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Heat and Human Comfort in a Town in Brazil's Semi-arid Region

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Abstract: The aim of this study was to assess the evolution of registered air temperatures in the town of Caicó, Rio Grande do Norte, Brazil, over a fifteen-year period (from 1996 to 2010), analysing the heat susceptibility of the local inhabitants through the human comfort indices for the same period. In order to discuss the relationship between the temperatures and the issue of human thermal comfort in Caicó, three indices of human thermal comfort were applied: Discomfort Index (DI), the Effective Temperature taking wind velocity (ETv), and the Universal Thermal Climate Index (UTCI). We found that in Caicó the air temperature is naturally very high, with daily means circa 30°C, maximum temperatures ~35°C and minimum temperatures around 24°C, putting Caicó at the limit of the human comfort zone almost year round. Even though temperature changes were not detected in the studied fifteen-year period, the thermal indices show us that Caicó experienced thermal stress due to heat each of the studied years(1996–2010), and it is only in the winter time—in July, August, and September—that Caicó has no thermal stress. We also verified a lack of compatibility between the construction materials used in the buildings, urban forestry, and the town's climatic reality in Caicó city. This situation could be exacerbated in the future if air temperatures rise due to global warming, bringing risks to the local inhabitants.

Keywords: Brazil's Semi-arid Region, Air Temperatures, Human Comfort Indices

Introduction

According to the future climate scenario projections published by the Intergovernmental Panel on Climate Change, global temperatures could rise 4.8°C by 2100 (IPCC 2013). The prognosis for Brazil's semi-arid region is that there will be a 3°C increase in summer temperatures in the same period (Marengo et al. 2011). Projections of these kinds must be appraised very carefully in places that are naturally hot, such as the area between the tropics. Another process that is just as important as climate change and global warming is globalization, which has produced and continues to disseminate architectural designs that are inappropriate for places where the temperature is naturally high, as is the case in much of Brazil, where poorly planned urban developments little suited to the local climate have triggered temperature increases as soil and vegetation have been replaced by construction materials that store more thermal energy (Oke 1996; Monteiro and Mendonça 2003; Bittencourt 2010)

In an increasingly urbanized world, transformations have been seen in land uses in many places, altering the balance of local radiation and tending to raise temperatures, causing the phenomenon known as "heat islands" inside urban agglomerations. According to Taha (1997), these have been recognised and documented since the early twentieth century, on different scales, and have different effects depending on the various interactions between the local climatic conditions, thermo physical conditions, and geometric configurations of the built-up areas. He adds that in low latitude regions, heat islands are not normally welcome because they can exacerbate thermal discomfort (Monteiro and Mendonça 2003).

Not only are the building materials used and the forms of the buildings often completely inappropriate for the climate, but the urban development projects often fail to take the local topography and urban forestry into account (Barbirato 2010). Many Brazilian towns and cities, like our current study site, have few street trees while those that they have are overpruned,

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heightening thermal discomfort in certain parts of these urban areas. Human thermal discomfort takes place when "physiological reactions to thermal stress include changes to the metabolism, dilation and contraction of blood vessels, faster or slower heart rate, sweating, and others" (Santos and Melo 2011, 154). The use of low-albedo materials and the lack of trees are factors that are strongly implicated in increasing the discomfort and even affecting the health of people living in these places (Sette and Ribeiro 2011).

In view of these circumstances, the main objective of this study was to analyse the behaviour of temperatures in the municipality of Caicó in the state of Rio Grande do Norte (in Brazil's semi-arid region) analysing the heat susceptibility of the local inhabitants through human comfort indices scientifically recognized. The human thermal comfort indices—despite being climatic classifications with subjective characteristics involving questions linked with human perception—is used by several meteorological services around the world and can be easily measured by users to describe the potential heat condition and thermo-regulation processes by which people are subjected (Winslow, Herrington, and Gagge 1937; Blazejczyc 2012). These indices are very important to climatic, health, urbanistics, and architecture studies; however, they are complex due to the implicit subjectivity. These indices represent, in a single parameter, the combined effect of two or more climatic variables (ASHRAE 2009).

