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A. Matzarakis

Influence of different urban configuration on human thermal conditions in a Typical Subtropical Coast City – Case of Santos, São Paulo

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1. Introduction

Urban open areas bring well-being and thermal comfort in both outdoor and indoor environments (Oke 1982; Givoni 1992; Mills 1999), especially in cities with high density construction. Urban design features as direction of streets, height of buildings, width of street, influences directly on thermal comfort and contribute to increase urban heat island (UHI). Quantitative analysis of thermal bioclimate in tropical cities can be used as parameters in architecture and urban planning, because open spaces are able to integrate buildings' envelop and open urban canopy.

Most of thermal comfort and urban heat island (UHI) researches refers only a cases studies and measurements campaigns are not enough to deliver long-term information about special climate conditions in urban areas (Nakamura and Oke 1988; Yoshida et al. 1990). On thermal comfort issues, studies about urban street canyons are able to quantify the effect of the different urban configurations that influenced human thermal conditions to develop an urban guidelines for improvement of urban climate (Abreu-Harbich et al. 2014a). Canyon geometry affects strongly the timing of magnitude of energy regime of the individual canyon surfaces and were very different from each other (Ali-Toudert and Mayer 2007). The orientation of urban canyon surfaces and material's surfaces of facing walls and floor influence the air temperature (Ta) and physiologically equivalent temperature (PET) changes, which is cooler by day and warmer by night. (Nunez and Oke 1977; Mills 1993; Santamouris et al. 1999). Shading enhancements through increased height-to-width (H / W) ratios is clearly capable of significant reductions in PET, and thus, improve outdoor thermal comfort (Lin et al. 2010, Abreu-Harbich et al. 2014a).

Considerely this parameters of urban design and buildings constructions can affect the thermal bioclimatic conditions in urban areas of subtropical cities, the study of different urban configuration using long term data to calculate mean radiant (T_{mrt}) and physiologically equivalent (PET) temperatures helps to develop urban design guidelines to adapt urban climate changes (Abreu-Harbich et al. 2014a; Abreu-Harbich et al., 2014b) This paper aims to quantify the human thermal condition on human thermal conditions at pedestrian level and develop strategies to adapt the urban climate. The urban configuration of Santos can be represented by typical urban street, a long urban park in front the seaside and forestry canal.

2. Urbanization of Santos

Santos is a coast city founded in 1546 by the Portuguese nobleman Brás Cubas. The city has been developed due to exportation of coffee from the Port of Santos. Today, exportation and importation through its port have turned it into the crucial outlet for the production of the powerhouse that is São Paulo State.

Fig. 1Urban Planning of Santos in 1896, 1910 and 2011

Around 1899, the population of Santos suffered from diseases, especially bubonic plague. Thus, city council invited Saturnino de Brito, remarkable Engineer in sanitarian field and also considered one of the first ones modern city planners who have a global vision of city, to remodel the city plan and landscape through draining canals in open air in 1910. This urban landscape's treatment could become Santos in a healthy city (ARRUDA and Sá, 2006).

Saturnino de Brito plan for the studied city based on flood and drainage issues of wetlands between the historic city and the bay. Systems of Canals linked the Channel to the Bay of Santos are able to work as linear structures drainage and rainwater storage, self-cleaning by the action of tide and able to drain the swampy areas and receive the rainwater runoff from the future urban area, making it possible your occupation. The system of sanitary and storm sewer proposed is absolute separator, ie sewage and storm water are transported in their own networks. Thus, open drainage channels could be linear parks associating aesthetic and environment functions, as Parisian boulevards of Haussmann with public spaces suitable for leisure and coexistence (ANDRADE, 1991). The aim of Saturnino Brito's plan was to expand the areas of parks and squares of 41 to 143 Ha. In Figure 1, it can observe the modification of urban plan of Santos in 1896, 1910 and 2010. It noted that large part of Saturnino de Brito's plan was implemented in 1910 as some forestry canal and a long urban park in front the seaside built in 1935.

