URBAN HEAT ISLAND AND LAND COVER DIVERSITY IN THE CITY OF RECIFE/PE BRASIL

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Summary: *This study analyzed the Urban Heat Island (UHI) according to different land use patterns in the city of Recife-PE. Seven thermo-hygrometers were installed in different locations to collect temperature and humidity data along the year of 2018 with a 30-minutes interval. The landscapes of the installation sites ranged from sparsely horizontal and well-vegetated to densely populated areas. A meteorological automatic station was considered as the rural reference station. Hourly and monthly average UHI were calculated for the year 2018. The highest UHI intensity was recorded near the sea with an average temperature gradient of 3.9°C at 5 a.m. in August. The results showed that the magnitude of the average UHI in Recife varies between medium (2.0 to 3.0 degrees) and weak (up to 2.0 degrees) presenting its greatest intensity at night, between 6:00 p.m. and 6:00 a.m., from the months of May to August. The proximity to the sea both favored the formation of a freshness island during the day and intensified the heat island during the night on the coastline, due to the combination of the thermal characteristics of the surface materials and the higher temperature of the sea surface.*

Key words: *urban heat island; urban climate; Recife; Brazil*

Résumé : ***Ilot de chaleur urbain et diversité de la couverture terrestre dans la ville de Recife/PE – Brésil.*** *Cette étude analyse l'îlot de chaleur urbain (ICU) en fonction de l'utilisation des terres dans la ville de Recife-PE. Sept thermo-hygromètres ont été installés à différents endroits pour collecter des données de température et d'humidité tout au long de l'année 2018 avec un pas de temps de 30 minutes. Les sites d'installation allaient de zones peu densément peuplées et bien végétalisées à des zones densément urbanisées et verticalisées. La station météorologique automatique de l'INMET a été considérée comme la station de référence rurale. L'ICU moyen horaire et mensuel a été calculé pour l'année 2018. L'intensité la plus élevée a été enregistrée près de la mer avec un gradient de température moyen de 3,9 ° C à 5 heures du matin en août. Les résultats ont montré que l'ampleur de l'ICU moyen à Recife varie entre moyen (2,0 à 3,0 degrés) et faible (jusqu'à 2,0 degrés) présentant sa plus grande intensité la nuit, entre 18h00 et 6h00 du matin, de mai à août. La proximité de la mer rafraîchit la ville pendant la journée mais intensifie l'îlot de chaleur pendant la nuit sur le littoral, en raison de la combinaison des caractéristiques thermiques des matériaux de surface et de la température plus élevée de la surface de la mer.*

Mots clés : *îlot de chaleur urbain ; climat urbain ; Recife ; Brésil*

Introduction

Urban structures modify parameters such as air temperature and humidity, exchanges of radiation and energy and air currents, characterizing the Urban Climate. The phenomenon of the Urban Heat Island (UHI) is the clearest and best documented example of climate change caused by anthropic action (Oke, 1987).

The three aspects that characterize UHI are the shape, intensity and location of its warmest core. These aspects vary between cities, due to factors such as the time of day, time of year, the area morphology and the surfaces thermal properties (Lucena, 2013).

The disposition of the natural and artificial elements in the city of Recife acts as obstacles or corridors of wind, in addition to their thermal characteristics, influencing the thermodynamic processes and the transport of radiation trapped in the urban canyon. The diversity of its physical components, conditions and the local climate generates its own climate, bringing densely urbanized areas to higher temperatures. The present work is aimed to study the behavior of ICU in relation to different land cover elements in the city of Recife.

1. Data and Method

1.1. Study area

The study area comprises the city of Recife the capital of the state of Pernambuco located in the extreme east of the Northeast Region of Brazil (Fig.1). Recife pertains to the Brazilian Tropical Coastal Climate of the Eastern Northeast climate type, characterized by autumn/winter rains and low temperature and humidity annual range. According to Dubreuil *et al*. (2019), the As climate type of Köppen's classification represents 55% of annual situations.

