ASSESSMENT OF OUTDOOR THERMAL HUMAN COMFORT OVER BEIRUT CITY, LEBANON

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ABSTRACT

This study applied Thom's Discomfort Index (DI), Kibler Discomfort Index (THI_1) (Temperature-Humidity Index) and National Oceanic and Atmospheric Administration (NOAA) Discomfort Index (THI_2) to assess the trend of thermal discomfort in Beirut City during (1999-2021). Temperature and relative humidity data for twenty-two years (1999-2021) from Beirut-Rafic Hariri International Airport (BRHIA) station were analyzed to determine the discomfort period. Seasonal variations in thermal conditions were found, with increased thermal stress levels occurring mainly during Summer, while Spring and Winter showed improved thermal comfort conditions with respect to Summer. December, January, and February were comparatively comfortable ($DI < 21$). Under 50% of the population experienced discomfort ($21 < DI < 24$) during March and November. From May to September, discomfort values varied between 25-27, which indicates that over 50% of population in Beirut suffered from discomfort during these months. Percentage frequencies of the monthly (DI) values from January to December in Beirut from the years 1999 to 2021 were also reported. Monthly variations of (THI_1) and (THI_2) showed no extreme discomfort conditions in Beirut. Data on air temperatures and relative humidity in Beirut were

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also investigated to study local climate change and understand potential impacts of urbanization on Beirut's climate as a result of industrialization and a significant influx of people from rural areas. An upward trend in the annual average air temperatures and downward trend in the annual average relative humidity of Beirut, the most highly populated and industrialized city of Lebanon, were found. The results of this study are crucial for comprehending, simulating, and tracking human thermal comfort/discomfort in Beirut's educational facilities, workplaces, and other places.
Key words: Air temperature, Relative Humidity, Discomfort Index (DI), Temperature-Humidity Index (THI), Urbanization.

INTRODUCTION

Urbanization is defined as the regular migration of population settlements from rural regions to urban areas. Multiple Indicators suggest the world is growing more urbanized; currently, 55% of people live in urban areas, and that number is expected to rise to 68% by 2050 (UN, 2018). According to the United Nation (UN) projections, because of rapid urbanization, there could be an additional 2.5 billion people living in urban areas by 2050. Nearly 90% of this increase is expected to occur in Asia and Africa, according to a recent UN's data set released (UN, 2018).

This urbanization-induced rapid population growth will largely drive the level and rate of environmental changes (Chu and Ren, 2005). Many of these changes are connected to cities' climate and atmospheric composition, including the canopy layer Urban Heat Island (UHI), numerous types of air pollution and thermal sensation. Human settlements modify the structure and the energy balance of the surface, the materials and the composition of the atmosphere compared to the surrounding 'natural' terrains. There has been documented evidence of such urbanization-induced significant changes and their resultant inadvertent local weather and climate changes in many cities (Ren *et al.*, 2008 and Xu *et al.*, 2013). In addition, in many cities, as urbanization progresses, minimum temperatures rise differently than maximum temperatures, and the trend for minimum temperatures is greater than for maximum temperatures. This difference is apparently linked to associated increases in low cloudiness and- aerosol effects as well as the enhanced greenhouse effect (Robaa, 2005 and Qian and Lin, 2004).

Moreover, the Intergovernmental Panel on Climate Change (IPCC) concluded in their latest assessment report (AR6) that each of the last four decades has been successively warmer than any decade that preceded it since 1850 and the global surface air temperature in the first two decades of the 21^{st} century (2001–2020) was 0.99 [0.84 to 1.10] °C higher than 1850–1900. They also estimated that the global surface temperature was 1.09 [0.95 to 1.20] °C higher in 2011–2020 than 1850–1900, with larger increases over land (1.59 [1.34 to 1.83] °C) than over the ocean (0.88 [0.68 to 1.01] °C). Methodological advances and new datasets contributed approximately 0.1°C to the updated estimate of warming in the last assessment report AR6. (IPCC 2021; AR6) (Masson-Delmotte *et al.,* 2021).

In the same regard, both Alcoforado and Andrade (2008) revealed that the population health would be impacted and effected more in the urban areas because of the global warming. Global and regional warming will exasperate the urban warming during summertime consequently, the air temperature will rise extremely, and this condition might be continued for a long while (Alcoforado and Andrade, 2008 and Fujibe, 2009 and Golden, 2004).

Some researchers specified that people living in a huge city have a great risk of morbidity and mortality due to the high temperature (Nastos and Matzarakis, 2006). Major diseases related to heat and nature of the thermal environment include heat stress that can be one or more of the following medical conditions including: heat rash (prickly heat), hyperthermia, heat oedema (swelling), heat cramps, hyperventilation, heat syncope and heat exhaustion, for these reasons, assessing outdoor thermal comfort is one of the vital issues of the climate control system (Ormandy and Ezratty, 2016 and Smith *et al.*, 2014).

Many factors can contribute to an adequate thermally comfortable environment, including temperature, relative humidity, solar radiation, wind speed and precipitation. A lot of effort has been made over more than a century to develop indices to adequately describe heat stress because combination of the above environmental factors causes heat stress. However, a number of indices have been proposed that combine various environmental factors to measure the extent of heat stress. The majority of studies on heat stress have mainly focused on temperature, relative humidity and wind speed (Kibler, 1964 and Thom, 1959 and Matzarakis and Mayer, 1996).

