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Thermal variability and apparent temperature between the years 1962 and 2015 in the great metropolis of Recife-PE, Brazil

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A B S T R A C T

This study is based on the hypothesis that the climatic trends observed on a global scale have also occurred in the Northeast of Brazil, especially in the Great Metropolis of Recife. The purpose of this work is to assess and analyze those climatic trends in terms of time and space, as well as their thermal variability and apparent temperature within fifty-four years (1962-2015) in that region, besides discussing possible causes. The information herein might help researchers and decision makers in several areas to assess the level of thermal discomfort and further understand the relationship between climate behavior and urban configuration. Monthly and annual data of mean temperature and relative humidity from 1962 to 2015 obtained by National Institute of Meteorology at the meteorological station in Recife were used in this study. The variability of mean temperature and relative humidity on global and regional scales was also observed in Recife in this study. The increase in the mean air temperature was due to the strong fluctuation of the minimum air temperature, which showed an increasing trend. As the global warming increases, so do the global, regional, and local climatic systems. Therefore, the results of this study might help in the planning of adaptation and/or mitigation strategies by providing information on climatic conditions that are favorable to the thermal comfort of the population.
Keywords: climate variables and changes, air temperature, relative humidity.

Variabilidade e Sensação Térmica do Período 1962-2015 na Grande Metrópole Recife-PE, Brasil

R E S U M O

Com a hipótese de que as tendências climáticas observadas em escala global estejam, também, ocorrendo no Nordeste Brasileiro em especial na grande metrópole Recife, objetiva-se avaliar, analisar, temporal e espacialmente, as tendências climáticas e suas variabilidades e sensação térmica no período de cinquenta e quatro anos (1962-2015) para a grande metrópole Recife-PE, bem como discutir possíveis causas. Espera-se que essas informações possam subsidiar pesquisadores e tomadores de decisão em diversas áreas de atividade, avaliar o nível de desconforto térmico e relacionar o comportamento do clima e a configuração urbana. Utilizaram-se dos dados mensais e anuais de temperatura média e umidade relativa do ar no período de 1962 a 2015, da estação meteorológica do Instituto Nacional de Meteorologia do município do Recife. Variabilidade de tendência climática observada na temperatura média e umidade relativa do ar em escala global e regional são constatadas no Recife pela serie estudada. O aumento da temperatura média do ar é devido à forte flutuação da tendência de aumento da temperatura mínima do ar. Com o aumento do efeito estufa e do aquecimento do sistema climático global, regional e local, espera-se que os resultados sirvam de auxílio para planejamento de estratégias de adaptação e/ou mitigação ou ainda para extrair informações de condições climáticas favoráveis ao conforto térmico para a população.
Palavras-chave: variáveis e mudanças climáticas, Temperatura do ar, umidade relativa do ar.

Introduction

Meteorologists and weather scientists agree that the climate trends observed - mainly since the late 20th century - have increased significantly. According to the Intergovernmental Panel on Climate Change (IPCC), these trends observed in the recent past are likely to continue in the 21st century (IPCC, 2007; IPCC, 2014).

Santos et al. (2012) utilized Thom's discomfort index to list the comfort/discomfort zones according to the changes that occurred in the urban climate system at ten points within the urban perimeter of the city of João Pessoa-PB, Brazil. The authors observed that the classification range of Thom's discomfort index is not appropriate for humid tropical regions. Santos et al. (2012) also proposed scenarios of thermal comfort that indicate conditions of strong environmental discomfort for the years 2050 and 2060 during the dry season, and of discomfort for the rainy season in the year 2060 throughout the study area. The authors concluded that the level of thermal comfort is mainly influenced by microclimatic conditions, whereas the intensity of the urban heat islands is influenced more strongly by macroclimatic conditions and local factors.

Assis (2011) states that there are a number of adverse effects on the local climate of tropical cities, such as: increasing air temperature and decreasing relative humidity, which leads to bioclimatic stress conditions that affect human health and productivity; increasing energy consumption for the artificial cooling of buildings, without actually solving the problem of thermal comfort; more frequent occurrence of severe episodes of rains and floods, which results in material and social damages; concentration of polluted air and reduction of natural ventilation due to increased urban roughness, which affect human health and impair the conservation of buildings; growth and development of the disordered urban space in the cities; waterproofing of the ground due to the new constructions, and the capping of public roads (Santamouris, 2014).

Bruse (2007) linked the urban microclimate to thermal comfort, which is the main parameter to assess the perception of inhabitants that attend public spaces and are exposed to the sun, wind, air temperature and relative humidity. Therefore, by assessing the microclimate conditions of these sites, one can identify the apparent temperature of the pedestrian and the sensations that will affect their behavior. Oke (1995) stated that urban heat islands are responsible for climate changes.

According to Kozmhinsky et al. (2016), environmental quality is based on the way of life that the population seeks both individually and collectively, and which is related to the values, perceptions, tastes, and preferences of society. These factors are linked to the culture, gender, history, economy, tastes, and aesthetic values of each space. The population of a large city might also have all these factors linked in a different way, which creates difficulty to meet all their demands uniformly and with a consensus of what is environmental quality.

By regarding the conception of development as a process of improvement, quality of life could represent actual gains in health, education, housing, among other areas. As defined by Souza (2002), the term "quality of life" refers to the satisfaction of the basic and non-basic needs of the population.

