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Daily periodic temperature variation in the city of Curitiba, Paraná

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ABSTRACT. To learn more about the local characteristics related to temperature variation in the urban area of Curitiba, Paraná, Brazil, we analyzed the temporal and spatial variation of the average air temperature in the parts of the day. Data were collected from 44 monitoring points arrayed along four transects of the city by means of Hobo® weather data loggers housed in mini-shields. The meteorological data were gathered in four campaigns in 2011, corresponding to the four seasons of the year, and stratified by parts of the day (predawn, morning, afternoon and night). In the four transects temperature differences were found between the monitoring points in the periods analyzed. The central and/or densely constructed areas of the city presented the highest temperatures during the night and predawn, while in those with large vehicle circulation, the highest temperature were recorded in the morning and afternoon. The monitoring points with greatest presence of vegetation presented the lowest temperature in all the periods analyzed, thus indicating the microclimatic balance promoted by vegetation.

Keywords: microclimate, spatial and temporal temperature variation, urban climate, urban heat island, urban land-cover.

Variação térmica periódica diária da cidade de Curitiba, Paraná

RESUMO. Para conhecer quais as características locais relacionadas à variação térmica da área intraurbana de Curitiba – Paraná – Brasil, este trabalho teve como objetivo analisar a variação temporal e espacial da temperatura média do ar nas partes do dia. Para a coleta dos dados meteorológicos foram estabelecidos 44 pontos de monitoramento em quatro transectos na malha urbana por meio de mini-abrigos meteorológicos com registradores modelo Hobo®. Os dados meteorológicos foram coletados em quatro campanhas em períodos correspondentes às quatro estações do ano em 2011, estratificados nas partes do dia (madrugada, manhã, tarde e noite). Nos quatro transectos foram encontradas diferenças térmicas entre os pontos de monitoramento nos períodos analisados. As áreas centrais e/ou com alta densidade de construção apresentaram as maiores temperaturas durante a noite e a madrugada, enquanto naquelas com grande circulação de veículos, as maiores temperaturas foram observadas durante a manhã e a tarde. Os pontos de monitoramento com maior presença de vegetação apresentaram as menores temperaturas em todos os períodos analisados, demonstrando o equilíbrio microclimático proporcionado pela vegetação.

Palavras-chave: microclima, variação espacial e temporal de temperatura, clima urbano, ilha de calor urbano, uso do solo urbano.

Introduction

Rapid and disorganized urban growth has unleashed a variety of environmental impacts due to human activities, including alteration of the urban climate (Nascimento & Oliveira, 2011).

According to Wong and Yu (2005), with rapid urbanization, there has been a tremendous growth in population and buildings in cities. The high concentration of hard surfaces actually triggered many environmental issues. The urban heat island (UHI) effect, one of these environmental issues, is a phenomenon where air temperatures in densely built cities are higher than the suburban rural areas. The primary root of heat island in cities is due to the absorption of solar radiation by mass building structures, roads, and other hard surfaces during daytime. The absorbed heat is subsequently re-radiated to the surroundings and increases ambient temperatures at night.

The urban climate have been studied in numerous cities around the world because the myriad factors leading to the existence of an urban heat island differ from city to city (Yow & Carbone, 2006). The temperature conditions varied between different landscapes communities within urban area (Cui, Liu, Kuang, & Wang, 2012).

Nduka and Abdulhamed (2011) consider that the effect of urbanization on the microclimate of cities is mostly due to the changes in the various land uses to which urban areas are placed. Klysik and Fortuniak (1999) reported that each city has its own characteristics, depending on local factors such as terrain, urban structure and types of construction materials.

The morphology of cities also has an influence, in terms of the height, foundation footprint and density of structures. The varying combinations of these characteristics affect the loss of radiation with longer wavelengths during the night and the rates of cooling and access of solar radiation during the day, and hence the daytime heating pattern. Within the city, temperature differences also have spatial and temporal variation (Grimmond, 2007).

The city of Curitiba, capital of the state of Paraná, Brazil, has interesting aspects and well-defined characteristics for urban climate studies, due to the different land uses, ordered by zoning laws that establish occupation parameters, and the quantity and irregular distribution of the vegetation within the urban boundaries.

Some studies have shown the temperature variation in the city of Curitiba, using remote heat sensing for the entire metropolitan region or involving collection of meteorological data in specific parts of the city, such as those by Mendonça and Dubreuil (2005), Rossi and Krüger (2005) and Young and Rocha (2006).

To learn more about the local characteristics related to temperature variation in the Curitiba urban region, we analyzed the temporal and spatial variation of the average air temperature in four periods of the day.