Thermal comfort expresses satisfaction with the thermal environment. The human body's thermoregulatory processes are triggered when external temperatures exceed particular thresholds in order to maintain a consistent internal body temperature. Air temperatures between 18°C and 23°C and Relative Humidity (RH) levels between 35% and 70% are considered to be the comfortable ranges for livability. However, these comfortable ranges may alter amongst people from different climatic regions and depend on the external weather conditions. When the human body is exposed to extreme heat and humidity, its cooling mechanisms, for example, increased heart rate and sweating, are triggered, these mechanisms can cause discomfort, weakness, loss of stamina, and muscle pains and, in severe cases, even heat strokes and heart attacks (Lin *et al.*, 2010, and HNICEM, 2017).

In Lebanon, research that associated the impact of urban climate on outdoor-human comfort conditions are insufficient and related mostly the discussing of the indoor comfort conditions. As discussed before, temperatures beyond the limits of comfort may cause thermal fatigue, and consequently, reduction of work performance, malaise, total loss of capability to perform intellectual activities, and health problems. Kaloustain and Diab (2015) demonstrates the substantial correlation between population increase and rising maximum and minimum temperatures over the last century, as well as the close relationship between high temperatures and mortality in Beirut (Kaloustain and Diab, 2015).

The present study applied Thom's Discomfort Index (DI), Kibler Discomfort Index (THI_1) and NOAA Discomfort Index (THI_2) to evaluate the tendency of thermal discomfort of the people living in Beirut City during the period from 1999 to 2021.

MATERIALS AND METHODS

1- Study area: The Lebanon's Capital, Beirut, has an area of about 19.8 km^2 and is situated at 33° 53' 19.0680" N and 35° 29' 43.7280" E (Figure 1). Within the Beirut region, there are over 2 million people. The Mediterranean Sea and the Beirut River form its western and northern boundaries respectively. Nearly 18 miles of the city's coastline are made up primarily of rocky coasts, though there are a few miles of sandy beaches (Figure 1).

With an average annual temperature of 15 ˚C, Beirut has a Mediterranean-type climate with hot, dry summers (June to September) and mild, rainy winters (December to mid-March). Along the shore, summers are hot and humid with temperatures crossing the 35°C in August. The coldest month is January, with temperatures of around 5°C to 10°C. On the seaside, the average annual precipitation is between 700 and 1,000 mm.

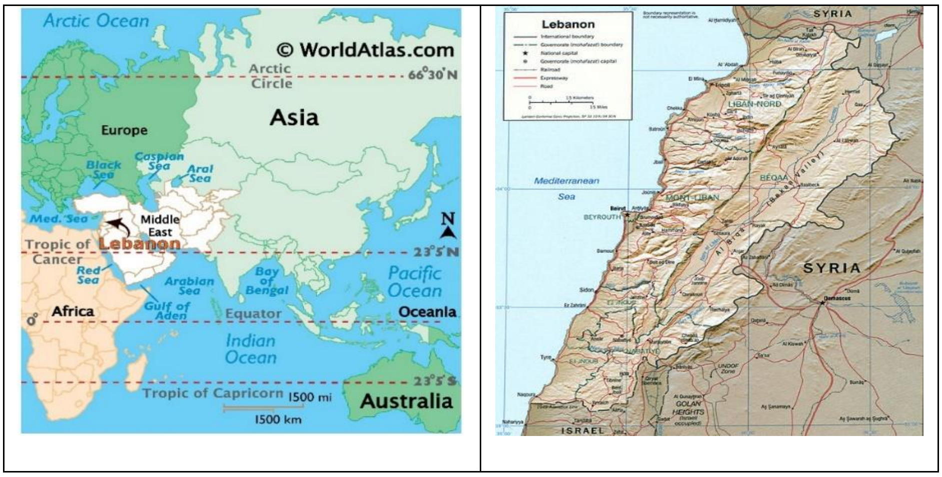

Figure (1): Map of Lebanon and its position in Asia (www.worldatlas.com)

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Beirut has experienced a sharp rise in urbanization and industrialization, especially in the latter half of the 20th century. Beirut Rafic Hariri International Airport (BRHIA), which is located close to the boundary between an urbanized and an industrialized area, has been used as the research area's representative meteorological station (Figure 2).

Figure (2): Meteorological Station at Beirut – RHIA / RWY 16/34.

The only ample open space near the airport runway is the sea. There are many buildings and human activities close to the airport, with the shortest distance between such buildings and the airport location is at least 0.5 km. Around the airport, there are numerous asphalt roads and the associated congestion to connect it to the neighboring regions.

2- Methods: Daily data on temperature and relative humidity were gathered for 22 years (1999 – 2021) from a station located at Beirut-Rafic Hariri International Airport (BRHIA). The Lebanese Meteorological Department

(LMD) and the National Center for Environment Information provided the observational climatic data that was used National Oceanic Atmospheric Administration (NOAA) According to the World Meteorological Organization's recommendation, the temperature and relative humidity were measured at a height of 2 meters (WMO, 2008) and data were analyzed using Excel Microsoft Office Professional Plus 2019.