From an environmental point of view, urban planning is fundamental, since it contributes to the urban management of green areas by bringing benefits to the urban microclimate, which is a deviation from the climatic characteristics attributed to a certain region, caused by the modifications made by humans in its surroundings (Paiva et al., 2013).

According to Araújo (2012), atmospheric conditions exert a strong influence on society and on states of health or disease in the human body. The author also mentions that the spatial organization of the population in each space may lead to conditions or situations of risk that influence public health and increase the occurrence of diseases. The onset of diseases can be determined by social, cultural, and environmental factors that act in space and time on populations at risk.

Most cities consist of warm and cool areas, so instead of using the term "urban microclimate", one should mention the set of local climates that is reflected in an organized thermal pattern, which is the result of the various typical microclimates of each element that characterizes the urban space (Alcoforado et al., 2005).

Labaki et al. (2011) believe that the active and passive activities of the population of a city require environments that are thermally comfortable.

There are several issues in what concerns to thermal comfort and/or discomfort in rural or urban areas. Considering the organization of society in cities worldwide and the great transformations that have occurred in urban spaces, the environmental comfort issue is pertinent to cities, especially those located in regions characterized by high temperatures (BRASIL, 2015).

The population dynamics of the city interferes with the atmospheric elements, such as heat and albedo storage, evapotranspiration, and surface energy balance, thus obtaining a microclimate known as urban climate, which is inherent to these regions. That dynamics leads to phenomena such as urban heat islands, topoclimates, and microclimates (Rovani et al., 2010). Monteiro (1976) describes the Urban Climate System as complex, open, and adaptive with urban coverage. In this system the atmosphere is seen as the active agent, whereas the man is subjected to its actions.

There are many possibilities for work and access to consumer goods and services in the cities, but they cause a range of problems, especially when the agglomeration of the population grows to the level where people are exposed to various health risks (Araújo, 2012).

Silva et al. (2014) analyzed the monthly heat index for Santa Maria (RS) from 1968 to 2011 at 12 p.m., 6 p.m. and 12 a.m. GMT. The authors observed that the maximum value of heat index occurred at 6 p.m. GMT and that these values increased over the years by 0.76°C decade^{-1} and 0.92°C decade^{-1} in the months of January and April, respectively. In the months of May and August, the values of heat index presented a decrease of 0.69°C decade^{-1} and 0.31°C decade^{-1}, respectively.

According to Silva et al. (2015), the rapid expansion of infrastructure in Brazilian cities without urban planning resulted in the waterproofing of soils, albedo increase, higher air pollution levels due to the flow of vehicles and industries, increased precipitation, formation of heat islands, and the suppression of vegetation for the installation of urban equipment, which is the most severe result.

The variability of air temperature in the last two decades has stood out due to the high anomalies of global mean air temperature (CLIMATE RESEARCH UNIT, 2009). Within 1961 and 1990, the year 1998 was the warmest, showing 0.55°C above the annual mean temperature. Within 2000 and 2010, 2009 was the sixth warmest year, behind the years 1998, 2003, 2002, 2004, and 2005 (Campos, 2010).

Rocha (2011) showed that the altercation of the thermal response between urban and rural environments is distinguished by the development of heat islands in urban areas.

Varejão-Silva (2006) pointed out that the relative humidity content varies sharply both in space and time. At a given location, the temporal variation depends on several factors, such as the circulation of the atmosphere, the relative location of the sources and sinks of water vapor, and the supply of solar energy. Due to these factors, the values presented by the parameters concerning to the relative humidity near the earth's surface are necessarily punctual.

Medeiros (2012) analyzed the monthly variability of relative humidity in Teresina, Piauí, Brazil, in the year 2009 to verify the times of better productivity for the works in civil construction and commerce. Relative humidity data acquired by the National Meteorological Institute at 03 a.m., 09 a.m., 03 p.m., and 09 p.m., local time, were used. Relative humidity was higher than 75% in 65% of the times from January to May. This value presents a moderate degree of discomfort for the civil construction and commerce.

In general, the literature shows that cloudless and windless nights under stable atmospheric conditions are ideal for the identification of heat islands (VOOGT et al., 2003). Amorim (2005) agrees with the authors by stating that in situ data collection should be performed in winter episodes under low wind speed conditions, which are favorable to the formation of urban heat islands. However, Roth (2007) found that in tropical urban cities the most intense urban heat islands are generally measured during the dry season, as in Singapore (*Aw* climate).

In that sense, the objectives of this work are to assess in terms of time and space the climatic trends and their variability of thermal comfort and discomfort; to describe the behavior of the climate and the urban configuration during the period of fifty-four years (1962-2016) in the Great Metropolis of Recife-PE, Brazil; and to discuss possible causes. The information herein might help researchers and decision makers in several areas.

Material and methods

Recife is one of the three largest urban agglomerations in the Northeast of Brazil. It is in the center of that region, approximately 800 km away from the other metropolises (Salvador and Fortaleza). The three capitals dispute for the strategic space of influence in the Region. With a territorial area of 330 km^2, Recife borders north with the cities of Olinda and Paulista, south with the city of Jaboatão dos Guararapes, west with São Lourenço da Mata and Camaragibe, and east with the Atlantic Ocean. Data from the 2010 census show that the City of Recife contains a population of more than two million inhabitants (IBGE, 2010). It is located at latitude 08º01'S; Longitude 34º51'W, with an average altitude of 72 meters above sea level (Figure 1).

