On the urban heat island in Beirut and transfer of urban climatic knowledge to urban planner

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1. Introduction

There are 2 reasons why this research was conducted. First, over the last three decades there has been significant attention directed to the causes of urban heat island (UHI) in densely populated cities worldwide that can be mitigated from an urban planning and design perspective. However, the literature clearly points to the lack of research on the (UHI phenomenon in Beirut. Second, the mechanisms through which the transfer of urban climatic knowledge is taking place between and amongst relevant authorities is weak as witnessed in the degradation of environmental quality, urban climate and quality of life or urban dwellers in Lebanon's urbanized areas (MOE/UNDP/ECODIT, 2010).

This research and paper therefore has 3 main objectives: 1) to model the urban heat island phenomenon across the entire city of Beirut using the Town Energy Balance model of Météo France (Masson, 2000), which is a single-layer meso-scale modeling tool; 2) to identify the urban factors that play the most significant role in exacerbating the UHI in Beirut; 3) to propose technical measures to alleviate the effects of the UHI from an urban planning and design perspective and to recommend measures to improve the transfer of urban climatic knowledge to relevant authorities and/or decision-makers.

2. Study Area

2.1 Beirut

Beirut is the capital city of Lebanon. It is a coastal city along the Mediterranean Sea, covering a surface area of approximately 20km^2 (Fig. 1a) with a population of about 500,000 (MOE/ECODIT/LEDO, 2001) and a very high population density of about 21,000 inhabitant/km^2. The city is relatively flat with two hills reaching elevations of about 90m A.S.L. in Ashrafiyeh and Moussaytbeh areas (Fig. 1b). Beirut is a predominantly artificial city (NPMPLT, 2005) comprised primarily of concrete roofs, asphalted roads and a small fraction of urban vegetation, therefore contributions to the effects on UHI are expected to be high.

Figure 1. a) Dense artificial city of Beirut b) Map showing elevation of Beirut city

2.2 Climate in Beirut

Beirut has a Mediterranean climate characterized by long, hot, dry summers and short, cool, rainy winters. The hottest days typically occur during the months of July and August while the coldest days occur in January and February (Beirut International Airport, 2014). Urban summer temperatures have been increasing significantly especially during this past decade (see Fig. 2).

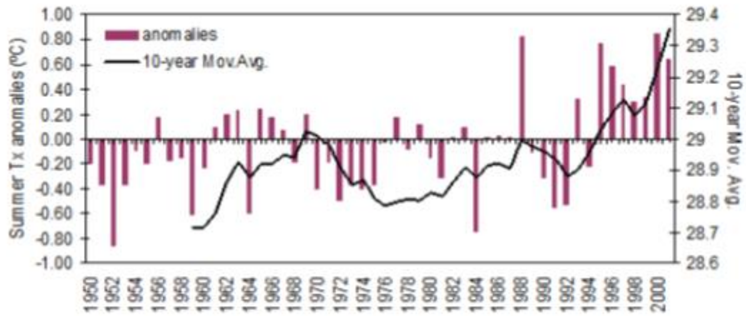

Figure 2. Number of 'hot days' (Tx > 31°C) anomalies from the 1971-2000 average (left axis, bars) for the Beirut International Airport (BIA) station. 10-year moving average of 'hot days' (right axis, solid line) for the BIA station. Source: Hatzaki, et al. 2010; CIRCE urban case studies: Beirut

3. Legal and Institutional Framework

3.1 Urban Planning Law #69

The Urban Planning Law of Lebanon, Law No. 69, was issued in September of 1983 further to modifications of the previous Urban Planning Law of July 24 1962. It is under this law that Lebanon functions today. Although drafted and approved during a period of great civil unrest and political insecurity in the country, the new modified Law took into consideration the environmental discipline in several of its directives. Having said this however, none of these mention the need to protect the urban microclimate.

3.2 Building Code #646

Moreover and more recently, another relevant law was issued in the building and construction sector, namely the Construction Law No. 646 (dated 2004) also known as the Building Code. The first construction laws of Lebanon stem from Beirut during the late 1800s. At the time, the municipality of Beirut developed building regulations that were subsequently adopted by other municipalities in response to the densification of certain areas and neighborhoods. Today, it is the Construction Law No. 646 that is the centerpiece of all construction activities in Lebanon. This code introduced some important changes to benefit the construction sector while at the same it introduced some requirements for the protection of the environment and landscape. However, again there are no specific requirements that take into consideration the urban climate.