According to Blazejczyc (2012, 515): "Throughout the last century there has been much active research on how to define thermal comfort and how to grade thermal stress. These efforts have resulted in various models attempting to describe thermal comfort and the resultant thermal stress. A large number of indices have been proposed, which are (or were) in use throughout the world [about 40 indices were listed by Epstein and Moran (2006) and there are many others]."

In this work, we chose the most user-friendly indices, that consider only meteorological variables, such as the Discomfort Index (DI), Effective Temperature with wind (ET*v*), and Universal Thermal Climate Index (UTCI). They were used by many scientists in the area, DI by Matzarakis and Mayer (1991), Moran and Epstein (2006), Yousif and Tahir (2013), Ongoma and Muthama (2014), Polydoros and Cartalis (2015); ET*v* by Suping et al. (1992), Makokha (1998), Nedel et al. (2006), Blazejczyk (2012); and UTCI, studied more recently by Jendritzky et al. (2012), Abdel-Ghany et al. (2013), and Bröde et al. (2014).

In an increasingly urbanized world, the human comfort climate indexes should be used more often and improved to infer the thermal situation of cities with respect to human comfort and quality of life of the population.

Location of the Study Area

The municipality of Caicó is in the northeast of Brazil (Figure 1.a) in a low-latitude zone (6° 27' 30" south and 37° 05' 52" west). The mean altitude is 161 meters, giving it very peculiar characteristics such as high radiation rates and high temperatures all year round. It covers 1,229 km^2 (BRASIL 2013a) and is the most important municipality in the Seridó region because of the relative strength of its commerce, livestock farming, large-scale festivities, number of educational establishments, etc. It has an estimated population of 63,000 (BRASIL 2013b). Caicó has a better human development index (HDI)—0.750—than other municipalities in the semi-arid region, where the average HDI is around 0.650 (Santana 2007).

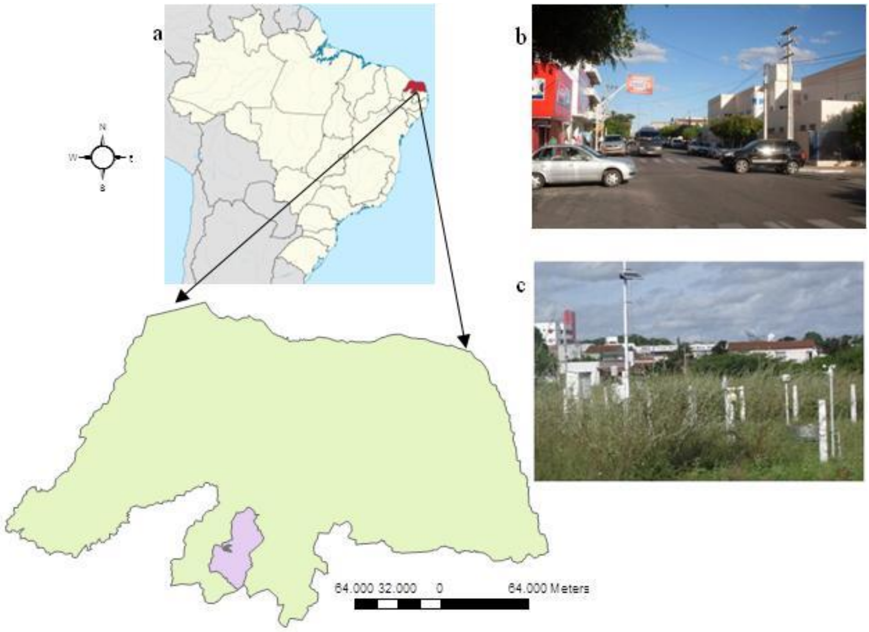

Figure 1: a) Map Showing the Location of Caicó in Brazil, the Borders of the State of Rio Grande do Norte, the Municipality and the Urban Area; b) Coronel Martiniano Avenue; c) Seridó Weather Station
Source: Research Data

Methodology

In order to discuss the relationship between the temperatures and the issue of human thermal comfort in Caicó, field studies were done that involved taking photographic records and applying three scientifically recognized indices of human thermal comfort: Discomfort Index (DI), Effective Temperature taking wind velocity (ET*v*), and Universal Thermal Climate Index (UTCI). To analyse the temperatures in Caicó, and how these affect the comfort of the local people, the following methodological procedures were adopted.

