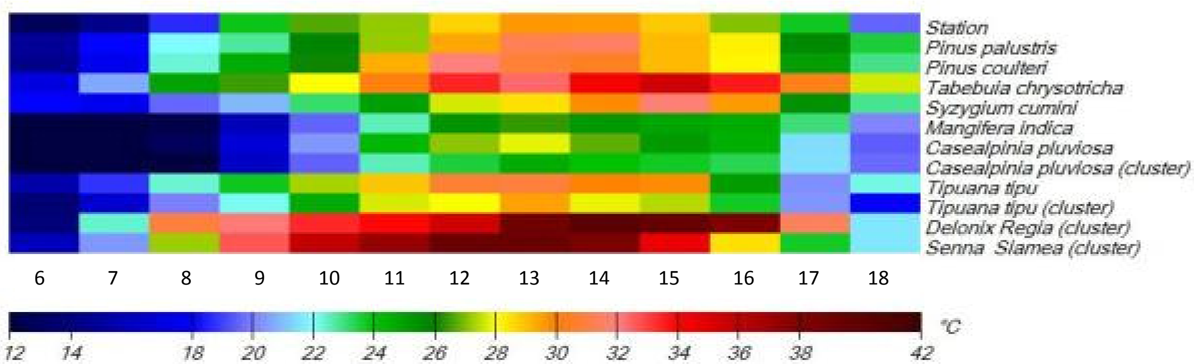


Fig 65. *Results of Physiologically Equivalent Temperature (PET) for shade provided by isolated and clusters of trees in the summer period*

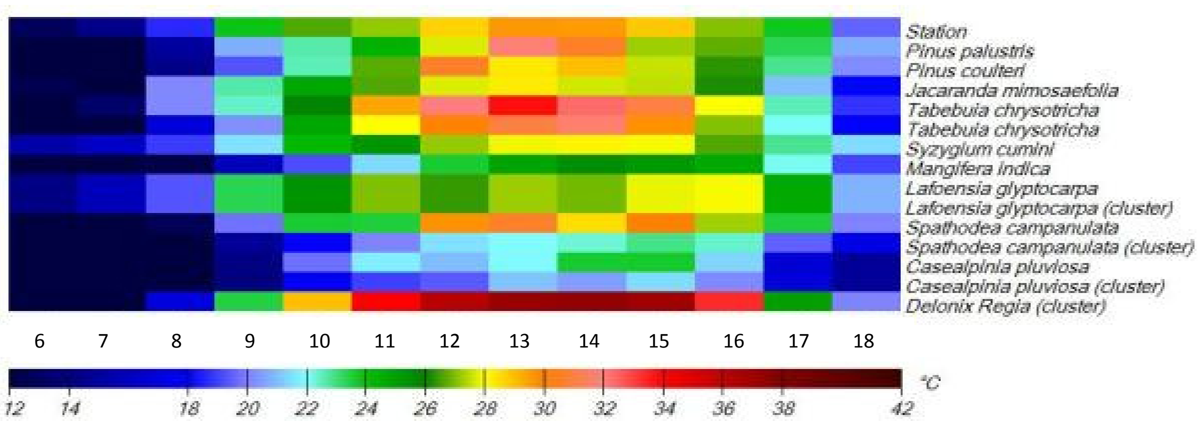


Fig 66. *Results of Physiologically Equivalent Temperature (PET) for shade provided by isolated and clusters of trees in the winter period*

Fig 67. and 68. summarize the T_{mrt} results for shade from 6:00 to 18:00 in both seasons, summer and winter, respectively. All species analysed can improve temperatures. The cluster of Sibipiruna (*Caesalpinia pluviosa F.*) specie presents the best behavior in attenuation of T_{mrt} during both seasons.

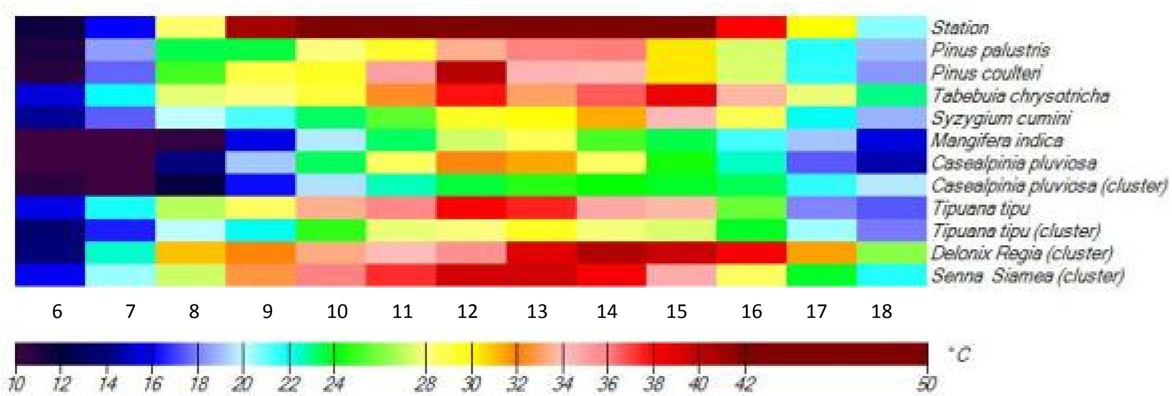


Fig 67. *Results of Mean Radiant Temperature (T_{mrt}) for shade provided by isolated and clusters of trees in the summer period*

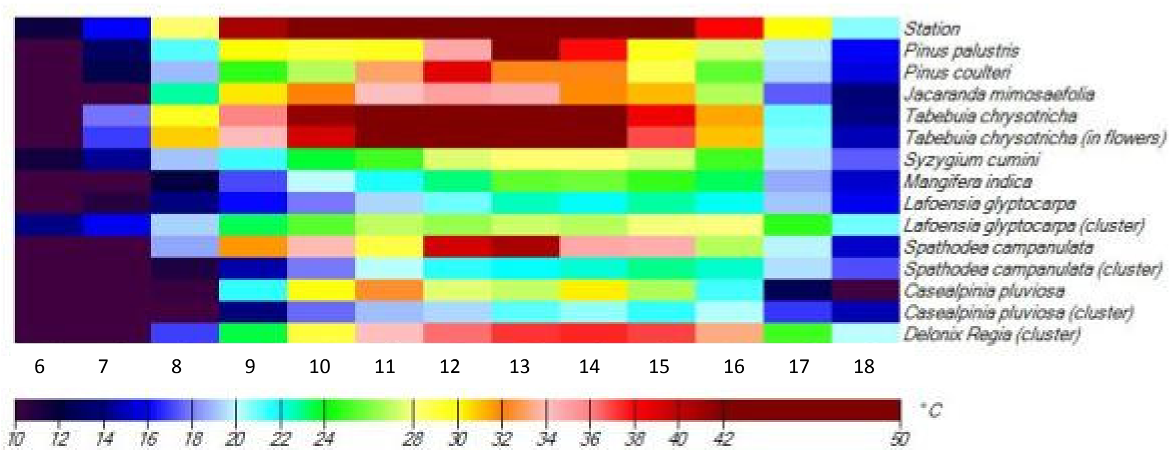


Fig 68. *Results of Mean Radiant Temperature (T_{mrt}) for shade provide by isolated and clusters of trees in the winter period*

5.3 Third Part : simulation of the tree's contribution on microclimates

Simulation of trees' features

Based on features of analyzed trees such as tree height, crown radius, trunk length and trunk diameter and their outdoor dispositions on outside, the tridimensional models was made. The meteorological data for the period of 2003-2010 was use to quantify the contributions of trees' shade on built-up spaces in terms of Equivalent Temperature (PET) (°C), figure 69.