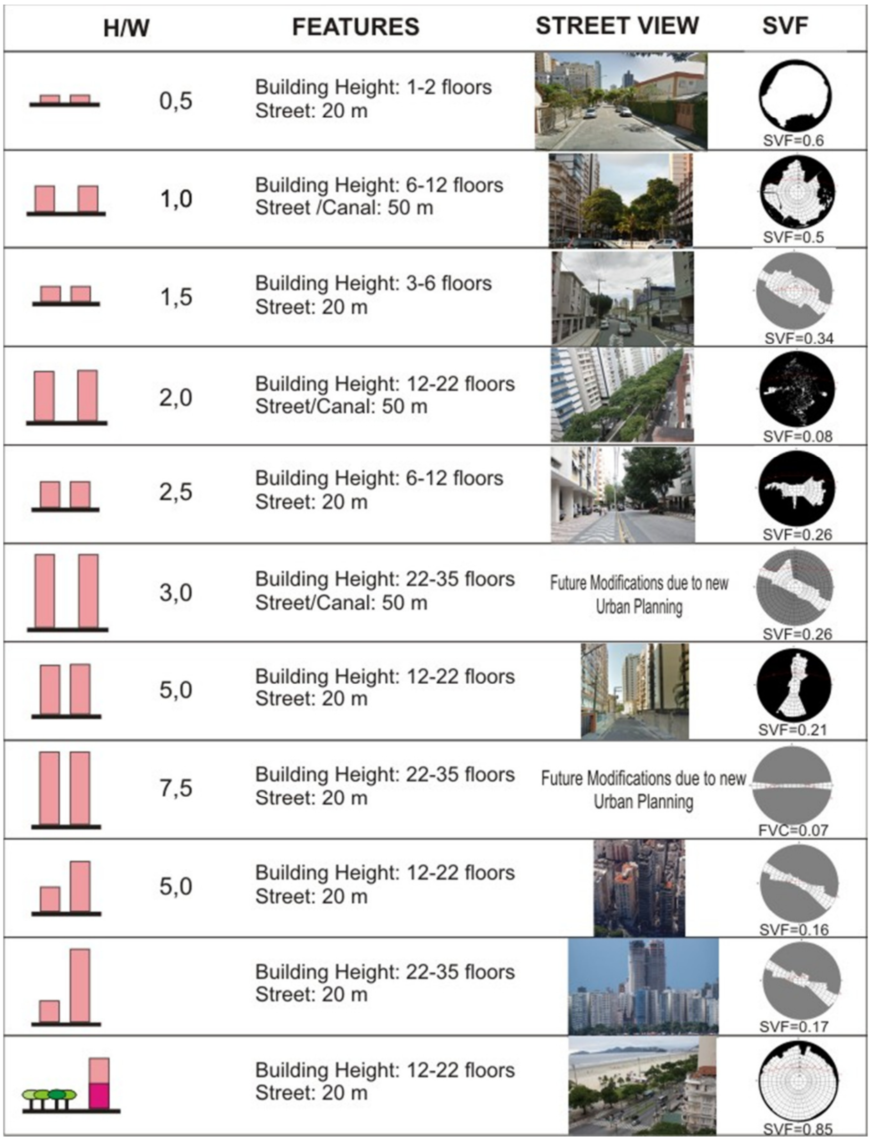

Fig. 2 Urban Configuration of Santos, Brazil

During 1940 to 1970, the urban sprawl of Santos has become its dense city which a lot building in front of beach. Due to socio-economic changes, the city needed to expand the building area. Just in 1998, the new legislation of city eliminates the requirement for maximum height of new developments in Santos. The current urban configuration of Santos can be represented by typical urban street, a long urban park in front the seaside and forestry canal. Relation H/W of typical street or canal varies between 0.5 to 5, with or without trees. The height of buildings founded in Santos are 10 m (until 3 floors), 30 m (between 3 to 6 floors), 50 m (between 6 to 12 floors), 100 m (between 12 to 22 floors), 150 m (between 22 to 40 floors) and width of typical street is 20 m and 50 m, but the distance between building can be 8 m. It can also found different combinations of height of buildings, i.e. buildings with 50 m and 100 m or 150 m in the same street. Based on this, it was develop a scheme of this urban configuration existent in studied city (Fig. 2).

Currently, Santos is a dense city and population lives in thermal discomfort during the all year. Warm waves can prompt a series of diseases such as dengue fever. The lack of urban landscape project has caused visual discomfort to resident. In addition, urban configuration changes have worried population due to reduction of city's quality of life. It is important to quantify the effect of process of densification of Santos to develop strategies to mitigate and adapt the urban climate changes.