Material and methods

Curitiba is located in the southern region of Brazil, at latitude 25°25'40"S and longitude 49°16'23"W (zero mark in Tiradentes Plaza). Its extension is 20 km from east to west and 35 km from north to south. The city's average monthly temperature ranges from 12.9°C in the coolest month to 22.5°C in the hottest month, with yearly mean temperature of 16.4°C. The average annual rainfall is 1,600 mm (Mendonça & Danni-Oliveira, 2007).

To collect the air temperature data we established 44 monitoring points by installing mini-shields to house weather data loggers at fixed spots along four transects within the urban area (Figure 1), crossing at a central point in Tiradentes Plaza. We established 15 points along the north-south transect, 10 points along the east-west transect, 12 points along the southwest-northeast transect and 10 points along the northwest-southeast transect.

In choosing the places to install the meteorological mini-shields, we considered criteria of standardization, ease access, and security during the data collection periods. The mini-shields were placed along streets at the top of traffic light poles and signs, to meet the listed criteria.

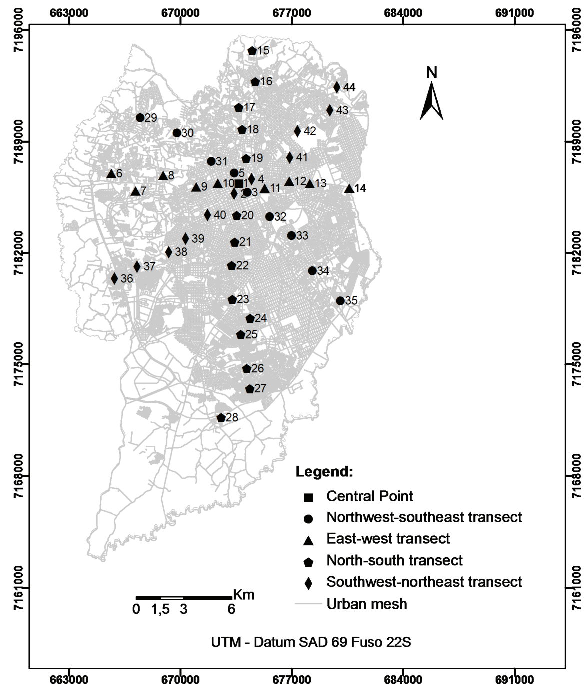

Figure 1. Location of monitoring points in the urban area of Curitiba.

The monitoring points were initially arrayed on a map at street intersections. The precise locations were then defined in the field according to the presence of traffic lights and signs. In choosing the points we avoided points very near trees or structures, such as buildings and walls.

The weather data loggers were installed on the poles of traffic lights or signs at an average height of four meters above the ground. According to the World Meteorological Organization, there is some flexibility for collecting weather data in urban areas at greater heights (3 to 5 m) than the standard height range (1.25 to 2.00 m), without the need to correct the data. This greater height has the added advantage of covering larger footprints and placing the sensor out of reach of vandals, besides assuring greater dilution of the heat from vehicle exhausts and reducing contamination from dust.

The air temperature data were gathered with a Hobo® weather data logger, made by Onset, previously calibrated. The loggers were placed in the mini-shields, which were designed for the sensor size, made of a section of PVC tube covered on the outside with aluminum foil.

The meteorological data were collected in four campaigns, each lasting 22 days, at intervals of 15 min., in periods corresponding to the seasons of the year in 2011: summer (February 7 to 28), autumn (May 9 to 30), winter (August 4 to 25) and spring (September 3 to 24).

The data from each monitoring campaign, corresponding to the four seasons, were stratified into four periods of the day: predawn (00h00 – 05h45min.), morning (06h00 – 11h45min.), afternoon (12h00 – 17h45min.) and night (18h00 – 23h45min.).

The mean temperatures in each season were evaluated by the F-test and compared by the Duncan test at 5% significance. We also calculated the temperature differences between the monitoring points along each transect and the 44 monitoring points. The results were compared with the land use zoning and vegetation characteristics, according to data from the Curitiba Institute of Urban Research and Planning.

Results and discussion

Temperature variation along the north-south transect

The data in Table 1 show that in the four seasons, in all four periods of day, significant temperature differences were found between the monitoring points, which varied from 1.2 to 2°C, corroborating the findings of Hamada and Ohta (2010), who mention that temperature variations vary between day and night and with the seasons of the year. Even in the coolest seasons, autumn and winter, there were significant thermal differences, probably related to the anthropogenic heat, which is generally higher in the winter than the summer.