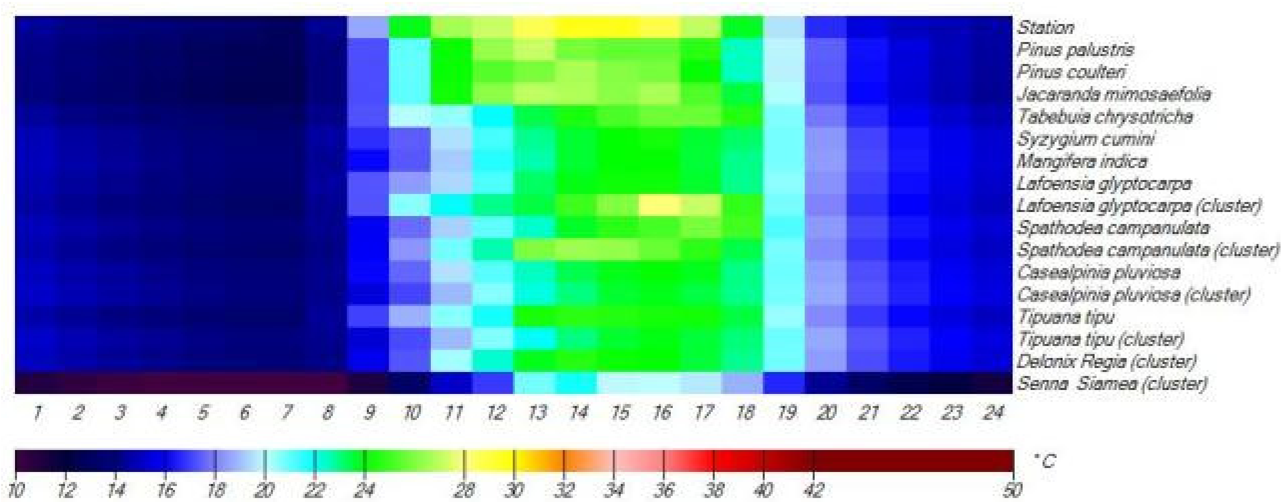


Fig 69. *Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for different species arboreal and dispositions (single trees or clusters of trees)*

From this figure, the influence of trees on urban microclimate changes can be observe. The cluster of trees can mitigate more temperatures than single trees. The trees' size and the canopies' homogeneity are species' features that may influence the improvement of thermal environment. The behavior of the single tree Sibipiruna (*Caesalpinia pluviosa F.*) behavior is better than others.

Simulation of vegetated street canyons

The Multi-Criteria Analysis was used to classify the influence of trees' features on thermal comfort. The characteristics of species analyzed were divided into three subgroups, crown, trunk and leaves, and each feature was assessed according to its importance criteria, figure 45.

The criteria of analysis are described on figure 70. The results of this anlysis comprising in four classes: High performance when its punctuation is above 65, very good performance, between 55 and 65, good performance, between 45 and 55, and regular below 45. Results show that Sibipiruna (*Caesalpinia pluviosa F.*) and Tipuana *(Tipuana tipu*) have high performance, Jambolão (*Syzygium cumini* L.) and Mangueira *(Mangifera indica* L.), very good performance, Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.), Jacarandá mimoso *(Jacaranda mimosaefolia* D. Don.), *Spathodea campanulata,* Mirindiba Bagre (*Lafoensia glyptocarpa* L.), good performance*, and* Pinheiro (*Pinus palustris* L.) and Pinheiro (*Pinus coulteri* L.), regular performance. By comparing both results we can conclude that the Sibipiruna (*Caesalpinia pluviosa F.*) (single) behavior is better than others during daily hours and also its higher performance in MCA.

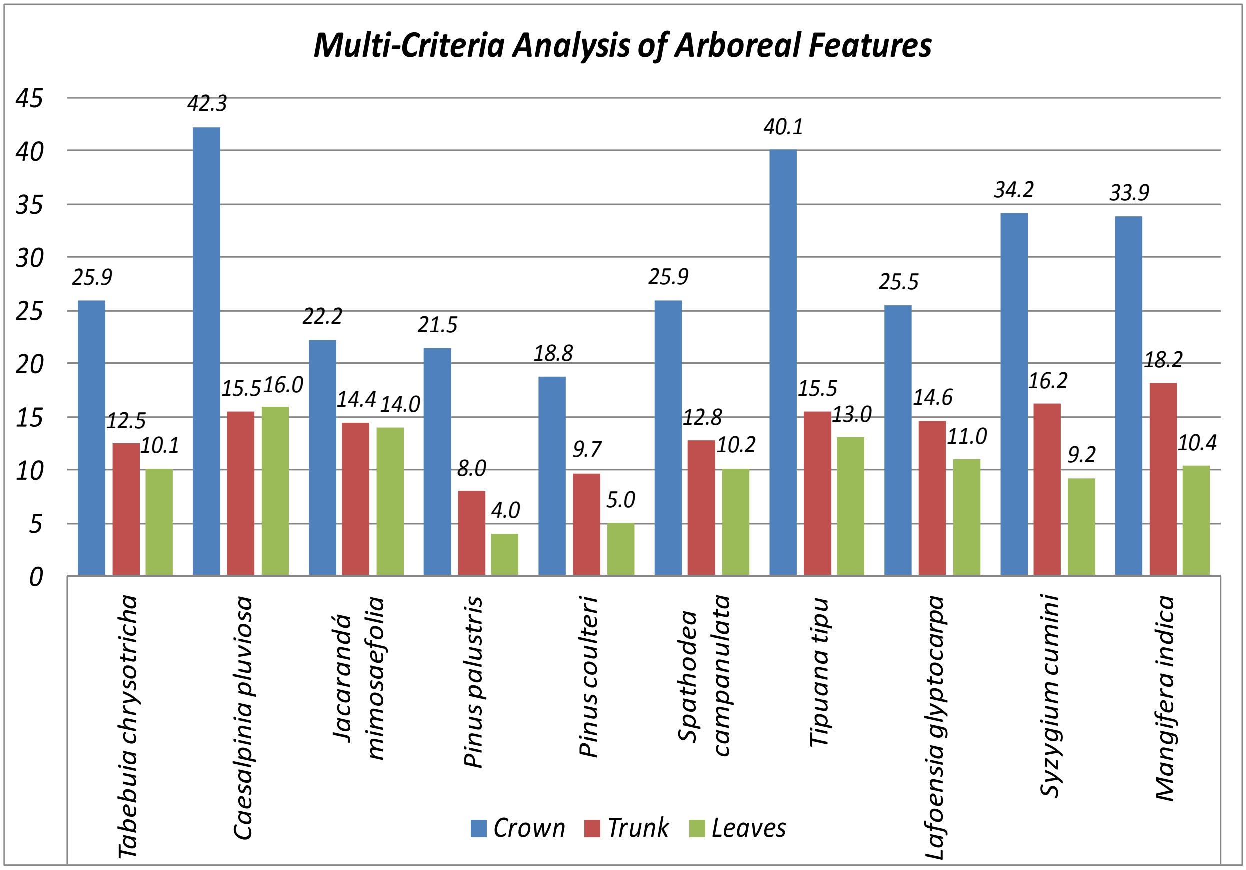


Fig. 70. *Results of Multicriterial analysis of tree subgroups: crown, trunk and leaves*

Four cases of Tree and urban geometry were analyzed: without trees, Sibipiruna (*Caesalpinia pluviosa F.*), Tipuana (*Tipuana tipu*), Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.) *and* Mirindiba Bagre (*Lafoensia glyptocarpa* L.). Fig 71. and 72. show the diurnal courses of the PET of idealized vegetated canyon in Campinas in north-south and east-west orientation, respectively. The height of the canyon in this case is 9 m and the width varies from 15 to 40 m. In addition, PET at urban climate station of Campinas is included.