Thom's DI was calculated in the present study using the following formula:

$$\mathbf{DI= T_a-(0.55-0.0055RH)\ (T_a-14.5)} \qquad \mathbf{(1)}$$

Where DI= Discomfort Index; T= Mean air temperature in °C; RH= Average relative humidity (%). Table 1 shows the classes of (DI), and it shows that as the (DI) values increases the human discomfort increases. The definition of (DI) is based on a straightforward calculation that accounts for the proportionate effects of relative humidity and air temperature on a person's thermal comfort. In numerous previous studies, this DI served as a marker for the impact of heat stress on people (Anderson *et al.*, 2013 and Giles *et al.*, 1990, Roghanchi and Kocsis, 2018 and Yasmeen and Liu, 2019).

Table (1): Classification of Human Thermal related to the Discomfort Index (DI).

CLASS NUMBER	**DI RANGE (°C)**	**DISCOMFORT CONDITIONS**
1	DI < 21	No discomfort
2	21 ≤ DI <24	< 50% feels discomfort
3	24 ≤ DI <27	> 50% feels discomfort
4	27 ≤ DI < 29	Most of the population feels discomfort
5	29 ≤ DI < 32	Everyone feels severe stress
6	DI ≥ 32	State of medical emergency

Vol. (52); Iss. (3); No. (4); March 2023
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The Kibler discomfort index (THI_1) was determined in this study using the following formula (Kibler, 1964).

$$\mathbf{THI_1 = 1.8 \times T_a - (1 - RH)(T_a - 14.3) + 32} \qquad \mathbf{(2)}$$

Where: Ta = average ambient temperature in °C.

RH = average relative humidity as a fraction of the unit.

The Temperature-Humidity Index (THI_2) was determined for each month using the formula established by NOAA (NOAA, 1976).

$$\mathbf{THI_2 = (1.8 \times T_a + 32) - (0.55 - 0.55 \times RH) \times [(1.8 \times T_a + 32) - 58]} \qquad \mathbf{(3)}$$

Where: T_a = average ambient temperature in °C.

RH = average relative humidity.

Table 2 below shows the fundamental significance of temperature-humidity index (THI).

Table (2): Temperature-Humidity Index (THI) developed by Kibler.

CLASS NUMBER	THI_1	HUMAN / ANIMAL AND PLANT FEELING
1	≥ 80	100% are not comfortable
2	75 - < 80	50% are not comfortable due to hot and humid weather.
3	65 - < 75	100% are quite comfortable
4	60 - < 65	50% are partially comfortable.
5	< 60	Almost 100% are comfortable due to cold and dry weather

Vol. (52); Iss. (3); No. (4); March 2023
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RESULTS AND DISCUSSION

First, we analyzed the monthly mean temperatures and the monthly mean RH (Figure 3) for Beirut over the period of 1999–2021. The monthly mean temperature in July, August and September (7, 8 & 9) was markedly higher than those in other months. (Figure 3) also shows how the air temperature varies from winter to summer.

High temperatures were recorded throughout the summer and the highest temperature was recorded in August (8) at 28.47 °C over the whole study period. The lowest temperature was recorded in January at 14.36 °C. Thus, January is the coldest month and August (8) is the hottest. Temperatures (> 22.54 ^{o}C) were typically higher in May through October than they were in any other months. The temperature is normally between the range of 14 and 19 °C throughout winter, December through February.

The average relative humidity was found to be 54.77 % at its lowest and 70.12 % at its highest, respectively, in November and July. It was obvious that the relative humidity of air varied throughout the year, with the highest readings (> 65%) occurring from May to August. Since the mean air temperature (^{o}C) and average relative humidity were greater in the corresponding months in Beirut city, a positive relationship between them has been noted from February to July (Figure 3).

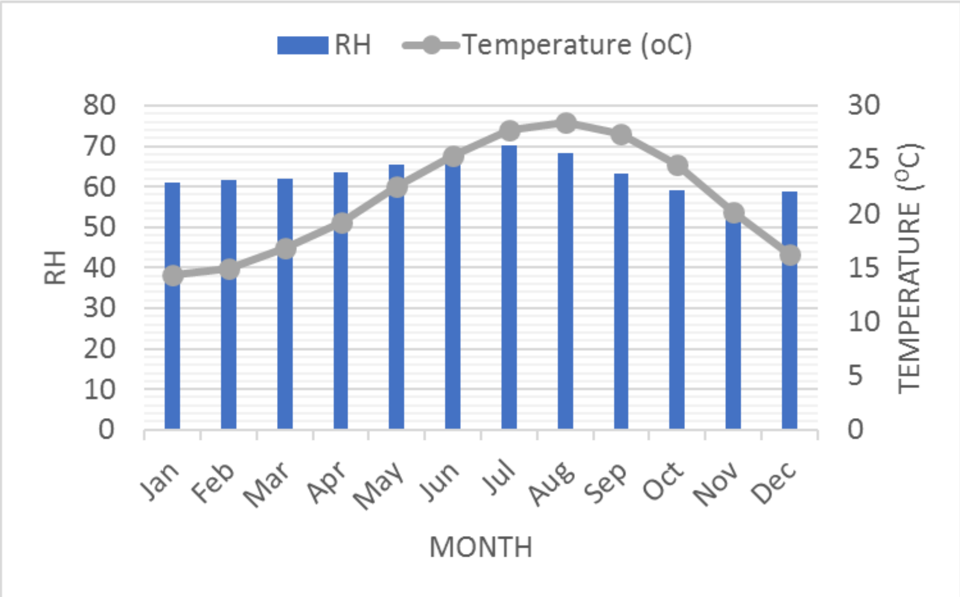

Figure (3): The trend of mean air temperature and average relative Humidity (RH) (1999-2021).