The different intensities of the temperature variations in the periods of the day and seasons of the year can be explained by the influence of solar radiation and anthropogenic heat. Aikawa, Hiraki, Eiho, and Miyazaki (2007) related the seasonal distribution of temperature in the urban climate with the variation of the intensity of solar radiation and anthropogenic heat. According to Oke (1982), the radiation from the sun and human activities are the two sources of heat in urban areas, and this heat is stored during the day in the atmosphere and on the surfaces of construction materials and released gradually at night. According to Geiger (1990), the heat accumulated during the day in brick and concrete structures, associated with reduced ventilation, retards cooling during the afternoon, and the exchange of air between the interior and exterior of the city only reduces urban temperatures slowly. The reduction of heat loss by irradiation at night is due to the presence of high levels of long wavelength radiation in the air pollution layer that typically covers cities, which acts as a blanket to keep the heat from escaping at night to higher layers of the atmosphere.

Table 1. Stratified mean temperature for parts of the day observed along the north-south transect in the city of Curitiba in 2011.

PD		Monitoring Points															TD
		P15	P16	P17	P18	P19	P1	P20	P21	P22	P23	P24	P25	P26	P27	P28	
SM	P	18.0 a	18.6 c	18.4 b	19.0 e	18.8 d	19.3 f	19.2 f	19.3 F	19.0 e	18.6 c	18.7 c	18.9 de	19.0 e	18.8 d	18.4 b	1.4
	M	21.1 a	21.7 bc	21.4 ab	22.2 de	22.1 cde	21.9 cd	22.5 e	22.5 E	21.9 cd	21.9 cd	22.3 de	22.2 de	22.4 e	21.2 a	22.3 de	1.4
	A	24.8 bc	25.1 cde	24.9 bcd	25.9 cde	25.2 ef	25.5 fg	25.5 fg	25.5 bcd	24.9 b	24.6 cde	25.3 de	25.3 de	25.3 de	24.0 a	24.1 a	1.9
	N	19.2 a	20.0 abc	19.9 b	20.7 f	20.3 cde	20.7 f	20.6 ef	20.6 ef	20.3 bcd	19.9 b	20.0 ab	20.3 de	20.4 de	20.0 ab	19.4 a	1.5
AU	P	12.0 bc	11.5 a	11.7 ab	12.2 cd	12.0 bc	13.1 g	12.9 fg	12.6 ef	12.4 de	12.2 cd	12.3 cde	12.4 de	12.6 def	12.2 cd	11.8 ab	1.6
	M	14.3 bc	13.4 a	14.1 b	14.8 d	14.1 b	14.8 d	15.4 e	14.8 D	14.4 bcd	14.2 b	14.5 bcd	14.8 cd	14.9 d	14.2 b	14.0 b	1.9
	A	18.8 cdef	18.1 ab	18.0 a	18.8 cde	18.2 ab	18.6 bcde	19.6 g	19.3 Fg	18.9 def	18.4 abc	19.0 ef	19.0 ef	18.5 abcd	18.6 bcde	18.1 a	1.6
	N	13.3 bc	12.6 a	13.0 b	13.9 def	13.6 cd	14.6 h	14.5 gh	14.2 Fg	13.9 def	13.6 cd	13.7 cde	14.0 def	14.1 efg	13.7 cde	13.0 b	2.0
WI	P	11.3 abc	11.4 bcd	10.9 ab	11.0 abc	11.1 abc	12.2 e	11.9 de	11.6 cd	11.5 Cd	11.2 abc	11.3 abc	11.3 abc	11.5 cd	11.2 abc	10.8 a	1.4
	M	13.2 a	13.9 abcd	13.6 abc	14.0 bcd	14.0 bcd	14.0 bcd	14.6 d	14.4 cd	13.7 abc	13.5 ab	13.6 abc	14.0 bcd	14.0 bcd	13.5 ab	13.4 ab	1.4
	A	18.1 a	18.7 abcd	18.7 abcd	19.3 d	18.9 abcd	19.0 abcd	19.3 cd	19.0 bcd	18.9 abcd	18.4 ab	19.0 bcd	18.9 abcd	18.7 abcd	18.4 abc	18.2 ab	1.2
	N	13.5 ab	13.9 bc	13.3 a	14.0 bcd	13.9 bc	15.0 f	14.8 ef	14.5 def	14.4 cde	14.0 bcd	14.3 cde	14.2 cd	14.3 cde	14.1 cd	13.5 ab	1.7
SP	P	12.8 a	14.6 bc	13.4 b	14.2 ghij	13.9 defg	14.4 i	14.3 ij	14.2 hij	13.9 cdef	13.7 cd	13.8 cde	14.0 efgh	14.1 fghi	13.8 cdef	13.4 b	1.8
	M	17.1 a	18.7 cd	18.0 b	18.7 cd	18.4 bcd	18.1 b	18.7 cd	18.9 d	17.9 B	18.0 b	18.3 bc	18.7 cd	18.7 cd	18.0 b	18.1 b	1.8
	A	22.0 a	22.7 abcd	21.9 a	23.3 abcd	22.6 abcd	23.3 d	23.4 d	23.0 cd	22.1 Ab	22.2 abc	23.4 d	23.2 d	22.9 bcd	22.1 ab	22.4 abc	1.5
	N	15.3 a	16.4 bcd	16.1 b	17.1 fg	16.7 def	17.2 g	17.2 g	16.9 efg	16.5 bcde	16.1 bc	16.4 bcd	16.7 def	16.6 cde	16.2 bc	15.5 a	1.9

PD – parts of the day, SU – summer, AU – autumn, WI – winter, SP – spring, P – predawn, M – morning, A – afternoon, N – night, TD – temperature difference. Means followed by the same letter in the rows (season) do not differ statistically at 5% significance by the Duncan test.