3. Methodology

3.1 Data

Santos (23° 56' 15"S, 46° 19' 30"W, 2 m elevation) is the main city in the metropolitan region of Baixada Santista which harbors a largest port of Latin America with 418 thousand inhabitants and very high population density: 1476/km² . The climate of Santos is classified as tropical rainforest climate with no real dry season (Af; Kottek et al. 2006); it is warm throughout the year, though June in Santos is somewhat cooler (and drier) than January. The mean annual air temperature is 28℃, and annual rainfall is amounting to 2081 mm. The predominant wind direction is southeasterly with an annual mean speed of 1.5 m s^{-1}. Annual sunshine duration is 1494 h.

Data were collected at an urban station situated at Santos Airport (23° 55' S, 46° 18' W; 2 m elevation). This station is unaffected by surrounding obstacles and furnishes meteorological data representative of the area. Meteorological data of air temperature, relative humidity, wind speed, and solar radiation from a period of just over 10 years (2002-2012) were used. Their time resolution was 1 h.

3.2 Method and analysis

Modern human biometeorological methods use the energy balance of the human body (Höppe 1993) to extract thermal indices to describe the effects of the thermal environment on humans (Mayer 1993; VDI 1998). For this purpose, hourly measurements of air temperature, air humidity, wind speed and total solar radiation over the seven year studied period have been used to calculate PET (Mayer and Höppe 1987, Höppe, 1999, Matzarakis et al., 1999).

The trhee-dimensional model of urban street canyons are used to analyzing the modifications in urban climate due to modification of urban configurations. The simulations are conducted using the RayMan model (Matzarakis et al. 2007; Matzarakis et al. 2010), which is able to transfer global radiation from a free horizon area into urban structures. The RayMan model is able to calculated thermal indices (i. e. PET) with less data availability. The estimation of PET depends on atmospheric influences, primarily clouds and other meteorological compounds such as vapor pressure or particles. The urban morphologies act as obstacles can be included as well. The main primary input parameters for RayMan in the present study are air temperature, air humidity wind speed and total solar radiation.

To quantify the background conditions at Santos climate, PET are calculated and analyzed in terms of PET classes (Matzarakis and Mayer 1996). Ranges of the thermal index PET for different grades of thermal perception by human beings and physiological stress on human beings - internal heat production: 80 W, heat transfer resistance of the clothing: 0.9 clo - can be applied in this analyses (Matzarakis et al. 1999).

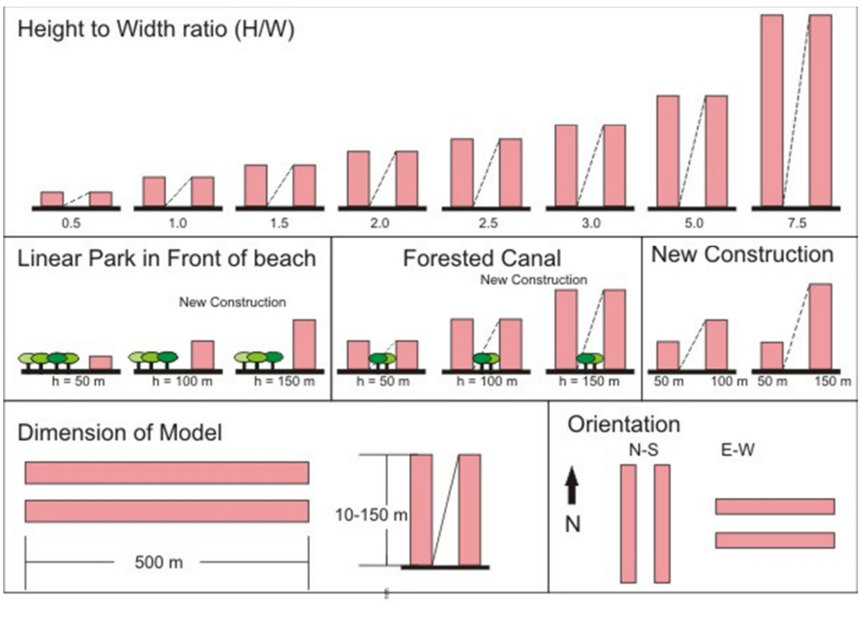

Fig. 3 Configurations and setups used

The following configurations and setups used are: the model canyon are 500 m in length, with values for the width – 10 m, 30 m, 50 m, 100 m, 150 m – and its height adopted was 20 (street) and 50 m (Canal). In addition, canyons are analyzed in North-South and East-West orientation (Fig. 3). These configurations are built based on current legislation - Master Plan and Land Use Construction Standards - and land occupation at Santos.