First, the meteorological variables to be analysed were selected: air temperature, relative humidity of the air, and wind speed. This information was gathered from the database run by the Brazilian meteorological institute (Instituto Nacional de Meteorologia do Brasil) (INMET 2009; 2012) and the Seridó weather station in Caicó, also managed by INMET. A fifteen-year time series was used (1996–2010) since the Seridó weather station only has complete data as of 1996.

Having gathered the data, an analysis of annual (month by month) and interannual variations in the maximum and minimum air temperatures was begun by preparing the climate normals. As such, the averages calculated were “provisional normal,” which, according to the WMO, can be based on observations over a period of at least ten years (WMO 1989, cited in Oliveira and Vecchia 2010).

Having obtained the maximum and minimum air temperatures, we calculated the mean (x), standard deviation (S), coefficient of variation (CV), and trend using the angular coefficient of the estimated regression line. The trend lines were prepared using the estimated equation (Formula 1):

$$\hat{Y} = b_0 + b_1 X_i \quad \text{, (f.1)}$$

where $\hat{Y}$ is the estimated temperature dependent variable, b_0 is the estimated linear coefficient of the line, b_1 is the estimated angular coefficient of the line, and X_i is year “i,” where “i” varies from 1996 to 2010 (time period over which temperatures were studied). Linear regression is a statistical method that identifies trends in data and analyses forecasting problems. It is widely used in climate research, such as Gonga et al. (2004), Ren Zhou (2011), and White-Newsome et al. (2012). Using the formulas, tables and graphs were prepared to identify the annual and interannual temperature variations in the municipality of Caicó, Rio Grande do Norte, Brazil, with the software Microsoft Excel 10.0 for data analyses.

In order to assess human thermal comfort in the Caicó climate, we chose three indices that have been used in a several works around the world with satisfactory results and published in national and international journals: Heat Stress, or Discomfort Index (DI, Formula 2), Effective Temperature taking wind velocity (ET*v*, Formula 3), and Universal Thermal Climate Index (UTCI), which was calculated directly by the site "UTCI calculation" (Wojtach 2014).

For the DI and TE*v*, we used the following equations:

$$DI = T - 0.55(1\text{-}0.01RH)(T - 14.5)$$ (formula 2), (Matzarakis and Mayer 1991)

Where DI is the discomfort index in (°C), T is the dry bulb temperature (°C), and RH is relative humidity (%). This gives the thermal discomfort index (DI), which is classified into the following categories.

Table 1: Categories of Thermal Discomfort Index

DI (ºC)	**Level of Thermal Discomfort**
DI < 21.0	no discomfort
21.0 ≤ DI < 24.0	under 50% of the population feels discomfort
24.0 ≤ DI < 27.0	around 50% of the population feels discomfort
27.0 ≤ DI < 29.0	most of population feels discomfort
29.0 ≤ DI < 32.0	everyone feels severe heat stress
DI ≥ 32.0	state of medical emergency

Source: Matzarakis and Mayer 1991

$$ET_v = 37-(37\text{-}T)/[0.68-0.0014RH+1/(1.76+1.4v0.75)]\text{-}0.29T(1\text{-}RH/100)$$ (formula 3), (Suping et al. 1992)

Where ET*v* is effective temperature as a function of wind speed, air temperature, and relative humidity; T is dry bulb temperature (°C); RH is relative humidity (%); and v is wind speed (m/s) (Suping et al. 1992).

The ET*v* values were divided into the following categories.

