The Seasonal Variation of the Urban Heat Island Effect and Estimating the Human - Discomfort Index at the City of Hillah

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Abstract

This research focuses on the nature and properties of urban heat island phenomenon such as the seasonal variation, and determining its intensity ΔT_{u-s} °C at the city of Hillah . In terms of environmental impacts it was estimated one of the more important indices that is related to psychological human comfort is the Temperature – Humidity Index THI , or as known Human – Discomfort index DI. The area of Hillah's urban city center is about 165 km^2 whilst the area of its rural surruoundings is about 56.645 km^2 .The study reveals that the air temperature difference ΔT between city center and its surrounding is about 1 – 4 °C . The specific sites in this study are : the urban site (u) represented by the automatic meteorological station of the city of Hillah suburban site (s) represented by the automatic meteorological station in department of physics - college of education Babylon university, furthermore approaches of field observing processes over four of different locations were selected within a city center .The meteorological data that have been derived from above stations based on 2013 . In general, it was observed during winter both of ΔT_u and ΔT_s were elevated at daytime compared to nighttime and reached to greatest value at noontime, and the amount of ΔT_{u-s} °C is ranging around the value 3°C of average 3.1 °C . The ΔT_{u-s} value was strongest in July during summer season where its average reached 3.4 °C . Additionally during spring the values of ΔT_{u-s} °C increased compared to winter season . Also in autumn it was found that values of ΔT_{u-s} °C are slightly less than the values during spring .

Keywords : urban heat island intensity, local climate, urban canopy layer , urban energy balance.

الخلاصة

ركز هذا البحث على دراسة طبيعة وخصائص ظاهرة الجزيرة الحرارية الحضرية المتكونه في مدينة الحلة. تناول هذا البحث دراسة بعض من خصائص هذه الظاهرة مثل خاصية التغاير الفصلي. أما التأثيرات البيئية لهذه الظاهرة فقد تناول البحث دراسة وحساب احد العوامل المهمة التي تتعلق براحة الانسان الفسيولوجية وهو دليل درجة الحرارة – الرطوبة أو كما يعرف (بدليل انزعاج البشـــر). ان مساحة مركز المدينة الحضري لمدينة الحلة تبلغ ١٦٥ كم٢ في حين تبلغ مساحة المناطق الريفية المحيطة بها ٥٦٦٤٥ كم٢. لقد أظهـــرت الدراسة بان هنالك فرق في درجة حرارة الهواء بين مركز المدينة الحضري والمناطق شبه الحضرية المحيطة بمدينة الحلة وقد تـــراوح مقدار هذا الفرق مابين (١–٤) م□ . ان المواقع المحدده في هذا البحث هي الموقع الحضري للمدينة وتمثل بمحطة الأنواء الجوية والرصد الزلزالي الأوتوماتيكية الواقعة في حي الجزائر إضافة الى الموقع شبه الحضري لمدينة الحلة وتمثل بمحطة الأنواء الجويه الأوتوماتيكيـــة الواقعة في جامعة بابل ، كلية التربية للعلوم الصرفه ، قسم الفيزياء،إضافة إلى اجراء قياسات عملية تمثلت بعمليات رصد ميداني من خلال اختيار اربع مناطق مختلفة ضمن مركز مدينة الحلة . ان البيانات الارصادية المعتمدة من المحطتين أعلاه قد استندت على بيانـــات العـــام ٢٠١٣ وذلك لعدم توفر بيانات للاعوام الاخرى ضمن المنطقة شبه الحضرية. ولقد تبين من خلال النتائج ان درجة حرارة الهواء لكـــل من المنطقة الحضرية وشبة الحضرية في فصل الشتاء عموما تكون مرتفعه في أوقات النهار مقارنة باوقات الليل وتصل الى أعظم قيمة لها خلال وقت الظهيرة حيث ان مقدار شدة الجزيرة الحرارية الحضرية تراوح حول القيمة (٣) م□ وبمعدل مقداره (٣,١) م□ كذلك تبـــين بان أعلى معدل لشدة الجزيرة الحرارية الحضرية كان خلال فصل الصيف وفي شهر تموز حيث بلغت (٤,٣) م□ أيضا" اتضح من خلال

النتائج إن قيم شدة الجزيرة الحرارية الحضرية في فصل الربيع تزداد مقارنة بفصل الشتاء . أما خلال فصل الخريف فقد وجد ان قيم شدة الجزيرة الحرارية الحضرية مقاربة الى حد ما الى قيمها المسجلة في فصل الربيع.