4. Results and Discussion

The frequency distribution on a monthly basis for the study period (2002-2012) have been produced to quantify the background climate conditions of Santos in terms of T_a and PET and are presented in Fig. 4. These diagrams include frequencies of the classes of temperature intervals based on thresholds in percentages as comfortable, cold, and hot conditions. Values less than 13 ℃ represent cold conditions, values between 13 and 29 ℃ are comfortable conditions, values higher than 29 ℃ are hot conditions, and values higher than 35 ℃ represent conditions of thermal stress.

Santos belongs warm and cool climate region according to the PET classification (Matzarakis and Mayer 1996) and PET higher than 29 ℃ represents conditions of thermal discomfort caused by heat. During winter, T_a considered as cold occurred around 23% of the time, and 4% as hot and 72% was neutral. In contrast, PET considered as cold occurred around 30% of the time, as neutral around 48%, as warm around 9% and as heat stress 7%. During summer, T_a considered as cold occurred around 1% of the time, and 17% as hot and 83% was neutral. At the same period, PET considered as cold occurred around 4% of the time, as neutral around 49%, as warm around 10% and as heat stress 10%.The differences between T_a and PET are very high and show the relevance of a separate discussion and description of the results. Santos are in a comfortable climate region according to PET classification, in which a temperature above 35 ℃ means a thermal sensation of discomfort for heat stress, especially in daytime hours.

Fig. 5 shows the frequencies of relative humidity and direction of wind at 14h during study period. Around 20% of day have relative humidity over than 80%. The predominant direction of wind at 14h (period warm of day) is South-West and it brings thermal comfort for habitants.

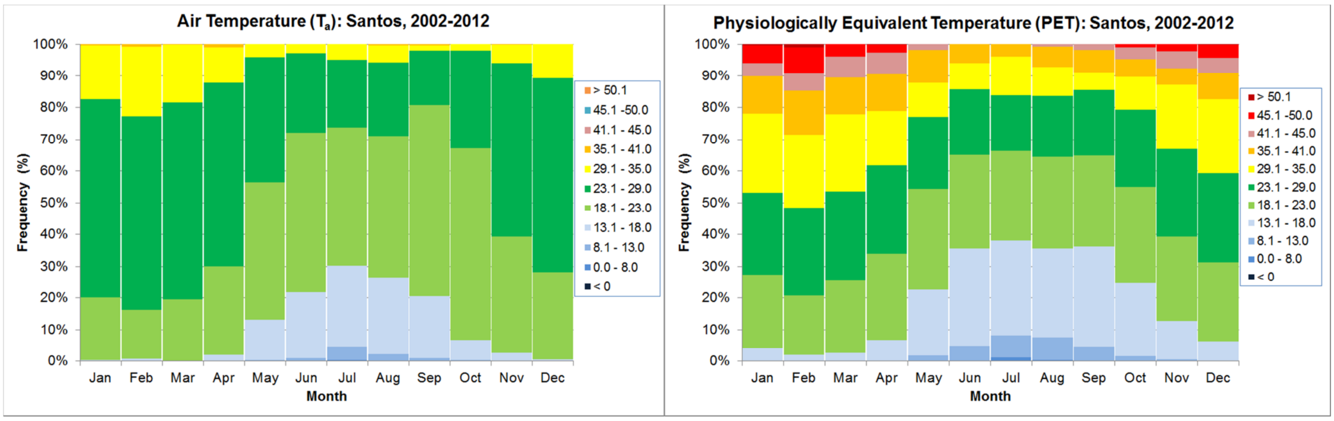

Fig. 4 Monthly frequency distribution of T_a and PET at urban climate station of Santos for the period January 1st, 2002 to December 31 st, 2012.