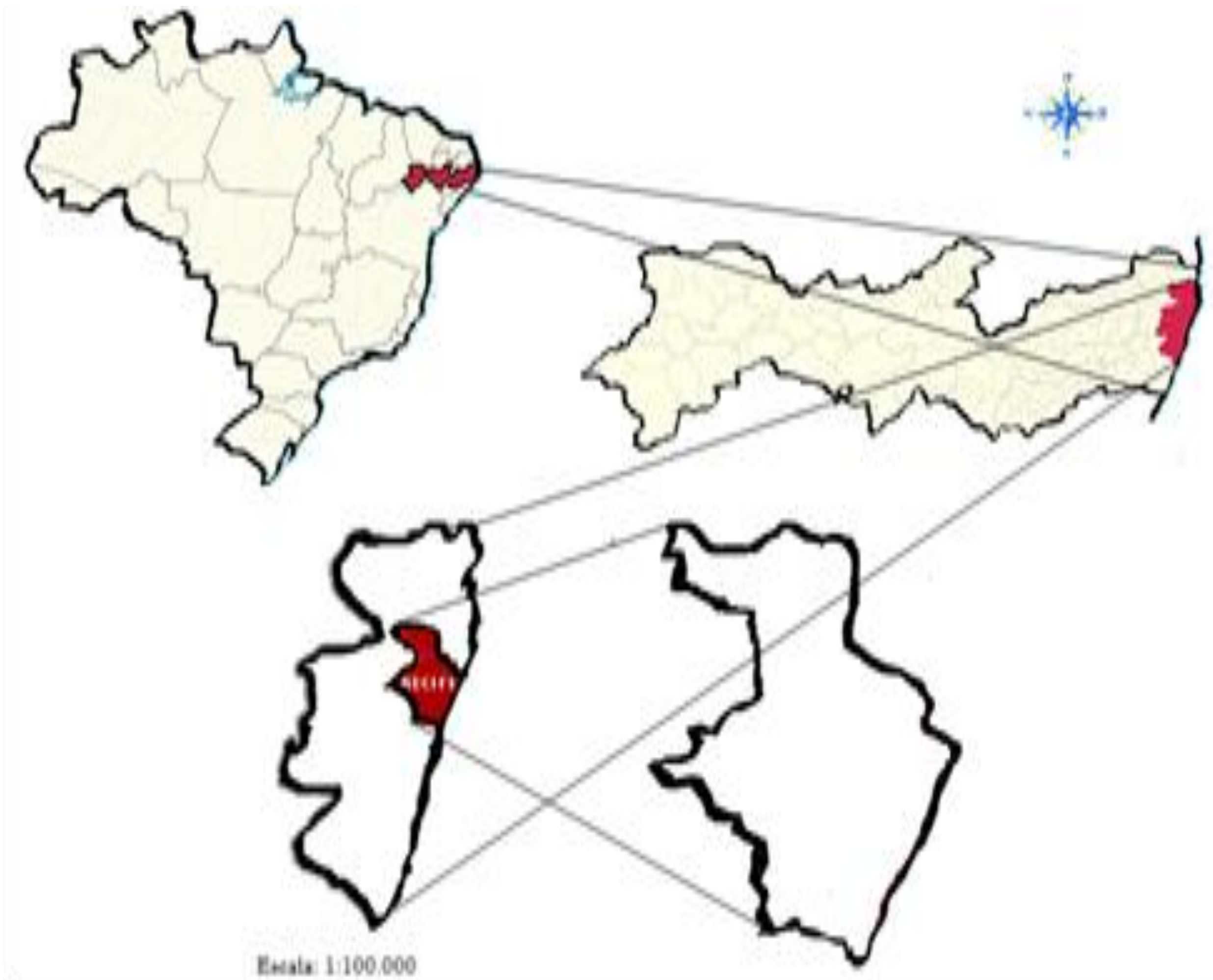

Figure 1. Location of Recife. Source: Adapted by Kozmhinsky.

The atmospheric systems that contribute to the precipitation in Recife are vestiges of the frontal systems, easterly wave disturbances, and sea and land breezes. Easterly waves are common in autumn and winter, aided by southeast trade winds, creating an Intertropical Convergence Zone (ITCZ), a disturbance associated with the expansion of the thermal equator to the southern hemisphere. The ITCZ reaches Recife mainly in the autumn and causes rains with thunderstorms, changes in the direction of the winds from SE to NE, or even calm winds.

The formation of upper level cyclonic vortices between February and April with their edges in the Northeast of Brazil, especially over the state of Pernambuco, increases the cloud cover and causes moderate to strong rains in a short period of time, causing floods and other accidents that damage communities and the socioeconomic sector (Medeiros, 2016). The local climate is classified according to the Köppen classification as type Am (Alvarez et al., 2013).

Data concerning to monthly mean air temperature (ºC) and relative humidity for the period 1962-2016 were obtained from the National Institute of Meteorology (INMET, 2017), and subjected to the processes of gap filling, consistency, and homogenization. Afterwards, these data were analyzed statistically, generating results of means, standard deviation, coefficient of variance, and absolute maximum and minimum values of the studied variables.