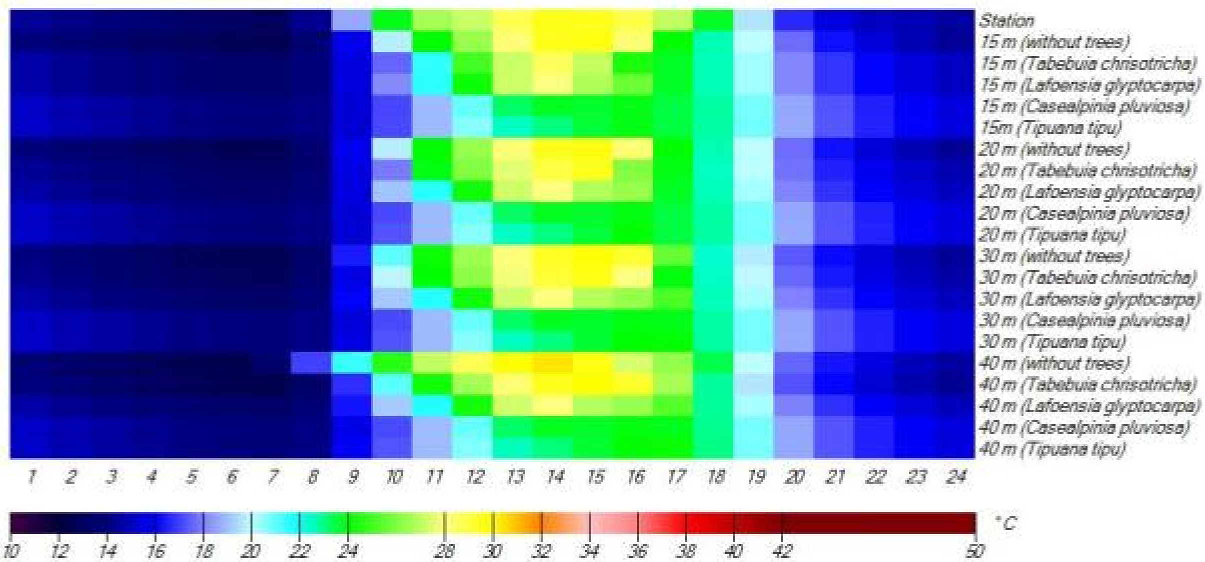


Fig. 71. *Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for an urban canyon with north-south orientation, 9m, height and variable width (15-40 m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.*

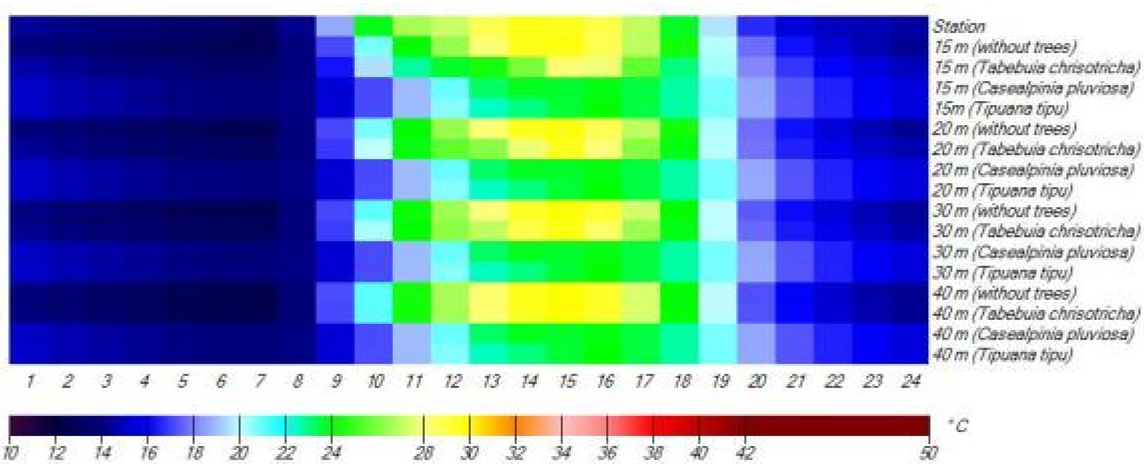


Fig. 72. *Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for an urban canyon with east-west orientation, 9m, height and variable width (15-40 m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.*

Fig 73 and 74 show the diurnal courses of the PET of idealized vegetated canyon in Campinas in north-south and east-west orientation, respectively. The height of the canyon in this case is 21 m and the width varies from 15 to 40 m. In addition, PET at urban climate station of Campinas is included.

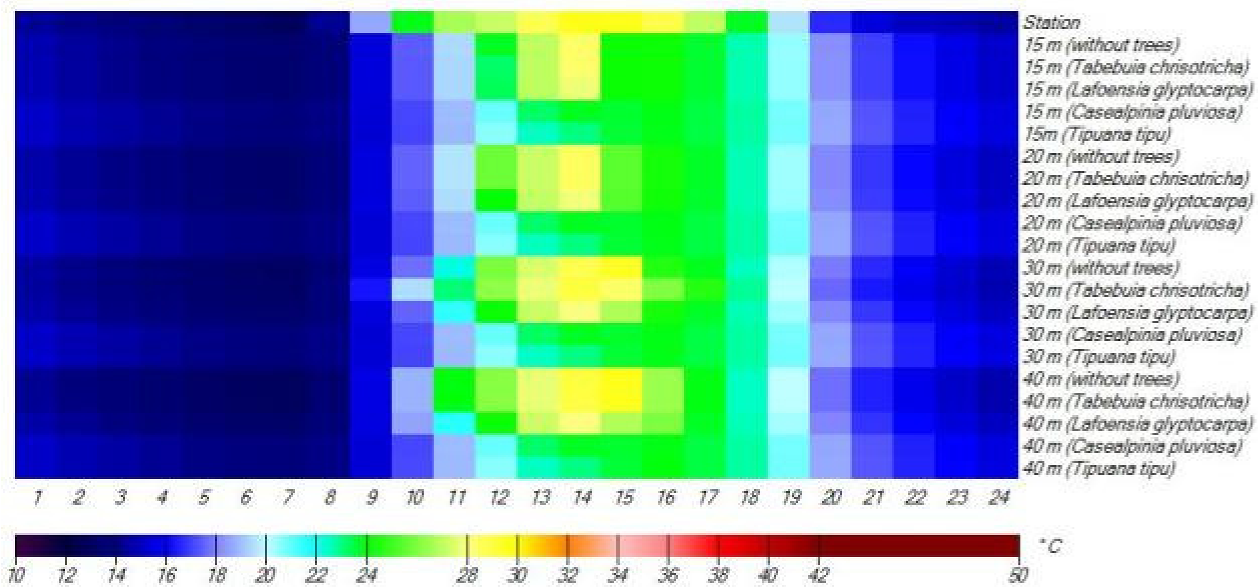


Fig. 73. *Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for an urban canyon with north-south orientation, 21 m, height and variable width (15-40 m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.*

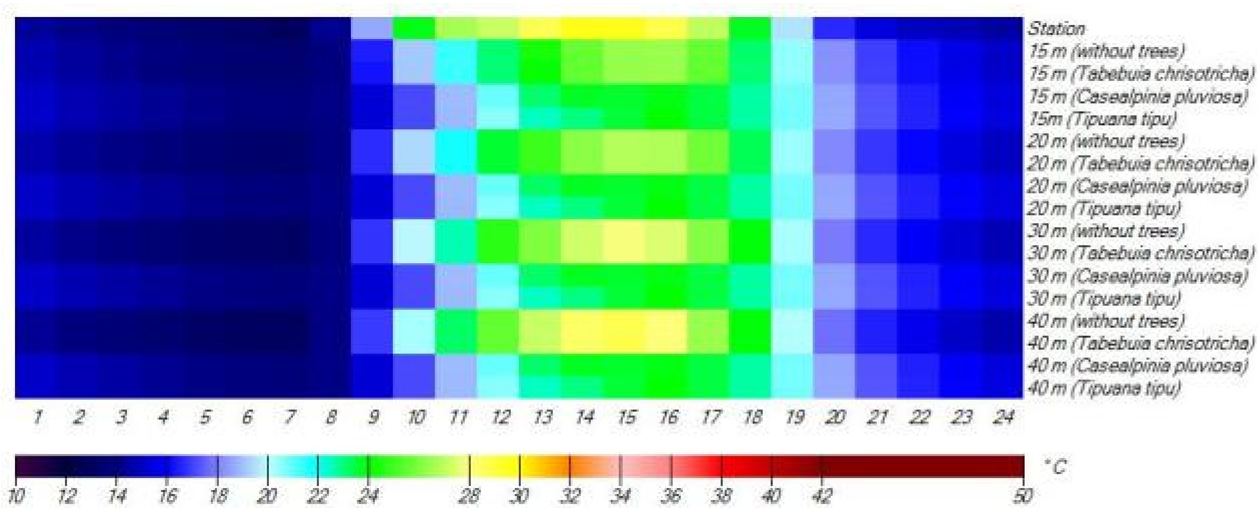


Fig. 74. *Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for an urban canyon with east-west orientation, 21m, height and variable width (15-40 m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.*

Fig 75. and 76. show the diurnal courses of the PET of idealized vegetated canyon in Campinas in north-south and east-west orientation, respectively. The height of the canyon in this case is 44 m and the width varies from 15 to 40 m. In addition, PET at urban climate station of Campinas is included.