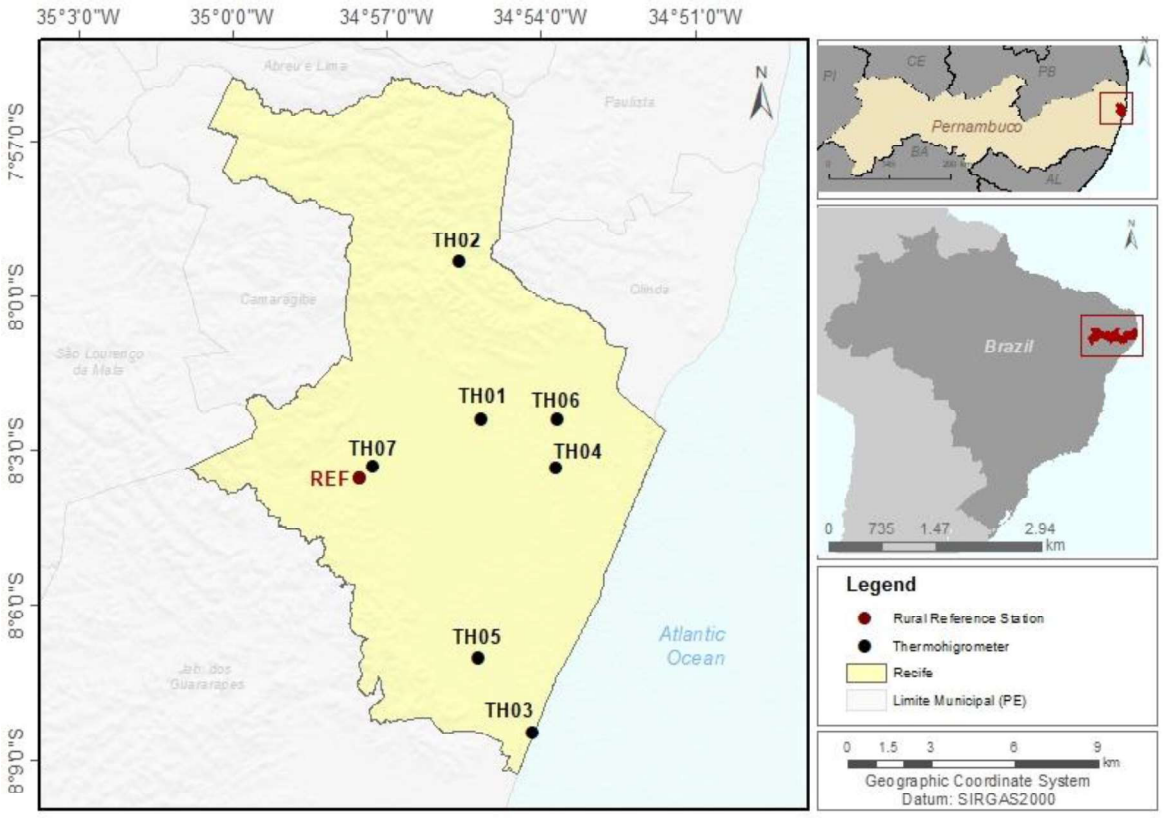


Figure 1. Location of the study area, the thermo-hygrometers and the rural reference station. (Fonts: The authors)

1.2. Methodological Procedure

The temperature and humidity data used are from seven HOBO thermo-hygrometers placed in the city of Recife. The rural reference station was the automatic station A301 of the Instituto Nacional de Meteorologia (INMET) (Fig.1). Data were recorded with an interval of 30 minutes in Celsius degrees throughout 2018 which presented an accumulated precipitation of 1707mm/year and is classified as "very dry" by the quantile classification method for standard climatic year considering the historical mean of 2300 mm/year.

Data analysis considered hourly, monthly and seasonal scales. The location of the thermo-hygrometers was chosen considering the presence of vegetation, water bodies, urban density and proximity to the sea. Figure 2 shows the locations within a radius of 500 m from its surroundings. The TH07 is emphasized to be 645 m away from the rural reference station. The land cover classes are presented in percentage values and vary between vertical constructed, regular constructed, vegetation and water bodies.

