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Analysis of some climatic variables of a coastal city in southeastern São Paulo State, Brazil

Abstract

The present work addresses the influence of urban structure on the microclimate of the municipality of Bertioga (São Paulo State, Brazil), which is located on the northeastern edge of Baixada Santista, aiming at the environmental comfort, more specifically thermal, of the city's residents and tourists. Data on temperatures, humidity relative, among other items, and information about the surroundings of each measured point were collected, with a measurement taken at thirty-eight points during winter and the same issues during spring, as just one measurement at three points made in the city of Santos during the winter. We observed some urban factors, such as the direction of the streets, the direction of the prevailing wind, the presence of construction barriers, the type of soil or paving, and shading due to trees influenced the differences found.

Keywords: urban ecology, thermal comfort, South America

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Vitória Arantes Arruda Azevedo,[1] Walter Barrella[2]

[1]Santa Cecília University, Brazil
[2]Paulista University, Brazil

Correspondence: Walter Barrella, Paulista University, Sorocaba, Brazil, Email walterbarrell@gmail.com

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Introduction

Within the scope of natural sciences, urban ecology is the term used to refer to that area of biology concerned with urban areas. "As a natural science is a new discipline. It was thought that urban areas were not worthy of study about ecology; cities were seen as "anti-life".[1]

Inadequate urban planning interferes with the city's environmental quality, directly affecting a region's population. Since man in contact with the environment, makes an integrated assessment of ecological, physical, and social attributes. Human activity creates the need for specific spatial concepts,[2] making the comfort of the environment essential to carry out these activities and to improve the quality of life of this population. Among all factors, real estate density impacts environmental comfort in cities. According to the United Nations Population Fund, we can find solutions to these impacts in cities themselves.

"Cities also reflect the environmental damage caused by modern civilization; however, experts and policymakers increasingly recognize the potential value of cities for long-term sustainability. Even though cities generate environmental problems, they also contain solutions. The potential benefits of urbanization largely outweigh its disadvantages".[3]

Planning a city can improve its environmental quality. They also believe that natural resources should guide urban planning, making the best use of the local topography, with streets channeling the winds necessary for ventilation, using a combination of open and closed spaces, creating favorable microclimates.[4]

The climate directly affects the built space and man, who modifies the environment.[5] Anthropogenic interventions contribute to climate change and changes in the ecosystem; action creates artificial microclimates; however, man still has no control over regional circulation, being passive and powerless in the face of climatic accidents.[6] Urban agglomeration forms a local microclimate different from the macroclimate and can create Heat Islands according to the city's urban design, land use, and occupation.

"...Climatic changes can be such that urban areas, especially the larger ones, result in true Heat Islands. Such heat islands are generated from changes imposed on soil drainage, notably by its covering with concrete and asphalt surfaces. In addition to this factor, cities are also heat producers. Large quantities of thermoelectric and combustion equipment are installed in them to produce goods and transport people and cargo. They also interfere with the real masses of buildings that modify the natural course of the winds, damaging natural ventilation inside the core...".[7]

The study of environmental comfort aims to adapt the physical characteristics of the urban environment to levels that are comfortable for humans to carry out their activities. Urbanism must serve man and his comfort, which includes thermal comfort (FROTA, 1999). Hence, the importance of land use and occupation for each city as required by Federal Law No. 10, 257 of July 10, 2001.

"The objectives of this work are based on the following aspects: a) analyze the thermal comfort of the city of Bertioga; b) carry out a comparative analysis between the microclimate in different neighborhoods and the macroclimate; c) analyze urban design and its influence on the population's quality of life."

Study area

The Municipality of Bertioga is located on the northeastern limit of Baixada Santista, in an area situated on the edge of the sea channel that separates Santo Amaro Island from the mainland.[8] It has a territorial extension of 482 km², of which 169.55 km ² are in Permanent Protection Areas, corresponding to 34.6% of its total area.[9] The municipality of Bertioga is in a region dominated by the Atlantic Forest, with 91% of its area covered by natural vegetation. This fact places Bertioga among the municipalities with the most extensive proportional vegetation cover of the Atlantic Forest in the entire State of São Paulo (Figure 1).[10] Rich in Atlantic Forest vegetation and watercourses, with significant remnants of mangroves and resting forests, the municipality of Bertioga presents substantial environmental restrictions on urban occupation, and there are also almost continuous corridors of resting forest from the coastline to the slopes of Serra do Mar.[11]

It is located close to the Metropolitan Region of Santos, around the influence of the Manuel Hipólito do Rego, Prestes Maia (Rio-Santos), and Anchieta – Imigrantes Highway System. It is located 123 km away from the capital (São Paulo), 30 km away from Guarujá and 100 km from São Sebastião. It has a population of 56,555 inhabitants.[12]

