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Impact of vegetation cover on urban and rural areas of arid climates

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Abstract

Analysis of air temperature differences between rural and urban areas in Al-Hassa oasis in the eastern province of the Kingdom Saudi Arabia has proven the existence of an urban heat island (UHI) phenomenon. This study was conducted to investigate the relationship between urban micro-climate and the density of the surrounding dates tree vegetation and also to estimate the cooling effect imposed by rural environment in Al-Hassa oasis. Results of temperature and relative humidity of the rural towns revealed a strong cooling tendency imposed by the thick vegetation cover. Results indicated a peak difference of the minimum temperatures of 9.8º C, maximum temperatures of 4ºC , and an average difference of 6.6ºC between the rural and urban areas. This outcome was evaluated through the calculation of UHI for the urban and rural areas. It is evident that the mean hourly UHI and relative humidity reference ΔRH have a negative correlation (r= - 0.61) at significance level of P≤ 0.01. In total, rural areas with a higher humidity difference would exhibits lower UHI.

Keywords: Temperature mitigation, heat islands, tree density, vegetation cover, cooling effect, rural environment.
Abbreviations: UHI_Urban Heat Island, ΔRH_Relative Humidity Reference.

Introduction

Temperature rising is one of the major problems of cities in Saudi Arabia. On hot summer days, one can feel the heat waves emanating from roads and concrete buildings, which keep urban areas hot long after the sun set, while rural areas have already begun to cool rapidly (Naeem et al., 2001). In today's complex urban environment, tree planting is something that has to be seriously considered in desert environments such as Saudi Arabia. Expansions of cities and towns tend to channel the net solar gains into sensible heat, thus magnifying the urban heat island (UHI) effect. On the contrary, the impact of trees in rural areas tends to balance the net solar gain and channel it to latent heat, which is a desirable effect, especially in hot desert climates. This subject has been investigated by many researchers in different regions of the world. It was found that increasing forest density reduces energy demand. In the Arabian Peninsula, desert climate (hot-dry) is a predominant condition. The district of Al-Hassa, located in the eastern province of Saudi Arabia Kingdom has geographical coordinates that is within a latitude of 25.33 (25° 19' 60 N) and a longitude of 49.63 (49° 37' 60 E)**.** Very little efforts have been done yet to quantify the consequences of UHI in Al-Hassa region. Therefore, it is necessary to designate and quantify heat characteristics of the date tree oasis, the surrounding desert, and the urban islands in a climate zone that is between hot-dry and hot-humid condition because of its closeness to the sea shore. The date tree oasis is located in the north and east of the city of Al-Hofuf. The 12,000 hectare vegetation cover is a major driving force for the improvement of the climate characteristics. There are over 51 small towns scattered over the oasis that are either fully or partially surrounded by date trees. The vegetation cover of the oasis moderates the hot climate produced by buildings and roads in these towns. The urban heat island (UHI) phenomenon serves as a trap for atmospheric pollutants, deteriorates the quality of life and has a socio-economic impact on the urban area. It is the most intensively studied climatic feature of cities and has been quantified by calculating air or surface temperature differences between urban and nearby rural areas with similar geographic features (Montvez et al., 2000; Gunnula et al., 2011). This is a widely accepted definition of UHI and has been adopted for conducting UHI studies. In fact, most UHI studies have reported higher temperatures in urban areas, or positive UHIs (Rizwan et al., 2009). Studies have shown that UHI have major effects on energy costs and the quality of urban life. It has been estimated that the heat island effect is responsible for 5-10% of the current urban electricity demand during the summer in the cities of the U.S (Sailor et al., 1992). The power usage of air conditioners significantly rises with each degree increase in air temperature. Vegetation has a large impact on micro-climates and is considered as an efficient mechanism for cooling communities (Akbari et al., 1989). An annual 4-8% total energy savings can be expected from a well-placed 25 ft deciduous tree near an air-conditioned home (McPherson et al., 1993). These findings are consistent with the results of a previous study by Parker (1983). In that study, it was found that peak power demands

Table 1. Geographical Description of Towns Under Study.