The livability of a region is significantly influenced by environmental factors such as temperature and Relative Humidity (RH) (Al Mayahi and Kabbash, 2019 and Liang *et al.*, 2020 and Pal and Eltahir, 2016). Considering this, Beirut's population growth was analyzed. The data show that Beirut's population has increased significantly (by about 100%) between 1991 and 2021 (Figure 4). This sharp population growth has accelerated urbanization (Carroll, 2007).

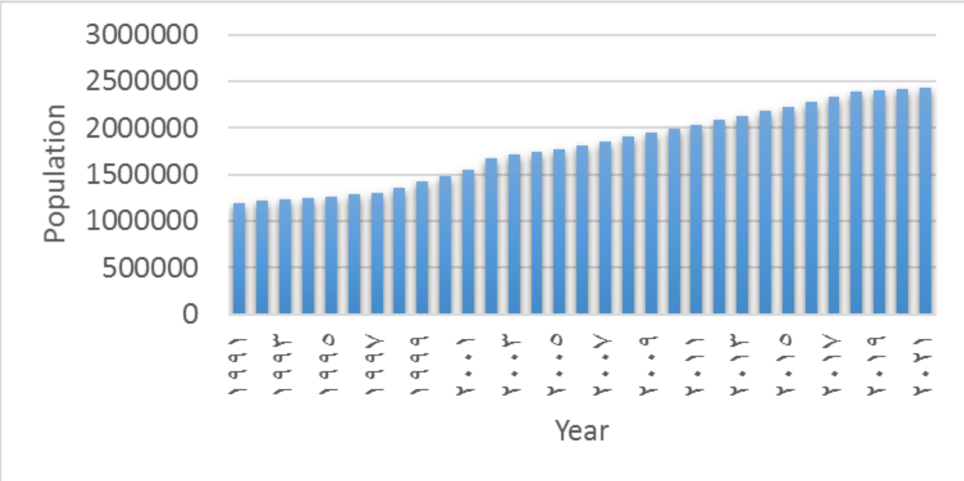

Figure (4): Population of Beirut city from the years 1991 to 2021.
(www.worldpopulationreview.com).

Heat stress is exacerbated by high temperatures and humidity, which could have negative health effects. According to several studies, prolonged exposure to heat makes people more vulnerable to serious health consequences, including long-term health issues such as psychological distress (Smith *et al.*, 1997 and Tawatsupa *et al.*, 2010) cardiovascular illness (Vangelova *et al.*, 2006) and kidney disease (Luo *et al.*, 2014). The long-term thermal discomfort index, its variability, and trends must therefore be examined in relation to Beirut's rapid urbanization and expanding population.

Figures 5-7 shows the monthly variation of DI, THI_1, and THI_2 for Beirut City. In this study, THI_1 and THI_2 discomfort indices were compared and both were found to be almost the same.

Vol. (52); Iss. (3); No. (4); March 2023
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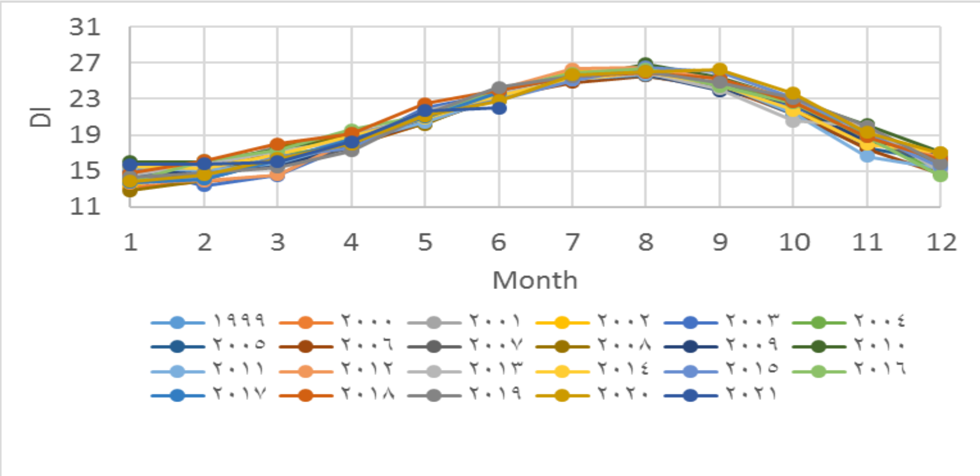

Figure (5): Time series of monthly average Discomfort Index (DI) values in Beirut from the years 1999-2020.