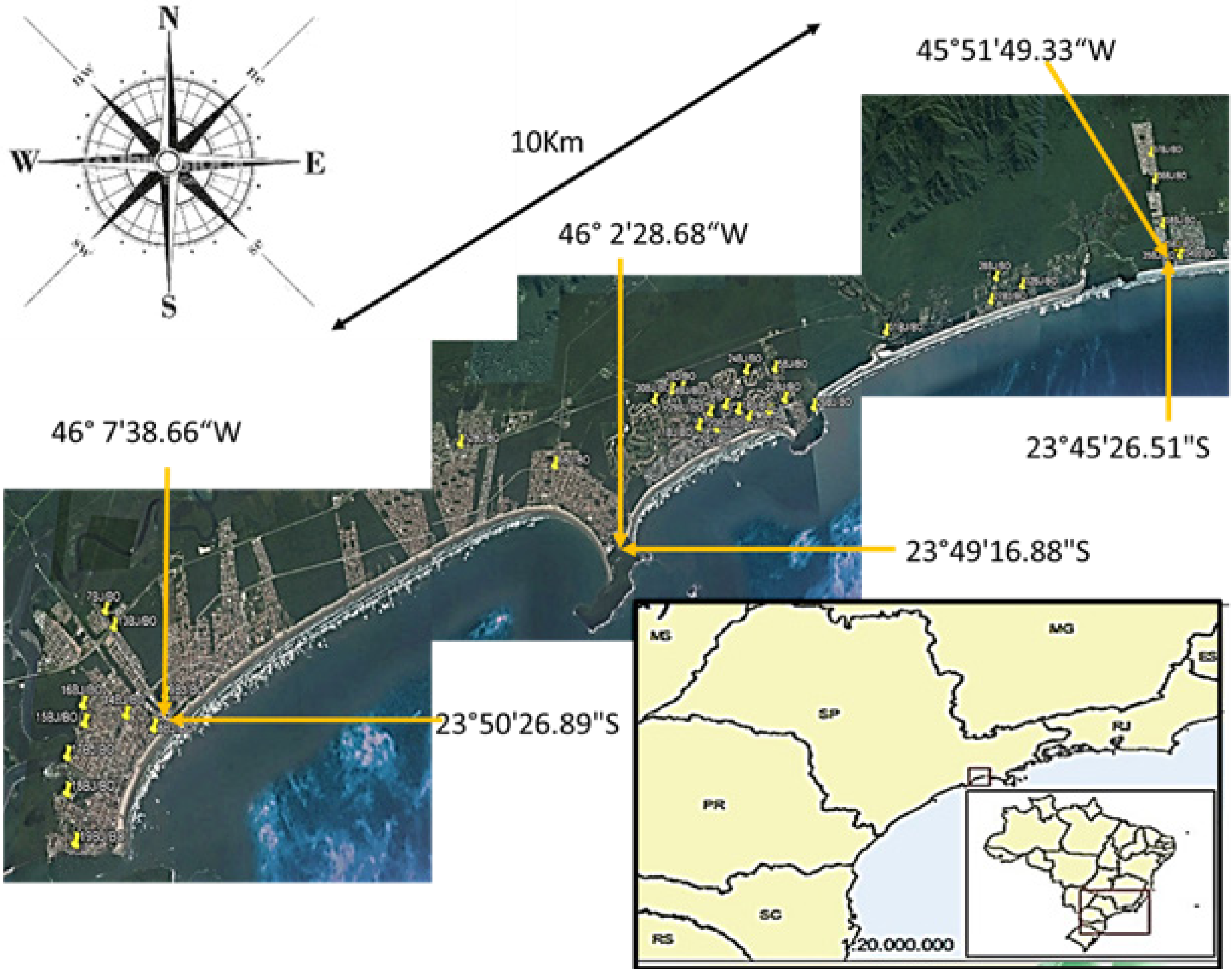

Figure 1 Location of sample points in the Bertioga City.

Its municipal human development index (HDI) is 0.792, higher than the State of São Paulo average of 0.814. Its population density is 97.21 inhabitants/km^2. The municipality's economy is mainly based on tourism and commerce, with a GDP per capita of R$17,604.74.[13]

According to Köppen,[14] the climate in the Bertioga region is classified as type Af (tropical with rain all year round), with annual average temperatures around 24 ºC and yearly rainfall of 3,207 mm, with the highest average values occurring in January, February, and March, while the lowest in June and July, revealing a water surplus in all months of the year.[15]

The city is contemplating the implementation of infrastructure, including a water supply system, sewage collection, drainage, lighting, gas, and paving. In general, the area is characterized by medium-density residences, with socioeconomic standards ranging from low to high and the presence of local businesses and services. A large part of the city is paved and is served by a sanitation network, electricity, telephone, public lighting, and garbage collection.

Bertioga has a large floating population, with most residences being summer homes, with 62.18% of homes for occasional use. The city's urban planning needs to be more cohesive and with disconnected nuclei, with a large amount of irregular occupation that harms the municipality's environmental preservation. Its urbanization was parallel to the seafront line, and its dispersed form maintains a connection via the SP-55 highway.[9] Bertioga generally has several urban layouts, varying according to the neighborhood. For example, the Riviera de São Lourenço neighborhood has more organic lines, preserving green masses. In the area, we see a 90° grid with streets parallel and perpendicular to the sea line.

Material and methods

Environmental variables such as temperature, air humidity, wind speed, wind direction, light intensity, and sound level were measured. In the times defined as hottest, between 12:00 and 15:00 hours, and in the summertime, from 11:00 to 14:00, that is, working with the period of the maximum temperature of the day, in two different seasons (winter and spring) and using equipment such as thermohydrometer, anemometer, and compass.

The temperature (C°), relative humidity (%), light intensity (Lux), and sound level (dB) were measured on the thermohydrometer (4x1 Hikari HTM-401 meter), while wind speed (m/s) was measured. An anemometer (HM-381 - Portable Digital Thermo-Anemometer) was used to check the wind direction (°N). A digital compass was used; as a result, for comparison purposes, the macro temperature of Bertioga was obtained through a history of weather available on the website.

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In each sample, information was also obtained about urban characteristics such as layout, paving, afforestation, infrastructure, street direction, urban equipment, aesthetics, density, and location activity, among other information. The collected data were recorded in spreadsheets and are presented in two tables presented here, one representing the location, being divided into two tables (Bertioga in winter and Bertioga in spring) containing the collection point, date, time, latitude, and longitude (ANNEX 1) and divided into two tables (Bertioga in winter and Bertioga in spring), representing the points, the difference between micro and macro temperature (°C), macro temperature (°C), micro temperature (°C), relative humidity (%), light intensity (Lux), wind speed (m/s), wind angle or wind direction (°N), noise (dB), building size (floors), angle of street or street direction (°N).

ANNEX 1

Location of points measured in Bertioga in winter

Bertioga location data				
points	date	hour	latitude	longitude
1BJ	7/7/2015	12:31	-23,797,247	-46,013,905
2BJ	7/7/2015	12:53	-23,800,629	-46,019,568
3BJ	7/7/2015	13:12	-23,792,901	-46,028,016
4BJ	7/7/2015	13:27	-23,793,284	-46,030,635
5BJ	7/7/2015	13:58	-23,788,808	-46,003,650
6BJ	7/7/2015	14:20	-23,807,388	-46,058,798
7BJ	7/7/2015	14:37	-23,827,091	-46,139,420
8BJ	7/7/2015	14:46	-23,842,556	-46,129,519
9BJ	7/7/2015	15:00	-23,838,557	-46,127,752
10BJ	7/13/2015	12:00	-23,796,300	-46,017,054
11BJ	7/13/2015	12:11	-23,800,363	-46,023,975
12BJ	7/13/2015	12:28	-23,803,458	-46,082,427
13BJ	7/13/2015	12:45	-23,829,357	-46,137,660
14BJ	7/13/2015	13:09	-23,840,948	-46,134,414
15BJ	7/13/2015	13:23	-23,841,972	-46,141,296
16BJ	7/13/2015	13:37	-23,839,713	-46,141,847
17BJ	7/13/2015	13:58	-23,845,873	-46,143,703
18BJ	7/13/2015	14:12	-23,850,025	-46,143,149
19BJ	7/13/2015	14:46	-23,855,562	-46,141,044
20BJ	7/14/2015	12:28	-23,798,538	-46,011,288
22BJ	7/14/2015	12:56	-23,797,258	-46,006,146
23BJ	7/14/2015	13:11	-23,795,007	-46,001,922
24BJ	7/14/2015	13:26	-23,789,237	-46,011,185
25BJ	7/14/2015	13:50	-23,794,873	-46,001,786
26BJ	7/14/2015	14:15	-23,796,564	-45,994,863
27BJ	7/14/2015	14:41	-23,770,025	-45,932,266
28BJ	7/14/2015	14:54	-23,763,673	-45,930,836
29BJ	7/15/2015	12:40	-23,797,694	-46,021,110
30BJ	7/15/2015	13:04	-23,795,280	-46,034,940
31BJ	7/15/2015	13:20	-23,778,121	-45,969,967
32BJ	7/15/2015	13:48	-23,765,910	-45,920,698
33BJ	7/15/2015	14:08	-23,755,333	-45,860,399
34BJ	7/15/2015	14:20	-23,755,220	-45,858,173
35BJ	7/15/2015	14:30	-23,757,176	-45,859,363
36BJ	7/15/2015	14:40	-23,733,561	-45,866,367
37BJ	7/15/2015	14:48	-23,724,334	-45,867,033
38BJ	7/15/2015	15:00	-23,747,975	-45,864,980