According to the results of the statistical analysis reported in Table 1, the place with highest average temperature varied in the parts of the day analyzed. Point P1 (Tiradentes Plaza - Centro), in the Central Zone - CZ, which includes the traditional downtown area, characterized by a large concentration of urban activities and functions, presented the highest temperature in the night and predawn periods, while point P20 (Brasílio Itiberê St. with Brigadeiro Franco St. - Rebouças), in a Medium-High Density Residential Zone – RZ-4, where the height limit is six floors, was the hottest during the daytime (morning and afternoon). Both points are located in areas that are mainly impermeable, with heavy circulation of vehicles and pedestrians.

The presence of large trees clustered in Tiradentes Plaza, while the other point is characterized by only small and medium trees irregularly distributed along the streets, explains why this public plaza is not the hottest during the day, although it also has high temperatures.

Also, points P18 (Mateus Leme St. 3238 - São Lourenço) and P21 (Presidente Kennedy Ave. with Minas Gerais St. – Guaíra), respectively located in a Low Density Residential Zone – RZ-2 (buildings up to two floors) and Medium Density Residential Zone – RZ-3 (up to three floors), both with land occupation rates (percentage of constructed area) of up to 50%, and with heavy vehicle circulation, stood out for high temperatures in all periods of the day.

The lowest temperatures were found at the end points of this transect, at points P15 (Anita Garibaldi Ave. with Rolando Salin Zappa Mansur St. – Cachoeira), P16 (Anita Garibaldi Ave. with Flávio Dallegrave St. – Barreirinha), P27 (Tijucas do Sul St., 1859 - Sítio Cercado) and P28 (Nicola Pelanda St. – Umbará), which are in areas of low construction density in either a Controlled Occupation Residential Zone - RZ-CO (maximum occupation rate of 30%) or Low Density Residential Zone - RZ-2 (maximum occupation rate of 50%), both of which have greater permeable area, remaining forest area or presence of public green spaces (Nascentes do Belém and Barreirinha Municipal Parks) in the extreme north. These lowest temperatures were observed in all four periods of the day.

According Rovani, Rodrigues, Sartori, and Cassol (2012), in less urbanized areas and greater presence of vegetation, the night cooling is faster, while the urbanized core, particulate matter, smoke and pollutants the heat stored during the day is lost rapidly from the surface into space.

There was also a reduction of temperatures in the northern region of the city, at points P17 (João Gava St. with Antonio Krainiski St. - Abranches) and P19 (Deputado Mário de Barros St. with Raul Viana St. – Centro Cívico), and the center-south part of the city, at points P22 (Wenceslau Braz St. with Camilo Castelo Branco St. – Bairro Lindóia) and P23 (Deputado Neo Martins St. with Linha Verde Highway (BR 116) – Bairro Fanny) in all periods of the day. The low construction density and presence of vegetation explains the lower temperatures found at these points in comparison with the adjacent areas.

Baris, Sahin, and Yazgan (2009) in research in the city of Ankara, Turkey, noted clearly that the landscape of any green area located among the settlements can change the thermal environment and create different microclimates. The measurements carried out showed that the temperature difference between the green areas and settlements around them can rise up to 5.2°C on some days.

Temperature variation along the east-west transect

Along this transect we also found statistically significant temperature differences between the monitoring points in all periods of the day, with variation from 1.0 to 2.1°C (Table 2).

In the summer, autumn and spring, the largest differences were found in the morning and afternoon, while in the winter the temperature differences were similar in all parts of the day (Table 2). Hamada and Ohta (2010), studying the daily and seasonal variations in the urban climate of Nagoya, Japan, observed that the differences were greater during the day than at night in the summer, while the opposite occurred in the winter.