Thom's discomfort index (TDI) was employed, as suggested by Silva et al. (2006), to utilize the parameters of temperature and relative humidity to assess the conditions of thermal comfort or discomfort for the locations studied, as seen in the following equation:

$$TDI = AT - (0.55 - 0.0055.RH).(AT - 14.5)$$

Where:

AT = air temperature (ºC) and
RH = relative humidity (%).

The reference presented by Giles et al. (1990) and Silva et al. (2006) was used to characterize the thermal conditions of each environment studied. According to this reference, the discomfort index is employed as a parameter to define the conditions of thermal comfort or discomfort, as shown in Table 1.

Table 1. Thom's Discomfort Index (TDI) Range.

Range	TDI (°C)	Level of Thermal Discomfort
1	TDI<21	No discomfort
2	21≤TDI<24	Less than half population feels discomfort
3	24≤TDI<27	More than half population feels discomfort
4	27≤TDI<29	The biggest part of the population feels discomfort
5	29≤TDI<32	The discomfort was strong and dangerous
6	TDI≥32	State of medical emergency

Source: Giles et al (1990).

Results and discussion

Table 2 shows variations of the maximum apparent temperature in the period 1962-2015 in the Great Metropolis of Recife.

The calculation of apparent temperature for the values of maximum temperature between 1962 and 2015, which were carried out by employing Thom's discomfort index, resulted in values over 31°C, as shown in Table 2.

According to the results obtained, the level of discomfort was strong and dangerous, and the state of medical emergency prevailed in all years and months studied.

Table 3 shows the calculation of the minimum apparent temperature for each month and year from 1962 to 2015 in Recife.

Thom's Discomfort Index results showed the same range described in Table 2 for the variability of the minimum apparent temperature from 1962 to 2015 in Recife.

Table 4 shows the fluctuation levels of the minimum apparent temperature levels from 1962 to 2015 in the Great Metropolis of Recife.

Zone 3 stands out for showing the greatest number of events reported in all months. Zone 2 shows weak fluctuation and is concentrated between June and December. Zones 1 and 4 took place in isolated months and their fluctuations were low. Such fluctuation levels are similar to those observed by Medeiros et al (2016).

Figure 2 shows that there was a decadal decrease in the maximum apparent temperature in all months when compared to the average. Such decrease might be related to local and regional atmospheric effects, small number of buildings and asphalt cover. There were irregular fluctuations even in the dry period. The minimum apparent temperature (Figure 3) presented significant decrease between 0.4 and 0.8°C from one month to another. From 1962 to 1971 the nights were colder and had cooler air.

Figures 4 and 5 depict the variation of maximum and minimum apparent temperature for the decade 1972-1981 and its comparison with the average from 1962-2015.

The maximum apparent temperature (Figure 4) from 1972 to 1981 stands out in the months of April, August, and November, in which the levels were similar. The minimum apparent temperature (Figure 5) during the months of June and October was close to the mean apparent temperature. There were no exaggerated apparent temperature fluctuations in that decade.