الكلمات المفتاحية: شدة الجزيرة الحرارية الحضرية،المناخ المحلي،الطبقة الستارية لحضرية ، توازن الطاقة الحضري.

1- Introduction

The air in the urban canopy is usually warmer than that in the surrounding countryside this Urban Heat Island (UHI) effect is probably the best documented example of inadvertent climate modification. The exact form and size of this phenomenon varies in time and space as a result of meteorological, local, regional and urban characteristics (Oke T.R ; 1987) **.** Urban heat island has been a central theme among climatologists, and it is well documented in many metropolitan areas around the world (Wilby; 2003) **.** Urban heat islands are caused by development and the changes in radiative and thermal properties of urban infrastructure as well as the impacts buildings can have on the local microclimate for example , tall buildings can slow the rate at which cities cool off at night.

Heat islands are influenced by a city's geographic location and by local weather patterns , and their intensity changes on a daily and seasonal basis **.** The warming that results from urban heat islands over small areas such as cities is an example of local climate change **.** Local climate changes resulting from urban heat islands fundamentally, differ from global climate changes, in that their effects are limited to the local scale and decrease with distance from their source . Global climate changes, such as those caused by increases in the sun's intensity or Greenhouse Gas concentrations, are not locally or regionally confined**.** (EPA's Climate Change 2003). The annual mean air temperature of a city with one million or more people can be 1 – 3 °C warmer than its surroundings,(Oke 1997), and on a clear, calm night, this temperature difference can be as much as 12 °C (Oke, T.R ; 1987) . UHI is not an instantaneous phenomenon but progressively develops following sunset, and varies in intensity from city to city and season to season, and every settlement is capable of generating an UHI, regardless of its size . Observations for a host of UHI studies display common characteristics reveals itself as a pool of warm air with largest values closest to the urban centre (Lowry w.p ; 1977). Fig. (1) shows the characteristic variation of air temperature with distance whilst passing from the countryside to the center of an urban area, under cloudless skies and light winds, just after sunset, with regarding the UHI of a large city . It demonstrates the aptness of the geomorphic analogy with the island , since the relative warmth of the city emerges distinctly out of the cool 'sea' of the surrounding landscape . The rural / urban boundary exhibits a steep temperature gradient , or 'cliff ' to the HUI . much of the rest of urban area appears as a 'plateau' is interrupted by the influence of distinct intra-urban land-uses such as parks, lakes and open areas (cool) and commercial , industrial or dense building areas (warm) the urban core shows a final 'peak' to the UHI where the urban maximum temperature is found . The difference between this value and the background rural temperature defines the urban heat island intensity ΔT_{u-r} °C . (Oke ,T.R, 1987) .

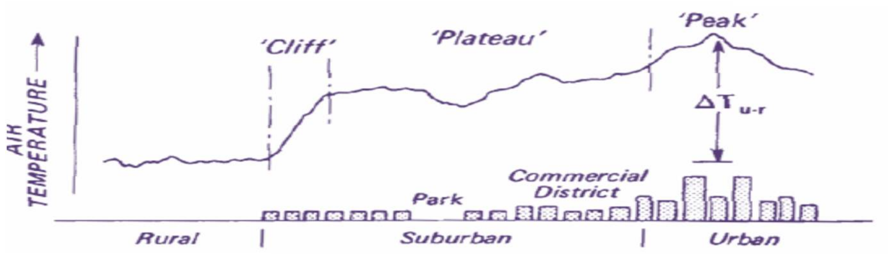


Figure 1 a sketch of an urban heat island profile (Oke; 1987)

2. Types of Urban Heat Islands

There are three main types of urban heat islands , Surface, Canopy, and Boundary layers

2- 1. Surface Urban Heat Islands SUHI

On average, the difference in nighttime surface temperatures between developed and rural areas is 10- 15 °C the difference in nighttime surface temperature . Is typically smaller at 5- 10 °C . Surface urban heat islands are typically present day and night, but tend to be the strongest during the day when the sun is shining. The magnitude of surface urban heat islands varies with seasons, due to changes in the sun's intensity as well as ground cover and weather. As a result of such variation, surface urban heat islands are typically largest in the summer **.** The studies reveal that to identify the surface urban heat islands often use Remote Sensing, an indirect measurement technique, and to estimate surface temperatures use the data collected to produce thermal images **.**

