Paper 237: Thermal bioclimate on idealized urban street canyons in Campinas, Brazil

Loyde Vieira de Abreu-Harbich [1]*, Lucila Chebel Labaki [2], Andreas Matzarakis [3]

School of Civil Engineering, University of Campinas, Campinas, Brazil[1,2]*
loydeabreu@gmail.com
Meteorological Institute, Albert Ludwig University of Freiburg, Freiburg, Germany[3]

Abstract

The height and width of building and urban structures orientation can modify or change the urban climate and thermal bioclimate of cities in the Tropics as well. This paper presents how the urban canyons can modify the thermal bioclimate in Campinas, Brazil. The meteorological data are: air temperature, air humidity, wind speed and solar radiation from the period 2003 to 2010, over were used for the simulations with the aid of RayMan Pro model which is able to transfer the global radiation from an area with a free horizon to urban structures. 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°. The results showed Campinas' typical urban structures and the influence in variation of thermal bioclimate over a range of more than 29°C. Width, height and orientation of an urban canyon are all very important parameters for the development of urban design guidelines based on thermal bioclimate conditions. Re-establishing the appropriate conditions for outdoor thermal comfort is an essential step towards achieving sustainability in urban spaces. An awareness of these issues would be valuable to architects, planners and urban designers, not by limiting possible solutions but rather by enriching the design possibilities.

Keywords: thermal bioclimate; physiologically equivalent temperature; urban spaces; tropical climate, Brazil (Campinas)

1. Introduction

The lack of integration between the climate dimension and the architectural and urban planning cause progressively the decline of thermal bioclimate in tropical cities environments (1; 2; 3)**.** In general, the open spaces share active facets between the building envelope and the open urban canopy. These urban obstacles and their orientation can influence the radiation fluxes expressed by mean radiant temperature and wind speed and consequently, change both outdoor and indoor environments. Studies on thermal comfort and urban heat islands often refer only to case studies and measurement campaigns, and are thus unable to deliver long-term information about conditions in urban areas. The aim of this study was to quantify the influence of the height-to-width ratio and the effect of orientation on radiation fluxes in a typical urban canyon in a Tropical city.

Studies of urban canyons showed that the radiations exchanges on the canyon geometry affected strongly the timing and magnitude of the energy regime of the individual canyon surfaces and were very different from each other (4; 5; 6; 7; 8)

Researches of urban canyon based "in loco" measurement show the modification in urban climate, where the air temperature was systematically cooler at daytime and warmer at night (9; 5). This result can be explained by the orientation of street canyons. In the Kyoto's canyon, the south facing wall and ground were the primary sites of solar absorption during the day, and their role as a source of sensible heat for the canyon continued in the night-time (9). In hot weather conditions, Santamouris et al. (7) and Romero (10) confirmed the same findings.

From performance of the urban structures and the relation between W/H of urban canyons of Tropical Savanna climate, it was detected the formation of heat islands in the residential areas of Brasilia. The buildings constructed from the 90s interfered on wind circulation and the increase the air temperature (10).

Others urban canyon studies based on radiation fluxes estimations and simulations results simulations present similar results of those found in cities. The existing long-term data of an urban climate station were used for a microscale (8; 11; 12).To quantify the influence of the height-width ratio and the effect or orientation on radiation fluxes in a typical urban canyon in a medium-

sized western European city, simulation based on data from urban station of Freiburg, Germany was done (12). The results show that day hours are cooler and nights are warmer than urban station temperatures. In the case of buildings close to 40 m high, thermal stress still occurs at noon for north-south orientated streets. But for buildings above 10 m high, thermal stress at noon is significantly mitigated. The street rotation reveals the daytime periods and height-width ratios of which the T_{mrt} is most affected by global radiation at each specific location and geographical latitude.

In Brazil, studies of street canyons based on CFC simulations shows that more densely built areas of São Paulo presented lower maximum temperatures due to decreased solar incidence in the canyons, which compensates for the lower wind speeds (13).

To investigate the typical urban configuration with typical dimensions, the influence on radiation flux and wind speed can be described. The effect of typical structures on the mean radiant temperature and the thermal index physiologically equivalent temperature (PET) based on over 7 years of measurements at the urban climate station in Campinas, Brazil was analyzed with the application of the RayMan model (14; 15). The RayMan model is able to calculate thermal indices (i.e. PET) and the mean radiant temperature with less data availability. The main primary input parameters for RayMan in the present study were air temperature, pressure vapor, wind speed and global radiation. The objective of this paper is to show how thermal bioclimatic conditions can be modified in urban canyons in tropical cities.

