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Effects of urbanization on the urban heat island in Beirut

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ABSTRACT

Given the growing urban populations in Beirut city and the increasing need for more housing and infrastructure, the impacts of the UHI can be felt more deeply. A recent study shows the close link between high temperatures and mortality in Beirut and the strong correlation between population growth and rising maximum and minimum temperatures over the last century. Urban planning policies and building codes are lacking in directives toward alleviating impacts of the UHI. This paper describes the methodology applied to conduct a preliminary study of the UHI in Beirut by simulating air temperatures 2 m above the ground, and heating and cooling energy demands for 1-day duration during winter and summer using the Town Energy Balance model. Results showed that areas with larger garden fractions have up to 6 °C cooler temperatures than surrounding dense artificial areas and lower cooling energy demands of about 80 W/m^2 as opposed to 350 W/m^2 in dense urban fabrics during the summer. The outputs of this research help to better understand the relationship between UHI and the urban morphology of Beirut. Preliminary recommendations are accordingly made for implementation of the findings of this research within relevant Lebanese regulations for urban planning and design.

1. Introduction

Urban heat island is the more widely documented phenomena of climate change. The term "heat island" describes urbanized areas that are hotter than nearby non-urbanized areas due to the fact that urban areas have typically darker surfaces and less vegetation than semi-urban and non-urban surroundings. Dark artificialized surfaces generally have lower solar reflectivity or albedo, which therefore have a greater capacity to absorb the incoming solar radiation thus becoming extremely hot and accordingly raising surrounding air temperatures. As the air temperature increases so does the demand for air-conditioning. This results in higher emissions from power plants and smog formation. Vegetated or natural areas have typically cooler air temperatures than artificialized urban areas due to the process of evapotranspiration of plants. Therefore this difference in daily temperatures between urban and non-urban areas affects not only the microclimate but also the energy use and habitability of cities. According to Landsberg (1981) the urban heat island is present in every town and city and is the most obvious climatic manifestation of urbanization with implications on the thermal comfort level of urban dwellers and the overall quality of life. Including more vegetation into cities and reducing albedos of typically used urban materials are planning strategies that have possible positive impacts on urban cooling.

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Considering the increased awareness being given to the implementation of sustainable development practices worldwide, urban planners and architects have been studying and investigating measures to minimize the impacts of their practices on the urban heat island increasingly over these last three decades including increasing albedos of urban materials as well as garden fractions. In doing so, they have used modeling tools like ENVI-met (Bruse, 2004) or, the Town Energy Balance (Masson, 2000) for example, to more closely investigate measures to minimize the effects of building and town designs on the urban microclimate at either neighborhood or city-scales.

Considering the growing urban populations and haphazard urbanization trends in Beirut, there is much cause for concern for the well-being and thermal comfort level of urban dwellers. Whereas most previous studies have studied the effects of individual building designs on urban microclimate in similar dense cities worldwide, this current study will investigate the effects of current city-scale urban planning and design practices on the urban heat island of Beirut, where the literature clearly points to the lack of research in this regard. Therefore in this paper a precursory study of the strong correlation between the existing urban morphology, and rising temperature trends in Beirut city is conducted. This is done to provide an indication of the main urban parameters responsible for exacerbating the UHI phenomenon and to stress the necessity of finding solutions to alleviate its unpleasant effects.

2. Methodology

2.1. Study area

Lebanon is a small country located on the eastern coast of the Mediterranean Sea, covering a total surface area of 10,452 km^2, and with a total population of 4,223,553 (World Bank, 2013). Recent figures show that 87% of this population currently lives in urban areas with the majority – estimated at 64%-residing in large agglomerations mostly Beirut, Greater Beirut Area (GBA) that spreads north, south and east of Beirut city, and Tripoli (UNH, 2009). This is the highest rate amongst Lebanon's neighbors including Syria (54.6%) and Jordan (78.5%). By 2020, it is estimated that the population of Lebanon will rise to 4,587,000 out of which 4,065,000, or approximately 89%, will be living in urban areas (UNH, 2011). The capital city of Beirut, which covers approximately 21.47 km^2, has about 400,000 residents with an estimated urban density of about 21,000 inhabitants per square kilometer (Population and Development Strategies Programme, 2014; MOE/LEDO/ECODIT, 2001), and this is one of the more significant urban densities in the Middle Eastern region. In fact, it is estimated that Lebanon's urban areas will grow by 10 km^2 per year over the next 30 years (DAR-IAURIF, 2005).

The study area encompasses Beirut administrative area and is situated along the Mediterranean coastline at Latitude 33° 52′ 15″ and Longitude 35° 30′ 13″. It is made up of a total of 12 cadastral districts covering a surface area of 21.47 km^2. Fig. 1 is a satellite image of Beirut. Although the densities are not clearly distinguished in this image, the contrast between artificial versus natural surfaces is emphasized when compared against the forested areas further to the east of the city. The National Land Use Master Plan (NLUMP) is the most recent land use study conducted for Lebanon classifying Beirut as an artificial/non-permeable area (*Territoire artificializé*.). The *Nahr* (River) Beirut lies on the eastern boundary of the Beirut administrative area (Fig. 2).

Although researchers have shown some interest in the case of the UHI in Lebanon (McCarthy, 2009[1]; Idso and Singer, 2009[2]), to date investigations have been minimal with the current attention being focused mainly on Climate Change. Such examples in this regard include Lebanon's Second National Communication Report to the United Nations Framework on Convention (UNFCC) (MOE/UNDP, 2011), and the report on "Climate Change and Variability: Impact on Land Use and Sustainable Agriculture Development (Karam, 2002). Therefore, the study of the UHI still appears to be in its infancy, even though there is increasing evidence of this phenomenon on the rise in Lebanon's urban areas. For example, analysis of climatic data from the American University of Beirut (AUB)[3] (see Fig. 1 for location of AUB campus) shows rising minimum temperature (T_{min}) and maximum temperature (T_{max}) trends in Beirut city dating from the 1870s to 1970s. Fig. 3 represents these rising temperature trends where these are more significant for average T_{min} values and which rise from around 5 °C in 1870s to 10 °C in the 1970s during which time urban populations quadrupled from 80,000 to around 350,000. In fact there is a very strong positive correlation of T_{min} and T_{max} values when compared against rising population figures with a resulting coefficient of determination or R^2 value of 0.9702. Since temperature data was only available from 1875 to 1975 at AUB, the respective population figures were plotted to reflect only this time period to show an accurate relationship between these variables.

The impacts of the UHI on human health can be detrimental (Changnon et al., 1996). An important study conducted in this regard for the case of Lebanon shows the close relationship between high temperatures and mortality in Beirut where "heat-related mortality at moderately high temperatures was indicated to have a significant public health risk in countries with warm climates" (El-Zein et al., 2004).

[1] Conducts climatic model simulations for sub-grid urban-land surfaces for the Mediterranean cities of Athens, Alexandria, and Beirut where Beirut was found to exhibit the largest summer heat island out of the three cities.

[2] Discusses general UHI records in North America, in Asia (including Beirut) and globally and emphasizes the importance of considering the UHI in surface temperature records.

[3] The American University of Beirut (AUB) is a private, secular, and independent university in Beirut, founded in 1862. A weather station was installed for the university soon after it was established up until 1975, what marked the start of the Civil War in Lebanon. AUB currently participates in independent environmental related projects that require basic weather data measurements e.g., Beirut Air Quality project in collaboration with Beirut Municipality, AUB and the University of Saint Joseph (USJ).

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