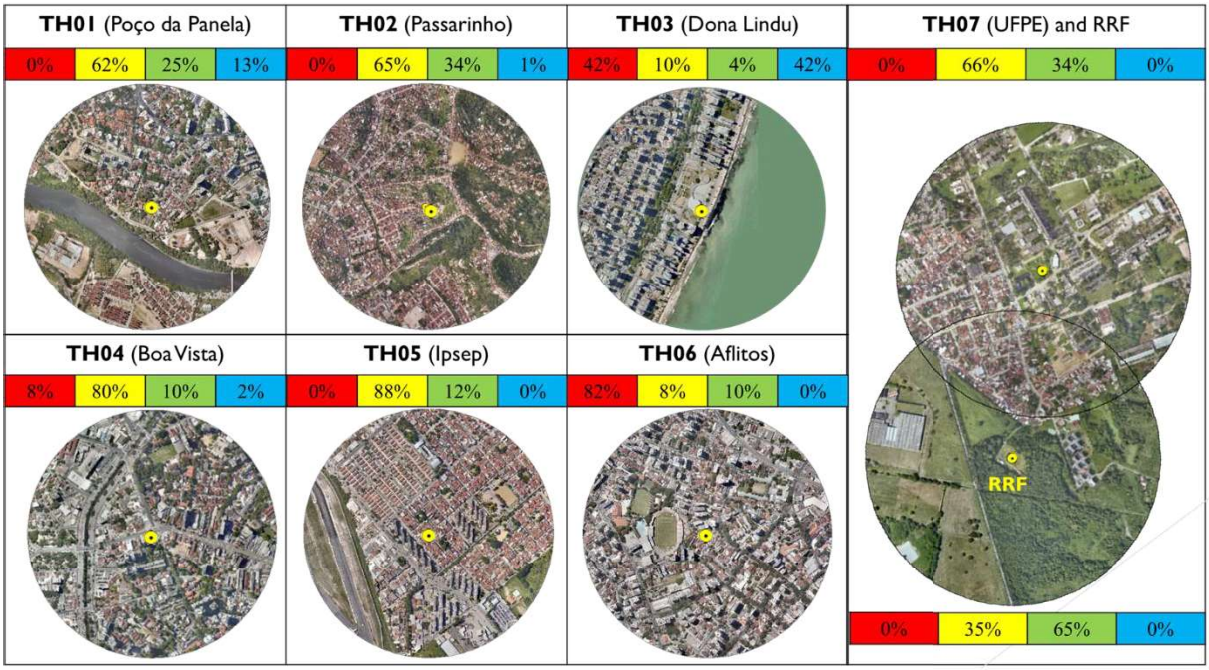
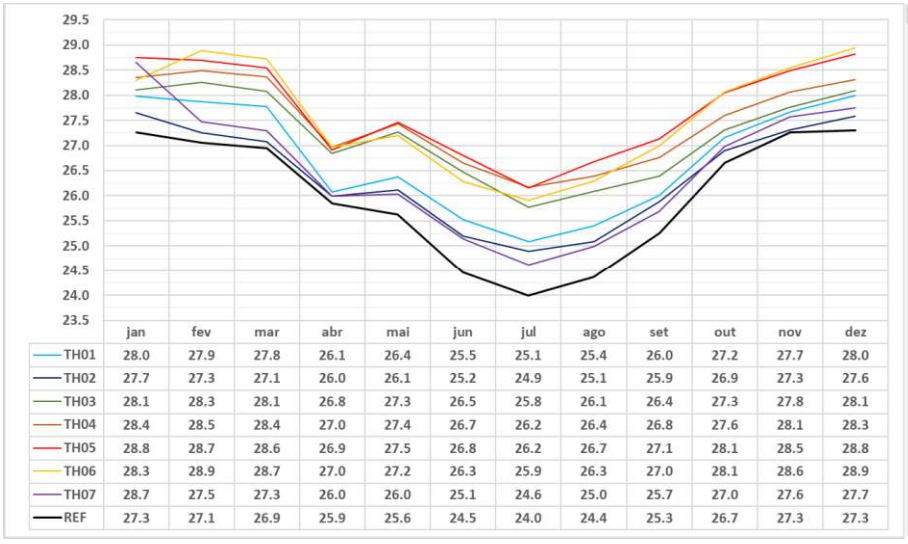


Figure 2. Location of thermohygrometers and a radius of 500 m from their surroundings and their respective percentages of surface class: vertical constructed (red), regular constructed (yellow), vegetation (green) and water bodies (blue). (Fonts: The authors)

2. Results

Figure 3 shows the graph of the average month temperature for each thermo-hygrometers and for the reference station with their respective values. On the right is the table of the average hourly UHI values for each thermo-hygrometer.