2. Data And Methods

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 used.

Modern human biometeorological methods use the energy balance of the human body (Höppe 1993) in order to extract thermal indices to describe the effects of the thermal environment on humans (16; 17). For this purpose, hourly measurements of air temperature, air humidity, wind speed and global radiation over a seven year studied period have been used in order to calculate the mean radiant temperature and the PET.

The simulations were conducted using the RayMan model (14; 15), which is able to transfer global radiation from a free horizon area to urban structures. The main target is the estimation of mean radiant temperature due to atmospheric influences, primarily clouds and other meteorological compounds such as pressure vapor or particles. In addition, topographical or urban morphologies act as obstacles, modifying not only wind but also radiation properties in the micro scale (18).

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

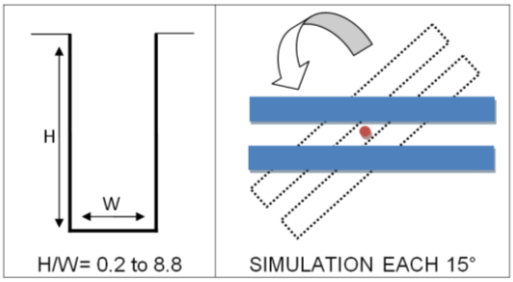

Fig 1. Street Canyon configurations and setups

3. Results

The data were analyzed in terms of PET classes (Matzarakis and Mayer 1996) in order to quantify the background conditions at the urban climate station.

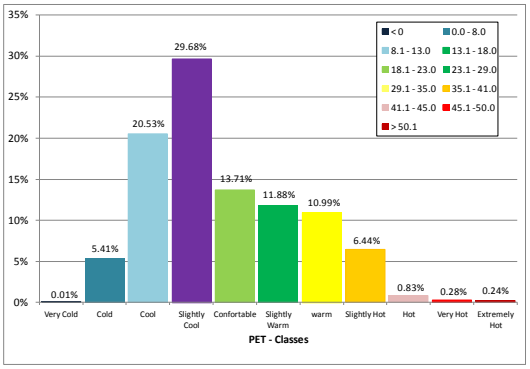

Fig 2. Physiologically Equivalent Temperature (PET) classes at the urban station Campinas for the period June 25th, 2003 to December 31st, 2010.

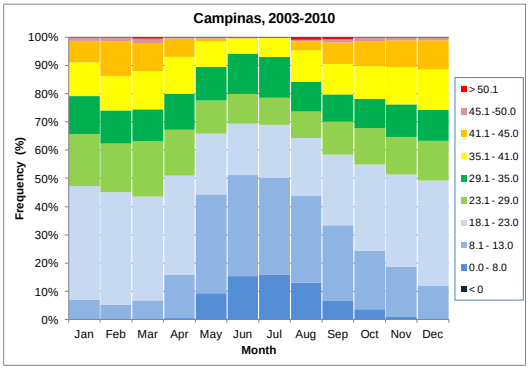

Fig 3. Monthly frequency distribution of PET at urban climate station Freiburg for the period June 25th, 2003 to December 31st, 2010.

Figure 2 shows the PET classes for the period 25 June 2003 to 14 December 2010. In general, Campinas belongs to a comfortable and warm climate region according to PET classification

(Matzarakis and Mayer 1996). Around 18.4% of the hours in the original dataset from the urban climate station in Campinas can be found in the warm (PET>29°), slightly hot (PET>35°), hot (PET>41°), very hot (PET>45°), and extremely hot (PET>50.1°).

Figure 3 shows the mean monthly frequency distribution of PET classes for the study period as Fig. 2. From the frequency diagram, different thermal stress level can be extracted, with heat stress level occurring during the year where the months as January to March, November and December can be found above 35% in the warm (PET>29°).

Figure 4 and 5 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 40m. In addition, PET at urban climate station of Campinas is included.