2- 2. Atmospheric Urban Heat Islands: AUHI

Warmer air in urban areas compared to cooler air in nearby rural surroundings defines atmospheric urban Heat islands. Atmospheric urban heat islands are often weak during the late morning and throughout the day and become more pronounced after sunset due to the slow release of heat from urban infrastructure .The timing of this peak however, depends on the properties of urban and rural surfaces, the season, and prevailing weather conditions .The studies often divides these heat islands into two different types:

2-2-1. Canopy layer urban heat islands UCL

Canopy layer heat island is a maximum at night, under calm and clear conditions reach to 12 °C , annual average 1 - 2 °C , may be small or even negative during the day. It exists in the layer of air where people live, from the ground to end roofs below the tops of trees . UCL is produced by micro – scale processes operating in the streets canyons between the buildings.

2-2-2. Boundary layer urban heat islands UBL

Start from the rooftop and treetop level and extend up to the point where urban landscapes no longer Influence the atmosphere . This region typically extends no more than one mile 1.5 km from the surface .(Maria Clark; 2005)**.** The UBL is above the roofline, and is a local to meso – scale phenomenon influenced by the general nature of the urban surface . UBL is generally positive both day and night but much smaller in magnitude than UCL or SHI **.** The UBL tends to maintain a more constant heat island intensity both day and night ~1.5° to 2 °C. However the UBL shows much less variability than the other heat island types (Oke, 1991) .

3. How urban heat island formed

There are several causes of an urban heat island UHI, The principal reason for the nighttime warming is that the (short – wave radiation) is still within the concrete, asphalt , and buildings that was absorbed during the day unlike suburban and rural areas .This energy is then slowly released during night as Long – Wave Radiation making cooling a slow process (Maria Clark; 2005) .Two other reasons are changes in the thermal properties of surface materials and lack of Evapotranspiration (Evaporation and Transpiration) in which plants release water to the surrounding air, dissipating ambient heat . In urban areas with a decreased amount of vegetation, cities also lose the shade and cooling effect of trees , the low Albedo of their leaves , and the removal of Carbon Dioxide materials commonly used in urban areas for pavement and roofs , such as concrete and asphalt have cignificantly different thermal bulk properties including: (Heat Capacity and Thermal Conductivity) and surface radiative properties (Albedo and Emissivity in %) than the surrounding rural areas . This causes a change in the energy balance of the urban area, often leading to higher temperatures than surrounding rural areas (Oke, 1982) **.** Degrees between the center of the city and other causes of UHI are due to geometric effects, the tall buildings within many urban areas provide multible reflection and absorption of sunlight increasing the efficiency with which urban areas are heate . This is called the Urban Canyon effect . Another effect of buildings is the blocking of wind, which also inhibits cooling by convection and pollution from dissipating (Waste Heat) from automobiles, air conditioning, industry, and other sources also contribute to the UHI . The effects of (Urban Geometry) on urban heat islands are often described through the sky view factor (SVF) which is the visible area of the sky from a given point on a surface (Sailor, 2011) . High levels of pollution in urban areas can also increase the UHI as many forms of pollution change the radiative properties of the atmosphere (Oke, 1982). Solar reflectance ,or albedo, is the percentage of solar energy reflected by a surface. Much of the sun’s energy is found in the visible wavelengths thus , solar reflectance is correlated with a material’s color. Darker surfaces tend to have lower solar reflectance values than lighter . Urban areas typically have surface materials, such as roofing and paving which have a lower albedo than those in rural settings. As a result, built up communities generally reflect less and absorb more of the sun’s energy, This absorbed heat increases surface temperatures and contributes to the formation of surface and atmospheric urban heat islands . Although solar reflectance is the main determinant of a material’s surface temperature, emissivity also plays a role. Thermal Emittance is a measure of a surface’s ability to shed heat, or emit long – wave (infrared) radiation . (Christen and Voogt, 2004) Also two primary weather characteristics affect urban heat island development: Wind and Cloud cover, in general urban heat islands form during periods of calm winds and clear skies, because these conditions maximize the amount of solar energy reaching urban surfaces and minimize the amount of heat that can be convected away. Conversely, strong winds and cloud cover suppress urban heat islands . Climate and Topography , which are in part determined by a city’s geographic location, influence urban heat island formation .