Table 2: Categories of ET*v* Values

ET (°C)	Thermal Sensation	Degree of Physiological Stress
ET < 5	very cold	extreme cold stress
5 ≤ ET < 10	Cold	extreme cold stress
10 ≤ ET < 13	moderately cold	Shivering
13 ≤ ET < 16	quite cool	cooling of the body
16 ≤ ET < 19	slightly cool	slight cooling of the body
19 ≤ ET < 22	Mild	contraction of blood vessels
22 ≤ ET < 25	Comfortable	thermal neutrality
25 ≤ ET < 28	Warm	slight sweating, dilation of blood vessels
28 ≤ ET < 31	quite hot	Sweating
31 ≤ ET < 34	Hot	profuse sweating
ET > 34	very hot	thermoregulatory failure

Source: Souza and Nery 2012

By using Wotjach's (2014) UTCI Calculator, we have the following result of the equivalent temperature:

Table 3: UTCI Equivalent Temperature

UTCI (°C)	Level of Thermal Comfort
0 – 10	Slight cold stress
10 ≤ UTCI < 26	No thermal stress
26 ≤ UTCI < 32	Moderate heat stress
22 ≤ UTCI < 38	Strong heat stress

Source: Bröde et al. 2014

The human comfort indices were calculated in an annual and monthly period from 1996 until 2010, where we analysed the annual and monthly mean for each index.

Results And Discussion

Temperature Analysis (1996–2010)

The northeast of Brazil has high temperatures almost all year round, with a few exceptions where the elevation is higher (Ab'saber 2003). Caicó is in the north of Brazil's northeast region (Figure 1). The altitude is low, it is about 200 km from the sea, and it has some of the highest temperatures in Brazil, which already has a predominantly hot climate, except in the south and southeast. The time series analysis from 1996 to 2010 showed that in the municipality of Caicó, temperatures are naturally very high in almost every month of the year (Table 4, Figure 2), with an average temperature of ~30°C, an average maximum temperature of ~35°C, and an average minimum temperature of ~24°C.

Table 4: Mean, Standard Deviation, and Coefficient of Variation of the Maximum and Minimum Air Temperatures, Caicó, Provisional Climate Normals, 1996–2010

Caicó/RN	**month/year**	**Mean_Max**	**StandDev**	**CoefVar**	**CoefVar (%)**
Max_Temp	**Jan**	**36,02**	**1,294**	**0,036**	**4%**
Max_Temp	Feb	36,02	1,294	0,036	4%
Max_Temp	Mar	35,49	1,365	0,038	4%
Max_Temp	Apr	34,56	1,306	0,038	4%
Max_Temp	May	33,96	1,482	0,044	4%
Max_Temp	Jun	33,54	1,319	0,039	4%
Max_Temp	Jul	32,89	1,329	0,040	4%
Max_Temp	Aug	32,97	0,605	0,018	2%
Max_Temp	Sep	33,78	0,539	0,016	2%
Max_Temp	Oct	35,49	0,643	0,018	2%
Max_Temp	Nov	36,86	0,789	0,021	2%
Max_Temp	Dec	37,23	0,353	0,009	1%
Max_Temp	Year	34,90	1,026	0,030	3%
Caicó/RN	**month/year**	**Mean_Min**	**StandDev**	**CoefVar**	**CoefVar (%)**
Min_Temp	Jan	25,73	2,333	0,091	9%
Min_Temp	Feb	25,49	2,199	0,086	9%
Min_Temp	Mar	24,86	1,836	0,074	7%
Min_Temp	Apr	24,27	1,321	0,054	5%
Min_Temp	May	23,83	1,246	0,052	5%
Min_Temp	Jun	23,37	1,519	0,065	6%
Min_Temp	Jul	22,93	1,730	0,075	8%
Min_Temp	Aug	23,33	2,248	0,096	10%
Min_Temp	Sep	24,27	2,319	0,096	10%
Min_Temp	Oct	24,83	2,373	0,096	10%
Min_Temp	Nov	25,89	2,395	0,093	9%
Min_Temp	Dec	26,33	2,556	0,097	10%
Min_Temp	Year	24,59	2,006	0,081	8%