Name of City/ Town	Geographic Location in the oasis	Approximate thickness (%)*	Location of thickness	Wind Direction	Classification of the region
Al -Battaliyah	Middle	100%	N-S-E-W	N-NW	Rural
Al-Qurain	North	80%	N-S-W	N-NW	Rural
Al-Taraf	South-East	50%	N-W	N-NW	Rural
Al-Hofuf City	South-West	5%	--	N-NW	Urban

*The radius of vegetation cover around the town.

Table 2. Descriptive statistics of daily temperature and relative humidity between urban and rural towns.

Items	Mean	Minimum	Maximum
Rural Temp.	33.15	19.42	45.21
Rural Rh.	32.59	22.55	85.19
Urban Temp.	37.50	24.96	48.62
Urban Rh.	31.02	23.66	81.26

due to air conditioning could be reduced by about five kilowatts. Vegetation is considered to be one of the simplest and most effective ways to moderate climate and save energy. In a study of planting for energy conservation, Sand (1991) reported that, "As much as 70 to 80 percent of the energy conservation benefit of trees may be attributed to reduction in urban heat island effects through the evapo-transpiration effects of trees". Conventionally, air temperature based UHI studies have been conducted through statistical analyses of weather station data, site survey data, and computer simulations. Due to the continuous availability of data, detailed temporal and spatial patterns are mostly available from the studies of weather station data or when UHI is modeled (Rizwan et al., 2009). The objective of this study is to investigate the relationship between urban micro-climate and the density and radius of vegetation cover around the rural towns of Al-Hassa in order to estimate the cooling effect imposed by the rural environment. This was achieved by studying heat flux behavior in four regions with different surrounding tree densities and radiuses.

Results and Discussion

The impact of trees on the maximum temperature of rural areas, which is result of channeling the solar gain into latent heat, is shown in Fig. 2. It also shows the heat island effects are made by the urban infrastructure. Under the similar geographical and climatological conditions the difference between the relative humidity for the rural and urban areas reveals the effect of the vegetation cover (Fig. 3). In addition, Fig. 4 shows the impact of trees on decreasing temperatures in rural areas. Our results demonstrated that waves of the heat are emanating from roads and concrete buildings long time after sunset which keeps urban areas hot, while the rural areas have already begun to become cool rapidly. The pattern of temperature in Fig. 5 leaves no doubts that the radius of vegetation cover around the small rural towns has a significant impact on temperature, when compared to the urban region of Al-Hofuf. A deeper look into the correlation between humidity and temperature reflects that they are inversely related, exhibiting the latent heat effect. This means that if radius of vegetation cover around the small rural town is longer, then the leaves of the trees become the direct receiving surface of the solar radiation. The latent heat of town increases and; therefore the humidity would also be higher and consequently the temperature drops. The figure also shows the duration of the temperature drop in urban areas is 12 hours while it was 5 hours in the rural ones. There is an obvious distinction between the climates of the four designated regions as shown in Fig. 6. The temperature patterns illustrate that the radius of vegetation cover around and the proximity of the town, towards the northern desert, are the two major factors of the temperature reduction inside the towns. Whatever the radius of vegetation cover around the town is thicker and closer to the northern desert, climate of the town is colder. For example, Al-Qurain was lowest in temperature than Al-Battaliyah and Al-Taraf in the far south-east while the urban area of Al-Hofuf had highest temperature. This phenomenon occurs due to the hot-dry high wind speed coming down from the north through the oasis, by which the wind speed becomes slower and thus decreases the process of evaporative cooling. The mean maximum hourly UHI (^{0}C) for Al-Hofuf and Al-Qurain shown in Fig. 7 indicates a peak difference of 4 ^{0}C between the highest urban and rural maximum temperatures. A minimum difference of 1.2 ^{0}C turned out between the highest urban and rural maximum temperatures. These results consent with the study conducted by Kim and Baik, (2005). They found that in Seoul, South Korea "the average maximum urban heat island intensity is 2.2°C over the 1-year period and it is 3.4°C at 0300 local standard time (LST) and 0.6°C at 1500 LST". Data illustrated in Fig. 8 indicates a peak difference of the minimum temperatures of 9.8 ºC between Al-Hofuf and Al-Qurain with an average difference of 6.6 ^{0}C. The graphs also show that heat islands fluxed by towns and cities are big storage of heats. These results were also reported by Lemonsu and Masson, (2002) for Paris, France (8 °C), Rizwan et al. (2009) for Hong Kong, China (10.5 °C), and Klysik and Fortuniak, (1999) for Łódź, Poland (12 °C). Rural areas with a higher humidity difference would exhibit lower UHI. Nevertheless, the influence of the RH appears to be very clear on UHI in rural areas. Descriptive statistics of daily temperature and relative humidity between urban and rural towns presented in Table 2 implies that the urban maximum temperature is around 48.62 ^{0}C with minimum of about 24.96 ^{0}C. However, the rural maximum and minimum temperatures are 45.21 ^{0}C and 19.42 ^{0}C, respectively. Maximum and minimum relative humidity data for the same period are read for the urban 81.26 % and 23.66 % and for the rural 85.19 % and 22.55 %, respectively. Ultimately, urban mean temperature is around 37.50 ^{0}C and the rural is about 33.15^{0}C. The urban and rural mean relative humidity