For example, large bodies of water moderate temperatures and can generate winds that convect heat away from cities . Nearby, mountain ranges can either block wind from reaching a city , or create wind patterns that pass through a city. Local terrain has a greater significance for heat island formation when larger- scale effects, such as prevailing wind patterns, are relatively weak (Akbari, 2005). In addition, the Anthropogenic heat emissions contribute additional warmth to the air . The communities currently can lower anthropogenic heat emissions through in the building and vehicle sectors (Voogt, 2002). Even towns with populations of 1000 people have urban heating of about 2.2℃ compared to the nearby rural countryside. The UHI in ℃ increases according to the formula : (Oke , 1973) .

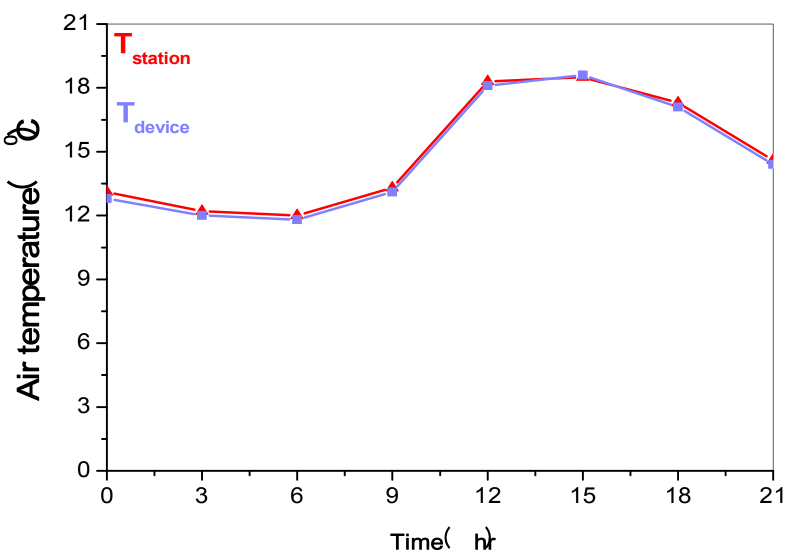
$$UHI = 0.73 \log (pop) \quad (1)$$

Where pop denotes population . this means that a village with a population of 100 has a warm bias of 1.46 ℃ , a town with a population of 1000 people has a warm bias of 2.2 ℃ , and a large city with a million people has a warm bias of 4.4 ℃ .

4 . Results and Discussion

4-1. Calibration and correction of data

Firstly it was adapted calibration process between the data of air temperature observations measured by both the device and meteorological station at a city center every hour for a whole day as plotted in Fig. (2) these results show that both data are slightly converged .



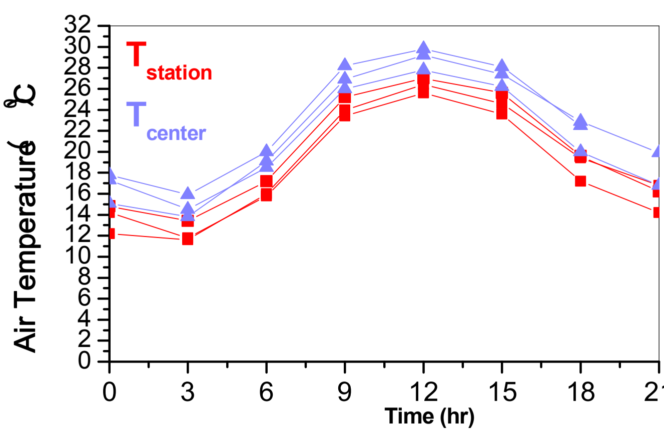
Figure(2) hourly observations during a whole day

Throughout the field measurements, it was discovered that the location of the automatic meteorological station at a city of Hillah at (Al-gezaair section) does not exactly correspond with typical urban center. Therefore it was adapted correction process of data that related to the meteorological station ,by selecting other sites in order to capture the highest air temperature that matches with a typical urban city center. For this reason four contrasting sites were selected within a city center : (Al– jamaiya - Intersection, Bab-Al-Mashehd, Al-Amer, and Al-Imam . The field observation data for three consecutive days during March – 2014 at this locations shows that AL–Jamaiyah –Intersection has the highest air temperature consequently, this site was represented the typical urban city center of a city of Hillah. Table (1) demonstrates the field observing data of both automatic meteorological station and Al– Jamaiyah-Intersection , as is evident from data, the air temperatures at Al– Jamaiyah– Intersection is higher than those registered at meteorological station .