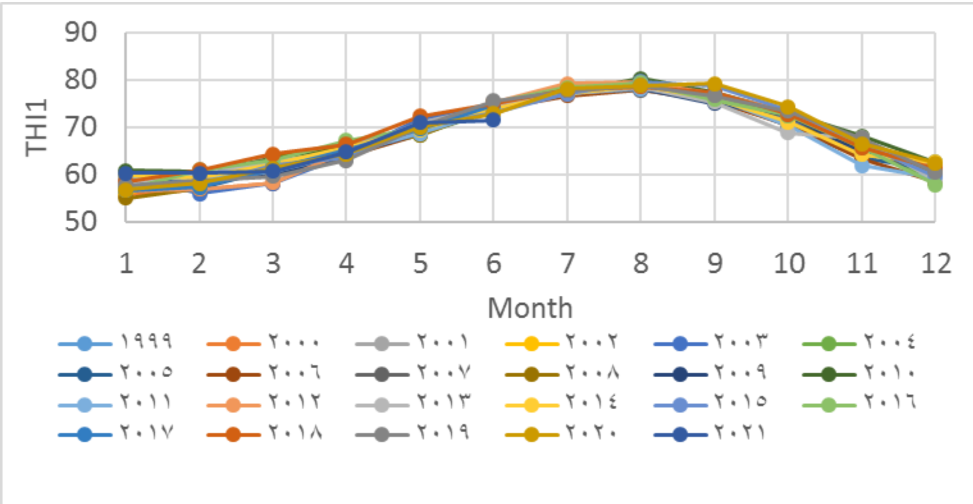

Figure (6): Time series of monthly average THI1 values in Beirut from the years 1999-2020.

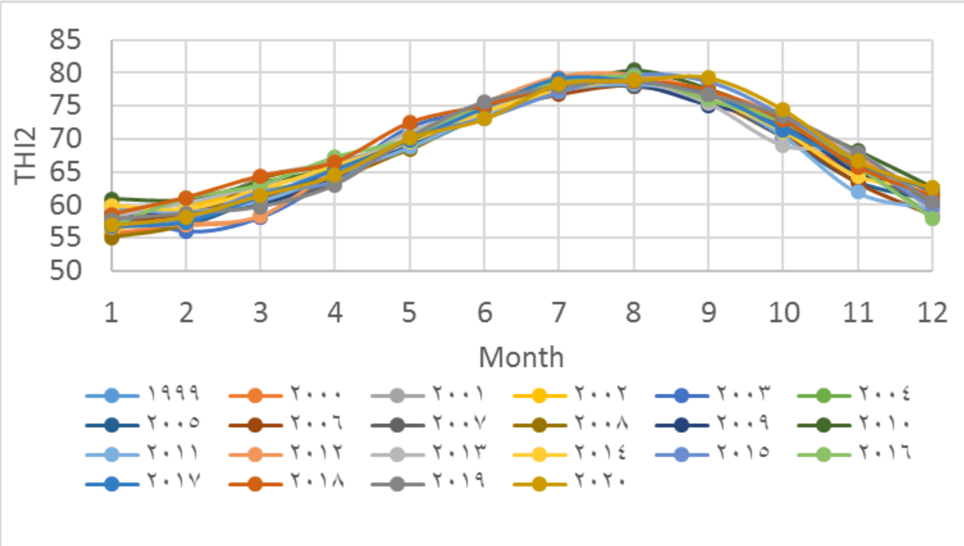

Figure (7): Time series of monthly average Temperature-Humidity Index (THI2) values in Beirut from 1999-2020.

There is a clear annual cycle of the heat indices (DI, THI_1 and THI_2) presenting peak values during summer and minimum values during winter season of the year. DI values ≥ 27 and THI values > 80 are not found in the DI and THI time series for Beirut (Figures 5-7). The Beirut city's discomfort index (DI) values for the years 1999 through 2021 are also listed in Table 3. Seasonal variations in DI values have been noted. From November to April, the DI values were typically within the comfort range of less than 21. Thus, it is expected that no one experienced any discomfort during these times because the temperature was typically lower than it was in other months. However, in the months of May

(1999, 2007, 2013, 2015, 2016 and 2018- 2021), June and October, the DI range was found to be between 21–24.

Table (3): Discomfort index (DI) of Beirut from the years 1999-2021.