During the summer and spring, in the predawn and night periods, the highest temperatures occurred at point P9 (Euclides da Cunha St. with Padre Agostinho St. – Bigorrilho), located in the Special Structural Sector – SS, with many tall buildings and intense vehicle flow, while the highest temperatures occurred in the morning and afternoon periods at point P13 (Vitor Ferreira do Amaral St. with Linha Verde Highway – Tarumã), an area of medium construction density but with high vehicle circulation because of the truck and car traffic on Linha Verde Highway (Table 2). The reduction of the temperatures at point P13 in the predawn period indicates that the high temperatures found at this site are the result of the circulation of vehicles, demonstrating the influence of traffic on the thermal variation in the urban area of Curitiba.

Table 2. Stratified mean temperature for parts of the day observed along the east-west transect in the city of Curitiba in 2011.

PD		Monitoring Points										TD
		P6	P7	P8	P9	P10	P1	P11	P12	P13	P14	
SM	P	18.7 bc	18.6 ab	18.5 a	19.2 e	19.0 d	19.3 e	19.0 d	18.8 c	19.0 d	19.0 d	1.1
	M	22.0 bcd	21.8 ab	21.4 a	22.0 bcd	22.4 d	21.9 bc	22.2 cd	22.0 bcd	22.9 e	22.8 e	1.5
	A	25.9 cd	25.3 a	25.1 a	25.1 a	25.9 bcd	25.5 abc	25.4 ab	25.0 a	26.2 d	25.3 a	1.6
	N	20.2 ab	19.9 a	20.0 a	20.6 de	20.5 cde	20.7 e	20.3 bcd	20.3 bc	20.7 e	20.4 bcd	1.1
AU	P	12.1 a	12.1 a	12.0 a	12.7 c	12.5 bc	13.1 d	12.6 c	12.3 abc	12.4 abc	12.2 ab	1.3
	M	14.4 bc	14.1 b	13.6 a	14.4 bc	15.0 d	14.8 cd	14.8 cd	14.3 bc	14.8 cd	14.2 b	1.7
	A	18.5 b	18.3 b	17.7 a	18.5 b	18.7 b	18.6 b	18.8 b	18.4 b	19.8 c	18.5 b	2.1
	N	13.7 ab	13.5 a	13.4 a	14.5 de	14.1 bc	14.6 e	14.0 bc	14.0 bc	14.2 cd	13.8 abc	1.3
WI	P	11.5 ab	11.4 ab	11.2 a	11.8 bc	11.6 abc	12.2 c	11.7 abc	11.4 ab	11.4 ab	11.2 a	1.3
	M	14.2 ab	14.2 ab	13.7 a	13.9 ab	14.6 b	14.0 ab	14.3 ab	14.0 ab	14.2 ab	13.9 ab	1.1
	A	18.8 ab	19.0 ab	18.6 a	18.9 ab	19.1 ab	19.0 ab	19.3 ab	18.9 ab	19.6 b	18.9 ab	1.3
	N	14.2 abc	13.9 ab	13.8 a	14.7 cd	14.3 abc	15.0 d	14.5 bcd	14.5 bcd	14.6 cd	14.3 abc	1.3
SP	P	13.7 ab	13.7 ab	13.6 a	14.4 e	14.1 de	14.4 e	14.1 cd	13.8 abc	14.1 cd	13.9 bcd	1.0
	M	18.5 cd	18.0 bc	17.3 a	17.7 ab	18.5 cd	18.1 bc	18.3 bc	18.1 bc	19.3 e	18.9 de	2.0
	A	22.8 cd	23.3 d	21.5 a	22.9 cd	23.3 d	23.3 d	22.1 b	22.2 b	24.1 e	22.4 bc	2.6
	N	16.7 ab	16.6 ab	16.3 a	17.4 bc	16.9 d	17.2 cd	16.6 ab	16.6 ab	17.0 bcd	16.4 a	1.1

PD – parts of the day, SU – summer, AU – autumn, WI – winter, SP – spring, P – predawn, M – morning, A – afternoon, N – night, TD – temperature difference. Means followed by the same letter in the rows (season) do not differ statistically at 5% significance by the Duncan test.

In the autumn and winter, the highest temperatures were found in the central areas. Point P1 (Tiradentes Plaza) had the highest temperatures in the predawn and night periods, while points P10 (Fernando Moreira St. with Desembargador Motta St. – Mercês) and P11 (Ubaldino do Amaral St. with Visconde de Guarapuava St. - Alto da Rua XV), in a Medium-High Density Residential Zone – RZ-4, had the highest temperatures during the morning and afternoon, the same as occurred along the north-south transect.

The lowest temperatures in all the seasons and parts of the day did not only occur at the end points of this transect, they also occurred at point P8 (Cândido Hartmann St. with Padre Ladislau Kula St. – Santo Inácio), located in a Low-Density Residential Zone – RZ-1, which is near Barigui Municipal Park, a large green area that includes forest cover and a lake, both of which act to soften climatic factors, besides other nearby forest remnants. This shows the role of vegetation on microclimate. As observed by Dimoudi and Nikolopoulou (2003), vegetation tends to stabilize the microclimatic variables in surrounding areas, reducing extreme values.