	jan	fev	mar	abr	mai	jun	jul	ago	set	out	nov	dez
TH01	28.0	27.9	27.8	26.1	26.4	25.5	25.1	25.4	26.0	27.2	27.7	28.0
TH02	27.7	27.3	27.1	26.0	26.1	25.2	24.9	25.1	25.9	26.9	27.3	27.6
TH03	28.1	28.3	28.1	26.8	27.3	26.5	25.8	26.1	26.4	27.3	27.8	28.1
TH04	28.4	28.5	28.4	27.0	27.4	26.7	26.2	26.4	26.8	27.6	28.1	28.3
TH05	28.8	28.7	28.6	26.9	27.5	26.8	26.2	26.7	27.1	28.1	28.5	28.8
TH06	28.3	28.9	28.7	27.0	27.2	26.3	25.9	26.3	27.0	28.1	28.6	28.9
TH07	28.7	27.5	27.3	26.0	26.0	25.1	24.6	25.0	25.7	27.0	27.6	27.7
REF	27.3	27.1	26.9	25.9	25.6	24.5	24.0	24.4	25.3	26.7	27.3	27.3

Annual hourly intensity

hour	TH01	TH02	TH03	TH04	TH05	TH06	TH07
0	1.5	0.7	2.6	2.4	2.2	2.3	1.0
1	1.4	0.7	2.6	2.4	2.3	2.2	1.0
2	1.7	0.7	2.7	2.5	2.3	2.3	1.0
3	1.5	0.8	2.9	2.6	2.4	2.4	1.0
4	1.5	0.8	3.0	2.7	2.5	2.5	1.1
5	1.6	0.8	3.0	2.7	2.4	2.5	1.0
6	1.3	0.4	2.5	2.3	2.1	1.9	0.8
7	0.7	-0.1	1.2	1.5	1.5	1.1	0.5
8	0.5	-0.1	0.2	0.9	1.3	0.7	0.3
9	0.5	0.0	-0.2	0.8	1.4	1.1	0.3
10	0.8	0.9	-0.2	0.8	2.2	1.4	0.3
11	0.4	0.3	-0.7	0.7	1.7	1.5	0.3
12	0.4	0.5	-0.6	0.8	1.9	1.6	0.4
13	0.3	0.6	-0.6	0.7	1.9	1.8	0.3
14	0.1	0.7	-0.5	0.6	1.8	1.7	0.3
15	0.2	0.7	0.0	0.7	1.5	1.7	0.4
16	0.3	0.8	0.5	0.9	1.2	1.4	0.5
17	0.8	0.9	1.4	1.4	1.5	1.6	0.7
18	1.1	0.9	1.9	1.8	1.8	1.8	0.9
19	1.2	0.9	2.1	2.0	1.9	1.9	1.0
20	1.4	0.9	2.3	2.1	2.0	2.0	1.0
21	1.4	0.9	2.4	2.2	2.1	2.1	1.0
22	1.4	0.8	2.4	2.3	2.2	2.2	0.9
23	1.4	0.7	2.2	2.2	2.2	2.1	0.8

Figure 3. Graph of average annual temperature with their respective values and UHI hourly average intensities for each thermo-hygrometer. (Fonts: The authors)

For the study period, the minimum monthly average temperature was 24 degrees and the maximum 27.3 degrees at the reference station, with a low thermal amplitude. For all months the reference station had the lowest average temperature values.

The thermo-hygrometers showed the values closest to the reference station were TH07, TH02 and TH01 respectively. The highest temperature values were related to the TH05, TH06, TH04 and TH03. Among these, the first two showed little contrast in the intensity of UHI

between daytime and nighttime. TH03 presented a well-defined island of freshness between 09:00 a.m and 02:00 p.m. In general, the graph of annual UHI intensity in Recife shows a predominance of UHI between 06:00 p.m and 06:00 a.m.

The UHI behavior can change throughout the year according to the seasons and / or between the rainy and the dry periods. Amorim (2019) explains that in the rainiest periods, the greater amount of vegetation and humidity in the countryside contribute to increase the thermal contrast in relation to the city. In the dry period the field gets warmer and this reduces the thermal contrast.

Despite Recife's high annual rainfall, the period between September and December is the warmest and driest. The period between January and April is characterized by a transition period between dry and rainy with isolated rainfall events on a regional scale. Finally, the period between the months of May and August concentrates most of the total rainfall, characterizing the rainy period (Wanderley *et al*., 2018).

Considering the periods described above, Figure 4 shows the average hourly intensity of each thermo-hygrometer for the three periods: January-April, May-August and September-December.