Table 2. Maximum apparent temperature from 1962 to 2015 in the Great Metropolis of Recife.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1962	36.3	35.9	36.0	36.1	34.4	32.8	31.9	32.0	32.8	34.8	29.5	35.7	33.2
1963	36.3	36.9	34.8	35.0	34.1	32.5	31.7	32.1	33.2	35.2	37.1	37.1	34.7
1964	36.8	36.8	36.5	35.5	34.7	33.0	32.4	32.5	32.2	33.6	35.3	36.0	33.8
1965	34.9	36.9	36.8	36.2	34.8	33.1	33.5	32.7	33.2	34.7	35.3	35.2	34.8
1966	36.0	35.1	35.4	37.0	34.7	33.2	32.3	32.6	33.1	34.3	35.0	36.0	34.6
1967	37.1	36.7	35.9	35.3	34.6	34.0	33.0	32.7	33.6	33.7	35.2	35.7	34.8
1968	35.7	36.4	35.8	35.6	34.2	33.1	33.1	32.6	34.0	35.7	36.0	36.3	34.9
1969	36.3	37.5	37.0	36.4	35.6	34.2	32.9	32.7	33.7	35.0	35.5	35.9	35.3
1970	35.8	35.8	35.5	34.8	34.3	33.5	31.9	32.1	33.4	35.2	35.9	36.4	34.6
1971	36.1	36.9	36.8	37.0	34.5	34.0	32.5	32.3	33.4	34.1	34.9	35.8	34.9
1972	37.1	36.0	36.1	35.7	34.7	33.9	33.4	33.4	33.6	35.0	36.0	36.5	35.1
1973	36.1	36.9	37.4	36.0	36.1	34.3	34.0	34.2	33.8	34.9	36.2	36.4	35.6
1974	36.2	35.6	36.0	35.8	35.0	33.5	32.2	32.5	32.7	34.8	36.1	35.7	34.7
1975	35.9	37.0	36.7	37.3	34.9	33.8	32.3	32.6	33.0	35.1	35.6	34.8	35.0
1976	35.2	35.3	35.4	35.3	34.5	33.5	32.4	32.7	33.9	34.6	35.3	35.3	34.5
1977	36.0	35.7	36.5	37.0	35.7	34.3	32.5	33.2	33.6	34.1	35.7	36.3	35.1
1978	36.1	36.0	35.5	35.9	35.2	33.4	33.2	32.8	32.9	34.1	34.5	35.2	34.6
1979	36.1	36.2	36.2	36.3	35.0	33.1	32.6	32.5	33.1	34.5	35.4	36.7	34.8
1980	36.5	35.9	35.3	35.3	34.3	33.4	33.2	33.4	33.9	33.8	34.9	35.5	34.6
1981	35.4	34.8	35.7	35.2	34.1	33.1	31.8	32.1	32.7	34.4	35.3	35.2	34.2
1982	35.2	35.4	35.9	35.8	34.8	33.8	32.9	33.1	33.6	34.5	35.2	35.7	34.7
1983	37.0	36.1	36.6	36.8	35.9	34.7	33.9	33.7	34.3	34.8	35.6	36.4	35.5
1984	36.5	37.9	38.2	35.9	35.2	34.4	32.7	32.8	34.1	35.1	35.6	37.3	35.5
1985	38.1	37.0	36.8	35.6	35.8	34.8	32.8	33.6	33.3	35.2	35.8	36.0	35.4
1986	36.9	36.3	36.3	35.7	35.3	32.9	33.1	33.1	33.5	34.8	35.3	35.5	34.9
1987	36.4	36.4	36.5	36.8	36.7	35.2	34.1	34.4	34.6	34.8	36.5	37.4	35.8
1988	37.4	37.1	38.6	37.0	35.9	34.3	33.0	32.4	33.3	35.3	35.6	36.1	35.5
1989	36.3	36.8	37.7	36.2	35.7	34.2	32.7	33.3	34.4	34.9	35.6	36.4	35.4
1990	35.7	36.6	37.8	36.6	35.7	34.0	33.6	33.3	34.4	35.2	36.7	36.8	35.6
1991	36.9	37.3	37.0	36.5	35.2	34.3	32.5	32.2	33.1	33.4	34.6	36.2	35.0
1992	36.7	35.9	35.4	36.1	35.6	33.8	32.6	32.6	33.0	34.2	34.1	35.1	34.6
1993	35.6	35.9	35.9	36.0	35.0	33.8	32.8	33.5	34.6	35.4	35.9	36.5	35.1
1994	36.2	36.7	37.6	36.4	35.3	34.6	33.7	33.5	33.7	34.6	35.7	36.3	35.4
1995	36.3	36.9	37.2	36.6	36.0	33.6	33.4	32.9	33.8	35.0	35.5	36.8	35.4
1996	36.3	36.2	36.9	36.4	36.1	33.9	32.9	33.0	33.5	35.2	35.7	36.4	35.2
1997	37.1	36.0	36.0	35.9	34.7	34.2	33.0	32.5	34.3	35.9	36.0	36.8	35.2
1998	37.6	38.5	38.9	37.9	36.2	34.6	33.9	33.5	34.0	35.0	36.4	36.8	36.1
1999	36.9	37.0	36.5	36.3	35.4	34.4	33.1	32.6	33.4	34.4	35.8	36.0	35.2
2000	35.9	36.5	36.3	36.0	35.3	33.7	32.5	32.8	33.7	34.4	35.3	35.0	34.8
2001	35.4	36.8	36.6	35.9	36.1	34.4	33.4	32.8	33.7	35.0	35.8	36.3	35.2
2002	35.8	36.2	36.1	36.0	35.1	33.4	33.2	33.0	33.8	34.4	35.4	36.7	34.9
2003	37.6	36.8	36.9	36.9	36.5	33.8	32.8	33.2	33.9	35.1	36.6	37.4	35.7
2004	37.2	37.2	37.1	36.6	35.8	34.4	33.7	34.1	34.2	35.2	36.2	36.8	35.7
2005	37.5	38.2	38.2	37.0	36.1	34.5	33.7	33.1	34.1	35.3	36.3	35.8	35.9
2006	36.3	37.9	38.1	37.2	36.3	34.4	34.2	33.9	34.5	35.8	36.6	36.8	36.0
2007	37.1	38.2	36.7	36.8	36.1	34.3	34.2	33.1	32.9	34.3	35.9	36.4	35.5
2008	36.1	37.8	37.3	37.1	35.7	34.0	32.6	32.9	34.0	34.8	36.0	36.8	35.5
2009	36.9	36.2	37.6	37.1	36.1	34.5	34.3	34.1	34.6	36.1	36.6	37.1	36.0
2010	36.4	37.8	39.1	38.0	37.0	35.4	33.9	32.9	33.4	35.6	36.2	36.8	36.1
2011	36.4	36.6	37.9	36.0	35.2	34.3	33.0	33.4	33.6	35.2	35.7	36.6	35.4
2012	36.1	35.6	36.6	36.4	35.7	34.6	33.4	32.6	33.6	34.4	36.5	36.8	35.2
2013	37.2	37.7	37.8	38.1	36.1	35.0	33.7	33.5	34.0	35.2	36.0	36.8	36.0
2014	36.3	36.8	37.5	37.9	35.9	34.4	33.9	33.4	34.1	34.9	36.4	36.8	35.6
2015	36.8	37.8	36.8	38.0	37.1	35.1	34.0	34.1	35.5	35.6	37.3	37.2	36.3