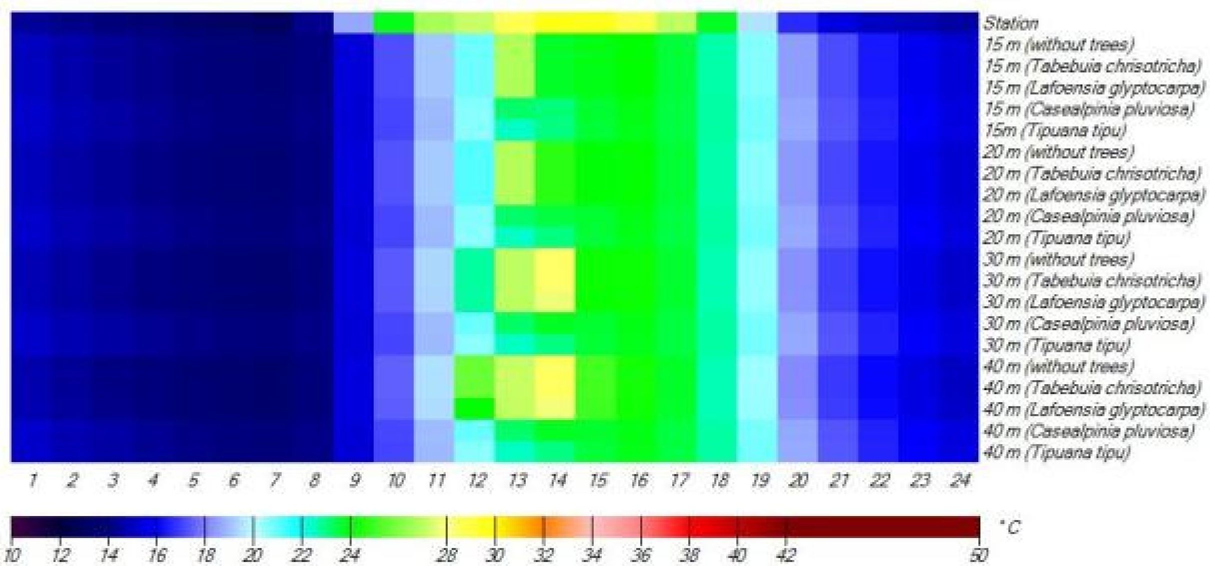


Fig 75. *Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for an urban canyon with north-south orientation, 44m, height and variable width (15-40 m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.*

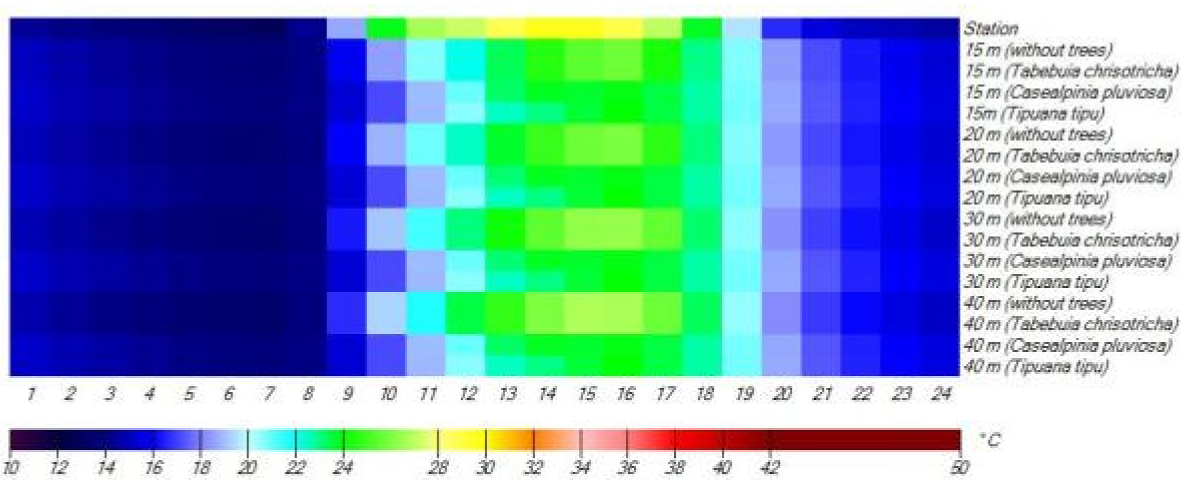
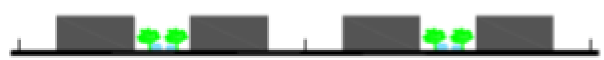
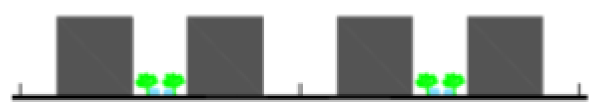
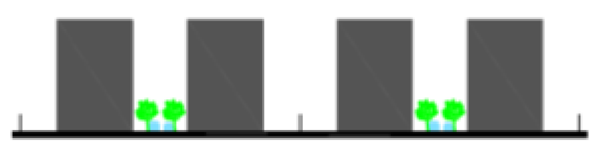
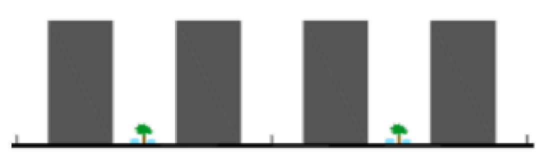


Fig 76. *Diurnal courses of Physiologically Equivalent Temperature (PET) (°C) for an urban canyon with east-west orientation, 44m, height and variable width (15-40 m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.*

This analysis shows that trees shading mitigate effects on thermal comfort in daily hours. In all cases, Sibipiruna (*Caesalpinia pluviosa F.*), Tipuana (*Tipuana tipu*)presented more cooling effects than others species during the day. The potential cooling effect of the tree was found to depend mostly on its canopy coverage level and planting density in the urban street, and little on other species characteristics. The orientation of the streets need to be considered. Based on simulations' results, the urban guidelines and forestry for Campinas was reached in table 12. This results suggest that height-width ratio until 1 need shade trees for improving thermal comfort and adapting the urban climate changes.

Table 12 - **Urban climate guidelines for Campinas based on thermal bioclimate**

H/W	**URBAN GUIDELINES**	**SIDE VIEW**
< 0.5	The management of forestry of Sibipiruna (*Caesalpinia pluviosa*) and Tipuana (*Tipuana tipu*) in all orientation.	
0.5 to 1.0	The management of forestry of Sibipiruna (*Caesalpinia pluviosa*) and Tipuana (*Tipuana tipu*) in all orientations and Mirindiba bagre (*Lafoensia glyptocarpa)* in north-south.	
1.0 to 1.5	The management of forestry of Sibipiruna (*Caesalpinia pluviosa*) and Tipuana (*Tipuana tipu*)in all orientations and Mirindiba bagre (*Lafoensia glyptocarpa)* and Ipê Amarelo (*Tabebuia chrysotricha)* in north-south orientation.	
1.5 to 2.0	The management of forestry in all orientation.	
>2.0	The buildings shading during the day.	

Chapter 6 - DISCUSSION

6.1 First Part: Background analysis of urban climate and bioclimate conditions of Campinas

6.1.1 Campinas bioclimate changes

The simulations performed in this study show that thermal bioclimate conditions can be affected by modifications of solar radiation and wind speed. It was observed that above 25°, 30°, 35° and 40°C thresholds, if the wind speed increases, the PET reduces in situations analyzed and if the wind speed decreases, the PET increases. In shade situation, if T_{mrt} is equal to T_{ar}, the PET will increase in situations above 25 and 30°C, and it will be less than PET in situations above 35 and 40 °C.

When comparing frequencies of air temperature, PET and T_{mrt}, it was observed that frequencies of air temperature provide an indicator of external thermal environment. However, the frequencies of PET reveal more information about thermal conditions as 20% of /PET temperature frequencies above 30ºC in daily hours during the year. The results of air temperature show that summer period is more thermal comfort than the winter. Considering PET for thermal bioclimate analysis, the results show the winter period as more thermal comfort than summer.