3.3 Institutional Framework

Regarding the institutional framework of the urban planning and land management sector in Lebanon, the following key actors are involved, the majority of which fall primarily under the responsibility of the Ministry of Public Works and Transport (MOPWT): 1) Higher Council of Urban Planning (HCUP); 2) Directorate General of Urban Planning (DGUP); 3) Order of Engineers and Architects (OEA), 4) Regional Departments of Urban Planning; 5) Ministry of Interior and Municipalities (MOIM); 6) public bodies like the Lebanese Standards Institution (LIBNOR) attached to the Ministry of Industry (MOI), and; 7) the Municipality of Beirut. Unfortunately, communication amongst these parties is not efficient and actions toward achieving more sustainable urban planning practices are weak. An example of an NGO actively involved in advocating sustainable urban planning measures but not involved as a stakeholder is the Lebanese Green Building Council (LGBC), which provides stewardship towards a sustainable built environment and accordingly promotes, spreads and helps implement high performance construction concepts that are environmentally responsible and healthy and that provide incentives to implement designs that take into consideration the urban microclimate.

4. Methodology

4.1 Modeling Tool

Further to the above therefore, it is evident that it is necessary to provide the decision-makers with scientific evidence to emphasize the significance of the impacts of the UHI of Beirut. This is therefore the purpose of this paper. As such, the methodology adopted included implementation of the Town Energy Balance (TEB) urban surface exchange modeling scheme (Masson, 2000). The mechanism by which TEB functions is based upon Oke’s energy balance equation. It is a single-layer model where the surface-atmosphere energy interactions are parameterized by forcing the boundary conditions with specific atmospheric data. TEB is an adequate model for carrying out large-scale studies for cities such as Beirut. TEB was used to run simulations for the existing condition or the ‘control run’ and 6 devised scenarios (see Table 1) which were compared against the control run results.

Table 1. Devised scenarios

Scenarios	Description
Scenario 1	Albedo of roofs increased to 0.7 (previously α =0.2) in all grid cells across Beirut
Scenario 2	Albedo of roads increased to 0,8 (previously α =0.225)
Scenario 3	Glass ratio increased from 40% to 80%
Scenario 4	Building height was increased from 15m to 35m and the roughness length was accordingly modified from 1.5 to 3.5m
Scenario 5	Increase in vegetation height from 10m to 25m height
Scenario 6	Increase in garden fraction by same amount by which road fraction was decreased (50%)

4.2 Data Collection

The material composition of the dominating urban surface materials in Beirut were collected and compiled from various concerned authorities and institutions and by assessment of aerial imagery. The majority of the urban surfaces in Beirut, namely roads and rooftops, have low albedo values. The low solar reflectivity of this artificial city is expected to have significant impacts on the UHI of Beirut (Table 2).

Table 2. Albedo (α) of dominating artificial urban surfaces in Beirut adapted from Oke (1987)

Description of dominating urban surfaces in Beirut	**Material compositions in contact with ambient air**	**Albedo (α)**
Facades of buildings	Beige/white paint and plaster	0.7
Rooftops	Grey concrete slab	0.225
Roads	Asphalted road surfaces	0.2

5. Results

5.1 Results of the Control Run

Figure 3. Canyon temperature simulations for Control Run across Beirut on 01-Feb. 1200UTC

Figure ***4.*** Canyon temperature simulations for the Control Run across Beirut on 01-Jul 1200UTC

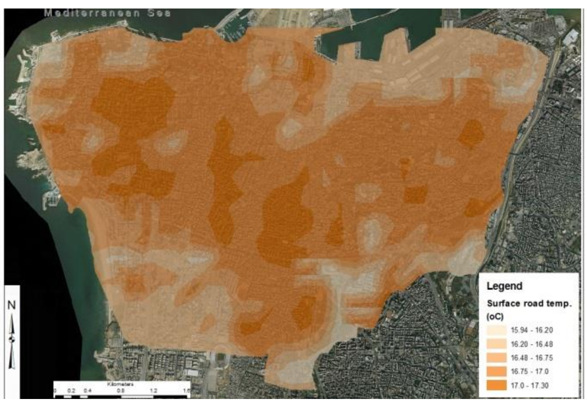

*Figure 5.*Surface road temperature simulation for Control Run across Beirut on 01-Feb 1200UTC

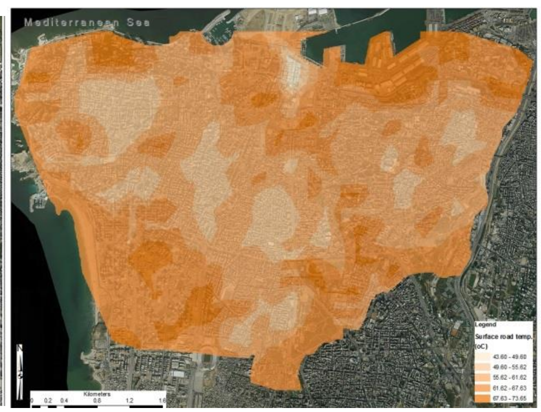

Figure 6. Surface road temperature simulations for Control Run across Beirut on 01-Jul 1200UTC