Table (1) comparison the air temperature between the meteorological station and urban city center of Hillah (AL – Jamaiyah – Intersection)

Time hr	T_s/ 20/3 °C	T_s/ 21/3 °C	T_s/ 22/3 °C	T_c/ 20/3 °C	T_c/ 21/3 °C	T_c/ 22/3 °C
00	14.2	12.2	14.8	17.3	15.1	17.8
03	11.8	11.6	13.4	14.5	13.8	15.9
06	15.8	16	17.2	18.5	19.1	20
09	23.4	24	25.2	26	26.9	28.2
12	25.6	26.4	27	27.8	29.2	29.8
15	23.6	24.6	25.6	26.2	27.4	28.1
18	17.2	19.4	19.6	20	22.9	22.5
21	14.2	16.8	16.2	16.8	19.9	18.8

According to Table (1) the Fig. (3) displays an evident air temperature difference between the observations measured by both meteorological station and urban city center respectively . The difference is clearly marked , whereby the three blue lines that related to the urban city center (Al- Jamaiyah- Intersection) observations , represent the higher measurements of air temperatures observation . In contrast the three red lines that related to the meteorological station observations represent the lower scales of air temperatures observation.



Figure(3) comparison the air temperatures between the meteorological station and the urban city center of Hillah

As is now evident there is a notable difference in air temperatures observation either to the meteorological station and urban city center. So to overcome this problem was required calculation this magnitude of air temperatures difference and for this purpose it was plotted in Fig. (4) based on Table (1) . The final results were governed by the equations :

$Y = A + BX$ $\quad B = 1 , \; A = 2.8$ $\quad$ (2)

$Y = 2.8 + X$ $\quad$ (3)

$T_C = 2.8 + T_s$ $\quad$ (4)

This is an evidence that the air temperatures observation within urban city center are higher than meteorological station data, as great as 2.8 °C . Consequently this value must be added for all meteorological data that have been recorded at the meteorological station , which now represents the typical urban location of the city of Hillah .

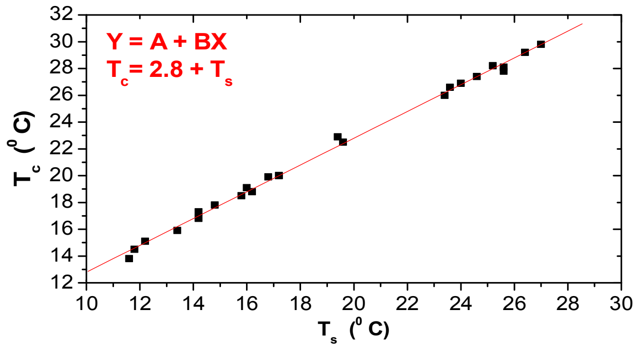
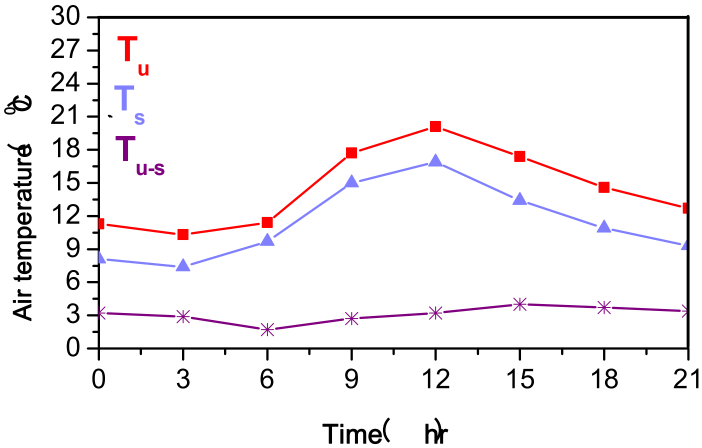


Figure (4) Calibration of air temperature measured at both the site of meteorolgical station and the urban city center of Hillah during three consecutive days in (March, 2014)

Based on the meteorological data of air temperatures observation for an entire year it was calculated the monthly averages air temperatures and through it determining the difference air temperatures between the urban and suburban sites, by this difference the urban heat island intensity ΔT_{u-s} °C can be created . As a result it was observed there is an urban heat island has been formed within city center of Hillah of amount ranging from 1– 4 °C . Furthermore the meteorological data of air temperature that related to both of urban and suburban sites , it has been employed the meteorological data which related to relative humidity R.H of the same locations in order to assess the environmental impacts by estimating the human - discomfort index DI .