Jan - Apr

	TH01	TH02	TH03	TH04	TH05	TH06	TH07
0	1.3	0.4	2.5	2.2	2.3	2.2	1.2
1	1.0	0.3	2.5	2.2	2.3	2.1	1.1
2	1.3	0.4	2.6	2.3	2.4	2.2	1.1
3	1.3	0.5	2.8	2.4	2.5	2.3	1.3
4	1.3	0.6	2.9	2.6	2.6	2.4	1.4
5	1.3	0.5	2.8	2.5	2.4	2.2	1.2
6	1.0	0.0	2.0	1.9	2.1	1.6	0.7
7	0.7	-0.3	1.0	1.3	2.0	1.0	0.4
8	0.7	0.0	0.1	0.7	2.1	0.6	0.0
9	0.6	-0.3	-0.4	0.5	1.9	0.8	0.0
10	1.1	0.8	-0.3	0.5	2.6	1.0	0.1
11	0.5	0.1	-0.8	0.3	2.3	1.1	0.1
12	0.6	0.3	-0.8	0.5	2.3	1.3	0.3
13	0.3	0.4	-0.8	0.3	2.0	1.4	0.2
14	0.3	0.5	-0.6	0.4	1.8	1.4	0.3
15	0.3	0.7	-0.1	0.5	1.6	1.4	0.5
16	0.2	0.7	0.5	0.7	1.4	1.3	0.5
17	0.6	0.7	1.3	1.2	1.6	1.3	0.8
18	0.8	0.7	1.8	1.6	1.9	1.6	1.0
19	0.9	0.6	1.9	1.8	1.9	1.7	1.1
20	1.0	0.5	2.1	1.9	2.0	1.8	1.1
21	1.1	0.5	2.2	2.1	2.1	1.9	1.2
22	1.1	0.5	2.0	2.0	2.3	2.0	0.8
23	1.0	0.3	1.5	1.7	2.1	1.7	0.5

May - Aug

	TH01	TH02	TH03	TH04	TH05	TH06	TH07
0	1.8	1.1	3.1	2.9	2.8	2.7	0.9
1	1.6	1.0	2.9	2.7	2.6	2.5	0.8
2	1.8	1.0	3.0	2.7	2.6	2.5	0.8
3	1.5	1.0	3.0	2.7	2.6	2.5	0.8
4	1.5	1.0	3.0	2.7	2.5	2.4	0.8
5	1.5	1.0	3.0	2.7	2.6	2.5	0.8
6	1.4	0.9	3.0	2.7	2.5	2.4	0.9
7	0.9	0.3	2.1	2.3	2.0	1.7	0.7
8	0.7	0.2	1.3	1.8	1.7	1.1	0.6
9	0.8	0.4	1.0	1.8	2.0	1.6	0.7
10	1.1	1.0	1.0	1.8	2.7	1.9	0.7
11	0.7	0.6	0.6	1.7	2.2	1.8	0.5
12	0.8	0.7	0.7	1.8	2.4	1.7	0.6
13	0.7	0.7	0.6	1.7	2.5	1.6	0.6
14	0.6	0.7	0.7	1.7	2.4	1.5	0.6
15	0.6	0.8	1.0	1.7	2.1	1.6	0.6
16	0.8	0.9	1.4	1.8	2.0	1.7	0.6
17	1.3	1.0	2.1	2.1	2.2	2.0	0.9
18	1.7	1.3	2.7	2.5	2.5	2.4	1.1
19	1.9	1.4	3.0	2.8	2.7	2.6	1.1
20	2.1	1.4	3.2	3.0	2.9	2.8	1.1
21	2.1	1.4	3.2	3.0	2.9	2.8	1.0
22	2.0	1.2	3.2	3.0	2.9	2.7	1.0
23	1.9	1.2	3.2	3.0	2.9	2.7	0.9

Sep - Dec

	TH01	TH02	TH03	TH04	TH05	TH06	TH07
0	1.4	0.7	2.1	2.0	1.7	1.9	0.9
1	1.5	0.7	2.3	2.2	1.8	2.1	1.0
2	1.8	0.7	2.5	2.3	2.0	2.2	1.0
3	1.7	0.8	2.8	2.5	2.1	2.4	1.0
4	1.8	0.8	3.0	2.7	2.2	2.5	1.0
5	1.9	0.9	3.1	2.8	2.3	2.6	1.2
6	1.4	0.3	2.2	2.2	1.5	1.8	0.9
7	0.7	-0.2	0.7	1.1	0.6	0.8	0.5
8	0.4	-0.2	-0.2	0.6	0.3	0.7	0.3
9	0.4	0.1	-0.6	0.5	0.4	1.1	0.3
10	0.5	0.9	-0.7	0.5	1.3	1.3	0.4
11	0.3	0.5	-0.9	0.4	0.7	1.6	0.3
12	0.3	0.6	-0.9	0.4	1.0	2.0	0.3
13	0.3	0.9	-0.8	0.5	1.4	2.5	0.4
14	0.1	0.8	-0.7	0.2	1.3	2.5	0.3
15	0.0	0.8	-0.4	0.1	1.0	2.3	0.2
16	0.2	0.8	0.3	0.6	0.6	1.7	0.3
17	0.7	0.8	1.2	1.2	0.9	1.5	0.6
18	0.8	0.7	1.5	1.4	1.0	1.6	0.7
19	0.9	0.7	1.6	1.5	1.1	1.5	0.8
20	0.9	0.6	1.6	1.5	1.2	1.5	0.8
21	1.1	0.7	1.8	1.6	1.3	1.6	0.9
22	1.2	0.7	1.9	1.8	1.5	1.7	0.9
23	1.3	0.6	1.9	1.8	1.5	1.8	0.9