Location of points measured in Bertioga in spring

Bertioga location data				
points	date	hour	latitude	longitude
1BO	10/9/2015	12:17	-23,797,247	-46,013,905
2BO	10/9/2015	13:30	-23,800,629	-46,019,568
3BO	10/9/2015	13:51	-23,792,901	-46,028,016
4BO	10/9/2015	14:01	-23,793,284	-46,030,635
5BO	10/20/2015	13:15	-23,788,808	-46,003,650
6BO	10/16/2015	12:20	-23,807,388	-46,058,798
7BO	10/16/2015	12:49	-23,827,091	-46,139,420
8BO	10/16/2015	13:53	-23,842,556	-46,129,519
9BO	10/16/2015	14:00	-23,838,557	-46,127,752
10BO	10/9/2015	13:23	-23,796,300	-46,017,054
11BO	10/9/2015	13:40	-23,800,363	-46,023,975
12BO	10/16/2015	12:33	-23,803,458	-46,082,427
13BO	10/16/2015	12:57	-23,829,357	-46,137,660
14BO	10/16/2015	13:09	-23,840,948	-46,134,414
15BO	10/16/2015	14:11	-23,841,972	-46,141,296
16BO	10/16/2015	14:19	-23,839,713	-46,141,847
17BO	10/16/2015	13:20	-23,845,873	-46,143,703
18BO	10/16/2015	13:27	-23,850,025	-46,143,149
19BO	10/16/2015	13:38	-23,855,562	-46,141,044
20BO	10/9/2015	12:30	-23,798,538	-46,011,288
22BO	10/9/2015	12:43	-23,797,258	-46,006,146
23BO	10/9/2015	12:56	-23,795,007	-46,001,922
24BO	10/9/2015	13:04	-23,789,237	-46,011,185
25BO	10/20/2015	13:15	-23,794,873	-46,001,786
26BO	10/20/2015	13:35	-23,796,564	-45,994,863
27BO	10/20/2015	14:08	-23,770,025	-45,932,266
28BO	10/20/2015	14:18	-23,763,673	-45,930,836
29BO	10/9/2015	13:15	-23,797,694	-46,021,110
30BO	10/9/2015	14:09	-23,795,280	-46,034,940
31BO	10/20/2015	13:54	-23,778,121	-45,969,967
32BO	10/20/2015	14:32	-23,765,910	-45,920,698
33BO	10/20/2015	14:48	-23,755,333	-45,860,399
34BO	10/20/2015	14:55	-23,755,220	-45,858,173
35BO	10/20/2015	15:00	-23,757,176	-45,859,363
36BO	10/20/2015	15:34	-23,733,561	-45,866,367
37BO	10/20/2015	15:44	-23,724,334	-45,867,033
38BO	10/20/2015	15:22	-23,747,975	-45,864,980

Data collection represents the reality of the specific situation of the urban microclimate in different parts of the city of Bertioga, serving as a comparison in two seasons of the year, winter and spring. There were 76 data collection points on July 7th, 13th, 14th, and 15th of July 2015 (winter) and October 9th, 16th, and 20th (spring). The definition of dates and seasons is justified by seeking to collect data on days without rain and by the schedule proposed for this dissertation.

The air temperature and relative humidity information were used to calculate the Discomfort Index or Temperature and Humidity Index (ITU) by Giles (1990), in which the ambient temperature (Ta) is given in ºC. The relative humidity (RH) is given in percentage terms (%), as shown in the equation: ITU = Ta – 0.55(1-0.01RH) (Ta –14.5). Therefore, UTI values above 25 indicate discomfort, while values between 15 and 20 are considered pleasant, and from 21 to 24 increase discomfort values.[16]

Was used in a Principal Component Analysis, where the weights (loadings) showed the importance of the variables in the respective components, and the projections (scores*)* located the samples on the first two axes. The score values were also used in a Cluster Analysis to classify the most similar samples. Multivariate ordering and grouping analyses were carried out in the PAST program, considering the variables:

The temperature in °C is the air temperature at a specific point, which is the microclimate. The temperature difference in C° is between the maximum daily temperature of the meteorological history (source of history), considering this temperature as the macroclimate, and the maximum daily temperature of the point, considering the microclimate.

Relative humidity of the specific point in %

Wind, wind speed in m/s

Sine of the difference between two angles, one angle being the wind direction and the other the street direction, to discover whether the street channels the prevailing wind

Lux is the luminous intensity of the location in Lux

Noise, measuring the sound of the location in decibels

Building template, using the maximum gauge surrounding the point measured in floors.

The air temperature and relative humidity information were used to calculate the Discomfort Index or Temperature and Humidity Index (ITU) by Giles (1990), in which the ambient temperature (Ta) is given in ºC. The relative humidity (RH) is given in percentage terms (%), as shown in the equation: ITU = Ta – 0.55(1-0.01RH) (Ta – 14.5). Therefore, UTI values above 25 indicate discomfort, while values between 15 and 20 are considered pleasant, and from 21 to 24 increase discomfort values.[16]

The locations were chosen due to the ease of parking to take measurements in the main urban areas of the city (Figure 1). To study the environmental variability in the urban network points with different urban characteristics were chosen, such as proximity to bodies of water, places close to the seaside, types, sizes, vegetation coverage, urban density, places with verticalization, and grass. All these elements influence the microclimate, so comparing how each factor affects the city's microclimate is possible. Once the stitches were chosen during the winter, the same stitches were repeated during the spring.

All this information was compiled into a single table that is sorted (Principal Component Analysis - PCA). They have been transformed and correspond to a particular data point on a new principal component axis. Loadings: the weights (loads) show the values by which each variable must be multiplied to obtain the projections of the samples on the respective component axis main.

Results and discussion

Analyzing the environmental comfort of the city of Bertioga, data were collected at eighty points, fourth in the city of Santos, thirty-eight in the municipality of Bertioga during the winter, and another thirty-eight points also in Bertioga during the spring (Tables 1, 2 and 3).