Source: Research Data

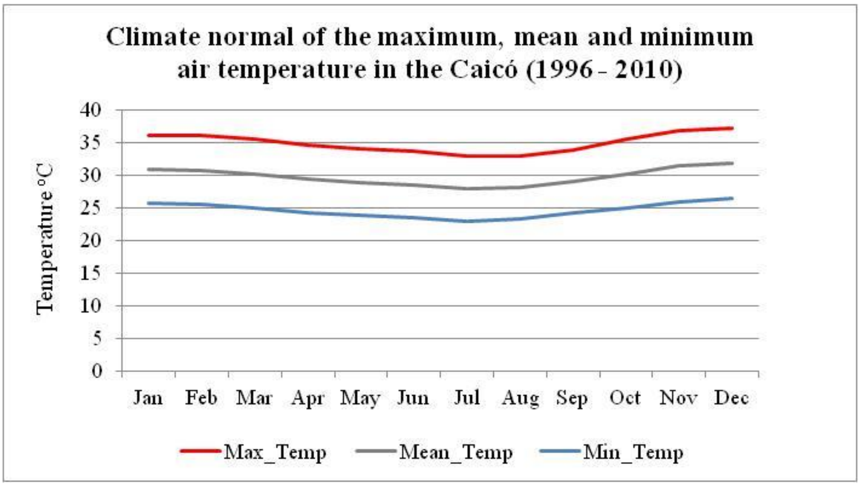

Figure 2: Graphic Representation of the Maximum, Mean, and Minimum Air Temperature in the Municipality of Caicó (1996–2010)
Source: Research Data

In Caicó, annual temperature differences are very subtle, and it does not really have a cold season; as Ayoade (2007) explains, there is no winter in this part of the globe. The highest temperatures are between November and March, which is part of the dry season and when the mean temperatures the highest. The lowest temperatures are between June and September, when it is winter in the southern hemisphere. This pattern applies to the maximum, mean, and minimum temperatures. Another finding was that the maximum and minimum temperatures did not vary much over the period studied, although the minimum temperature did oscillate more. These data can be seen using the coefficient of variation (Table 4).

No upward or downward trend was identified in the interannual temperature variation. Despite the IPCC's statement that average temperatures could rise by 3°C this century in Brazil's semi-arid and northeastern regions, the temperature data are flat, and the angular coefficient of the regression line is statistically zero, showing that the maximum and minimum temperatures have remained practically constant, although there is more oscillation in the minimum temperatures (Figures 3 and 4).

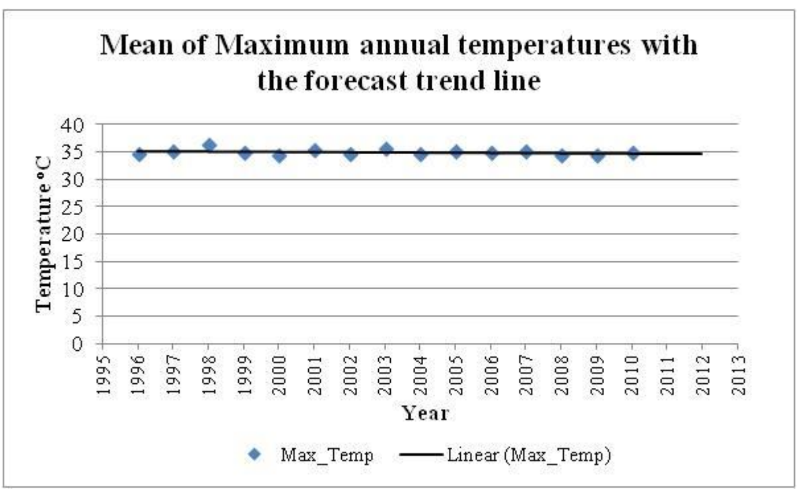

Figure 3: Maximum Annual Temperatures for the Municipality of Caicó (1996–2010) with the Forecast Trend Line
Source: Research Data

The minimum temperatures oscillated more than the maximum temperatures in the interannual comparison. This can be seen in Figures 3 and 4 and Table 4, where the coefficient of variation was 3% for the maximum temperatures, but 8% for the minimum temperatures. The regression analysis yielded an estimated straight line almost parallel to the horizontal axis, which was not statistically significant, as was the case of the maximum temperature line (Figures 3 and 4). The lowest annual minimum temperatures (below 25°C) were recorded in 1999, 2000, 2002, and 2010.