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1999	14.83	15.09	16.34	17.89	21.20	23.58	25.33	25.97	24.50	22.21	18.43	16.27
2000	13.20	13.84	14.56	18.54	20.42	23.65	26.04	25.79	24.40	21.31	18.40	15.72
2001	14.85	14.77	17.88	19.17	20.95	23.57	25.41	26.15	24.74	22.46	18.40	15.61
2002	13.32	15.44	16.83	17.79	20.39	23.43	26.10	25.98	24.47	22.71	19.20	15.35
2003	15.50	13.35	14.51	17.94	22.07	23.64	25.66	26.27	24.12	22.19	18.95	15.72
2004	14.06	14.17	16.54	18.00	20.29	23.20	25.67	25.79	24.39	23.11	18.90	14.72
2005	14.66	14.02	16.24	18.27	20.40	23.15	25.46	25.91	24.57	21.33	17.57	16.07
2006	14.03	14.87	16.14	17.80	20.34	23.27	24.83	25.58	24.31	21.57	17.42	14.71
2007	13.75	14.54	15.77	17.52	21.19	23.29	25.26	25.57	24.41	22.48	18.70	15.60
2008	12.82	13.96	17.71	18.90	20.21	23.65	25.33	26.01	24.53	21.68	18.86	15.86
2009	14.74	14.86	15.51	17.96	20.54	23.90	25.55	25.72	23.95	22.54	18.20	16.68
2010	16.03	15.95	17.41	18.65	20.99	23.54	25.32	26.90	25.36	22.91	20.14	17.05
2011	15.32	15.03	15.92	18.13	20.40	23.16	25.19	25.71	24.67	21.41	16.63	15.25
2012	13.68	13.91	14.59	18.39	20.98	24.07	26.32	26.47	25.11	23.04	19.46	16.29
2013	14.54	15.69	17.15	18.43	21.69	23.55	25.14	25.92	24.10	20.54	19.93	14.94
2014	15.54	15.21	16.86	18.86	20.88	23.38	25.19	26.03	24.59	21.78	17.96	17.05
2015	14.01	14.34	16.64	17.55	21.22	22.86	25.06	26.54	25.98	23.11	19.27	15.40
2016	13.80	16.11	17.26	19.58	21.13	24.01	25.86	26.34	24.41	22.54	18.81	14.43
2017	13.71	14.11	16.25	18.50	20.97	23.69	26.15	25.93	24.89	21.91	19.00	16.81
2018	14.75	16.16	17.98	19.15	22.47	23.93	25.58	25.95	25.24	22.68	18.77	16.27
2019	14.30	14.81	15.38	17.24	21.25	24.28	25.49	26.06	24.85	23.09	19.96	15.79
2020	13.82	14.57	16.35	18.04	21.17	22.78	25.71	26.03	26.28	23.61	19.25	16.96
2021	15.73	15.75	15.99	18.25	21.71	21.98						

Therefore, in Beirut, less than 50% of the population experienced discomfort during these months (Table 1). In July and August, the (DI) range was between 25 and 27, and as a result, almost 50% of the people in Beirut city experienced discomfort (Table 1). In these months, August 2010 had the highest DI value (26.9), and July 2006 had the lowest DI value (24.83). These months typically had high average temperatures and relative humidity, which has an impact on the DI ranges for those months. According to (DI) indices, the majority of the population experienced discomfort from May to October, with July and August being the most uncomfortable months in Beirut.

Likewise, according to the Temperature-Humidity Index (THI) developed by Kibler (Table 2), the THI values for January, February, March and December indicated partial comfortability and pleasant feelings for citizens in Beirut (Figures 6 and 7). THI values for April show that Beirut is experiencing just mild heat stress. THI values from May, June, October, and November showed that 100% of people are quite comfortable during these months (Table 2). The (THI) data during the remaining months, which are July, August and September, reveal that more that 50% of people are not comfortable in Beirut.

The Percentage frequencies of the monthly (DI) values from January to December in Beirut from the years 1999 to 2021 reveal that for Beirut city there are no records of 100% un-comfortability as a result of cold or dry weather. An inspection of Tables 3 and 4 indicates that November, December, January, February, March and April are characterized with 100 % comfortable and pleasant

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weather. June and October are characterized with moderate heat stress where 50% are not comfortable due to hot and humid weather. May is the month with probable moderate heat stress with percentage frequencies of 41%. In July, August and September record high heat stress where more than 50% of population feel thermal discomfort.

Table (4): Percentage Frequency of monthly mean Discomfort index (DI) values from January to December in Beirut from the years 1999 to 2021.

DI	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC	DISCOMFORT CONDITIONS
< 21	100	100	100	100	59	0	0	0	0	0	100	100	No discomfort
21≤DI< 24	0	0	0	0	41	100	0	0	0	100	0	0	< 50% feels discomfort
24≤DI< 27	0	0	0	0	0	0	100	100	100	0	0	0	> 50% feels discomfort
27≤DI< 29	0	0	0	0	0	0	0	0	0	0	0	0	Most of population suffers discomfort
29≤DI< 32	0	0	0	0	0	0	0	0	0	0	0	0	Everyone feels sever stress
≥ 32	0	0	0	0	0	0	0	0	0	0	0	0	State of medical emergency
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	

Shojaei *et. al.*, (2017) and Tong, *et. al.*, (2018) demonstrated the impact of fast urbanization on air temperature have been widely documented (Shojaei *et al.*, 2017 and Mushore *et al.*, 2017 and Tong *et al.*, 2018). A statistically significant (p = 0.036) increase in annual air temperature and air temperature anomaly

(Difference between average annual Air temperature and annual Air temperature) were both detected in the current investigation (Figure 8).

A mean annual air temperature of 21.46 °C and air temperature anomalies of 0.28 °C between 1999 and 2021 was observed. This increase in air temperature may be attributed to the significant increase in urban zones. The Mann–Kendall trend test detected a statistically warming trend of 0.04 °C/20 years in the mean annual air temperature. This may be attributed to urbanization and/or the built-up areas (Tong *et al.*, 2018 and Xiong et al., 2012).