Table 1 Climatic data was collected in winter in Bertioga, Brazil

Bertioga winter data										
points	**Diff temp (°C)**	**Temp macro(°C)**	**temp micro(°C)**	**UR (%)**	**lux**	**wind (m/s)**	**ang. vent (°)**	**Noises (DB)**	**template**	**ang. Road**
1BJ	2.5	20	22.5	72.2	19000	0.79	225	56.2	10	225
2BJ	5	20	25	63.5	19800	1.5	251	54.5	two	251
3BJ	7.3	20	27.3	74.2	480	0	-	52.8	0	-
4BJ	6.7	20	26.7	74.1	17600	0.9	181	52.9	two	181
5BJ	6	20	26	67.8	5510	0.26	260	53	two	253
6BJ	8.6	20	28.6	60.4	9590	1.2	270	51	two	270
7BJ	6.6	20	26.6	71	8120	0.82	98	57	1	183
8BJ	6.5	20	26.5	64.6	5340	0.52	66	62.6	6	32
9BJ	7.2	20	27.2	58.9	3390	0.03	187	61.5	10	187
10BJ	0	29	29	58.4	17000	0.72	295	53.1	two	345
11BJ	4.6	29	33.6	55.1	14400	0.66	36	51.6	two	63
12BJ	5	29	34	45.5	15800	1.18	191	68	two	245
13BJ	2.1	29	31.1	45.3	19500	2.21	340	67.4	two	340
14BJ	4.3	29	33.3	61.8	15600	0.39	46	69.6	two	209
15BJ	4.8	29	33.8	61.5	15600	3.62	303	63.6	4	303
16BJ	5.6	29	34.6	71	17200	1.6	200	52.8	two	200
17BJ	0.6	29	29.6	59.2	16640	1.25	292	53.9	two	292
18BJ	0.3	29	29.3	59.6	14440	0.03	170	54.5	two	340

Table 1 Continued....

Bertioga winter data										
points	**Diff temp (°C)**	**Temp macro(°C)**	**temp micro(°C)**	**UR (%)**	**lux**	**wind (m/s)**	**ang. vent (°)**	**Noises (DB)**	**template**	**ang. Road**
19BJ	0.2	29	29.2	62.5	19570	1.29	183	66.5	two	86
20BJ	9.1	29	38.1	23.6	19060	0.09	320	56.6	10	50
22BJ	6.6	29	35.6	23.7	19500	0.62	196	52.9	10	81
23BJ	6.1	29	35.1	24.9	19700	1.45	173	54.6	10	173
24BJ	7.2	29	36.2	23.1	16200	2.25	72	49.2	two	143
25BJ	5.6	29	34.6	26.5	18770	0.03	188	63.3	10	188
26BJ	7.7	29	36.7	28.6	5370	0.33	234	49.9	two	234
27BJ	5	29	34	26.4	16500	0.72	302	50.5	two	173
28BJ	6.3	29	35.3	26.1	15940	0.39	232	49.2	1	251
29BJ	-0.8	27	26.2	69.7	142260	1.12	315	68.7	two	315
30BJ	0.5	27	27.5	64.5	18000	0.85	317	71	two	317
31BJ	1.4	27	28.4	59.7	18510	0.03	313	55.8	1	313
32BJ	2.5	27	29.5	59.1	17070	0.49	85	53.1	two	136
33BJ	3.4	27	30.4	71.1	18400	two	350	53.2	two	350
34BJ	5	27	32	66	13120	0.49	272	54.8	two	272
35BJ	4.8	27	31.8	61.8	13530	0.16	288	66.5	two	288
36BJ	3.5	27	30.5	59	13900	0.36	13	65.2	0	4
37BJ	2.5	27	29.5	63.1	8910	0.33	93	64.7	two	16
38BJ	1.9	27	28.9	71.3	4770	0.89	7	65.7	two	7

Table 2 Climatic data was collected in spring in Bertioga, Brazil

Primavera Bertioga data										
points	**Diff temp (°C)**	**Temp macro(°C)**	**temp micro(°C)**	**UR (%)**	**lux**	**wind (m/s)**	**ang. vent (°)**	**noises (DB)**	**template**	**ang. Road**
1BO	4.2	29	33.2	35.3	18700	0.13	90	58	10	225
2BO	6.5	29	35.5	43.9	11650	0.46	232	56.4	two	251
3BO	6.6	29	35.6	40.8	1090	0		53.4	0	-
4BO	7.6	29	36.6	35.2	121400	0.19	20	52.5	two	181
5BO	0.4	36	36.4	46.6	18880	0.23	47	51.9	two	253
6BO	-7.1	36	28.9	61.3	18390	1.12	52	57.1	two	270
7BO	-4.5	36	31.5	53.1	12700	1.35	327	57.1	1	183
8BO	-0.5	36	35.5	51.8	17030	1.23	341	59.2	6	32
9BO	-0.1	36	35.9	56.8	19940	0		57.9	10	187
10BO	4.8	29	33.8	40.6	17890	0.33	353	52.1	two	345
11BO	5.6	29	34.6	39.5	12640	0.16	256	55.1	two	63
12BO	-4	36	32	60.1	15710	1.47	5	65.5	two	245
13BO	-3.8	36	32.2	53.4	19780	0.72	248	69.9	two	340
14BO	-3.2	36	32.8	47.8	15710	1.5	325	66.7	two	209
15BO	-0.3	36	35.7	52.9	16310	0.03	292	78.8	4	303
16BO	0.1	36	36.1	57.9	14390	1.26	16	58.8	two	200
17BO	-1.9	36	34.1	46.1	17060	1.18	61	57.1	two	292
18BO	-1	36	35	59	19810	1.74	320	55.2	two	340
19BO	-1.2	36	34.8	58.6	16990	3.44	316	57	two	86
20BO	5.6	29	34.6	51	9500	1.47	254	59.4	10	50
22BO	5.8	29	34.8	37.3	12880	0.62	132	61.7	10	81
23BO	7.8	29	36.8	35.5	11030	1.74	242	58	10	173
24BO	5.4	29	34.4	38.6	16000	1.02	277	56.1	two	143
25BO	1	36	37	49.5	18160	0.59	258	58.5	10	188
26BO	0.1	36	36.1	58.2	8600	0	-	51.7	two	234
27BO	-2.3	36	33.7	48.1	12080	0	-	49.1	two	173
28BO	-2.1	36	33.9	55	16880	1.82	347	48.4	1	251
29BO	5.8	29	34.8	42.5	16800	2.5	270	56.1	two	315
30BO	7.8	29	36.8	34.8	15560	0.19	302	53.1	two	317
31BO	-0.6	36	35.4	52.3	5820	0	-	55.5	1	313
32BO	-1.5	36	34.5	35.2	19790	0	-	50.1	two	136
33BO	-two	36	34	61.7	16470	1.19	0	46.01	two	350
34BO	-2.6	36	33.4	56.5	19970	1.12	30	42.8	two	272
35BO	-0.5	36	35.5	67.6	18510	1.18	84	65.7	two	288
36BO	-1.9	36	34.1	46.5	18500	0.85	128	74.5	0	4
37BO	0.4	36	36.4	51.5	15150	0		36	two	16
38BO	-1.3	36	34.7	53.2	11200	2.59	320	54	two	7