Other studies applied only air temperature as indicator of thermal comfort on tropical cities (SOBRAL, 2005). Our results show a different pattern by using PET instead of air temperature. Although the summer in Campinas region is mostly rainy and cloudy, this is not enough to make it thermal comfortable because there are high air temperatures during this period. This can be further explained by the energy balance of human body (HÖPPE, 1993) since it is used to deduce the thermal indices and describing the effects of thermal environment on humans (MAYER, 1993; VDI, 1998). The variation of air temperature, relative humidity, wind speed and solar radiation can modify the results and should be considered.

Nevertheless, it becomes evident that the solar radiation contributes to the high PET during the year. Several studies (VDI 1998; Matzarakis et al. 2007, 2010; Shashua-Bar et al. 2006) have indicated that during an extreme situation i.e. heat waves or very hot conditions the biggest influence can occur because of the radiation field and the wind conditions. Our findings confirm the results observed by Lin et al. (2010).

The present study shows the simulation of variation of wind speed and shade conditions of Campinas, Brazil, where the shade can improve thermal comfort in above 35 ºC and the wind speed increase, in above 25 ºC. The people in Tropical regions prefer to stay in shade during hot day hours. The relation between the number of people and the thermal environment demonstrated that the number of people using a space increases as air temperature increases (or other thermal environment indices increase) in public spaces in temperate regions (ELIASSON et al., 2007; NICOLOPOULOU et al., 2001; THORSSON et al., 2004; THORSSON et al., 2007). On the contrary, studies in hot-humid regions indicate that during the cool season, the number of people visiting the square increases as the thermal index value rises. However, the number of people who frequently visited the square decreased as the thermal index increased in the hot season (LIN, 2009).

The management of forestry and green areas promotes shade on pedestrian areas and facades and it can modify microclimate in tropical cities as Campinas, Brazil. There are planned neighborhoods with tree-lined streets and green areas and at the same time, housing clusters in poor conditions. The urban configuration of "favelas" hampers the trees plantation for shading façades and prevents the permeability of the wind around the buildings and inside (SOBRAL, 2005). The expansion of streets in cities and modifications on geometries of buildings and fragmented urban areas can reduce the green areas (LABAKI; KOWALTOWSKI, 1998) and thus reducing the thermal comfort.

These results suggest that urban and architectural planning in tropical climates, as Campinas, Brazil, must be developed considering thermal bioclimate. The typical urban configuration of Brazilian cities is in mesh form with long lots where buildings occupy all lot limits and also the narrow streets and avenues draw without regard in the direction of the wind (LABAKI; KOWALTOWSKI, 1998). Building with specific width and high height can modify urban climate, mainly radiation fluxes and wind speed and directions (HERRMANN; MATZARAKIS, 2012). These setups reduce the wind speed and make it difficult for air permeability in the inner cities, squares and inside. And also the materials used in facades and roof of buildings and the pavement of urban ground can influence in heat gains (OKE, 1984; MATZARAKIS, 2001).

6.1.2 Urban Street Canyons

The combined effect of height, width and orientation on street canyons modify the PET and T_{mrt}, where the day hour condition are reduced and the night hours temperatures became warmer than urban station. Our findings confirm the results of other researches (NAKAMURA; OKE, 1988; SANTAMOURIS et al., 1999; HERRMANN; MATZARAKIS, 2012; ALI-TOUDERT; MAYER, 2005; MILLS, 1993).

The global radiation at each specific location and geographical latitude are affected by the street orientations and height-width that observed on daytime periods. When the height-width is more than 2, the constructions shade the façades and sidewalk and the conditions are cooler than conditions of urban station. When the height-width is low than 0.5, the buildings cannot shade the sidewalk, influencing the global radiation on surfaces.

By comparing our results with Herrmann and Matzarakis (2012), the east-west orientation have the capacity to reduce the extremely conditions in both locations. While the height-width ratio until 1.0 became the temperatures higher than urban station of Freiburg, this ratio became the temperatures lower than urban station of Campinas. The heat conditions provided by urban configurations is important strategies to control mild climate cities such as Freiburg, as well as the shading of urban surfaces can be use for cooling and controlling thermal comfort in Tropical cities such as Campinas.

To developing urban guidelines based on thermal comfort, not only street canyons simulation are required, but also the local climate need to be described. The identification of climate requisites for thermal comfort in outdoor and indoor spaces helps architects and urban planners on the correct use of the urban obstacle**.**

6.2 Second Part: Assessment of the influence on microclimate

6.2.1 Attenuation of Solar Radiation by certain trees

One of the main causes of the air temperature increase and of the energy consumption, as well as the change of the people's behaviors, is the lack of appropriate landscape treatments around a building. To qualify and quantify the influence of trees on thermal comfort becomes meaningful for control of the incident solar radiation and regulator of the urban climatic changes.

In this work, it was observed trees influences in microclimate by three different method: Plant Area Index (PAI) and Solar Radiation Attenuation (SRA). This results suggest this parameters must be consider together in vegetations studies due to the solar radiation absorption by trees .

To compare ours and Bueno-Bartholomei (2003) findings of SRA , the trees' features as structure and density of the treetop, size, shape and color of the leaves, tree age and stage of growth must be considered (Table 13).

Table 13 – Solar Radiation Attenuated by certain species and different sites configurations

Species	Our findings		Bueno-Bartholomei (2003)	
	Summer (%)	Winter (%)	Summer (%)	Winter (%)
Ipê Amarelo (*Tabebuia Chrysotricha)* - isolated tree	82,8	46,4	75,6	--
Jambolão (*Syzygium cumini*) - isolated tree	87,2	89,1	92,8	--
Sibipiruna (*Caesalpinia pluviosa*)- isolated tree	83,9	69,5	88,5	--

Bueno-Bartholomei (2003) suggest the importance of structure and density of trees as well as the leaves' shape in while the small leaves of Sibipiruna (*Caesalpinia pluviosa F.*) may provide more thermal comfort than others.

This research suggests that trunk structure characterization as orthotropic and plagiotropic can influences as well. Most of the trees analyzed in both studied with plagiotropic trunk had SRA results around 80 %, table 10. Besides, it was detected the small differences, around 4 %, among two species. Jambolão (*Syzygium cumini* L.) and Sibipiruna (*Caesalpinia pluviosa F.*) for SRA results, table 8. Most of these differences are considered insignificantly and can be explained by changes in the canopy due to drastic pruning. It is emphasized that canopy pruning can significantly alter the capacity of solar radiantion attenuated by trees and consequently, the thermal comfort. However, all species' features that can modify the canopy uniformity may observed when the Plant Area Index (HOLST et al., 2004) are calculated.

From the collected data for isolated trees, it was observed that the maximum air temperature difference is 0.9^{o} C while the maximum PET differences are 7.3^{o} C in the summer and 5.5 ^{o} C in the winter. For clusters of trees, the maximum air temperature difference is 0.7^{o} C while the maximum PET differences are 4.7^{o} C in the summer and 3.1^{o} C in the winter. This results suggest the influences the vegetation on microclimate.

In general, the studies about vegetation influeces (TSUTSUMI et al., 2003) enphasize the importance of characteriscs of Green Canopy and Leaves Area Index (LAI). In this study, the results of correlation between Green Canopy Ratio (GC) and Plant Area Index (PAI) suggest that not only plant's structures but also ground covering plants may modify the microclimate and thermal comfort.

6.2.2 Distance of influence on microclimate by certain arboreal species

The trees plantings is a important strategy of the climate changes control in tropical cities due to shade and thermoregulation work (LIN et al., 2010). Different tree species behave in different ways in urban microclimate and this features can be effectively used to improve the thermal comfort indoor and outdoor spaces (SCUDO, 2002; BUENO-BARTHOLOMEI; LABAKI, 2003).

In this work, it was evaluated the scale of influence provide by certain arboreal species in urban microclimate through the measurements of environmental parameters "in loco" and comparison of Physiologically Equivalent Temperature (PET) and Mean Radiant Temperature (T_{mrt}) provided by them. The results show that trees improve thermal comfort, not only in the shade but in surrounds. Recently, studies of vegetation influences in urban microclimate have been focused in mitigation of air temperatures (TSUTSUMI et al., 2003; MORENO; LABAKI, 2008; FALCON, 2007) intead of Physiologically Equivalent Temperature (PET) and Mean Radiant Temperature (T_{mrt}). Ours findings suggest tha vegetation can improve not only air temperatures bur also in terms of PET and T_{mrt}.