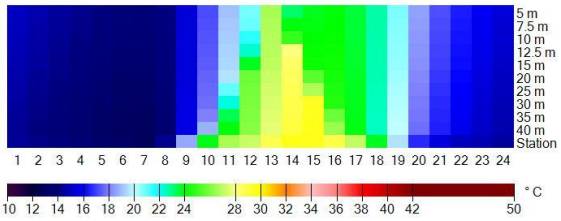

Fig 4. Diurnal Courses of Physiologically Equivalent Temperature (PET) (°C) for an urban canyon with north-south orientation, 21m, height and variable width (5-40m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.

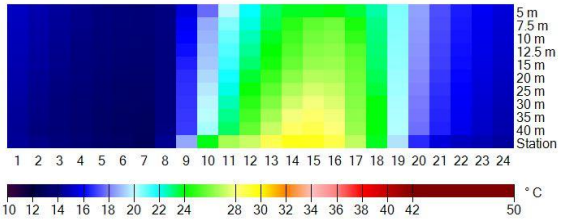

Fig 5. Diurnal Courses of Physiologically Equivalent Temperature (PET) (°C) for an urban canyon with east-west orientation, 21m, height and variable width (5-40m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.

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 2° during 19:00 to 24:00. During the day, the effect of solar radiation in north-south orientated canyon with widths above 12.5 m where the highest values are reached. For the east-west orientation (fig. 7), the increase is lower, reaching high PET values when the width approaches 40m.

Figure 6 and 7 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.

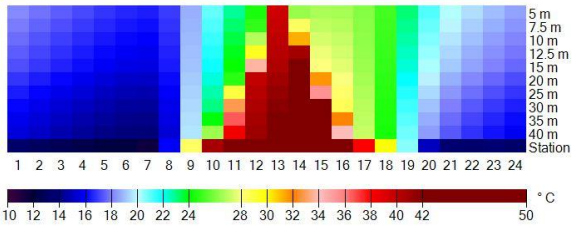

Fig 6. Diurnal Courses of Mean Radiant Temperature (T_{mrt}) (°C) for an urban canyon with north-south orientation, 21m, height and variable width (5-40m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.

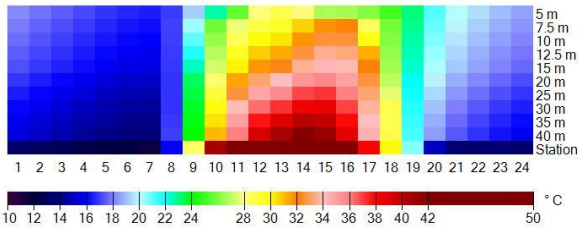

Fig 7. Diurnal Courses of Mean Radiant Temperature (T_{mrt}) (°C) for an urban canyon with east-west orientation, 21m, height and variable width (5-40m) based on data from climate station for the period June 25th, 2003 to December 31st, 2010.

From both figures, it can observed 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 of 5m. During the day, the effect of solar radiation in north-south orientated canyon 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. 7), the increase is lower, reaching high PET values when the width approaches of 40m as PET results of the same orientation.

Figures 8 and 9 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 to 44m. PET and T_{mrt} from urban station of Campinas are included.

From figure 8 and 9, it can extracted the significant differences on temperatures during the night. By concerning the different orientation, the conditions depends on the different height of building. From both, figures 10 and 11, there is a little influence on canyon orientation for width equal 9 m (H/W = 0.45). From figure 10, the east-west and northeast-southwest orientations can improve thermal comfort with PET under 29 ° in width equal 21 m (H/W = 1.05), but when the

width is 44 m (H/W= 2.2), the northeast-southwest orientation present temperatures above 29 ^{o} from 13:00 to 16:00. From figure 11, all orientation have extremely temperatures, excepted the east-west orientation by width equal 44m (H/W= 2.2).

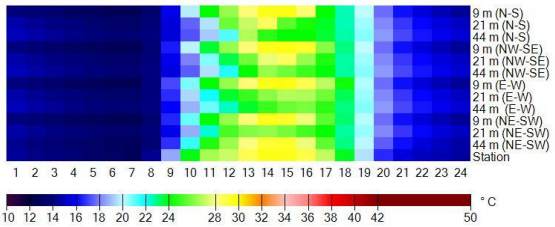

Fig 8. Diurnal Courses of Physiologically Equivalent Temperature (PET) (^{o}C) for an urban canyon with north-south, northwest-southeast, east-west and northeast-southwest orientations, variable height (9 m, 21 m, 44 m)based on data from climate station for the period June 25th, 2003 to December 31st, 2010.