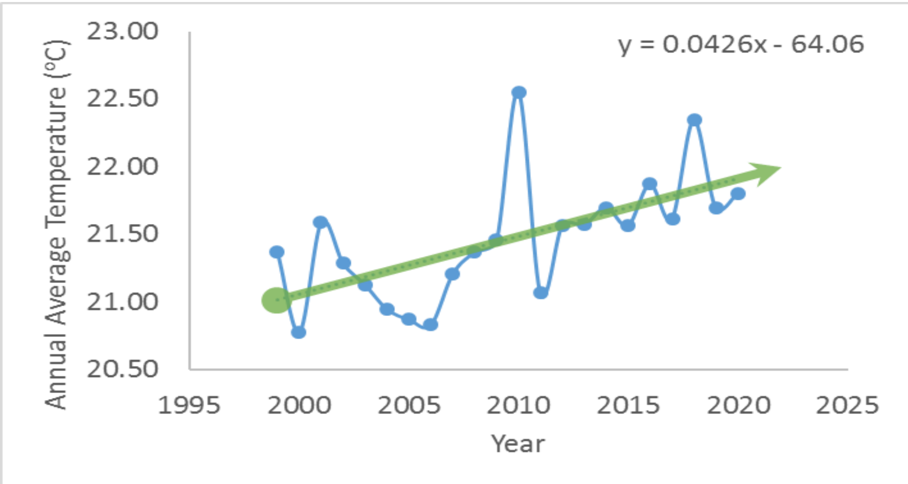

Figure (8): Annual Average air temperature over the period 1999-2021.

Studies have shown that rapid urbanization has significantly reduced the relative humidity of urban areas (Adebayo, 1991 and Zhang *et al.*, 2016). Trend analysis techniques were used on monthly, annually, and anomalies relative humidity data to explore the effects of Beirut's rapid urban growth on the city's

Vol. (52); Iss. (3); No. (4); March 2023
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relative humidity. Since 1999, there have been statistically significant ($p = 0.002$) downward trend in the mean monthly relative humidity, decreasing at a rate of 0.247%/20 years (Figures 9 and 10).

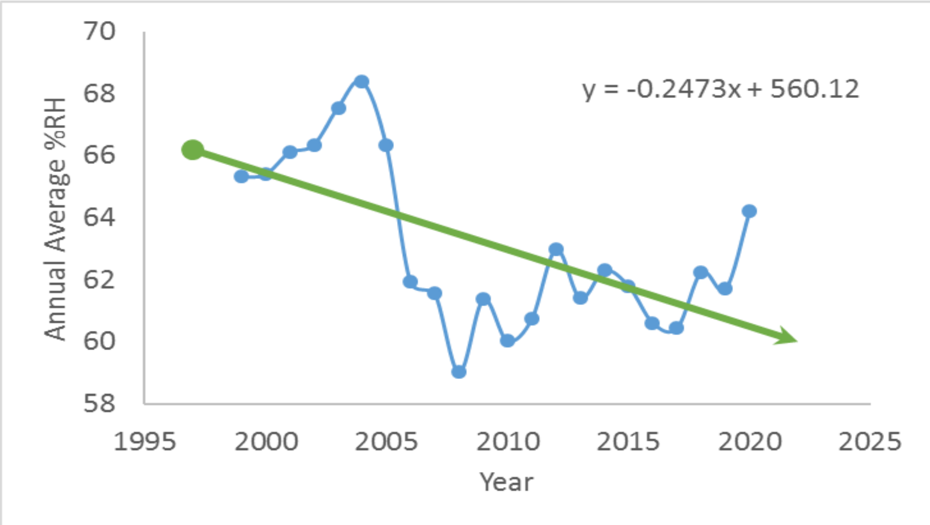

Figure (9): Annual Average relative humidity over the period 1999-2021.

The results also show a very high variability in relative humidity due to a significant increase in impervious surfaces of Beirut. In addition, Figure 10 shows a continuous decline in relative humidity after 2005. The increase in impervious surfaces and built-up areas has led to a decrease in the long-term average relative humidity anomaly from 3.25 % in 2005 to -1.36 % in 2019. This finding is in agreement with previous studies (Adebayo, 1991 and Zhang *et al.*, 2016). Therefore, the urban effect has reduced long-term air humidity trend values because of both an increase in air temperature and changes to the land surface;

these changes have also caused a quick runoff of precipitation (reduction of mean annual precipitation by 4%) and a decline in vegetation.