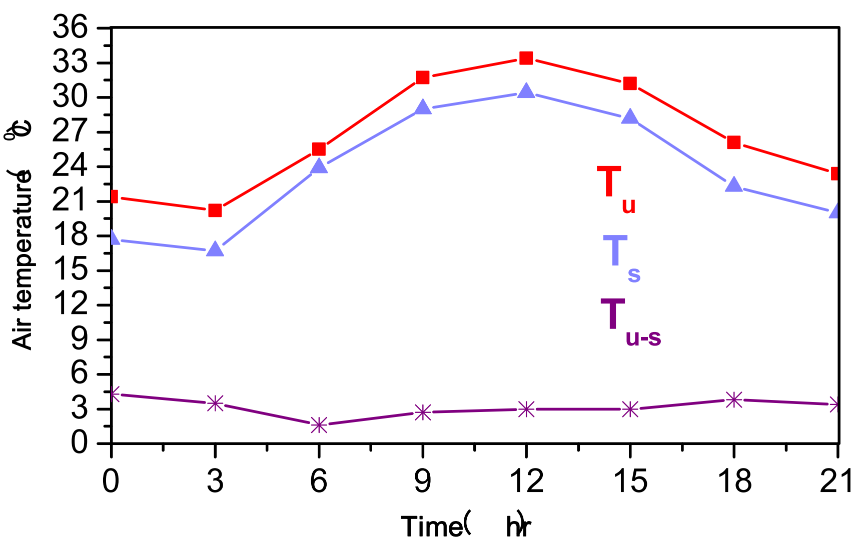
4-2 . The Seasnal Variation of (ΔT_{u-s}) °C

In this section it has been investigated the seasonal behavior of urban heat island intensity $\Delta \, T_{u-s}$ during four seasons in 2013, by choosing the months: January, April , July and October to represent this seasons respectively. The seasonal mean air temperature was calculated as the monthly mean air temperatures of Both $\Delta \, T_u$ and ΔT_s at each time (00),(03),(09),…….(21), and for each season .Then it was determined $\Delta \, T_{u-s}$ magnitudes by subtraction $\Delta \, T_u$ value from ΔT_s for each time. Whereby it was plotted each of $\Delta \, T_u$, ΔT_s, $\Delta \, T_{u-s}$ Fig. (5) illustrates the seasonal variation during January and shows that both ΔT_u and $\Delta \; T_s$ commonly increased at daytime compared to the nighttime and reached the largest values at noontime . Also it was found there is marked contrast over the daily averages of both ΔT_U and ΔT_S particularly in noontime (12) LMT , after calculating the value of ΔT_{u-s} it was found ranging around the value 3°C of average 3.1 °C **.** In addition there is a notable lack in ΔT_{u-s} value during early morning accurately at the time (0 6) whereby this reduction reaches to the weakest value : 1.7 °C .



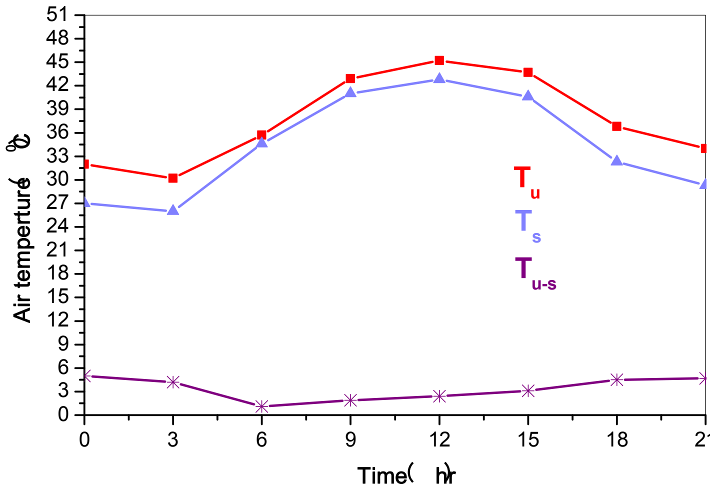
Figure(5) seasnal variation of(UHI) intensity in winter during January / 2013