Table 3 Temperature and humidity index (ITU) from Bertioga

Winter		Spring	
points	**ITU**	**points**	**ITU**
1BJ	21.28	1BO	26.55
2BJ	22.89	2BO	29.02
3BJ	25.48	3BO	28.73
4BJ	24.96	4BO	28.72
5BJ	23.96	5BO	29.97
6BJ	25.53	6BO	25.83
7BJ	24.67	7BO	27.11
8BJ	24.16	8BO	29.93
9BJ	24.33	9BO	30.82
10BJ	25.68	10BO	27.49
11BJ	28.88	11BO	27.91
12BJ	28.15	12BO	28.16
13BJ	26.11	13BO	27.66
14BJ	29.35	14BO	27.55
15BJ	29.71	15BO	30.21
16BJ	31.39	16BO	31.1
17BJ	26.21	17BO	28.29
18BJ	26.01	18BO	30.38
19BJ	26.17	19BO	30.18
20BJ	28.18	20BO	29.18
22BJ	26.75	22BO	27.8
23BJ	26.59	23BO	28.89
24BJ	27.02	24BO	27.68
25BJ	26.47	25BO	30.75
26BJ	27.98	26BO	31.13
27BJ	26.11	27BO	28.22
28BJ	26.85	28BO	29.1
29BJ	24.25	29BO	28.38
30BJ	24.96	30BO	28.8
31BJ	25.32	31BO	29.92
32BJ	26.13	32BO	27.37
33BJ	27.87	33BO	29.89
34BJ	28.73	34BO	28.88
35BJ	28.17	35BO	31.76
36BJ	26.89	36BO	28.33
37BJ	26.46	37BO	30.56
38BJ	26.63	38BO	29.5

In the case of the first Principal Component (PC1), the variables with the most significant weight were temperature, relative humidity, and the difference between the temperatures of the region (macro) and local (micro). In the second component (PC2), the most crucial element was Lux, the difference between temperatures and wind speed. From this, the projections (scores) of the samples were gathered on the first two principal axes and used for a cluster analysis. Obtaining the dendrogram as a result, with a correlation coefficient of 0.873, using the Chord similarity index, a cut line was drawn in this graph, and groups with similar characteristics were identified and enumerated.

Moreover, the projection of the axes on the principal component (Figure 2), where the same groups were found, tries to identify and characterize the similarities. The Dendrogram (Figure 3) with a cutoff line in height close to 0.4 gives rise to twelve subgroups with similar characteristics, and three large groups that involve the twelve, found when characterized by the subgroups and showing similarities:

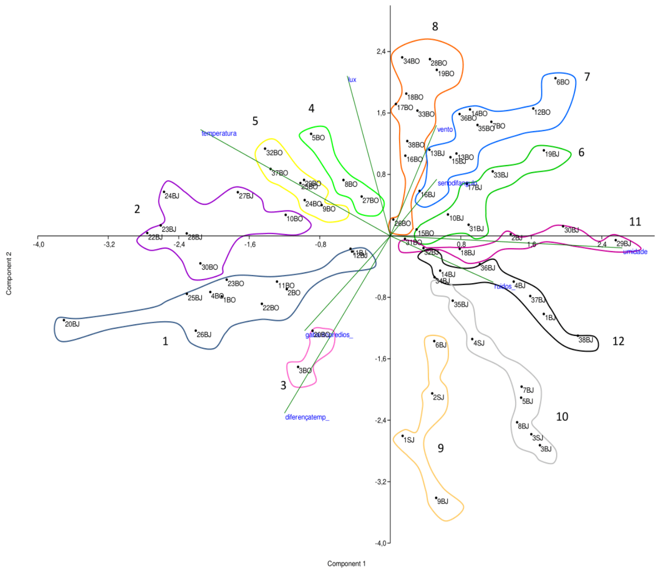

Figure 2 Sample projections on principal components axes.

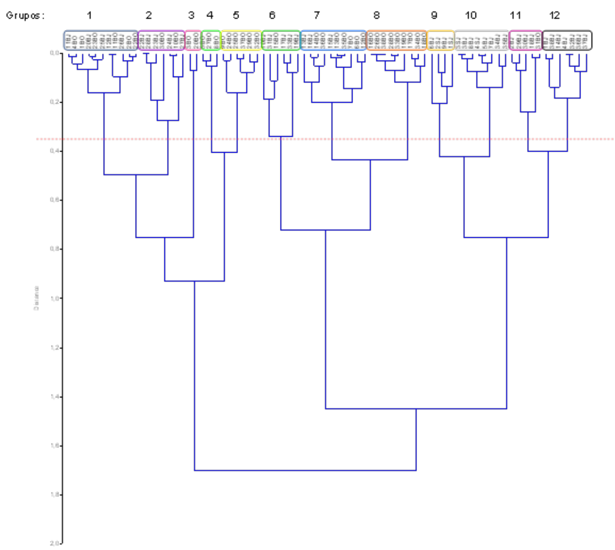

Figure 3 Dendrogram showing grouped sampling stations according to their scores in the principal axes.

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The first large group was the one with high temperature, the difference between high micro and macro temperatures, and streets that do not channel the wind, involving subgroups 1, 2, and 3. Group 01 presented characteristics such as differences between high macro and micro temperatures, high temperature micro high, low humidity, light wind, streets with non-channelized wind, and high light intensity, with only one place that presented low Lux, 26BJ, it is a place with dense and preserved vegetation, thus protecting the place from the Sun, being the third place with the highest temperature difference compared to the temperature recorded in history, is located in the neighborhood of São Lourenço (26BJ), at the entrance to a virgin beach with few buildings around the collection area and well-preserved natural vegetation.

Vegetation contributes to the establishment of microclimates; a row of trees can reduce wind speed by 63%, and vegetation helps to reduce air temperature;[17] we can notice adverse effects of vegetation: trees block the wind. In native forests or green massifs, cooling does not occur; on the contrary, the temperature in the microclimate of these areas is more stable (warmer in winter).

Despite the power of vegetation to lower the temperature, in the native forest, the wind does not have the opportunity to flow, being blocked by the large mass of vegetation, thus not achieving its cooling function. Ideally, vegetation should only be used separately in urban planning in a hot climate. According to the World Health Organization, it recommends 12m² of green area per inhabitant.