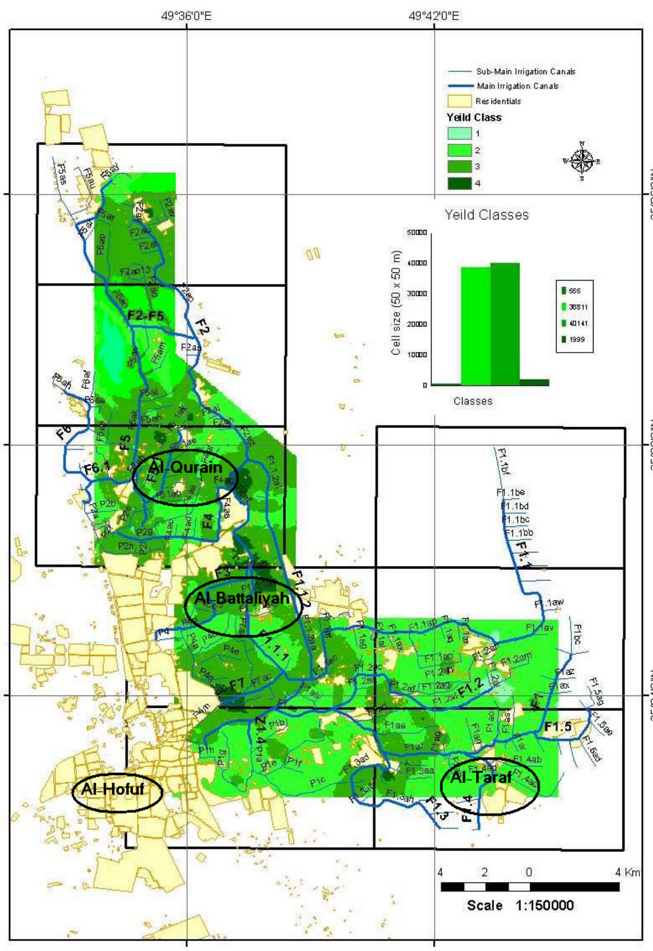

Fig 1. Four selected Locations Under Study Al–Battaliyah, Al-Qurain, Al-Taraf, and the City of Al-Hofuf. (HIDA (2011).

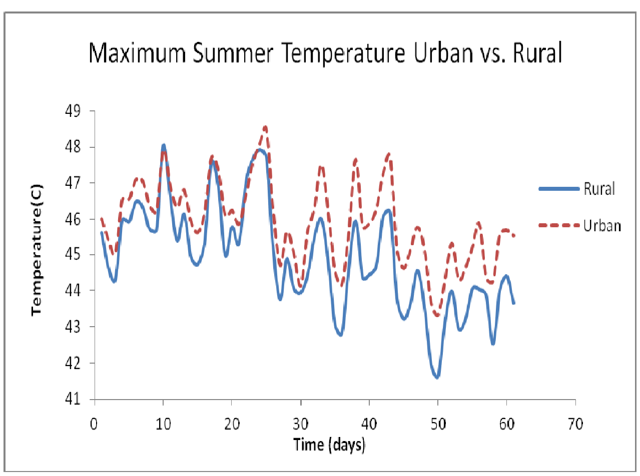

Fig 2. Mean maximum urban vs. rural summer temperature.