Table 3. Minimum Apparent temperature from 1962 to 2015 in Recife.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1962	2	3	3	3	3	2	2	2	2	2	2	3	2
1964	3	3	3	3	3	3	2	2	2	1	1	1	2
1965	2	1	2	2	2	2	1	1	1	1	3	3	2
1966	3	3	3	3	3	3	3	2	2	2	3	3	3
1967	3	3	3	3	3	3	2	2	2	3	2	2	3
1968	2	3	3	3	2	2	2	2	3	3	3	2	3
1969	3	3	3	3	3	3	3	2	2	2	3	3	3
1970	3	3	3	3	3	3	2	2	2	2	2	3	3
1971	3	3	3	3	3	3	2	2	2	3	3	2	3
1972	2	3	3	3	3	3	2	2	3	3	2	3	3
1973	3	3	3	4	3	3	3	2	2	3	3	3	3
1974	3	3	3	3	3	3	2	2	2	2	2	3	3
1975	3	3	3	3	3	3	2	2	2	2	3	3	3
1976	3	3	3	3	2	2	2	2	2	3	3	3	2
1977	3	3	3	3	3	3	3	2	3	3	3	3	3
1978	3	3	3	3	3	3	3	2	3	3	3	3	3
1979	3	3	3	3	3	3	2	2	3	3	3	3	3
1980	3	3	3	3	3	3	2	2	2	2	3	3	3
1981	3	3	3	3	3	2	2	2	2	3	3	4	3
1982	3	3	3	3	3	3	2	2	2	2	3	3	3
1983	3	4	4	3	3	2	2	2	2	3	2	3	3
1984	3	3	3	3	3	3	2	2	2	3	3	3	3
1985	3	3	3	3	3	3	3	2	2	2	2	3	3
1986	3	3	3	3	3	3	2	2	2	2	3	3	3
1987	3	3	3	4	3	3	3	3	2	2	3	3	3
1988	3	3	3	3	3	3	2	2	2	3	3	3	3
1989	3	3	3	3	3	3	2	2	2	3	3	3	3
1990	3	3	3	3	2	3	2	2	2	3	3	4	3
1991	3	3	3	3	3	3	2	2	2	2	2	2	3
1992	3	4	4	3	3	3	2	2	3	3	3	3	3
1993	3	3	3	3	3	3	2	2	3	3	4	3	3
1994	3	3	3	3	3	3	3	2	2	3	3	3	3
1995	3	3	3	3	3	2	2	2	2	3	3	3	3
1996	4	3	3	4	3	3	3	3	3	3	3	3	3
1997	3	3	3	3	3	2	2	2	2	3	3	3	3
1998	3	4	4	4	3	4	2	2	2	3	3	3	3
1999	3	4	3	3	3	3	2	2	3	3	3	4	3
2000	3	3	3	3	3	3	3	2	3	3	3	3	3
2001	3	3	3	3	3	3	2	2	3	3	3	4	3
2002	3	3	3	3	3	3	3	2	2	3	3	3	3
2003	3	3	3	3	3	3	2	2	3	3	3	3	3
2004	4	3	3	3	3	3	2	2	2	3	3	3	3
2005	3	4	4	3	3	3	2	2	2	3	3	3	3
2006	3	3	3	3	3	3	2	2	3	3	3	3	3
2007	3	3	3	3	3	3	2	3	3	3	3	3	3
2008	3	3	3	3	3	2	2	2	3	3	3	3	3
2009	3	3	3	3	3	3	3	3	3	3	3	3	3
2010	3	4	3	3	3	3	3	2	3	3	3	3	3
2011	3	3	3	3	3	3	2	2	2	3	3	3	3
2012	3	3	3	2	2	2	2	2	2	3	3	3	3
2013	3	3	3	3	3	3	2	3	3	3	3	3	3
2014	3	3	3	3	3	3	2	2	2	3	3	3	3
2015	3	3	3	3	3	3	3	2	2	3	3	3	3

1 – No discomfort; 2 – Less than half population feels discomfort; 3 - More than half population feels discomfort; 4 – The biggest part of the population feels discomfort. Source: Author.

Table 4. Summary of the results obtained in the calculation of the minimum apparent temperature from 1962 to 2015 in Recife.

Range/month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1		1	2	2			1	1	1	2	1	1	
2	4					10	37	47	33	12	9	4	4
3	47	46	47	47	48	42	15	5	19	39	42	44	49
4	2	6	4	4		1					1	4	
5					5								
Total	53	53	53	53	53	53	53	53	53	53	53	53	53

1 = No discomfort; 2 = Less than half population feels discomfort; 3 = More than half population feels discomfort; 4 = The biggest part of the population feels discomfort; 5 = The discomfort was strong and dangerous. Source: Author.

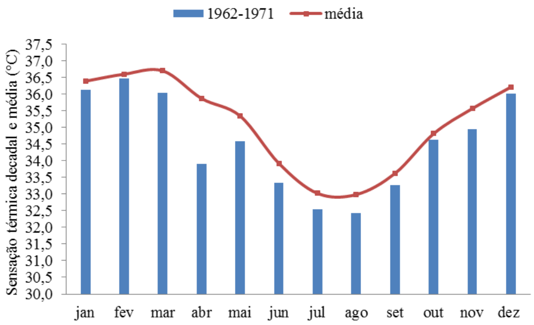

Figure 2. Maximum apparent temperature between 1962 and 1971 and its comparison with the mean apparent temperature between 1962 and 2015.