Temperature variation along the northwest-southeast transect

The greatest thermal difference (3.9°C) among the monitoring points in the afternoon period in the summer was found along the northwest-southeast transect (Table 3). The greatest heating of urban materials and surfaces occurs in the afternoon, and summer is the hottest season of the year. Along this transect, significant temperature differences were also found in other periods of the day and seasons of the year.

Point P3 (André de Barros St. with Barão do Rio Branco St. – Centro), located in the Central Zone - CZ, presented the highest temperatures in all periods of the day. This is related to the heating effect in the most built-up and impermeable area of the city. The city center is also the setting for the greatest concentration of human activities and traffic (cars and buses).

The lowest temperatures occurred at points P29 (Fredolin Wolf St. with Saturnino de Miranda St. – Lamenha Pequena), P30 (José Vale St. – São João) and P31 (Jacarezinho St. with Solimões St. – Vista Alegre), all of which are residential areas in the northeastern part of the city, the region that has the greatest plant cover in the city, according Vieira and Biondi (2008).

Table 3. Stratified mean temperature for parts of the day observed in the northwest-southeast transect in the city of Curitiba in 2011.

PD		Monitoring Points										TD
		P29	P30	P31	P5	P1	P3	P32	P33	P34	P35	
SM	P	18.4 b	18.2 a	18.7 c	19.0 d	19.3 e	19.6 f	19.0 d	18.9 d	18.9 d	19.0 d	1.4
	M	21.4 a	21.1 a	23.2 g	22.4 cde	21.9 b	22.9 fg	22.7 ef	22.1 bcd	22.0 bc	22.5 de	2.1
	A	24.8 bc	24.6 b	22.5 a	25.7 d	25.5 d	26.4 e	25.6 d	25.2 cd	25.2 cd	25.7 d	3.9
	N	19.9 bc	19.6 b	19.2 a	20.5 fg	20.7 g	21.0 h	20.4 ef	20.1 de	20.1 cd	20.2 de	1.9
AU	P	11.6 a	11.5 a	12.1 b	12.7 d	13.1 e	13.3 e	12.5 cd	12.5 cd	12.3 bcd	12.2 bc	1.8
	M	13.7 a	14.0 a	14.1 a	14.9 cd	14.8 b	15.3 d	15.0 cd	14.5 b	14.8 b	14.8 b	1.6
	A	18.2 b	17.6 a	17.6 a	19.1 cd	18.6 bc	19.5 e	19.2 e	19.0 cd	18.5 b	19.0 cd	1.9
	N	13.1 a	12.9 a	13.5 b	14.2 d	14.6 e	14.7 e	14.0 cd	14.0 cd	13.7 bc	13.7 bc	1.8
WI	P	11.3 ab	11.1 a	11.4 ab	11.8 bc	12.2 c	12.2 c	11.4 ab	11.5 ab	11.1 a	11.0 a	1.2
	M	13.5 a	13.4 a	13.7 ab	14.1 abc	14.0 ab	14.8 c	14.3 bc	14.1 ab	13.7 ab	13.9 ab	1.4
	A	18.6 b	18.3 a	18.2 a	19.2 cd	19.0 bc	20.0 d	19.2 d	19.4 cd	19.3 b	19.1 cd	1.8
	N	13.7 a	13.6 a	14.0 ab	14.6 cd	15.0 d	15.0 d	14.5 bcd	14.5 bcd	14.1 abc	14.0 ab	1.4
SP	P	13.4 a	13.3 a	13.6 a	14.2 bc	14.4 cd	14.6 d	14.1 bc	14.1 b	13.9 b	13.9 b	1.3
	M	17.9 bc	17.7 b	17.1 a	18.6 de	18.1 bc	19.0 e	18.9 de	18.6 de	18.4 cd	18.5 cd	1.9
	A	22.3 bc	21.7 a	21.9 ab	22.5 c	23.3 de	23.6 e	22.7 cd	23.0 cde	22.9 cd	23.0 cde	1.9
	N	16.2 ab	15.9 a	16.3 ab	16.8 c	17.2 d	17.4 d	16.7 c	16.7 c	16.4 bc	16.3 ab	1.4

PD – parts of the day, SU – summer, AU – autumn, WI – winter, SP – spring, P – predawn, M – morning, A – afternoon, N – night, TD – temperature difference. Means followed by the same letter in the rows (season) do not differ statistically at 5% significance by the Duncan test.