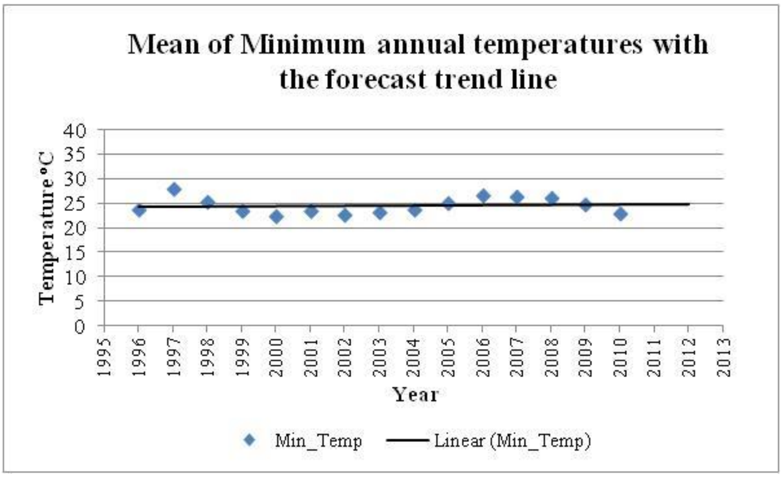

Figure 4: Graph of the Minimum Annual Temperature for the Municipality of Caicó (1996–2010) with the Forecast Trend Line
Source: Research Data

Temperatures and Human Thermal Comfort

Based on the climate data for Caicó used to calculate the provisional normals for the fifteen-year period from 1996 to 2010, three thermal comfort indices were calculated—DI, ET*v*, and UTCI. The results of the annual mean temperature for the period in question were as follows: a DI according to which "most of the population suffers discomfort," an ET*v* that is a "warm climate, inducing sweating and the dilation of blood vessels," and a UTCI that "moderate heat stress." Table 5 shows the qualitative and quantitative results for Caicó city.

Table 5: The Annual Mean to Human Comfort Indices DI, Et*v*, and UTCI in Caicó, Based on the Time Series for 1996–2010 in Caicó, Brazil.

Human Thermal Comfort Indices	**Caicó (1996–2010)**
DI Discomfort Index	28.44—most of the population feels discomfort
ET*v* Effective Temperature	27.13—warm, sweating, dilation of blood vessels
UTCI Universal Thermal Climate Index	28.05— Moderate heat stress

Source: Research Data

The human thermal comfort indices were also applied for each month of the year for the period in question, and the monthly mean showed that, annually, in Caicó months with thermal stress due to the heat prevail. Figures 5, 6, and 7 depicts graphics of the average behaviour for each month of the year according to DI, TE*v*, and UTCI.

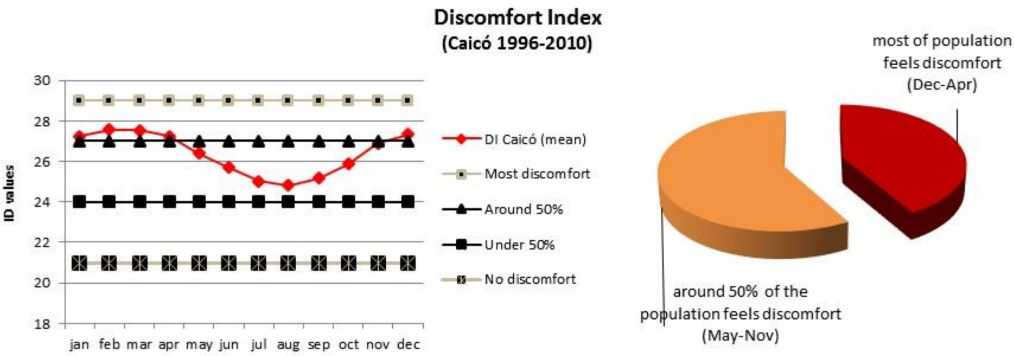

Figure 5: Graphic Representation of Annual Human Comfort by Discomfort Index in the Municipality of Caicó (1996–2010)
Source: Research Data