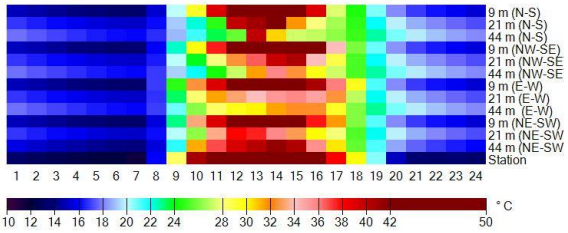

Fig 9. Diurnal Courses of Mean Radiant Temperature (T_{mrt}) (^{o}C) for an urban canyon with north-south, northwest-southeast, east-west and northeast-southwest orientations, variable height (9 m, 21 m, 44 m)based on data from climate station for the period June 25th, 2003 to December 31st, 2010.

Figure 10 and 11 shows the stepwise (15^{o}) 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 ^{o} and 180^{o} in figures 10 and 11 are identical and are marked as the north-south in preceding figures; likewise, east-west is market as 90 ^{o} in figure 10 and 11. The results of these orientation can also be found in the other diurnal courses of PET and T_{mrt} (figures 4 to 9).

The figure 10 and 11 shows that north-south and east-west orientations are the two extreme, 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 offset the maximum value of Tmrt 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 Tmrt in the morning.

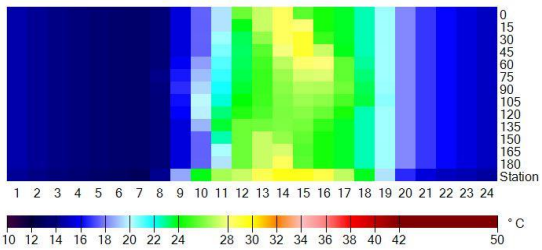

Fig 10. Diurnal Courses of Physiologically Equivalent Temperature (PET) (^{o}C) for the stepwise (15^{o}) rotation of an urban canyon with a height and width of 15m based on data from climate station for the period June 25th, 2003 to December 31st, 2010.

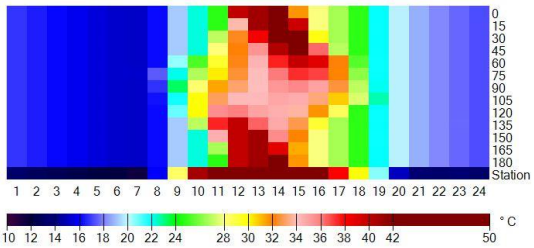

Fig 11. Diurnal Courses of Mean Radiant Temperature (T_{mrt}) (^{o}C) for the stepwise (15^{o}) rotation of an urban canyon with a height and width of 15m based on data from climate station for the period June 25th, 2003 to December 31st, 2010.

Based on radiation fluxes estimations and simulations results, the urban guidelines for Campinas was done in table 01. From this table, it was observed that there is low influence of street orientation in height-width ratio until 0.5. Thus, there is recommended the management of forestry and green areas promotes shade on pedestrian ways and façades. For height-width ratio above 0.5, the east-west is recommend, but is possible improve the sidewalk spaces with trees.

Table 1: Urban Guidelines for Campinas based on thermal bioclimate

HEIGHT/WIDTH	URBAN GUIDELINES
< 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 90^{o} and 120^{o}; 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 45^{o} and 135^{o}; for the others orientation, it is recommended the management of forestry and green areas.
>2.0	The north-south street orientation is not recommended.

4. Discussion

The combined effect of height, width and orientation on street canyons modify the PET and T_{mrt} temperatures, where the day hours temperatures are reduced and the night hours temperatures became warmer than urban station. Ours findings confirm the results of some researches (Nakamura, et al., 1988; Santamouris, et al., 1999; Herrmann, et al., 2010; Ali-Toudert, et al., 2005; Mills, 1993).

The global radiation at each specific location and geographical latitude are affected by the street rotation and height-width that observed on daytime periods. In Tropical Climates, when the height-width is more than 2, the constructions shade the façades and sidewalk and the temperatures are cooler than temperatures of urban station. When the height-width is low than 0.5, the buildings cannot shade the sidewalk, influencing the global radiation on surface. Our finding confirms the results of Romero (10) and Brandão and Alucci (13).