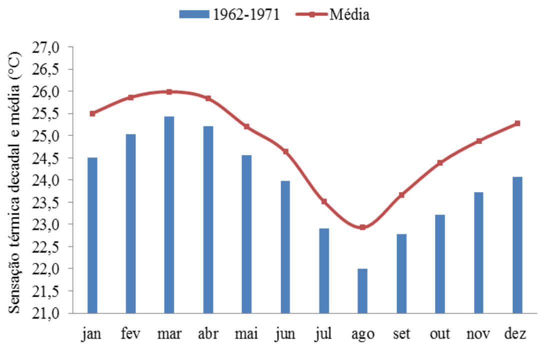

Figure 3. Minimum apparent temperature between 1962 and 1971 and its comparison with the mean apparent temperature between 1962 and 2015.

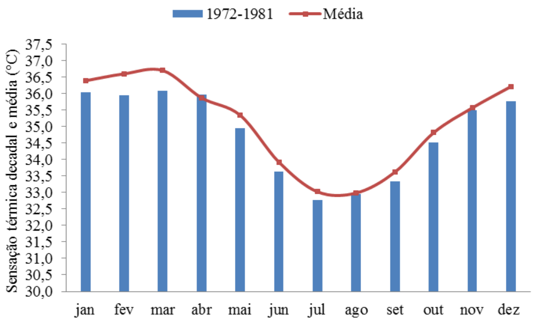

Figure 4. Maximum apparent temperature between 1972 and 1981 and its comparison with the mean apparent temperature between 1962 and 2015.

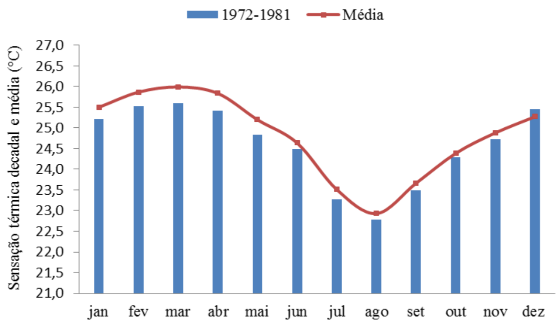

Figure 5. Minimum apparent temperature between 1972 and 1981 and its comparison with the mean apparent temperature between 1962 and 2015.

There was an increase in the fluctuations of maximum and minimum apparent temperature in the decade 1982-1991. The maximum apparent temperature (Figure 6) in the months of January, March, April, May, June, August, and December were higher than the average from the period 1962-2015.

There was an increase in the minimum apparent temperature (Figure 7) in the months of

April, July, and August. Afternoons and nights presented higher apparent temperatures.

There were significant increases (up to 1.5°C) in the apparent temperature during the third decade of study (1982-1991) when compared to the first and second decades.

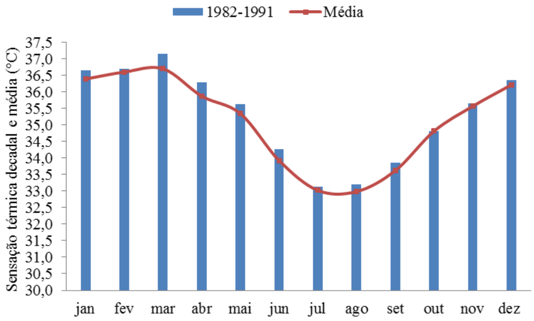

Figure 6. Maximum apparent temperature between 1982 and 1991 and its comparison with the mean apparent temperature between 1962 and 2015.

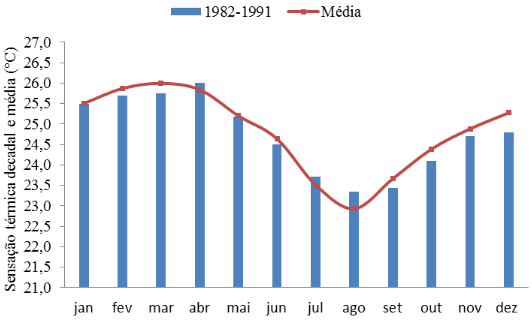

Figure 7. Minimum apparent temperature between 1982 and 1991 and its comparison with the mean apparent temperature between 1962 and 2015.

The maximum apparent temperature (Figure 8) in the period 1992-2001 matched the average. The minimum apparent temperature (Figure 9) showed values up to 0.5°C higher than the average. One can notice that nights are becoming warmer than in past decades. Similar results were observed by Varejão–Silva (2006).

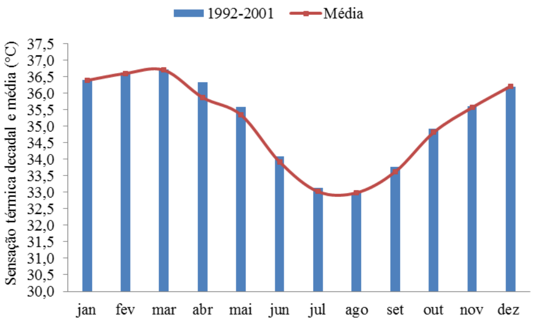

Figure 8. Maximum apparent temperature between 1992 and 2001 and its comparison with the mean apparent temperature between 1962 and 2015.