The isolated tree such as Jambolão (*Syzygium cumini* L.), Mangueira *(Mangifera indica* L.), Sibipiruna (*Caesalpinia pluviosa F.*) presents the best and similar results at shadow in both seasons. These trees have the same specie's features such as density, trunk structure and crown shape. Other characteristics such as structure and density of the treetop, size, shape and color of leaves, tree age and growth, can also influence performance of solar radiation attenuation, air temperature and air humidity as well.

The clusters of analyzed trees improve thermal comfort not only in the shade, but also in different distances, except the species Flamboyant (*Delonix indica*) and Chuva de ouro (*Senna siamea*). This species have plagiotropic trunk and low density of crown. In terms of T_{mrt}, the clusters of trees have the best results. This results suggest that the combination of tree's features with planting strategy is the best solution for upgrading thermal comfort provide by vegetation.

Table 14 - Recommendation for planting trees

SPECIES	RECOMMENDATIONS
Ipê Amarelo *Tabebuia chrysotricha*	Native tree for specimen, mass planting and street tree. Management in the center divider of streets with wide tree lawn, sidewalks and backyards Deciduous tree and tolerant of urban sites.
Jacarandá mimoso *Jacaranda mimosaefolia*	Native tree for specimen and street tree. Provide light shade. Management in the center divider of streets with wide tree lawn, sidewalks and backyards. Tolerant of urban sites.
Jambolão *Syzygium cumini*	Specimen tree for street or shade tree. needs wide tree lawn to avoid sidewalk damage. Management in residential street and backyards
Mangueira *Mangifera indica*	Good shade tree. needs wide tree lawn to avoid sidewalk damage. Management in backyards
Pinheiro *Pinus palustris*	Specimen tree not recommended for street or shade. Frequently used in mass planting or woods.
Pinheiro *Pinus coulteri*	Specimen tree not recommended for street or shade. Frequently used in mass planting or woods.
Mirindiba bagre *Lafoensia glyptocarpa*	Small tree suitable for planting as a street tree under utility lines, or as a hedge or specimen planting. Tolerant of urban sites. Management in the center divider of streets with wide tree lawn, sidewalks and backyards
Sibipiruna *Caesalpinia pluviosa*	Native tree for street or shade tree. Needs wide tree lawn to avoid sidewalk damage. Provide light shade. Management in the center divider of streets with wide tree lawn, sidewalks and backyards
Espatódea *Spathodea campanulata*	Specimen tree for street or shade tree. Needs wide tree lawn to avoid sidewalk damage. Management in the center divider of streets with wide tree lawn, sidewalks and backyards
Tipuana *Tipuana tipu*	Specimen tree for Street or shade tree. Needs large tree lawn to avoid sidewalk damage. Provide light shade. Management in the center divider of streets with large tree lawn , parks. Suitable for street tree where large tree lawns exist.
Flamboyant *Delonix indica*	Specimen tree for large sites, parks. Provide light shade. Suitable for street tree where large tree lawns exist.
Chuva de ouro *Senna siamea*	Street or shade tree. Provide light shade. Needs wide tree lawn to avoid sidewalk damage.

Tropical Cities as Campinas, Brazil, should use trees to control thermal comfort. The solar radiation intercepted by tree crowns provides natural protection of outdoor spaces, mitigating temperatures and reducing energy spent on cooling indoor spaces. For outdoor spaces, the urban forestry is able to controlling and improving thermal comfort, mitigated air temperature and controlling relative humidity, consequently, it provides pleasure sensations. And indoor spaces, the shadows can reduce the solar radiation influence in facades, accordingly, it can improve the thermal comfort, save energy spend in cooling and keep the environment healthy. 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. Based on this result, we suggest tree planting of street for shading sidewalks and in backyards for shading the buildings, table14.

6.3 Third Part : simulation of the tree's contribution on microclimates

The study analyzed the microclimate work and its significance in urban planning through two components that dominantly affect the city's microclimate – built-up density and urban shade trees. Both elements are multivariate in nature, hence, regularity is sought throughout the analysis in order to enable the designer to draw general conclusions and guidelines. The trees planning strategies associated with urban configuration are important to data for urban design based on thermal comfort strategies.

The thermal bioclimatic conditions can be modified by different trees in urban canyons in Tropical cities. The effect of vegetated street canyons on the thermal index physiologically equivalent temperature (PET) based on over seven years of measurements at the urban climate station in Campinas, Brazil can be quantified by application of the RayMan model (MATZARAKIS et al., 2007; 2010). Ours findings confirms the results of Shashua-Bar et al. (2010) and Lindberg et al. (2010).

The plant area index (PAI) of the canopies suggest that they can identify the homogeneity of canopies, while having a significant influence on the microclimate. The canopies features depend on the width type, height, age, season and disposition (PEIXOTO et al., 1995; BROWN; GILLESPIE, 1995; FALCON, 2007). For an efficient thermoregulation work, the dispositions of clusters may provide their shade's homogeneity. Ours findings confirm the results of Dacanal and Labaki (2011).

CONCLUSÕES

As diferentes espécies apresentam comportamentos distintos no microclima urbano (SCUDO, 2002; BUENO-BARTHOLOMEI, 2003; ABREU, 2008) e o plantio estratégico de árvores no meio urbano é capaz de melhorar o bioclima térmico em cidades tropicais (LIN et al., 2010). A partir da quantificação da contribuição de certas árvores para o bioclima térmico de Campinas, São Paulo, verificou-se a relação entre a melhoria do conforto térmico e as características ligadas às espécies arbóreas – copa, estrutura do tronco e folhas - e sua disposição no ambiente construído.

As simulações e cálculos com base em índices térmico atuais, como o PET, realizados na primeira parte da pesquisa mostram que o sombreamento e aumento da velocidade do vento podem melhorar substancialmente o bioclima térmico em cidades tropicais. Plantar árvores é uma estratégia prática importante para o sombreamento das cidades, onde a radiação solar pode ser interceptada pela copa da árvores, trazendo conforto térmico para lugares abertos e fechados. Para melhor aproveitamento dos ventos, deve-se observar não só a orientação das ruas e edifícios, mas também a relação altura e largura (H/W) entre ruas e edifícios.

A partir de medições de campo, observou-se que as espécies com tronco plagiotrópico e copa grande, tais como Jambolão (*Syzygium cumini* L.), Mangueira *(Mangifera indica* L.), Sibipiruna *(Caesalpinia pluviosa F.) e* Tipuana *(Tipuana tipu* F.), possuem uma maior capacidade de produção de sombra e consequentemente, proporcionam mais conforto térmico. Em relação à disposição das árvores no ambiente natural, verificou-se que os agrupamentos arbóreos, principalmente das espécies Sibipiruna *(Caesalpinia pluviosa F.) e* Tipuana *(Tipuana tipu* F.), intensificaram os seus benefícios térmicos em relação às árvores isoladas. Os agrupamentos arbóreos atenuam a radiação solar cerca de 10% a mais do que árvores isoladas, bem como reduzem o estresse térmico em até 30%.

Todas as árvores analisadas foram capazes de mitigar as temperaturas em relação aos dados da estação, portanto a inserção da vegetação no meio urbano é forma de adaptação às mudanças climáticas decorrentes das alterações do solo urbano. O manejo estratégico das árvores nas cidades deve levar em conta as relações entre as configurações urbanas e a orientação da rua. Em cânions urbanos com relação largura e altura (H/W) até 1, como os bairros residenciais, sugere-se o plantio de árvore com cobertura vegetal mais densa.

Com relação à aplicação desta pesquisa em desenho urbano e arquitetônico, os resultados podem ser utilizados para a adaptação nos espaços das cidades e ao mesmo tempo, tornar o ambiente urbano mais confortável. O planejamento urbano em cidades tropicais deve considerar dados meteorológicos como temperatura do ar, temperatura média radiante (T_{mrt}) e PET, bem como dados coletados em campo. Assim, as diretrizes urbanas podem ser estabelecidas, a fim de melhorar o microclima das cidades e construir novas possibilidades de mitigação de seu aquecimento.

Trabalhos Futuros

Os resultados sugerem desdobramentos da pesquisa como a seguir:

1) Análise do Bioclima Térmico para outras cidades brasileiras;

2) Ensaios de cânions urbanos com árvores em túnel de vento;

3) Calibração de índices térmicos como PET para Campinas, com base em pesquisas de campo e entrevistas;

4) Simulação de diferentes configurações urbanas para Campinas a partir de softwares como Envi-Met, RayMan e SkyHelios.