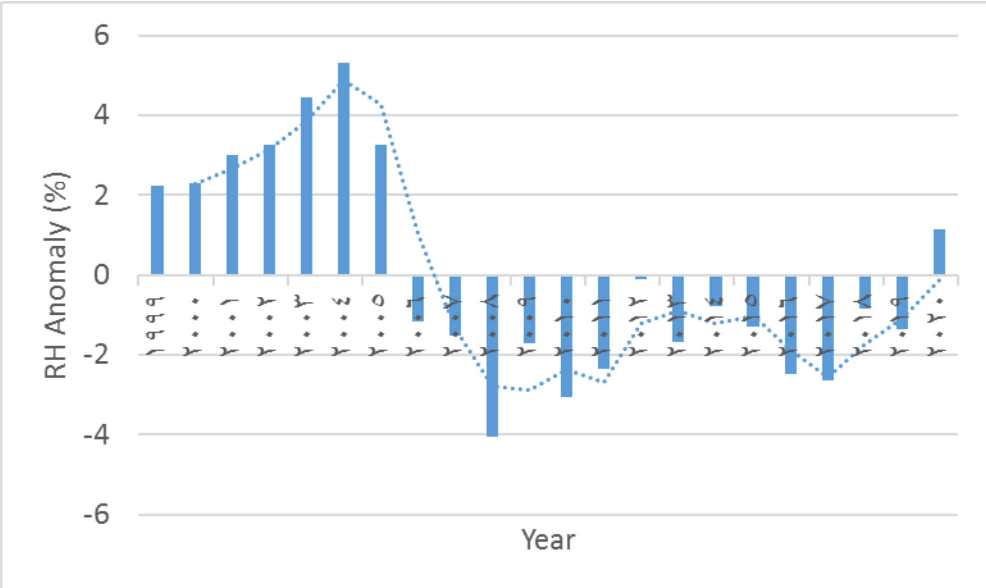

Figure (10): Average Relative humidity anomaly over the period 1999-2020.

CONCLUSION AND RECOMMENDATIONS

The current study's main goal was to evaluate the degree of thermal discomfort in Beirut. The findings showed that from December to April, nobody experienced any discomfort (DI < 21), (Table 2). In contrast, hot and humid weather in July, August, and September was reported to cause thermal discomfort (24 < DI < 27) in people. August is the month with the most heat stress during these months, whereas May and October are the months with the least heat stress. During June and October and from July to September, respectively, less than 50%

and more than 50% of the population felt uncomfortable. Between 1999 and 2021, there was a considerable rise in urban and built-up regions, which led to an increase in air temperature of 0.04 °C over 22 years and a decrease in relative humidity of 0.247% during the same period. Policy makers and urban planners can use information on the variability and trends in outdoor thermal discomfort in Beirut as a resource for future plans. Engineers will benefit greatly from understanding Beirut's climatology and its effects on the long-term trends of DI, this knowledge is necessary to design effective ventilation and cooling capacity into their infrastructure while also updating the current protocols to meet the needs of the population's safety, health, and comfort. The findings also demonstrated that when discussing parameters impacting human health and comfort, environmental elements like air temperature and relative humidity should be considered along with various types of pollution.

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CONFLICTS OF INTEREST

The Authors declare no conflict of interest.

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تقييم وسائل الراحة البشرية الخارجية في مدينة بيروت، لبنان

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المستخلص

طبقت الدراسة الحالية مؤشر انزعاج (DI) Thom، مؤشر عدم الراحة (THI_1) Kibler ومؤشر الانزعاج (THI_2) الخاص بالإدارة الوطنية للمحيطات والغلاف الجوي (NOAA) لتقييم اتجاه الانزعاج الحراري في مدينة بيروت خلال الفترة ١٩٩٩–٢٠٢١. تم تحليل بيانات درجة الحرارة والرطوبة النسبية لمدة ٢٢ عامًا (١٩٩٩–٢٠٢١) من محطة الرصد الجوي في مطار رفيق الحريري الدولي–بيروت لتحديد فترة الانزعاج. تم العثور على اختلافات موسمية في الظروف الحرارية، مع زيادة مستويات الإجهاد الحراري التي تحدث بشكل رئيسي خلال فصل الصيف، بينما أظهر الربيع والشتاء ظروف راحة حرارية محسنة بالنسبة للصيف. وجد أن الأشهر ديسمبر، يناير وفبراير كانت مريحة نسبيًا ($DI < 21$). من ناحية أخرى، وقد عانى أقل من ٥٠٪ من السكان من عدم الراحة ($21 < DI < 24$) خلال شهري مارس ونوفمبر. من مايو إلى سبتمبر، تفاوتت قيم عدم الراحة بين ٢٥–٢٧، مما يشير إلى أن أكثر من ٥٠٪ من السكان في بيروت عانوا من عدم الراحة في هذه الفترة. تم الإبلاغ عن النسب المئوية للترددات الشهرية لقيم (DI) من شهر يناير إلى ديسمبر في بيروت للأعوام ١٩٩٩ إلى ٢٠٢١. لم تظهر الاختلافات الشهرية في THI_1 و THI_2 أي ظروف مزعجة شديدة في بيروت. كما تم فحص البيانات الخاصة بدرجات حرارة الهواء والرطوبة النسبية في بيروت لدراسة تغير المناخ المحلي وفهم الآثار المحتملة للتحضر على مناخ بيروت نتيجة

للتصنيع والتدفق الكبير للنَّاس من المناطق الريفية في البلاد. تم العثور على اتجاه تصاعدي للمتوسط السنوي لدرجات حرارة الهواء واتجاه تنازلي للمتوسط السنوي للرطوبة النسبية في بيروت؛ الجزء الأكثر كثافة سكانية وصناعية في لبنان. تعتبر نتائج هذه الدراسة مهمة لفهم ومحاكاة وتتبع الراحة الحرارية البشرية/عدم الراحة في المرافق التعليمية لبيروت وأماكن العمل الأخرى.

الكلمات المفتاحيّة: درجة حرارة الهواء، الرطوبة النسبية، مؤشر الانزعاج (DI)، مؤشر درجة الحرارة والرطوبة (THI)، التحضر