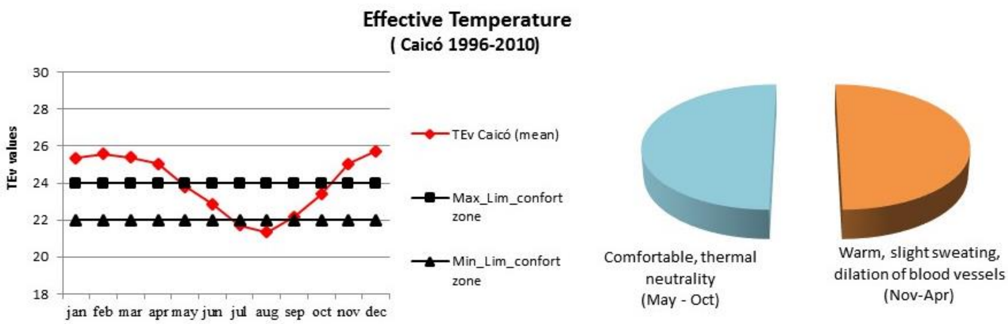

Figure 6: Graphic Representation of Annual Human Comfort by Effective Temperature in the Municipality of Caicó (1996–2010)
Source: Research Data

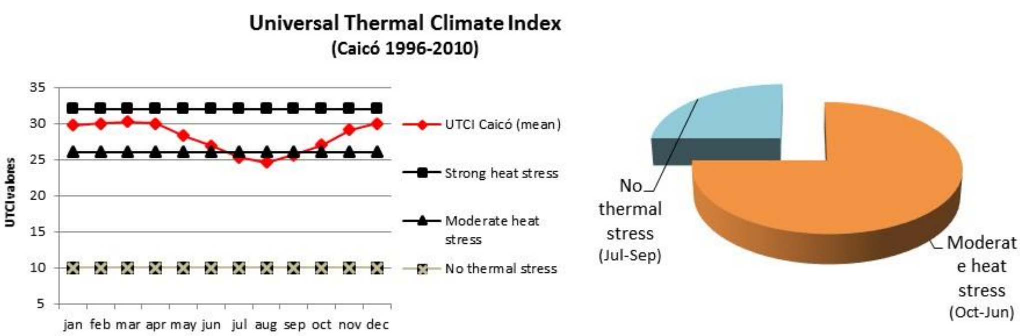

Figure 7: Graphic Representation of Annual Human Comfort by Universal Thermal Climate Index in the Municipality of Caicó (1996–2010)
Source: Research Data

According to the applied indices, the results for the DI showed that Caicó presents discomfort due to the heat in every month of the year. For TE*v*, the months of June, July, August, September, and October appear within the thermal comfort, especially August that presents as "slightly cold." According to UTCI, the months of July, August, and September are included in the human comfort zone on the limit between the "comfort zone" and "moderate discomfort due to heat."

The results show that only DI put Caicó off the human comfort zone during every month of the year. However, we must emphasize that this index, although widely used, does not include the "wind speed," one great important variable in facilitating human comfort, since wind velocity is as important as temperature and humidity in determining thermal exchanges between the body and the environment.

Studies by Santos (2011) and Santos et al. (2012) showed that the opinion of the people regarding the comfort ranges of the DI were not satisfactory when applied in a warm and humid place. This probably occurred due to the absence of the "wind" variable that relieves thermal sensation provided by the high temperatures and humidity in these places. Thus, detecting the incompatibility between the results obtained through a questionnaire applied to the population and those proposed by Giles and Balafoutis (1990), the authors proposed an adjustment and adaptation in the DI index in their study.

The indexes used in this paper that include "wind" showed in some months a favorable condition for human comfort. This occurs in the winter season in Southern hemisphere, mainly due the temperature drop and the increasing of wind speed by rising of southeast trade winds. Therefore, both the TE*v* as UTCI indicated a comfort situation for a few months of winter in Caicó, unlike the DI that did not present climatic comfort in any time of the year.