However, as it is a well-preserved environment of natural vegetation with few buildings and not an urban area, the blocking of the wind by the vegetation makes the microclimate of the place hotter as it does not facilitate the circulation of the wind, forming a barrier against the sea breeze. -land, typical of the coast, during the day, the land heats up more quickly than the water, and the air, when ascending from the coldest region to the hottest, will circulate the sea breeze in the sea-land direction. At night, this direction will be reversed, as the water, taking longer to cool down than the land, will be momentarily warmer, generating a land-sea breeze.[18]

The area is devoid of paving, but it has low humidity. All points are in the middle region of Bertioga. Only two points in this group channel the wind, although ventilation in the majority of group 01 is weak; these points are 26BJ and 25BJ, one at an entrance to the beach and the other on an avenue connected to the beach. The other points have in common some barrier preventing good wind circulation in the area, for example, at point 20BJ, the place with the most significant difference between micro and macro temperatures, in the Riviera de São Lourenço neighborhood in module 6, close to the beach in a roundabout surrounded by buildings with ten floors and with light wind coming from a different angle to the direction of the street, perpendicularly, forming inadequate ventilation for that area. The buildings act as a barrier against the prevailing wind from the beach, which forces the sea breeze to circulate in a sea-to-land direction during the day.

The relief helps as an element that modifies the climate; in general, the topography of Bertioga is flat, but the buildings can obtain the same function as at the study point. We can observe a different microclimate from the macroclimate, just behind a barrier of buildings, as it would work in the case of a mountain or a natural barrier. Affecting the location's temperature, in addition to the genuine difference in solar radiation received by slopes with different orientations, a rugged relief can constitute a barrier to winds, often modifying humidity and air temperature conditions concerning the regional scale[7].

Constructions can also be considered relief formation, as they achieve the same function for climate change by forming microclimates, whose barriers impact thermal comfort. They also interfere with the actual masses of buildings that modify the natural course of the winds, damaging natural ventilation within the urban core. The combined effects of elevation and orientation can produce spectacular climate anomalies.[17] Another common characteristic in the group is the layout of the streets parallel to the beachfront, preventing the circulation and channeling of the sea breeze, making the places hotter and drier. The roundabout of module 7 in the Riviera neighborhood, located in front of the sea, point 22BO, has an open field and allows wind passage. However, the absence of vegetation does not allow cooling and humidification, being more open to the incidence of sunlight, thus making the place hotter and drier.

In addition to having the two places with the biggest difference between temperatures in the winter season, 20BJ and 26BJ, group 01 also has the two biggest differences between temperatures in spring (points 4BO and 23BO), places that also had a big difference during winter. These are points in the Riviera neighborhood (4BO in module 26), located in the middle of a street that does not channel wind as it is on a curve surrounded by green masses, which reduces the wind speed beyond the position of the street and being away from the beach. Point 3BO, also far from the beach, is close to a large urban development with high levels and paving that produces greater area heating. The urban fabric absorbs heat during the day and reradiates it at night, adding the heat produced by machines and men concentrated in small spaces on the earth's surface.[4]

Verticalization is today considered an optimization of land use, rationalizing housing costs, minimizing distances traveled and increasing safety. Nevertheless, on the other hand, verticalization causes overload on infrastructure, waterproofing of soils, and an increase in the area exposed to radiation, thus increasing the temperature and causing a heat island.[19]

On the other hand, the shading effect of buildings reduces insolation and increases humidity, causing the proliferation of fungi and an increase in respiratory diseases, compromising comfort for residents. This phenomenon has also been changing the urban landscape without a judicious policy, with studies focused on the urban climate of each city.

The idea is four-story buildings, as suggested in some countries such as France, to balance the macroclimate while also maintaining a reasonable distance from each other; according to research by the WHO,[9] from this point onwards, psychological problems are increasingly detected.[20] Doctors say that children who live in large buildings tend to have less-than-desirable muscle development, paleness, and aggression.[21]

Group 02 presented characteristics, like group 01, such as micro high temperature, differences between macro and micro high temperatures, low humidity, high light intensity, streets that do not channel the wind, and slightly stronger wind.

Only point 23BJ, located in the Riviera neighborhood, had a street channeling the wind, as it is an avenue and has a direct connection with the beach, being in a perpendicular direction with the sea line. Most of the streets in this group are perpendicular to the sea or the mountains, with most of the group's points located in the middle region of Bertioga and a minority in the northern part.

It also has most points located in places further away from the beach. Only two closer areas and roundabouts, some already explained in the group above with an open field in its surroundings, 22BJ in the Riviera modulo Seven neighborhoods, and the other roundabout in Guaratuba in the condominium Costa do Sol, where the large amount of vegetation and houses prevents the passage of the wind necessary for the comfort of the place.

Also containing the difference between the highest macro and micro temperatures in the research carried out in the spring, point 30BO, which in winter had a slight difference in a place with large open spaces, as it is a new module in the Riviera neighborhood where there are only a few houses built, streets of unpaved sand, sand has a high thermal capacity and leaves the microclimate unstable. The absence of vegetation allows for an increased incidence of solar radiation and intense emissions from the soil.

Group 03, composed of only 2 points, is characterized by high temperature, high micro and macro temperature difference, average humidity, and low light intensity. This microclimate is considered hotter since they both have barriers against the wind, hindering cooling; both are in the Riviera neighborhood, one in a natural environment, 3BO, preventing the incidence of Sun and forming a barrier against the wind, the green massif. Moreover, the other anthropic, 20BO, formed a barrier of 10-story buildings, damaging insolation, and local ventilation, which, despite the stronger wind, resulted in a high difference in the temperature of the microclimate.

Next, the group of low templates and cooler temperatures, within them the subgroups 04, 05, 06, 07, and 08. Subgroup 04 has low and negative differences between the micro and macroclimate, considering these places have a cooler microclimate. Cooler than the macroclimate, high temperatures, average humidity, non-channeled wind, and low gauge. With the most diverse locations, one in each region of Bertioga, low temperatures are related to cooler microclimates and average humidity.

With all the data collected in spring, group 05 is characterized by most microclimate with a temperature closer to the macroclimate, high temperature, lower humidity, high light intensity, lower noise, and mostly lower gauges. We can then relate the low temperature to minor differences between macro and micro temperatures. All points in this group have green masses surrounding the site.

In group 06, most points were measured in winter and only one in spring, with low gauges, differences between low temperatures, low temperatures, high humidity, high light intensity, well-ventilated, and half of the streets channeling the wind. All points in this group are located very close to bodies of water, such as rivers, seas, and canals. The effect of any body of water on its immediate surroundings reduces extreme daytime and seasonal temperatures and has a stabilizing effect.[4] This is due to the low temperature of group 06 microclimates and high humidity.