5) Estudo em campo de cânions urbanos típicos da cidade de Campinas com e sem arborização, bem como definição de zonas climáticas;

6) Avaliação de outras espécies arbóreas não analisadas nessa pesquisa.

RECOMENDAÇÕES

Os principios para diretrizes de desenho urbano baseados na quantificação da contribuição dos benefícios da vegetação no ambiente construído podem ser descritos a seguir:

1. Reconhecer o clima local: classificar suas condições e as modificações do clima urbano, bem como refletir sobre as possibilidades de mitigação do clima local, bem como aplicar os principios de desenho urbano bioblimático para adaptação do clima urbano em novos empreendimentos.

2. Diversificar o ambiente construído: incorporar diversidade de densidades de construção, onde a relação altura e largura (H/W) deve ser usada para controle do microclima.

3. Considerar as características do ambiente construído local: observar o estilo da arquitetura e urbanismo comtemporâneos e o uso dos materiais na construção dos espaços urbanos.

4. Considerar a orientação: o projeto deve respeitar a orientação solar adequada, proporcionando sombra e permitindo a penetração da luz e ventilação natural, ao mesmo tempo que integra o ambiente construido com a natureza (fig. 77)

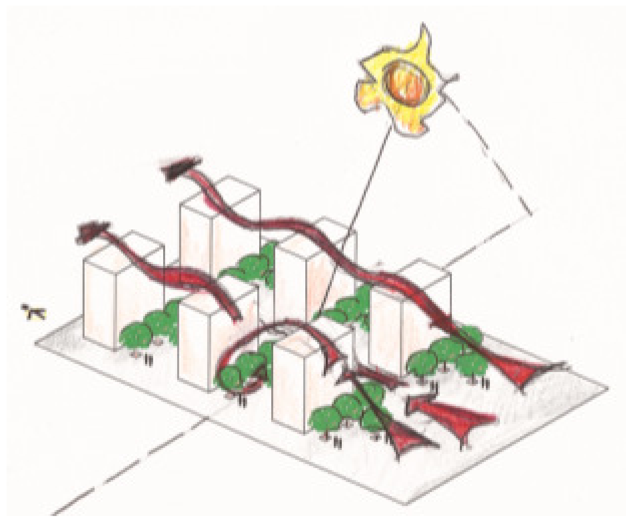


Fig. 77. *Orientação Solar e simulação da vegetação natural*

5. Usar a vegetação nativa para sombreamento de áreas públicas e privadas: é essencial para garantir o equilibrio entre o crescimento urbano e cobertura de árvores, especialmente para criar um espaço psicologicamente tranquilo e desejável. A seguir apresenta-se algumas sugestões para implementação:
   - Desenvolver o paisagismo de forma que o verde seja integrado à paisagem urbana, garantindo o predomínio do verde. Sugere-se o plantio de uma árvore por lote.
   - Promover o manejo da vegetação no bairro, considerando as condições de água no solo urbano, para a melhor adaptação das espécies arbóreas. Por exemplo, espécies como Jambolão *(Syzygium cumini* L.), Mangueira *(Mangifera indica* L.) preferem solos com maior presença de água, ao passo que o Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.) é resistente a grandes períodos de seca.

Fig. 78 . *Ilustração do predomínio do verde nas cidades*

- Plantar de árvores nativas em toda a cidade e, ao mesmo tempo, preservar as árvores pré-existentes (Fig.78);
- Promover a biodiversidade das espécies arbóreas (Fig. 79);
- Minimizar a perda da vegetação, monitorando a saúde das árvores; quando necessário, substituir as árvores existentes;

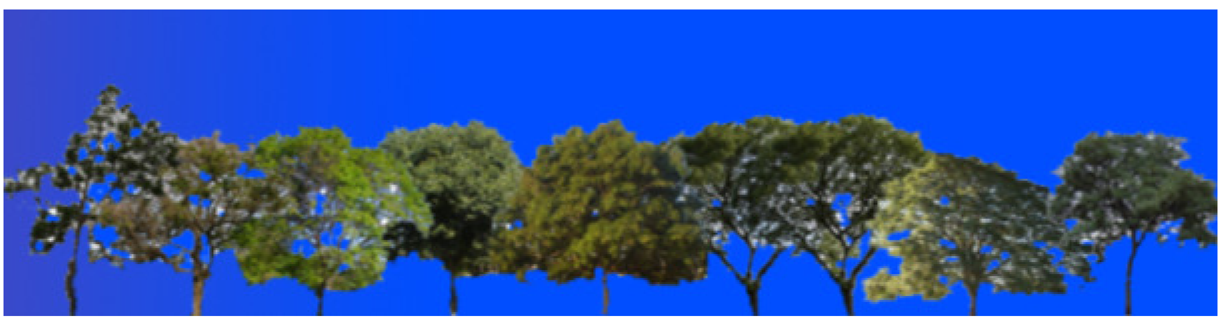
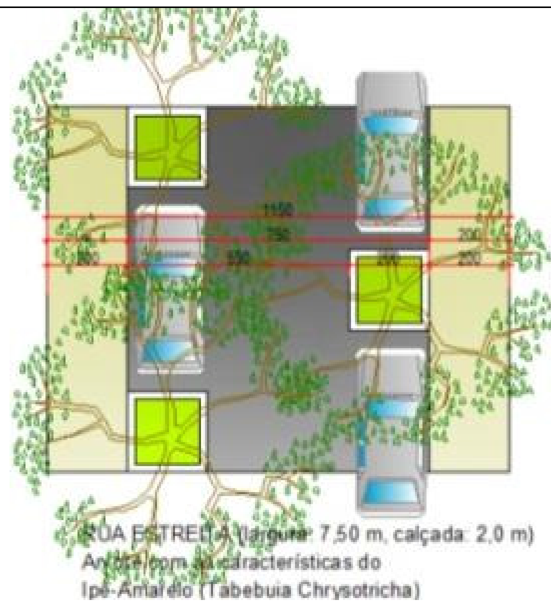


Fig 79 . *Biodiversidade das espécies*

- Incoorporar no projeto de ruas e avenidas o plantio de árvores que proporcionem sombreamento das calçadas e estacionamento de carros. Três sugestões de plantio de árvores em ruas típicas de Campinas, SP são apresentadas no quadro a seguir:

RUA ESTREITA

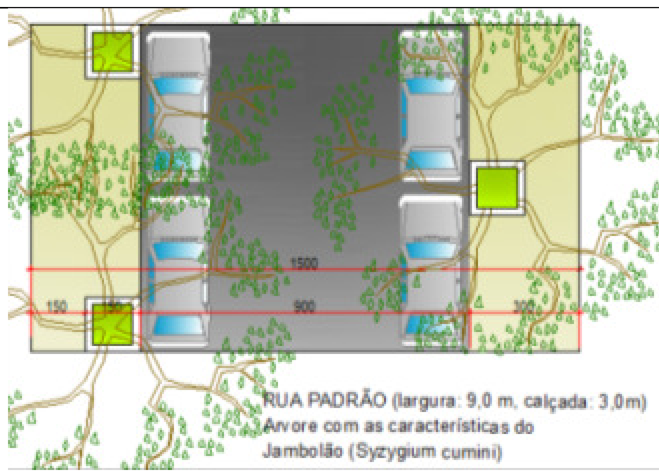
Características	**Recomendações**
Leito carroçável: 7,50m Calçada: 2,00 m	Construção de um canteiro 2,00 x 2,00m dentro do leito carroçável para as árvores sombrearem as calçadas e o estacionamento dos carros, Fig. 78. Sugere-se o plantio de árvores de porte médio, tais como Ipê Amarelo (*Tabebuia chrysotricha* (*Mart.* ex DC.) Stand.), Jacarandá mimoso (*Jacaranda mimosaefolia* D. Don.) e Mirindiba Bagre (*Lafoensia glyptocarpa* L.).