Climate, Urban Practices, and Human Comfort: Some Considerations

In towns and cities where the climate is naturally hot, the poor adaptation of the architecture of the buildings, the limited number of street trees, and the overpruning of existing trees only tend to heighten thermal discomfort. Different studies have shown that urban forestry not only has a positive impact on the landscape, but also helps reduce the temperature by covering surfaces that reflect the heat and by retaining part of the dust in the air (Grey and Deneke 1978; Junior and Lima 2007; and Ferreira et al. 2012).

According to Barbirato (2010, 86), "Plants reduce the air and soil temperature by shading and evapotranspiration, increasing local humidity. . . . likewise, large paved areas can cause discomfort because of the high absorption of radiation near the soil."

In Caicó, the built-up area has paved roads and pavements as well as buildings made of bricks and cement. The façades of the buildings are made of glass, and the more high-end the establishment, the more glass is used. Urban forestry in the built-up area is hampered because of the overhead electricity cables: small and medium-sized species have been planted that do not provide a great deal of shade, and they are often cut back drastically. Figure 6 (a, b, c, d, e, and f) shows the glass fronts of the buildings on the town's main streets and some of the many cases of severe pruning in 2014.

Figure 6: (a, b, c, d, e and f) Glass Fronts of the Buildings on the Main Streets of Caicó, and Some of the Severely Pruned Trees in 2014
Source: Research Data

Glass, synonymous with luxury in Brazilian architecture, is very inappropriate for towns with a hot semi-arid climate like Caicó. Even so, glass is often used on shop fronts, and is often protected by awnings at the hottest times of day. As glass promotes the greenhouse effect, more has to be spent on air conditioning to keep these spaces cool. This in turn increases the consumption of electricity by commercial establishments and homes.

In hot, dry climates, shading must be a priority in urban planning for both streets and buildings in the same way that daytime and nighttime wind control can increase human comfort without the need to resort to artificial cooling (Romero 2013). Planned tree planting using species that cast more shade is also a way to keep temperatures down, controlling the micro-climate according to local climatic conditions. Towns and cities that grow in line with the globalized paradigms of urban development tend to expose their residents to thermal discomfort because their architecture and landscape design is not adapted to the climate. And in towns naturally hot, like Caicó, it will be very dangerous for the future of the local population.

Concluding Remarks

In this study, it was found that in the municipality of Caicó, the air temperature is naturally very high, with an average temperature of ~30°C, an average maximum temperature of ~35°C, and an average minimum temperature of ~24°C. Most of the year, it is at the limit of human comfort because of the excessive heat, as was confirmed by calculating the human comfort indices DI, ET*v* and UTCI. However, the regression analysis for 1996 to 2010 showed that the maximum and minimum air temperatures showed no upward or downward trend, since the trend line ran parallel to the horizontal axis and showed no statistically significant variations. The minimum temperatures oscillated more than the maximum temperatures in the interannual comparison, where the coefficient of variation was 3% for the maximum temperatures, but 8% for the minimum temperatures.

Even though the air temperature time series was flat, the analysis of human comfort indices showed that in Caicó, only in the winter season—mainly during the months of July, August, and September—the conditions are favorable to human thermal comfort, showing that in the remaining months the city is outside of the comfort zone due to heat. Using the DI index, Caicó does not have any month inside the comfort level, appearing outside of the comfort zone due to heat throughout the year. ET*v* revealed that May, June, July, August, September, and October are inside of the human comfort zone, emphasizing August as being categorized as "slightly cool." The UTCI index showed that Caicó has three months that can be considered comfortable: June, July, and August.

The DI index exposed the most rigorous answers about climate comfort conditions for the city, since this index does not have the wind speed variable in its formula, and it is a very important variable to analyze the human comfort. So, we suggest, for warmer and hotter places the utilization of indexes that use the wind speed variable.

Finally, it was observed that the design of the buildings was inappropriate, with many using concrete and glass, while the absence of trees in the town and the severe pruning of those trees that it has tends to heighten the thermal discomfort in Caicó. As such, any increase in the air temperature brought about either by global climate change or even by changes in local land uses could have a major negative impact on the residents who already experience daily atmospheric conditions that cause discomfort because of the excessive heat.

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