With most of its negative differences, group 07 also features lower temperatures, high light intensity, good ventilation, low headroom, and loud noises. We can notice again how the template is related to cooler temperature differences, as it allows better ventilation passage, as shown in this group with solid ventilation compared to the other points in the study. This group has the highest negative temperature of the data collected in spring in Bertioga, 6BO. This location collected in winter was given the second temperature with the greatest positive difference from micro to macro, showing great temperature instability due to the densification in the area.

Group 08 includes all points measured during spring, has minor differences, and the majority are negative, that is, a microclimate with a similar temperature, also with a low gauge, well-ventilated (except point 26BO), little noise, and perpendicular streets. Once again, we observed the relationship between lower meters and a microclimate closer to the macroclimate or cooler. Point 26BO, being the only one without ventilation, is also the only one in the group with low light intensity, as it is a place with natural vegetation, more specifically in the São Lourenço neighborhood at the entrance to Itaguaré beach, which is a virgin beach, thus blocking the passage of wind and preventing the incidence of solar radiation, making the place darker.

The group with differences in high temperatures and low temperatures is composed only of a subgroup, 09, which is characterized by all points having been measured in winter, with a difference between high temperatures, low temperatures, higher humidity, streets channeling the wind, poor ventilation, louder noises, and increased feedback. The second most significant difference between temperatures (observed and recorded) in data collection during winter was found at the location (6BJ) located in the Indaiá neighborhood, in the middle of the urban fabric on a street parallel to the beach and the mountains, so even with poor ventilation and sparsely treed, with an urban fabric perpendicular to the direction of the prevailing wind, preventing it from being well distributed throughout the streets.

In general, vegetation tends to stabilize the effects of climate on its immediate surroundings, reducing environmental extremes. It plays a vital role in maintaining the city's thermal comfort, but due to urbanization, vegetation is scarce in many tropical towns.[17] There has often been a tendency to replace natural vegetation and permeable soils with impermeable surfaces such as asphalt and concrete, which raises the temperature to latent heat.[22] By replacing natural vegetation cover with buildings and paved streets, it changes the balance of the microenvironment. Also, street paving contributes to heating the area, reduces humidity, and causes the cooling effect produced by evaporation to be lost. Creating thermal disturbances due to differences between solar radiation received by built surfaces and the heat storage capacity of construction materials. Climate changes can be such that urban areas result in authentic Heat Islands; the cities themselves are heat producers. The replacement of natural vegetation cover by buildings alters the balance of the microenvironment, producing thermal disturbances due to the differences between solar radiation received by built surfaces and the heat storage capacity of construction materials. Two of the group's locations are in the city of Santos, the others in Bertioga, but all in very urbanized locations, with paved streets making the microclimate hotter and presenting louder noises.

The group with high humidity and low temperature, with cooler temperatures, involves subgroups 10, 11, and 12. Group 10 presents characteristics such as the difference between micro and macro temperatures, low temperature, high humidity, low light intensity, streets channeling the wind, lots of noise, and standard gauges. Although most groups that presented low gauges showed a difference between low temperatures, in this case, it was different thanks to the high density of real estate around most of the points, except point 3BJ, which is a natural environment. However, in general, group 10 is all inserted into the urban fabric, with paving everywhere, bringing instability to the temperature and heating of the microclimate.

In group 11, we notice little difference between temperatures, low temperature, high humidity, high Lux, streets channeling the wind, louder noises, and low building dimensions. The only record with a negative difference in temperature in the winter season was in module 18 in the middle of the Riviera de São Lourenço neighborhood, 29BJ, and even the measurement in the spring season obtained a low difference between micro and macro temperatures. Where there is an urban design composed of organic lines, in this area, there is a wide road in the direction of the beach, creating more robust and more channeled breezes compared to other points, making the place well-ventilated and with only houses up to 2 floors, making the passage of wind even easier. This spot is very humid and wooded, helping with the low temperature, as unlike a dense forest, ventilation flows and reaches greater speed. The site is devoid of paving, one of the elements responsible for the cooling effect produced by evaporation, generating greater thermal comfort in this area.

Most areas are unpaved, well-wooded, and with a low elevation; one point is a natural environment, facilitating local cooling. The main benefits of vegetation in hot climates are reduced solar radiation and air temperature due to shading and evapotranspiration.[23] Vegetation contributes to creating a microclimate, as the photosynthesis process helps humidify the air through water vapor. It helps to reduce air temperature, absorbs energy, and favors the maintenance of the oxygen and carbon dioxide cycle and air renewal. A grassy space, for example, can absorb more solar radiation and, in turn, radiate a smaller amount of heat than any built surface since a large part of the energy absorbed by the leaves is used for their metabolic process. In contrast, in other materials, all absorbed energy is transformed into heat.[4]

Finally, group 12 has minor positive differences: lower temperatures, high humidity, little wind, much noise, and low gauge. With all the data measured in winter, all locations within the urban fabric become well-ventilated due to the low gauge, except point 4BJ, which, even in spring, showed high differences.

Humidity influences the climate; for example, the drier it is, the higher the minimum and maximum temperatures will be. This phenomenon occurs because water particles suspended in the air can receive heat from the Sun and heat up and maintain their temperature.

Furthermore, these particles also function as a barrier to solar radiation that reaches the ground, and during the night, they trap the heat dissipated by the ground. In other words, soil in a dry climate receives greater solar radiation than soil in a humid climate. At night, the air temperature is lower than the ground's, causing the ground to enter thermal equilibrium and dissipating the heat stored during the day. If the air is humid, the water particles that held heat during the day will return heat and make it difficult to dissipate heat from the ground, causing part of the heat to be produced to the ground and another aspect to the atmosphere, thus variations day and night temperatures are lower. In a hot, dry climate at night, the soil can lose heat much more quickly due to the lack of water particles, presenting a greater thermal amplitude.[7]

According to the temperature and humidity index, none of the research locations were considered comfortable or pleasant; most obtained a value indicating discomfort and some obtained an increasing discomfort value. The places considered most uncomfortable, according to this environmental comfort index, were in Bertioga in winter at point 16BJ, which is in the Center, close to the Itapanhau River, with the ITU= 31.39 and the same place with the measurement taken in spring also obtained a high discomfort value (ITU= 31.10). As it is close to a river, we found humidity to be one of the highest in the entire survey, thus compromising the comfort of that location. However, the most uncomfortable point in the spring was point 35 BO, located in the Boraceia neighborhood, on the side of the highway, with ITU= 31.76. Also, it has air humidification sources very close, as well as at point 16BJ, such as water and vegetation, and it is a very open area, causing high humidity and discomfort in the environment.