Figure (6) displays the seasonal variation of ΔT_{u-s} during April and shows the elevated magnitudes of ΔT_{u-s} compared to winter values where it was ranging around 3.2 ℃ . Also the values of both ΔT_U and ΔT_S over all increased at daytime compared to nighttime and reache largest value at noon hours . As is evident there is a sharply reduction in ΔT_{u-s} magnitude, during early morning at the time (06) was registered 1.6 ℃ . On the other hand there is a marked convergence in the amounts of both ΔT_U and ΔT_S at the time 06 . The highest values of ΔT_{u-s} were 4. 3 ℃ in midnight registered at the time (00) , and over nighttime at (21) was recorded (3.4) ℃ .



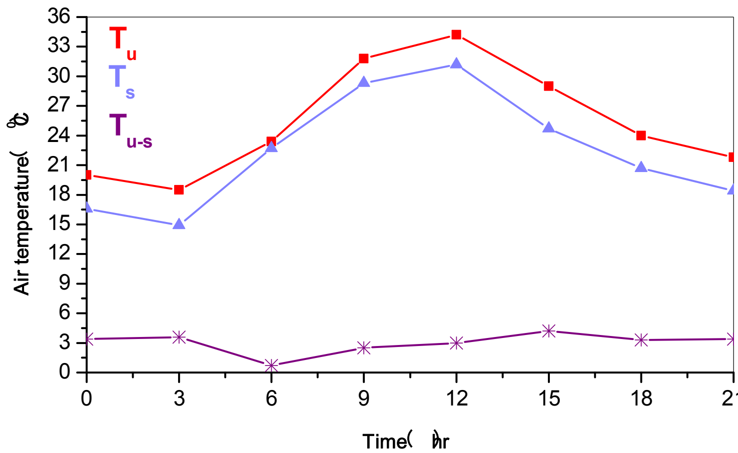
Figure(6) seasnal variation of(UHI) intensity in spring during April / 2013

Figure (7) illustrates the seasonal variation of ΔT_{u-s} during July in 2013. As is obvious there is a noticeable difference in values of both ΔT_u and ΔT_s in midnight (00), dawn time (03), and in the evening (06) durations , Whilst there is an evident convergence between them in the morning at (06) o'clock . Also it was observed gradual elevation for each ΔT_u and ΔT_s magnitudes spanning from morning (09) until (21) at nighttime .Also both values of ΔT_u and ΔT_s were elevated all over the urban and suburban sites, as registered rates of 37.5 °C and 34.5 °C respectively In general the highest air temperatures of T_{u-s} magnitudes were observed during this season as the amount of ΔT_{u-s} ranging around the value 4.5 °C with rate reaches 3.4 °C . The highest value of ΔT_{u-s} was 5 °C during midnight at (00) whereas the lowest value was 1.1 °C in the morning at (06), that Which represents rapidly reduction in ΔT_{u-s} value .



Figure(7) seasnal variation of UHI intensity in summer during July / 2013

Fig. (8) explains the seasonal variation of ΔT_{u-s} in Autumn during October 2013. It was observed there is a marked converging in ΔT_{u-s} values of both Autumn and Spring seasons . Also the values of both ΔT_U and ΔT_S generally increased at daytime compared to nighttime and reaches to the largest values at noon hours . It was noted there is a reduction in the amount of ΔT_{u-s} compared to spring season where the average of ΔT_{u-s} during this season reached 3 °C . The highest ΔT_{u-s} value was 4.2 °C registered in afternoon duration at the time (15), and the lowest value was 0.7 °C registered during early morning duration at the time (06) this value represented the fewer value among the ΔT_{u-s} values during the four seasons In addition there is a general access in values of T_{u-s} starts from morning (09) to nighttime (21) , As is evident both ΔT_U and ΔT_S have a fixed difference begins from noon period until nighttime at (21) .