Figure 7. Heating energy demand simulations for Control Run across Beirut on 01-Feb. 1200UTC

Figure 8. Cooling energy demand simulations for Control Run across Beirut on 01-Jul 1200UTC

5.2 Results of Scenarios versus Control Run

Table 3. Output results for all 6 scenarios in comparison to control run results

Outputs for Scenario 1	Impact during winter	Impact during summer
TCANYON		
TROOF1		
TROAD1		
TWALL1		
TI_BLD		
HVAC_HT		
HVAC_CL		
Outputs for Scenario 2	**Winter results**	**Summer results**
TCANYON		
TROOF1		
TROAD1		
TWALL1		
TI_BLD		
HVAC_HT		
HVAC_CL		
Output for Scenario 3	**Winter results**	**Summer results**
TCANYON		
TROOF1		
TROAD1		
TWALL1		
TI_BLD		
HVAC_HT		
HVAC_CL		
Outputs for Scenario 4	**Winter results**	**Summer results**
TCANYON		
TROOF1		
TROAD1		
TWALL1		
TI_BLD		
HVAC_HT		
HVAC_CL		
Outputs for Scenario 5	**Winter results**	**Summer results**
TCANYON		
TROOF1		
TROAD1		
TWALL1		
TI_BLD		
HVAC_HT		
HVAC_CL		
Outputs for Scenario 6	**Winter results**	**Summer results**
TCANYON		
TROOF1		
TROAD1		

Legend

Cooling impact <1°C	
Cooling impact >1°C	
Heating impact <1°C	
No significant changes in heating or cooling	
Energy savings <10W/m	
Energy savings >10W/m	
Energy savings >50W/m	
Energy demand <10W/m	
Energy demand >10W/m	
Energy demand >50W/m	
No heating and/or demand depending on time of year	

6. Recommendations

6.1 Technical Recommendations

Technical recommendations to alleviate urban temperatures in Beirut are presented in Fig. 10 below.

Figure 10. Recommendations for strategic mitigation actions for UHI in Beirut (inspired by Colombert, 2008)

6.2 Administrative Recommendations

It is suggested to improve communication between all relevant authorities, academic institutions and NGOs. In addition, TEB is recommended as a suitable tool to provide the scientific evidence required for decision-making from urban planning and design perspectives (see Fig. 11).

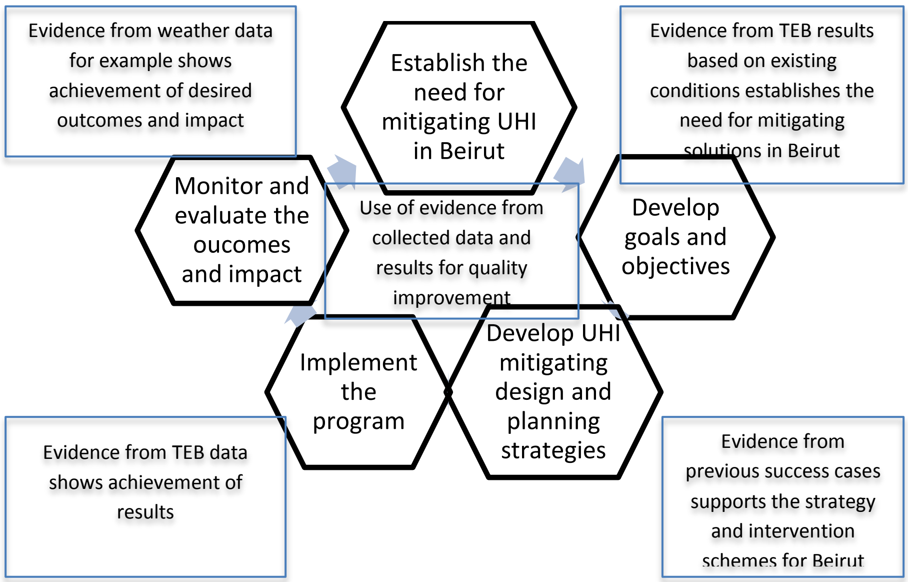

Figure 11. Recommended evidence-based planning approach to mitigate the UHI in Beirut

7. Conclusions

To conclude, areas of larger vegetated fractions have the greatest cooling impact on air temperatures in comparison to dense artificialized urban areas. In addition increasing the albedo value of urban surfaces like rooftops and roads has a significant impact in alleviating the UHI. Institutionally, there exists a major gap in climatic knowledge amongst urban planners and designers in Lebanon. It is important to strengthen the communication channels between all involved authorities and this process can be supported by evidence-based planning scheme where TEB is used to provide the evidence upon which decision-making for urban planning and design practices are made.

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