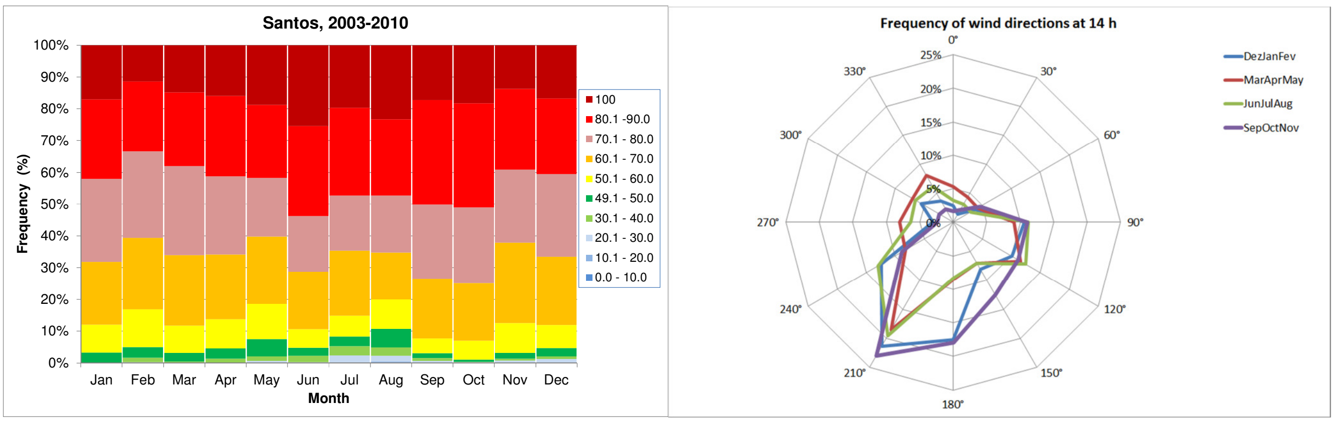

Fig. 5 Monthly frequency distribution of Relative Humidity (RH) and Wind Direction at urban climate station of Santos for the period January 1st, 2002 to December 31 st, 2012.