Figure(8) seasnal variation of (UHI)
intensity in autumn during October / 2013

4-3. The Environmental Impacts

High temperature causes human thermal discomfort . Therefore the knowledge of human discomfort conditions is necessary because many people particularly those who live in large cities have greater risk to morbidity and mortality due to higher air temperature than the surrounding countryside (Nastos & Matzarakis, 2006). The main factor in human discomfort is the thermal component of environmental conditions and was calculated by many indices taking into consideration air temperature, relative humidity and wind speed (BBC Weather 2009). The air temperature and relative humidity observations were taken simultaneously at an approximately 1.5–2 meters height human beings live (Heisler, and OeWalle, 1988). A number of studies have been expressed on the effect of climatic parameters upon human comfort by means of certain expressions including two or more of these parameters a few of the more generally used expressions such as: the discomfort index (DI),Effective Temperature (E.T) , Desert Equivalent Temperature (D.E.T) , Wind - chill index (k) .. etc (Griffiths, 1968). The goal is to estimate one of the more important indices that related to human comfort : Temperature – Humidity Index (THI) or as known Discomfort- Index (DI) at the city of Hillah . This index denotes the degree of discomfort felt by the normal office worker, hence the aspects of radiation and wind flow are not regarded . Under such conditions, Thom has suggested the use of his expression . However the calculations in this study have been based on Thom's formula is one of the most famous formulae used for computation of Discomfort Index based on temperature and relative humidity, as follows : (Thom , 1959) .

$$DI = T - 0.55 (1 - 0.01 RH) (T - 14) \qquad (5)$$

Where:

DI = Discomfort Index (°C) , T = monthly mean temperature in (°C)

RH = monthly mean relative humidity of air (%) .

By substituting in equation (5) it was found that THI values which are lower than 21 °C, there is no body feels discomfortable but when equal to 21 °C < THI < 24 °C there is some humans feel discomfortable, lastly when THI reaches higher than 24 °C then most of human have feeling of discomfort within opened conditions (Griffiths, 1968**)**. The meteorological data of both air temperature (°C) and relative Humidity (%) observation have been taken from the urban and suburban sites at the city of Hillah during 2013. It was calculated the monthly means of both air temperature and relative humidity observations, moreover the monthly means of both ΔT_U and ΔT_S for a whole year . The collected data were used for calculating the discomfort index DI at each of urban and suburban sites .

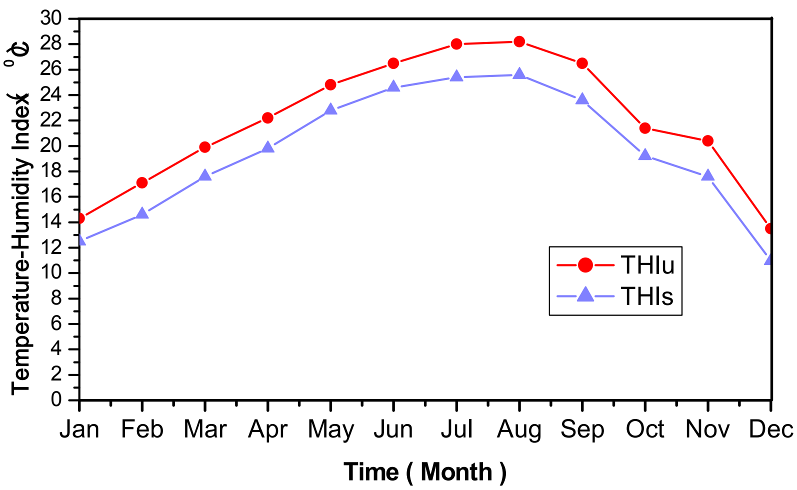


Figure (9) monthly mean variation of THI at the city of Hillah during 2013

Fig. (9) shows that the amount of difference between THI_u and THI_s is approximately fixed during all months of the year . As is evident the magnitudes of THI_u are larger than THI_s during all of months , this result reveals an evidence that the air temperature at metropolitan area is usually higher than its surroundings and this difference creates an urban heat island . In addition it was noted that the values of both THI_u and THI_s have gradually elevated particularly during the summer months starts from May to August. Also it was observed there is a notable reduction in magnitudes of both THI_u and THI_s especially during Winter, Spring and Autumn months . The maximal value of THI_u was registered during August of 28.2 °C and the minimal value was 13.5 °C during December while the maximal THI_s value was 25.6 °C recorded during August and the minimal value was 10.95 °C during December . From the findings it was found that the residents at a city center of Hillah have been experienced discomfort conditions during May, June, July , August , and September were registered 24.8 °C , 26.5 °C, 28 °C , 28.2 °C , 26.5 °C respectively . In contrast the residents at suburban locations have suffered discomfort conditions just during June, July, and August were registered 24.6 °C 25.4 °C 25.6 °C respectively .

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