Legend -1.0 0.0 1.0 2.0 3.0

Figure 4. UHI hourly average intensities for each thermo-hygrometer for the intervals between January to April, May to august and September to December. (Fonts: The authors)

The first and third periods had the lowest UHI intensity, with an island of freshness in two thermo-hygrometers (TH02 and TH03). The second period showed the highest UHI intensity, with positive values during all hours, mainly between 5 pm and 7 am, while the other four months follow the annual period between 6 pm and 6 am.

TH03 showed low diurnal values, defining a well-defined urban freshness island in the first and third periods. In contrast, the values recorded during the nighttime were the highest. The proximity between this sensor and the sea intensifies the contrast, despite being located on the coastline and outside the urban canyon, its surrounding is composed of an impervious surface (concrete and asphalt mainly).

The constant sea winds contribute to the dispersion of income radiation during the day. At night the behavior of the terrestrial breeze, the higher sea surface temperature and the emission of radiation absorbed by the surface contribute to the formation of UHI in this location. Comparing to the UHI recorded in TH03 and its surroundings, Gomez *et al*. (2017) also found the highest UHI values in the city of Ubatuba (Brazil) in high densely constructed areas near the sea.

Teixeira (2018) discusses the relationship between intense verticalization and the concentration of sea winds in the coastal neighborhoods of Recife. The values presented by TH05 confirms this. TH05, which is located leeward of the largest vertical density area of the city, showed high UHI intensity during all hours. Santos *et al*. (2017) also discusses the high values of air temperature in this location.

When observing the general characteristics of the UHI in Recife (Tab.1), it shows that TH03 also has the highest mean UHI intensity, it's followed by TH04, TH05 and TH06. These four sensors are surrounded by a low percentage of vegetation. Both TH04 and TH05 are predominantly surrounded by horizontal constructions (80% and 88% respectively) While TH06 is surrounded by 82% of vertical buildings. These values are in accordance to the correlation between UHI and land surface of Foissard *et al*. (2019) which founded higher preponderance of built-up fractions and low vegetation to explain the UHI intensity.

According to the classification of Fernández (1996), the intensity of the average intensity of the UHI in Recife is of low magnitude for the TH01, TH02 and TH07 thermo-hygrometers and of medium magnitude for the others.

Table 1. Summary of UHI characteristics in Recife. (Fonts: The authors)

	TH01	*TH02*	*TH03*	*TH04*	*TH05*	*TH06*	*TH07*
Mean UHI (in°C)	1.4	0.8	2.5	2.3	2.1	2.1	1.0
UHI highest monthly intensity (in °C)	2.5	1.8	3.9	3.4	4.5	3.3	2.9
Highest intensity period	May to august	July	May to September	May to August	March to Septembre	May to August	April
Highest intensity frequency	20h – 05h	19h – 00h	18h – 06h	18h – 06h	19h – 07h	18h – 06h	18h – 06h

Conclusions and Discussion

The low thermal amplitude is one of the main climatic characteristics of the tropical environment to which the city of Recife belongs. Despite its tropical characteristics such as: low thermal amplitude, proximity to the sea and high records of pluviosity and nebulosity. The presence of UHI was recorded in all studied locations.

The results showed that the magnitude of the average UHI in Recife varies between medium (2.0 to 3.0 degrees) and low (up to 2.0 degrees) presenting its greatest intensity at night, between 6:00 p.m. and 6:00 a.m., from the months of May to August.

The proximity to the sea both favored the formation of a freshness island during the day and intensified the heat island during the night on the coastline, due to the combination of the thermal characteristics of the surface materials and the higher temperature of the sea surface.

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