In the southeastern part of the city the same intensity of temperature reduction did not occur in the municipal boundary area. Only in the winter did the points in the extreme southeastern part of the city have statistically similar temperatures to those of the northwestern part. This is explained by the land use in these regions. Point P35 (Velci Bolívar Grando St. with Amauri Mauad Gueiros St. – Uberaba), the last point of the southeastern end of the transect, is a located in an area called the Special Social Interest Habitation Sector – SEHIS, which features a large housing project with small lot sizes and few trees along the streets or public squares containing trees. Another factor is the continuation of the urban sprawl outside the Curitiba municipal limits, into the city of São José dos Pinhais, along Torres and Rui Barbosa avenues.

Temperature variation along the southwest-northeast transect

Along the southwest-northeast transect, statistically significant temperature differences were found among the monitoring points in all periods of the day and seasons of the year, except in winter mornings, when the differences were only 0.6ºC (Table 4).

In the predawn and night periods, the highest temperatures occurred at point P2 (Visconde de Nacar St. with Emiliano Perneta St. – Centro), in the Central Zone – CZ, which is characterized by tall buildings and intense circulation of vehicles and pedestrians, but this did not occur in the morning and afternoon, when this point was those having the lowest temperature (Table 4), probably due to the thermal mass of the buildings and the blockage of sunlight by the tall structures. This confirms the findings of Klysik and Fortuniak (1999) that certain spots in downtown areas can be cooler than surrounding spots during the day due to the shade provided by tall buildings.

Point P40 (Sete de Setembro Ave. with Castro Alves St. - Batel), located in area with tall buildings just outside the heart of downtown, also presented temperature reduction compared to the downtown points. This can be related to the blockage of sunlight by buildings.

In the afternoon the highest temperatures, besides point P4 (Luis Leão St. with Conselheiro Araújo St. – Centro), are located in a Medium-High Density Residential Zone – RZ-4, points P38 (Carlos Klemtz St. – Portão), P36 (Raul Pompéia St. with Ludovico Kaminski St. – Cidade Industrial de Curitiba) and P37 (Raul Pompéia St. with João Debimski St. – Fazendinha). The last two points are at the end of this transect, in areas with medium land occupation, small lot sizes and little vegetation.

Table 4. Stratified mean temperature for parts of the day observed along the southwest-northeast transect in the city of Curitiba in 2011.

PD		Monitoring Points												TD
		P36	P37	P38	P39	P40	P2	P1	P4	P41	P42	P43	P44	
SM	P	18.8 ab	19.0 c	19.0 c	19.0 cd	19.0 cd	19.6 f	19.3 e	19.1 d	18.7 ab	18.8 b	18.8 b	18.6 a	1.0
	M	22.5 de	22.2 bcd	21.1 a	22.4 cde	21.9 b	22.1 bc	21.9 b	22.8 e	21.8 b	22.0 bc	21.9 b	22.2 bcd	1.7
	A	26.1 de	25.5 bc	26.3 e	25.4 bc	25.5 bc	24.8 a	25.5 bc	25.8 cde	25.6 cd	25.5 bc	25.0 ab	25.7 cd	1.5
	N	20.2 ab	20.4 bc	20.8 d	20.4 b	20.4 bc	20.8 d	20.7 d	20.7 cd	20.1 ab	20.2 ab	20.2 ab	20.0 a	0.9
AU	P	12.1 b	12.4 bcd	12.3 bc	12.4 bcd	12.8 de	13.2 f	13.1 ef	12.6 cd	12.2 b	12.2 b	12.2 b	11.7 a	1.5
	M	14.8 abc	15.3 c	15.0 bc	14.6 ab	14.4 a	14.6 ab	14.8 abc	15.0 bc	14.3 a	14.4 a	14.7 ab	14.4 a	1.0
	A	19.6 f	19.0 de	18.8 cde	18.5 bcd	19.3 ef	18.1 ab	18.6 bcd	18.3 abc	18.6 bcd	19.2 ef	18.4 bc	17.9 a	1.7
	N	13.7 bc	14.1 de	13.9 bcd	13.9 cd	14.1 de	14.7 f	14.6 f	14.3 ef	13.5 b	13.6 bc	13.5 bc	13.0 a	1.7
WI	P	11.1 a	11.5 abc	11.3 ab	11.5 abc	11.8 cd	12.4 e	12.2 de	11.8 bcd	11.3 ab	11.3 ab	11.5 abc	11.0 a	1.4
	M	14.1 a	14.2 a	14.3 a	14.1 a	13.7 a	14.2 a	14.0 a	14.0 a	13.8 a	13.8 a	14.0 a	13.7 a	0.6
	A	19.2 ab	19.2 ab	19.0 ab	19.1 ab	19.0 ab	18.8 a	19.0 ab	19.8 b	18.8 a	19.1 ab	18.6 a	18.7 a	1.2
	N	14.0 b	14.3 bc	14.1 b	14.4 bc	14.5 bc	15.1 d	15.0 d	14.8 cd	14.0 b	14.1 b	14.1 b	13.5 a	1.6
SP	P	14.1 cd	14.0 bcd	13.8 abc	14.2 de	14.1 bcd	14.5 f	14.4 ef	14.3 def	13.7 a	13.8 ab	13.7 a	13.6 a	0.9
	M	18.7 cd	18.6 bcd	18.9 d	18.8 cd	17.6 a	18.2 bc	18.1 ab	19.1 d	18.2 bc	18.5 bcd	18.6 bcd	18.8 cd	1.5
	A	23.0 c	23.9 d	23.9 d	22.9 c	23.4 cd	21.9 a	23.3 cd	23.8 d	22.3 ab	22.8 bc	22.3 ab	23.1 c	2.0
	N	17.0 de	17.1 de	16.7 cd	16.8 de	16.9 de	17.1 de	17.2 e	17.1 de	16.3 bc	16.3 bc	15.8 a	16.0 ab	1.4