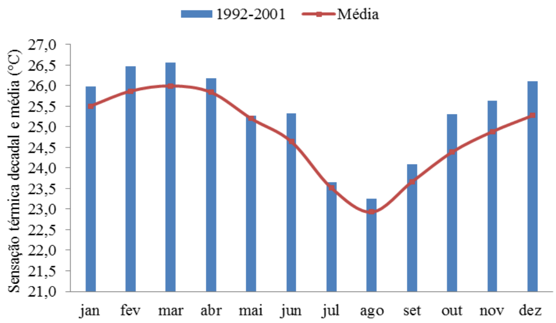

Figure 9. Minimum apparent temperature between 1992 and 2001 and its comparison with the mean apparent temperature between 1962 and 2015.

Figures 10 and 11 correspond to the maximum and minimum apparent temperatures during the decade 2002-2011. Figure 11 shows that the mean temperature is equal to the minimum apparent temperature in the months of April, June, and July. In the months between August and March, the apparent temperature in that decade was above the average, showing that nights are indeed becoming warmer. Figure 10 shows balance between the decadal apparent temperature and the average, showing that afternoons have presented normal apparent temperatures.

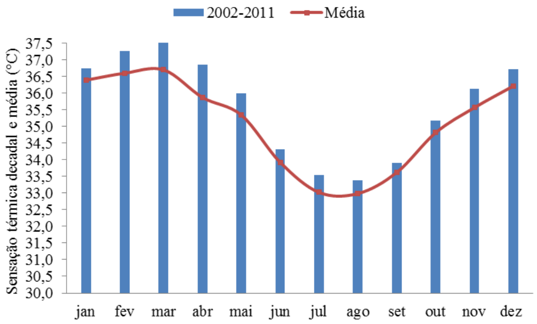

Figure 10. Maximum apparent temperature between 2002 and 2011 and its comparison with the mean apparent temperature between 1962 and 2015.

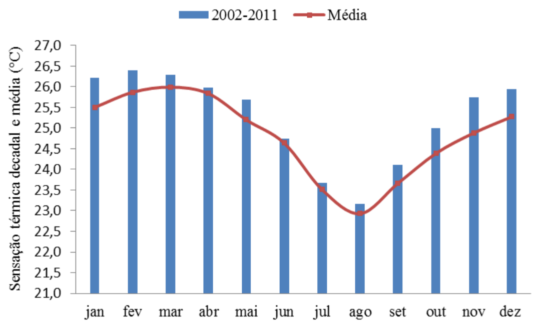

Figure 11. Minimum apparent temperature between 2002 and 2011 and its comparison with the mean apparent temperature between 1962 and 2015.

Figure 12 depicts the maximum annual apparent temperature. During the decades 1962-1971 and 1972-1981 apparent temperature levels were below the average, whereas during the decades 1982-1991, 1992-2001 and 2002-2011 they were above the mean apparent temperature for the period 1962-2015. In that sense, in the last three decades the apparent temperature was abnormal and caused harm to the population.

The minimum annual apparent temperature and its comparison with the mean apparent temperature in the period 1962-2015 are represented in Figure 13, which highlights the decades 1992-2001 and 2002-2011 for showing higher levels than the average of that period. The lowest apparent temperature was observed in the decade 1962-1971. There was a gradual increase in the minimum apparent temperature throughout the other decades studied.

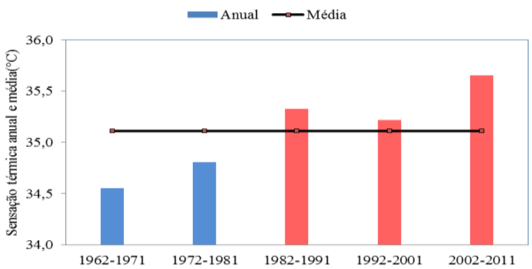

Figure 12. Annual maximum apparent temperature and its comparison with the mean apparent temperature between 1962 and 2015.

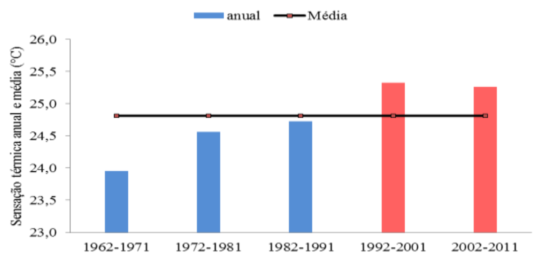

Figure 13. Annual minimum apparent temperature and its comparison with the mean apparent temperature between 1962 and 2015.

The results in study agree with those obtained by Marengo et al. (2008), who analyzed the trends of maximum and minimum temperatures in Southern Brazil between 1960 and 2002, and indicated a systematic temperature increase in that region.

Conclusions

Nights are becoming warmer and more muffled whereas afternoons show stationary apparent temperature fluctuations.

The variability of temperature and relative humidity observed might be more related to winds than climatic changes, however, it might also be linked to urban growth, as heat islands affect the local microclimate.

Temperature and relative humidity presented variability of climate trends in global and regional scale in Recife during the studied period.

The increase in air temperature happens due to the strong fluctuation in the increase trend of the minimum air temperature.

As the greenhouse effect and the global, regional, and local climate systems increase, the results presented in this study might help in the planning of adaptation and/or mitigation strategies or provide further information on climatic conditions that are favorable to the thermal comfort of the population.

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