The humid heat that is the case in the region to be treated is more uncomfortable because high humidity makes evaporation difficult, taking away the cooling effect caused by the evaporation of sweat.

Thermal comfort indices rely on a series of variables, for example, how the individual is dressed and whether they have health or acclimatization problems—considering that the environmental conditions that provide thermal comfort for inhabitants differ according to the local climate. Studies must determine thermal comfort conditions and the degrees of comfort or discomfort caused by cold or heat.[7]

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) considers the ideal (external) values in winter for the hottest climates in North America: a) Temperature of 25°C, varying between 23 and 27°C; b) Airspeed 0.5 m/s; c) Relative humidity between 30 and 70%; d) Average radiant temperature equal to the air temperature.[7] Despite not having an external comfort index for the Bertioga region and North America being considerably colder in winter, they prevent comparing these values.

According to this research, humidity values in Bertioga were within the standards of the North American region, with the temperature being warmer than in the North American winter. Thermal comfort indices seek to encompass, in one parameter, the joint effect of the variables.[7]

Many existing methodologies for studying climate and thermal comfort, among other names, have different objectives. The important thing is to add as much as possible to develop a study with more excellent information, aiming to help build urban and architectural projects to improve the quality of life of human beings.

The first studies on the influence of thermal conditions related to work performance were developed by the American Ventilation Commission in 1916, focusing on physical work with an interest in production, which arose with the Industrial Revolution and war situations when troops were deployed, for regions with different climates.[7] Gomes[4] differentiate between meteorological or climatic elements and climatic factors, attributing to the former the function of defining the climate and the latter the function of giving rise to or determining them. The climatic factors are solar radiation, atmospheric circulation, distribution of land and seas, soil relief, sea currents, and soil covering. And the elements of the climate: air temperature, wind regime, air humidity, cloudiness, and atmospheric precipitation.

Ferreira[4] define climatic elements as the physical components of the climate, mainly temperature, air humidity, precipitation, wind, and duration of sun exposure, varying under the action of several factors or causes. These elements are latitude, solar radiation, wind direction, distance from the sea, relief, vegetation, air masses, and others.

The lack of play between closed and open spaces is what most harms the ventilation of the city of Bertioga; the verticalization of the edges is mainly responsible for the impact on thermal comfort, altering the land-sea breeze, and the course of all the winds forming a kind of "anthropic relief." Buildings can constitute barriers against the Sun or wind; conversely, the urban environment favors precipitation due to solid particles suspended in the air, helping to bring water particles together and forming raindrops.

Detwyler[24] explains in his study about changes in the climate caused by urbanization and raises three main topics that change the climate: 1st) change in the physical surface of the earth due to dense construction and paving, making the surface impermeable, increasing its thermal capacity and roughness and, at the same time, altering the air movement; 2nd) increase in heat storage capacity with a decrease in albedo and; 3rd) emission of contaminants, which increase precipitation and modify the transparency of the atmosphere.

It is fully proven that the city has a higher temperature than its surroundings.[20] The heat island represents the most significant phenomenon of the urban climate, and its intensity depends on each city's local micro and microclimatic conditions.[25] In this study, topics 1 and 2 could be observed. To reduce this impact, architects and urban planners must plan a city, improving its environmental quality and respecting the natural resources of each location. Every town must have the help of an adequate master plan.

The study by Carvalho,[25] which investigated the hypothesis that Parque das Dunas operates in the urban climate of Natal, sought to understand how this influence occurs—showing the critical role of vegetation in the urban climate, presenting climate relief due to the presence of the park. As in the present study, we noticed cooler streets compared to the macroclimate where there was vegetation.

The study by Silva,[26] whose theme Bioclimatic Pathways: Environmental Performance of Public Roads in the City of Teresina – PI, presents the efficiency of vegetation in gaining environmental comfort in the road systems of the city of Teresina – PI, also proves the effect of climate relief in tree-lined streets, but as we observed in this study, areas with vegetation forming green masses or closing canopies prevent good local ventilation.

Rocha's[27] article deals with Urban Design, Climate, and Health in São José do Rio Preto. In this research, the author concludes that in São José do Rio Preto, urban densification and lack of afforestation cause heat islands and a drop in relative air humidity. As in Rocha's article, we noticed the same thing happening in the present work: the streets were not tree-lined, in places with greater urban density and more vertical.

The objective of the work by Tabalipa,[28] on the Climate Study of the Municipality of Pato Branco. It was to characterize the climate to assist in drafting land use and occupation laws. Just like the Tabalipa study, this study can assist in municipal land division laws, helping to improve the impact on the region's climate due to a climate characterization that was possible to observe.

According to the study by Borges,[29] on the Influence of the Built Environment on the Urban Microclimate. He sought to survey the campus of the Federal University of Santa Catarina and concluded that vegetation plays a significant role in the formation and mitigation of the heat island; in this study, we could see that vegetation in urban areas makes the environment cooler.[30]

The impact of changes in a building's CPS on natural ventilation depends on several factors. The greater the speed of the wind affecting the structure, the clearer the surroundings and the larger and more numerous the openings, the greater the natural ventilation due to the wind and consequently the greater the natural ventilation.[31]

In the architectural design, the effect of natural ventilation due to the action of the wind resides in the positioning of the openings depending on the areas of high and low pressure on the facade, which makes it possible to make better use of this comfort strategy.[32–35] The natural ventilation project must be able to observe and take advantage of the areas of most significant pressure or create them, as necessary, with alternative facade design, envelope elements, or even taking advantage of the surrounding surfaces/buildings. A small hole was made for each pressure point in the model, where the catheter was introduced - a small diameter plastic hose (+/- 1.5mm) was used to connect the pressure point to the pressure sensors placed outside the wind tunnel. Connections must be made carefully to avoid leaks. Identifying each hose with the pressure tap number is essential to obtain each face's measured points and values accurately.[36,37]

The climate is drier during spring and wetter during winter. Streets perpendicular to the seafront channel the wind better. Overall, in winter, the microclimate was warmer than the macroclimate, and in only one situation, the micro-temperature presented negative values about the macroclimate. In spring, half of the micro temperatures had negative, and half had positive differences than the macro temperature. The microclimate in natural environments is warmer, with more significant differences and humidity. The vegetation forms green masses, which block the wind and make the microclimate hot. It does an uncomfortable temperature and humidity index at all points. Bertioga would have a master plan that contributes to constructing spaces to produce a comfortable microclimate. The ideal design for the Bertioga region would be with low levels and curved streets, avoiding streets parallel to the coast, allowing wind passage and better city ventilation. Riviera is considered the most suitable neighborhood for thermal comfort, as it has curved roads allowing good ventilation, erring on the size of tall buildings (10 floors), especially in front of the beach, blocking the sea-land breeze.

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None

Conflicts of interest

The authors declare that there are no conflicts of interest.

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