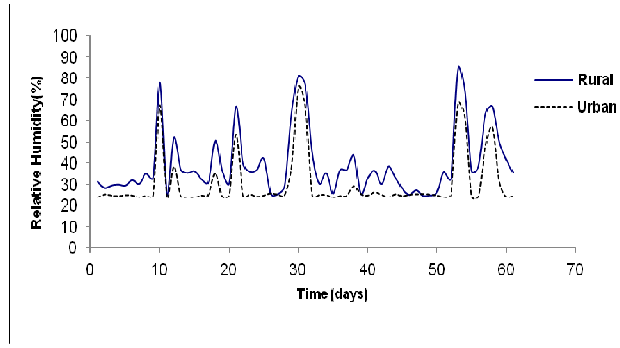

Fig 3. Difference in RH for the Rural and Urban areas.

are 31.02 % and 32.59 %, respectively. The cooling effect of the rural towns is apparent by examining the correlation between the regression of UHI and the relative humidity difference for the urban and rural areas. The presence of the vegetation cover is probably the main reason of the higher humidity in the selected rural areas. The mean hourly relative humidity difference (ΔRH) was determined by subtracting the mean hourly RH of the urban area from that of the rural areas (Fig 9). The possible impact of the tree density on the UHI has been investigated by calculating a linear regression between UHI and ΔRH. A negative correlation coefficient among the UHI and ΔRH ($r = -0.61$) at level of significance $P \leq 0.01$ is presented in Fig. 9, which suggests that increase of the UHI, is associated with a decrease in the ΔRH.

Materials and methods

An aerial view of the oasis depicts an L shape of the vegetation cover pointing north as shown in Fig. 1. Based on the above description of the area, four towns were selected, which spanned similar geographical and topographical conditions but have different tree densities as shown in Fig 1 and detailed in Table 1. Thirty temperature and humidity sensors were distributed over the four designated regions to achieve a fair representation of the data. The two hottest months, July and August, were chosen to study this effect because; there is a peak load demand for electricity, air conditioning and other cooling methods during these months. Also the cooling effect of the date tree coverage would be at its maximum during this period of the years, and would therefore be easiest to be detected. Sensors were distributed inside these small towns to assure data accuracy and fairness. The average data of five sensors that were disseminated in each town reading an hourly temperature were collected to give a fair representation of the climate.

Conclusion

The main features of the UHI in Al-Hassa have been analyzed using hourly data from seven urban stations and four rural stations. The data was recorded over a period of three months revealing that the warmest core of the UHI is represented by Al-Hofuf zone of Al-Hassa, whereas the coldest rural area was Al-Qurain. The temperature in urban regions drops in a 12 hour period from its afternoon peak,

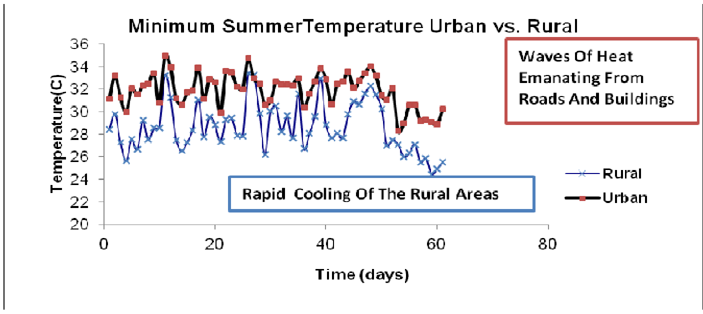

Fig 4. Minimum Summer Temperature Urban vs. Rural

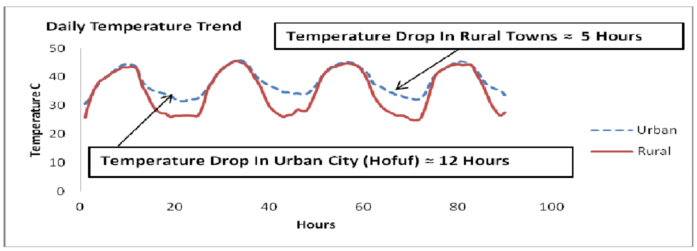

Fig 5. The duration of Temperature Drop between Rural and Urban Areas.