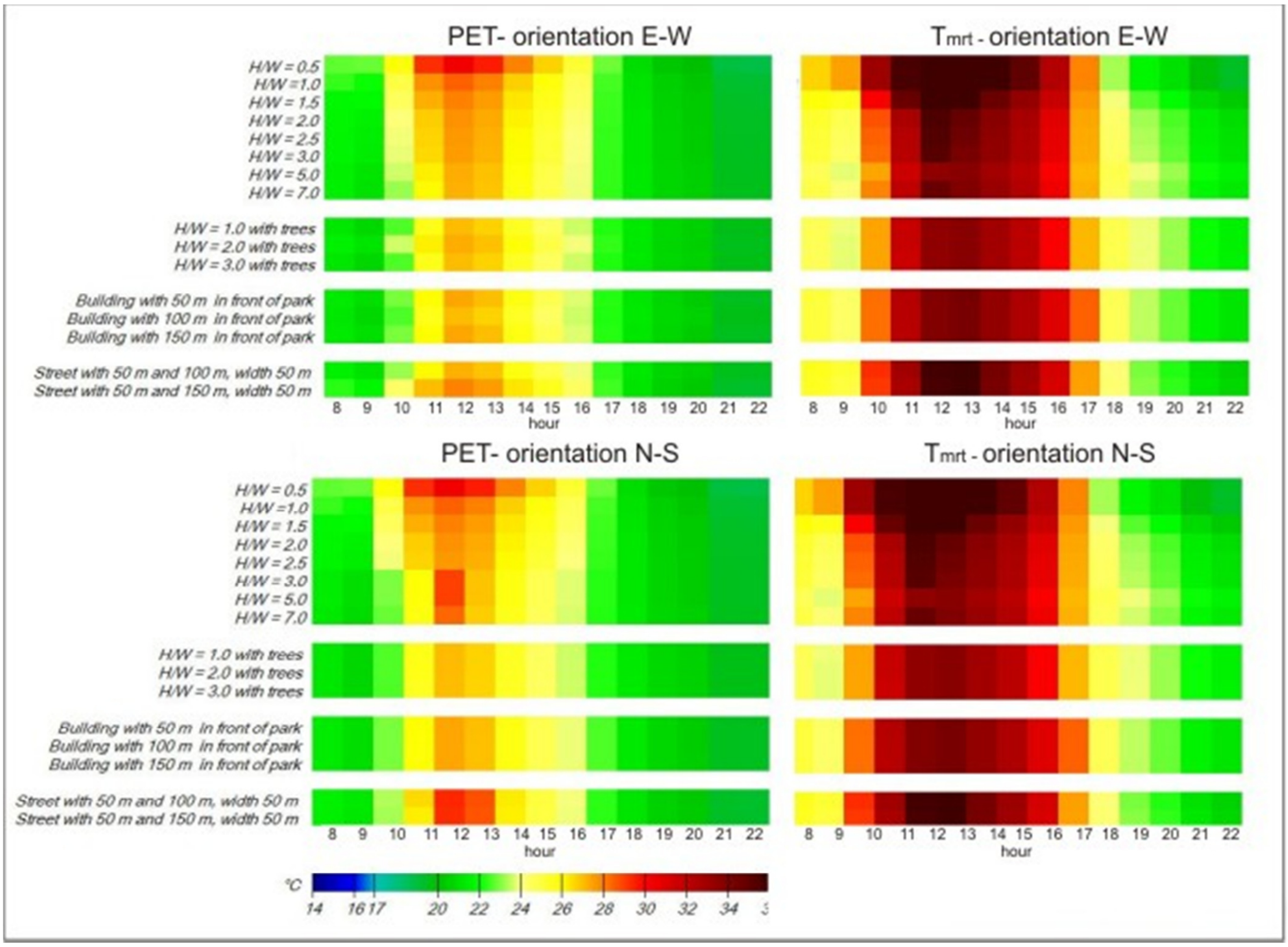

Fig. 6 Diurnal courses of PET (^oC) for typical urban configuration and future modifications, north-south, east-west orientations, based on data from climate station for the period Janurary 1 st, 2002 to December 31st, 2012

Fig. 6 shows diurnal courses of PET (^oC) and T_{mrt} for typical urban configuration of Santos and theirs future scenarios, north-south, east-west orientations accordingly current legislation - Master Plan and Land Use Construction Standards - and land occupation at Santos.
Studied street orientations presented the two results extremes at midday, with highest values of PET for north-south orientations and lowest values for east-west orientations at midday. The conditions during the night are very similar due to the lack of total solar radiation, but the orientation of the canyon also affects the timing of the first increase of PET in the morning. H/W ratio above 3 are effected by heat stress at midday and urban heat island (UHI) at evening. Results of Tmrt show that heat fluxes can influence all the day and forestry and urban parks can mitigate thermal comfort and mitigate the urban heat island.

5. Conclusion

The frequency distribution on a monthly basis for the study period (2002-2012) have been analysed to quantify the background conditions of thermal bioclimate of Santos. The simulation results shows that the height, width and orientation of urban canyon are important parameters for the evaluation of specific thermal bioclimatic conditions in Tropical cities and also develop responsive urban guidelines. To quantify the mean thermal bioclimate condition of a region or location, the radiation fluxes estimations and simulations results based on existing long-term data are important for planning issues. The findings show that east-west orientation and the H/W ratio between 2.0 and 3.0 can improve thermal comfort, but H/W ratio above 3.0 requires additional measures such as planting vertical gardens to control the heat fluxes in the street canyon. The findings suggest that trees can improve thermal comfort of tropical cities, and it confirms results of Abreu-Harbich et al. (2015). Not only shading provided by buildings but also trees can improve thermal comfort in summer of tropical cities (Lin et al. 2010). It is known however that the people in Tropical regions prefer to stay in trees' shade during hot day hours. In additional, to alleviate the negative effects of high-density cities, the wind can infiltrate in the city and improve thermal comfort, particularly at midday, the most warm day hour. This study presents a realistic scenario, especially the comparison of different street configurations with the same input data. It could be an effective way for a global comparison of different urban areas in different climate regions. The presented methods and results can be applied for architectures and urban planning interested in making sustainable cities. The strategically cities management need to developing urban guidelines and making intervention in the existing city. The study of urban forestry for shade sidewalk and building envelop are required. By developing responsive urban guidelines about study of influence of urban obstacles on microclimate and also the energy balance of materials of pavement and buildings are necessary.

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