By comparing ours results with Herrmann and Matzarakis (2010), it can observed that east-west orientation have the capacity to make low the extremely temperatures in both locations, and this modification are desired in Tropical Climate. Therefore, the influence of height-width ratio on Freiburg, Germany are different in relation of Campinas, Brazil. 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.

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**.**

5. Conclusions

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. Ours findings show that east-west orientation and the height-width ratio above 2.0 can improve thermal comfort. For the height-width ratio until 1.0 are recommended to sidewalk and building façades.

This study present 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.

6. Acknowledgements

This work was sponsored by FAPESP/Fundação de Amparo à Pesquisa do Estado de São Paulo (Research Support Foundation for the State of São Paulo) and CAPES/DAAD.

7. References

1. **Oke, T.R.** The energetic basis of urban heat island. *Journal of the Royal Meteorological Society.* 1982, Vol. 108 (455), pp. 1-24.

2. **Givoni, B.** Urban Design in Different Climates. *WMO Technical Report 346.* 1989.

3. *Urban climatology and urban design.* **Mills, G.** Sydney, Australia : s.n., 1999. ICB-ICUC. pp. pp. 541-544.

4. *The energy balance of an urban canyon.* **Nunez, M. and Oke, T. R.** 1977, J. Appl. Meteorol., Vol. 16, pp. 11-19.

5. **Yoshida, A., Tominaga, K. and Watani, S.** Field measurements on energy balance of an urban canyon in the summer season. *Energy and Buildings.* 1990, Vols. 15-16, pp. 417-423.

6. *Simulation of the energy budget of an urban canyon I. Model structure and sensitivity test.* **Mills, G.** 1993, Atmos. Environmental, Vol. 27B, pp. 157-170.

7. **Santamouris, M., et al.** Thermal and air flow characteristics in a deep pedestrian canyon under hot weather conditions. 33:. *Atmos. Envir.* 1999, Vol. 33, pp. 4503-4521.

8. *Thermal comfort in urban streets with trees under hot summer conditions.* **Ali-Toudert, F. and Mayer, H.** Beirut, Lebanon : s.n., 2005. 22th Passive and Low Energy Architecture (PLEA). pp. 699-704.

9. **Nakamura, Y. and Oke, T.** Wind, temperature and stability conditions in an east-west oriented urban canyon. *Atmos. Envir.* 1988, Vol. 22, pp. 2691-2700.

10. *Urban Microclimate and the Residential Space Configuration of Brasília.* **Romero, M. A. B.** Rhodes : s.n., 2010. Passive and Low Energy Cooling for the Built Environment.

11. *Microclimate in Urban Forest Fragments.* **Dacanal, C. and Labaki, L.C.** Louvain-la-Neuve, Belgium. : s.n., 2011. 7th Conference on Passive and Low Energy Architecture (PLEA).

12. **Herrmann, J. and Matzarakis, A.** Mean radiant temperature in idealized urban canyons – Examples from Freiburg, Germany. *International Journal of Biometeorology (Online).* 2010.

13. *Thermal behavior of urban canyons using numerical modeling.* **Brandão, R. S. and Alucci, M. A.** New York : s.n., 2010. Fourth National Conference of IBPSA-USA.

14. **Matzarakis, A., Rutz, F. and Mayer, H.** Modelling Radiation fluxes in simple and complex environments – Application of the RayMan model. *International Journal of Biometeorology.* 2007, Vol. 51, pp. 323-334.
15. —. Modelling Radiation fluxes in simple and complex environments – Basics of the RayMan model. *International Journal of Biometeorology.* 2010, Vol. 54, pp. 131-139.
16. **Mayer, H.** Urban bioclimatology. *Experientia.* 1993, Vol. 49, pp. 957-963.
17. **VDI.** Methods for the human-biometerological assessment of climate and air hygiene for urban and regional planning. *Part I: Climate, VDI guideline 3787. Part 2. Beuth.* 1998.
18. **Lin, T.P., Matzarakis, A. and Hwang, R.L.** Lin, T.P., Matzarakis, A., Hwang, R.L., 2010, Shading effect on long-term outdoor thermal comfort, Building and Environment. *Building and Environment.* 1, 2010, Vol. 45, 213-221.
19. **Höppe, P.** Heat balance modelling. *Experientia.* 1993, Vol. 49, pp. 741-746.