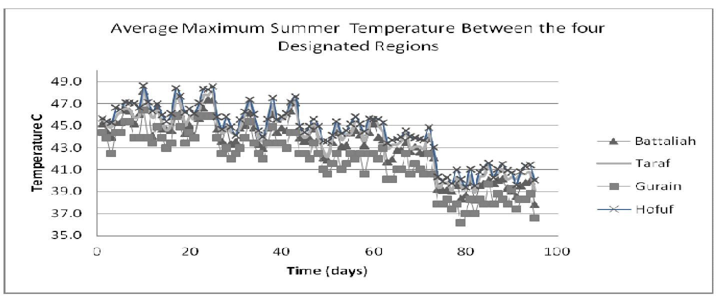

Fig 6. Mean maximum summer temperature for the four designated regions.

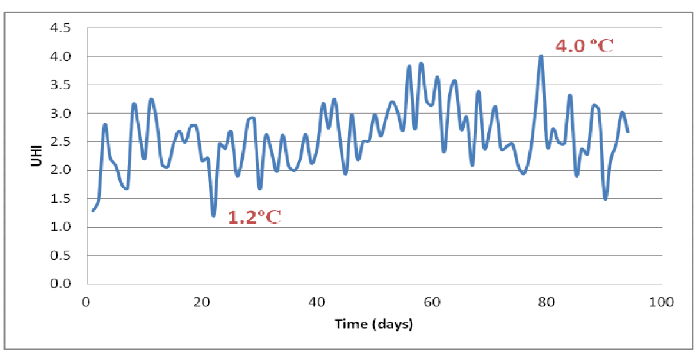

Fig 7. The Average Maximum Hourly UHI (^{0}C) for Al-Hofuf and Al-Qurain.

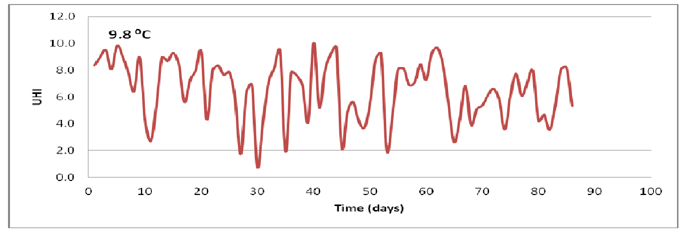

Fig 8. The Average Minimum Hourly UHI (°C) for Al-Hofuf and Al-Qurain.

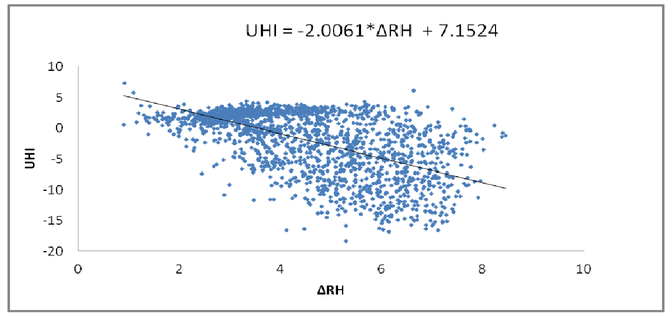

Fig 9. Graphical representation of linear regression between UHII and relative humidity difference (ΔRH).

whereas the temperature in rural regions cool down to the same temperature within 5 hours period. The results of temperature and relative humidity of the rural towns showed a strong cooling tendency imposed by the thick vegetation cover. This outcome was also evaluated through calculating the UHI for the urban and rural areas. Regression and correlation analysis of UHI and relative humidity differences confirmed the findings. Increasing the radius of vegetation cover to north and north-west of the town is therefore considered to be the most effective way to cool our communities and to save energy. It helps protecting buildings and surroundings against the scorching heat of sun in the summer. Besides the cooling effect of the vegetation cover improves the urban environment by reducing pollution and dust storm. The relatively cool climate of the rural town suggests dividing of big cities into suburbs with a vegetation cover from north and north-west of each suburb to achieve the best cooling effect. Further studies should be carried out to investigate the climate design using the four parameters: temperature, relative humidity, solar radiation, and wind speed. A bioclimatic chart can be developed to study the interaction between the four parameters and its reflection on the comfort zone for humans and plants, and animals. After obtaining the bioclimatic data, a base climatic design can designated to help getting the optimum benefit of the climate characteristics and suggest the best alternative to reach the comfort zone. Therefore, there is a real challenge for researchers in choosing the best climatic solutions. Modeling the temperature drop due to vegetation cover intensity is another way to predict tree location and plantation that has to be investigated.

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