PD – parts of the day, SU – summer, AU – autumn, WI – winter, SP – spring, P – predawn, M – morning, A – afternoon, N – night, TD – temperature difference. Means followed by the same letter in the rows (season) do not differ statistically at 5% significance by the Duncan test.

Temperature variation for the 44 monitoring points

By analyzing all the points together, the higher thermal difference was 3.9°C in the afternoon period in the summer (Table 5). The points P2 (Visconde de Nacar St. with Emiliano Perneta St. - Centro) and P3 (André de Barros St. with Barão do Rio Branco St. - Centro), located in the central region, stood out for high temperatures in the area urban Curitiba in the morning and night periods and the points P13 (Vitor Ferreira do Amaral St. with Green Line Highway - Tarumã) and P20 (Brasílio Itiberê St. with Brigadeiro Franco St. - Rebouças), with high vehicle traffic in daytime. P3 also showed the hottest temperatures during the morning and afternoon in the periods corresponding to winter and summer. This shows that the higher temperatures in the city of Curitiba were found in highly impermeable areas and with anthropogenic heat sources.

The points with lowest temperatures varied with the season and part of the day analyzed (Table 5). All these points with the lowest temperature, as described in this paper, are located in the peripheral or residential neighborhoods with lower building density, greater amount of permeable areas, concentration of forest remnants or public green spaces, confirming the influence of building density and the presence of vegetation on the variation of temperature in the city of Curitiba.

Table 5. Temperature extremes stratified for parts of the day observed among 44 monitoring points in the city of Curitiba in 2011.

PD		HT	LT	TD	DP		HT	LT	TD
SM	P	19.6 (P3)	18.0 (P15)	1.6	WI	P	12.4 (P2)	10.8 (P28)	1.7
	M	23.2 (P3)	21.1 (P38)	2.1		M	14.8 (P3)	13.2 (P15)	1.6
	A	26.4 (P3)	22.5 (P29)	3.9		A	20.0 (P3)	18.1 (P15)	1.9
	N	21.0 (P3)	19.2 (P29)	1.9		N	15.1 (P2)	13.3 (P17)	1.8
AU	P	13.3 (P3)	11.5 (P30, P16)	1.8	SP	P	14.6 (P3)	12.8 (P15)	1.8
	M	15.4 (P20)	13.4 (P16)	1.9		M	19.3 (P13)	17.1 (P29)	2.2
	A	19.8 (P13)	17.6 (P30)	2.2		A	24.1 (P13)	21.5 (P8)	2.6
	N	14.7 (P2, P3)	12.6 (P16)	2.1		N	17.4 (P3, P9)	15.3 (P2, P9)	2.1

PD – parts of the day, HT – higher temperature, LT – lower temperature, SU – summer, AU – autumn, WI – winter, SP – spring, P – predawn, M – morning, A – afternoon, N – night, TD – temperature difference.

Conclusion

In the urban area of Curitiba, temperature differences were found between monitoring points in all seasons of the year and periods of the day analyzed. Even in the coolest seasons (autumn and winter), thermal differences were found, related to anthropogenic heat.

The areas of higher temperature were located in the central and south-central, and in neighborhoods with greater intensity of occupation and human activities. The lowest temperatures were found at points located in residential districts and the suburbs, such as in the north and northwest areas and the southern city border, which account for the largest amount of permeable areas and concentration of remaining forests, in addition to evidence the effect of cooling of urban forests present in the intra-urban area of Curitiba.

The stratification of the data into periods of the day showed that the downtown areas and others with high construction density had the highest temperatures during the night and predawn hours and those with heavy vehicle circulation were the warmest during the morning and afternoon periods. The monitoring points with the greatest presence of vegetation presented the lowest temperatures in all the periods analyzed, indicating the microclimatic equilibrium provided by vegetation.

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