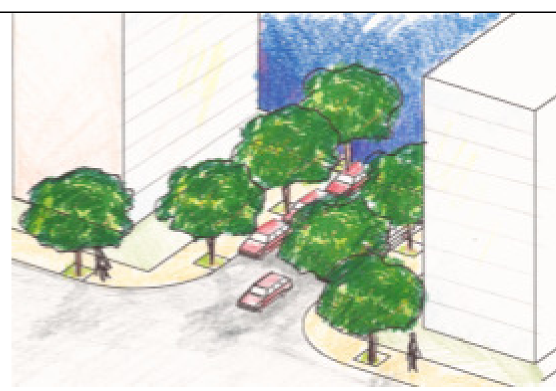


Planta Baixa da Rua

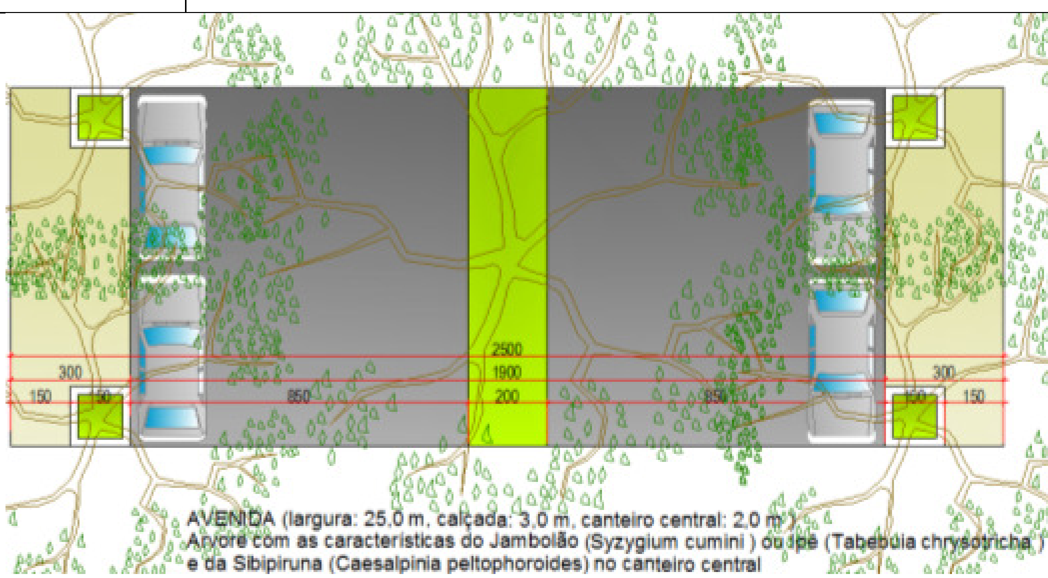
Perfil da Rua

Perspectiva da Rua

<table>
<tr><th colspan="2">RUA COMUM</th></tr>
<tr><th>Características</th><th>Recomendações</th></tr>
<tr><td>Leito carroçável: acima de 9,00 m
Calçada: a partir de 3,00 m</td><td>Construção de um canteiro 2,00 x 2,00m dentro em cima da calçada. Caso a rua comporte estabelecimentos comerciais, ou locais onde haja um grande fluxo de pedestre, sugere a colocação de uma grade, ampliando o caminho de pedestres.
Sugere-se o plantio de árvores, tais como Ipê Amarelo (Tabebuia chrysotricha (Mart. ex DC.) Stand.), Jacarandá mimoso (Jacaranda mimosaefolia D. Don.) e Mirindiba Bagre (Lafoensia glyptocarpa L.), Jambolão (Syzygium cumini L.), Sibipiruna (Caesalpinia pluviosa F.), Espatódea (Spathodea campanulata P.Beauv.).</td></tr>
<tr><td colspan="2">

Planta Baixa da Rua</td></tr>
<tr><td>
Perfil da Rua</td><td>
Perspectiva da rua</td></tr>
</table>

AVENIDA COM CANTEIRO CENTRAL	
Características	**Recomendações**
Leito carroçável: 19,00m Canteiro central: 2,00m Calçada: 2,00 m	Construção de um canteiro 2,00 x 2,00m dentro do leito carroçável para as árvores sombrearem as calçadas e o estacionamento dos carros, Fig. 78. Sugere-se o plantio de árvores de porte médio, tais como nas calçadas e no canteiro central, espécies de porte grande, tais como Sibipiruna *(Caesalpinia pluviosa F.),* Tipuana *(Tipuana tipu* F.).



Planta Baixa da Rua

Perfil da Rua

Perspectiva da rua

- Desenvolver o manejo de espécies de grande porte, como Tipuana (Tipuana tipu) e Sibipiruna (*Caesalpinia pluviosa F.*), em espaços públicos, como praças e canteiros centrais, e privados, como quintais e áreas entre edificios (Fig 80.);

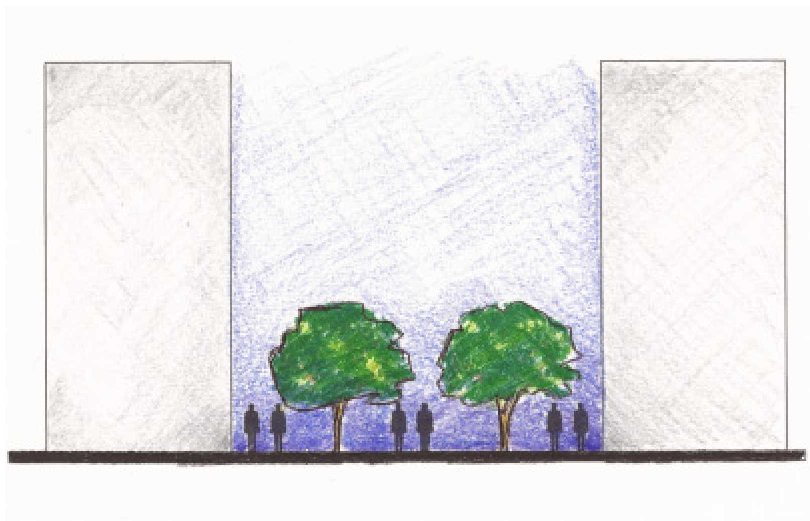


Fig 80. *Inserção da vegetação entre edifícios*

- Assegurar que as arvores permitam a permeabilidade do vento no ambiente construído;

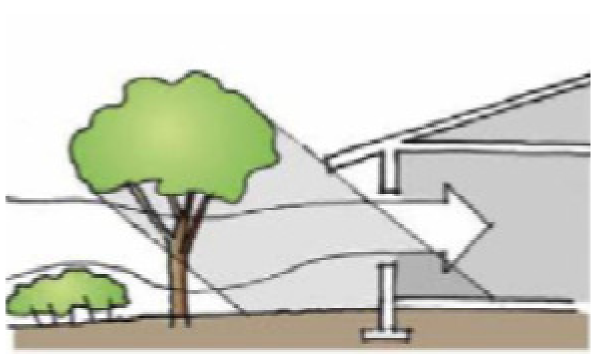


Fig 81. *Árvores permitindo a ventilação natural no ambiente construído (Kennedy; Katoshevski, 2009)*

- Manter uma proporção entre a altura dos edifícios e a vegetação, de forma que as árvores complementem o ambiente construído;

Fig. 82. Proporção entre vegetação e edifícios (Kennedy; Katoshevski, 2009)

- Incluir áreas com vegetação sempre que possível;
- Desenvolver paredes verdes e jardins nos terraços dos prédios em áreas com alta densidade. As superfícies vegetadas ajudam a controlar as trocas térmicas.
- Promover sombra por vegetação ou outras edificações para superfícies como fachadas e piso;
- Desenvolver cobertura arbórea contínua, sempre que possível, nos percursos de pedestres. Árvores grandes como Tipuana (Tipuana tipu) e Sibipiruna (*Caesalpinia pluviosa F.*) podem ser dispostas em linhas de forma a proporcionar uma sombra mais homogênea;
- Melhorar a circulação do vento, através do uso da paisagem, para refriamento do ambiente construído.
- Proporcionar equilíbrio entre as superfícies que absorvem calor, como os materiais utilizados na pavimentação, e áreas ajardinadas, onde a cobertura arbórea pode ser usada para sombrear as áreas pavimentadas.

6. Incorporar a vegetação nos corredores de transporte, como ruas, avenidas, calçadas e ciclovias.

7. Desenvolver áreas ao ar livre para refeições, prática de esportes, recreação, entretenimento, onde os acessos dos pedetres ao transporte público ou particular sejam percursos sombreados.

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